How do you make an image of an object ?

Use a camera to take a picture !

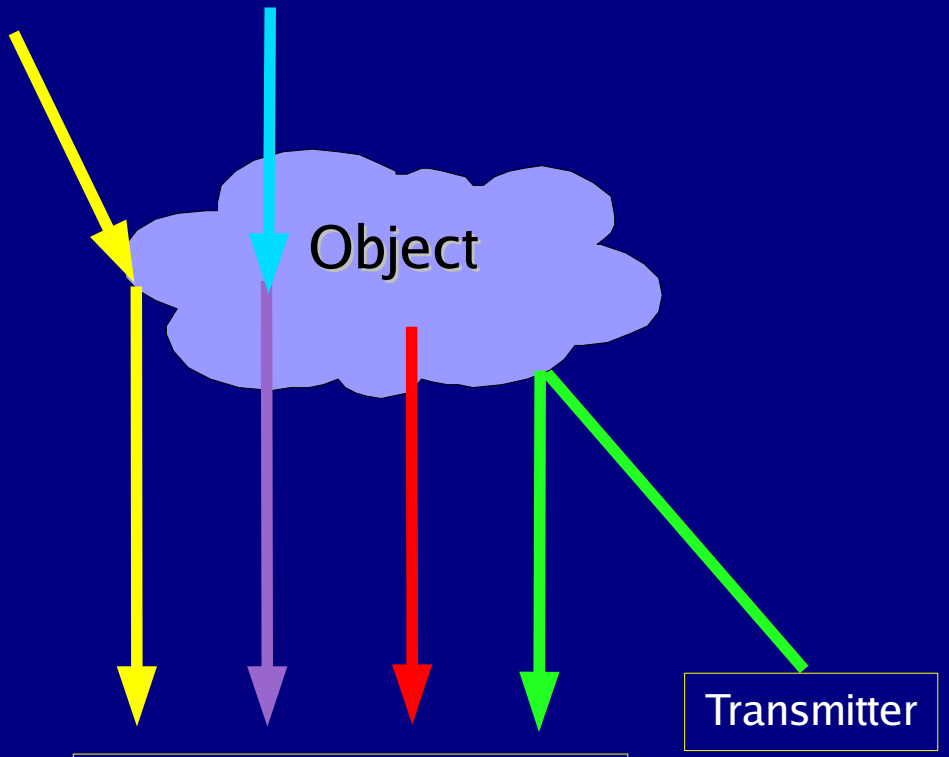
But what if the object is hidden ?

...or invisible to the human eye ?

...or too far away to see enough detail ?

Build instruments that use electromagnetic and sound waves to gather information about the object, and make an image / map / picture.

=> This is called "Remote Sensing"



Electromagnetic Waves

Reflection of ambient signal

Refraction and Absorption of background signal

Intrinsic Emission from the object

Artificial Illumination of the object

Detector
& Receiver System

Data Processing

Image

Spectrum

Time Series

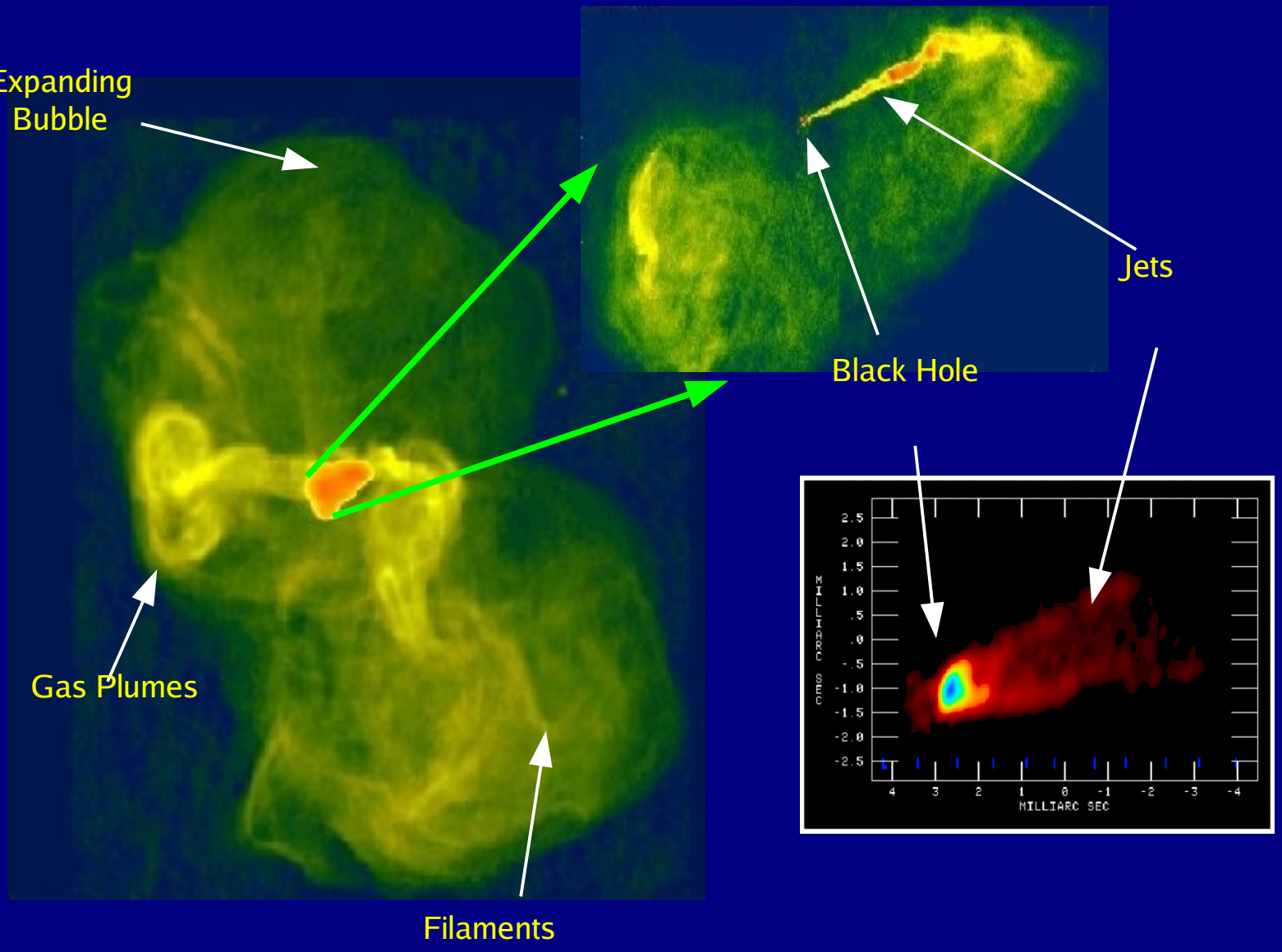
Structure
shape, brightness, size

Properties
mass,velocity,
temperature, density,
magnetic fields....

Chemistry
Ch_3OH, H_2O, NH_3....

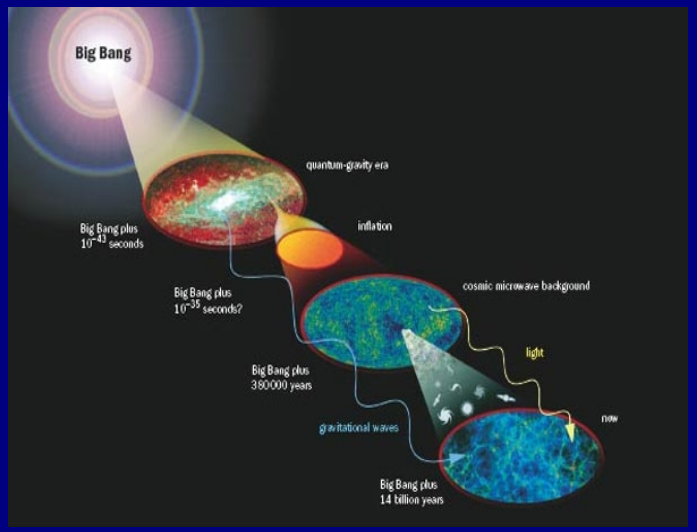
Space is a unique laboratory to observe extreme physics in action

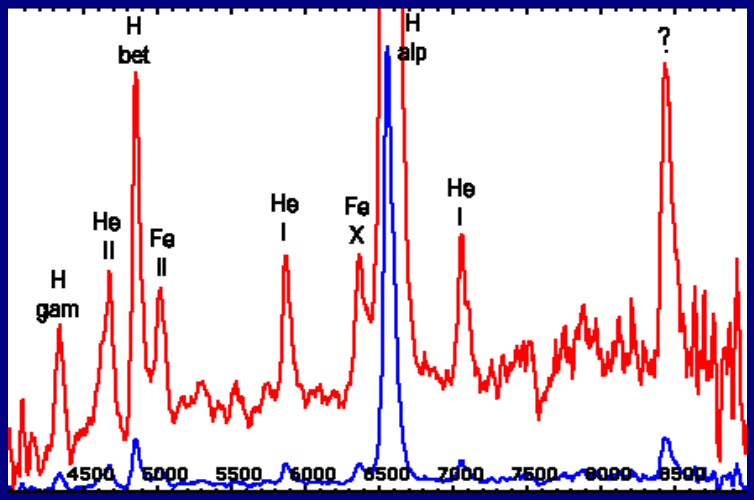
=> Can study processes that cannot be re-created on Earth



Looking farther away == Looking back in time

=> Can probe the history and evolution of the universe

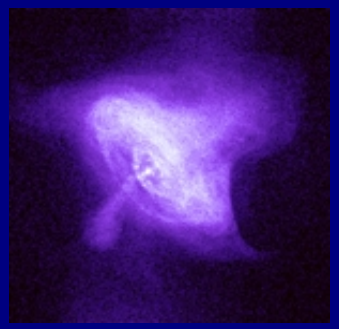




Measuring the chemical composition of matter in space

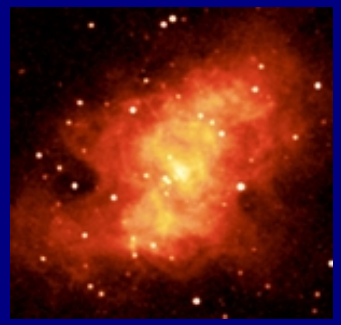
=> Can search for organic compounds to probe the origins of life

Make images at multiple wavelengths => Understand the larger picture

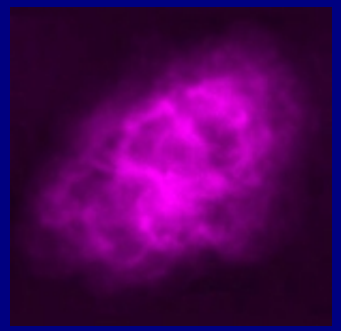


X-ray

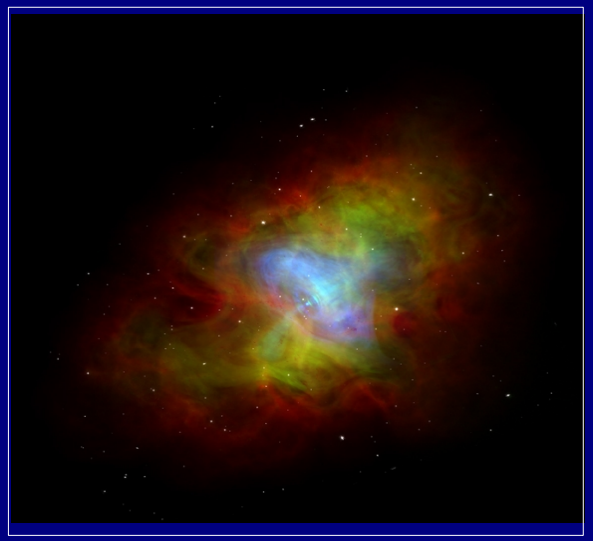
Optical
(visible)



Infra-Red

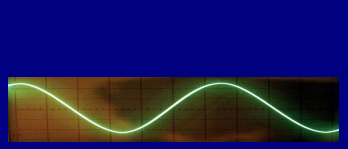


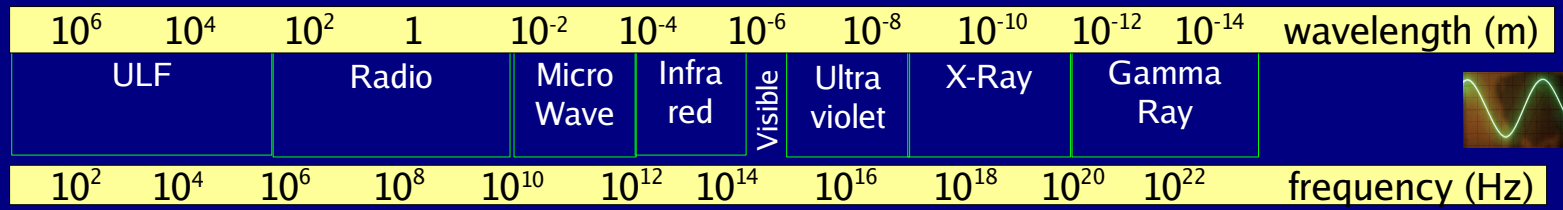
Radio

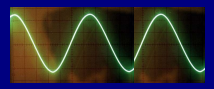


Crab Nebula

The Electromagnetic Spectrum







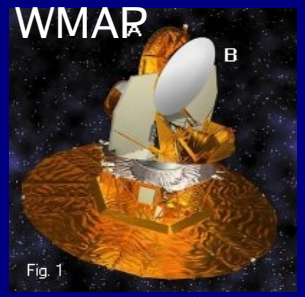
Objects can look different at different wavelengths (colours vs shades of grey)

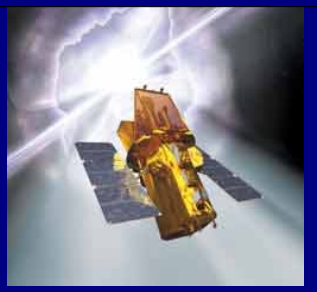
=> Make images at all wavelengths
with the same level of detail.

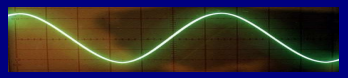
$$\text{Resolution} = \frac{\text{Wavelength}}{\text{Size of Detector}}$$

Fixed Resolution → Short Wavelengths => Small detector = Long Wavelengths => Large detector

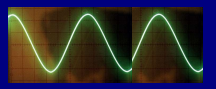
Detectors at Multiple Wavelengths (Astronomy)







10^{6}	10^{4}	10^{2}	1	10^{-2}	10^{-4}	10^{-6}	10^{-8}	10^{-10}	10^{-12}	10^{-14}	wavelength (m)
ULF		Radio		Micro Wave	Infra red	Visible	Ultra violet	X-Ray		Gamma Ray	
10^{2}	10^{4}	10^{6}	10^{8}	10^{10}	10^{12}	10^{14}	10^{16}	10^{18}	10^{20}	10^{22}	frequency (Hz)



Longer Wavelengths
(50m - 0.5m)

Cannot build larger dishes !!

How do you build a really large detector ?

Artificially create a large “dish”using many smaller ones...

Very Large Array

Austraila Telescope Compact Array

Giant Meterwave Radio Telescope

Westerbork Radio Telescope

... this is called ‘Aperture Synthesis ‘

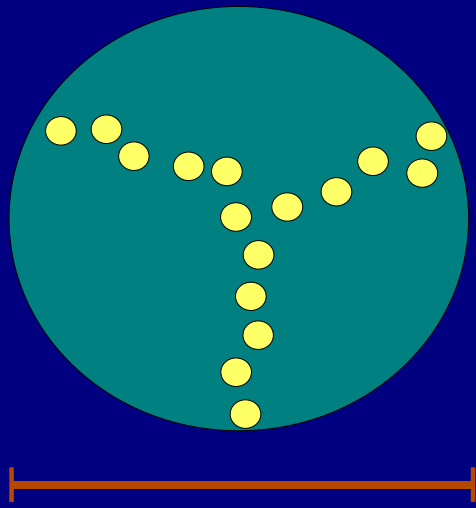
... used in many Remote Sensing applications.

How do you synthesize a large "dish" (aperture) ?

Single Dish

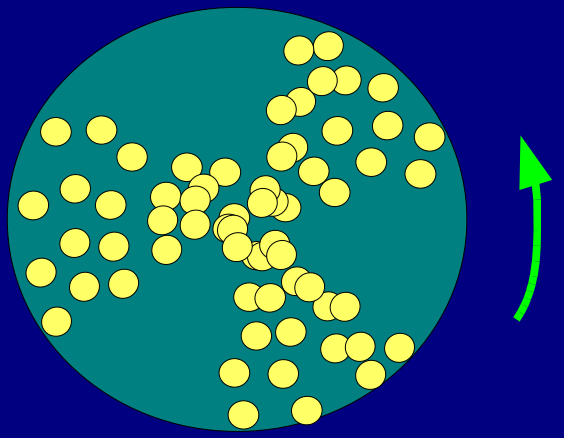
16 dishes, arranged in a "Y"

Synthesized aperture



Final diameter = Largest separation between antennas

As the Earth rotates...



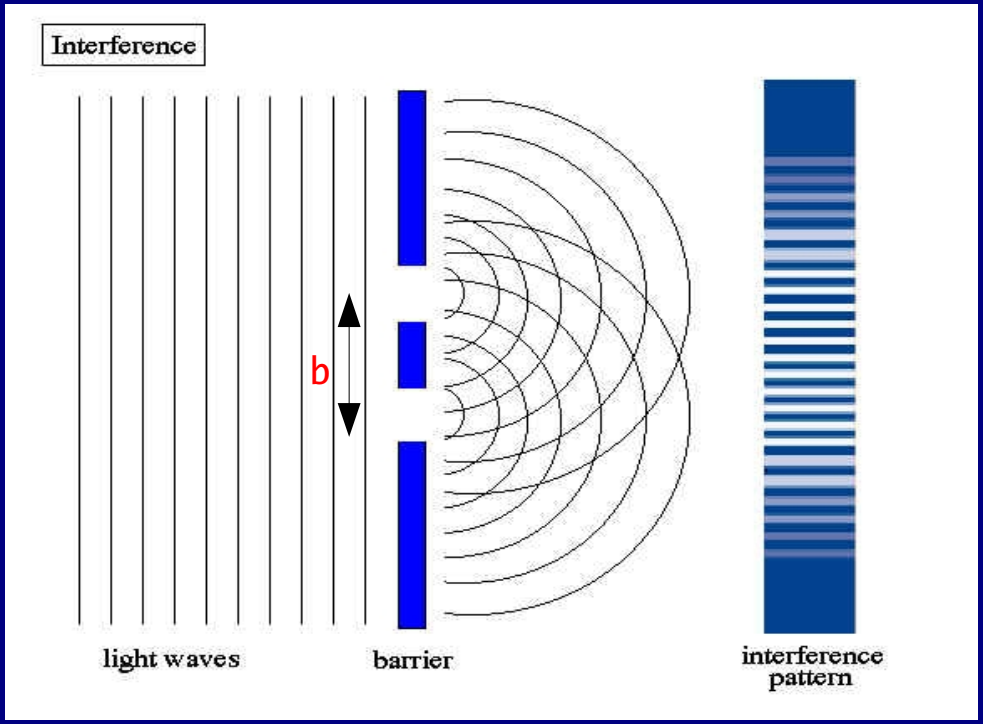
... the aperture fills up.

But ... this large "dish" is not a real "reflecting surface"... .

So how do you make it behave like one ?

... by imitating how an ordinary lens works.

Measure interference fringes

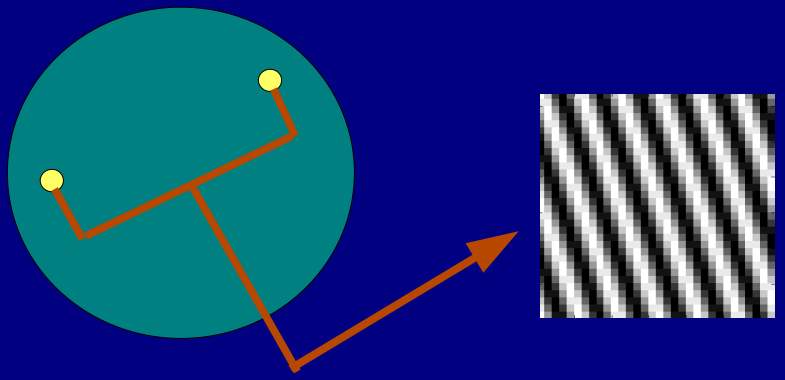


Young's Double-Slit Experiment

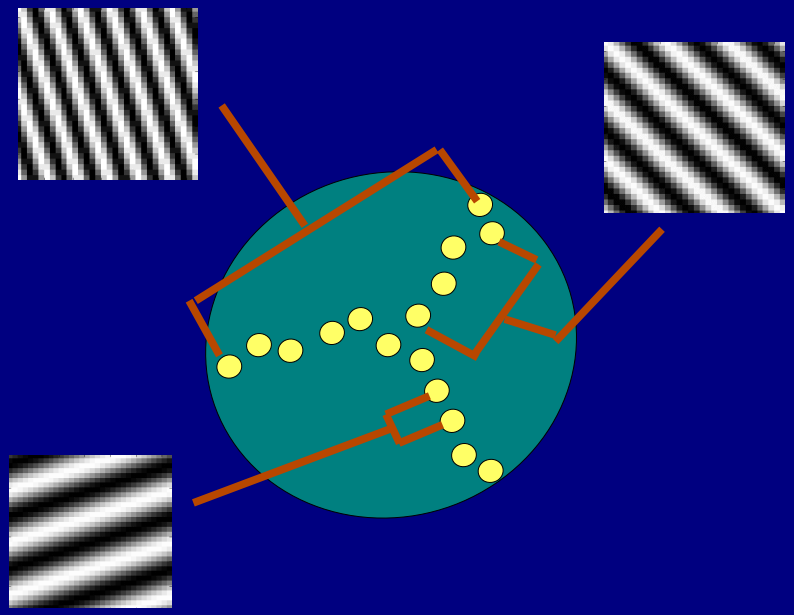
Distance between slits controls the wavelength of interference fringes

One dish == One slit

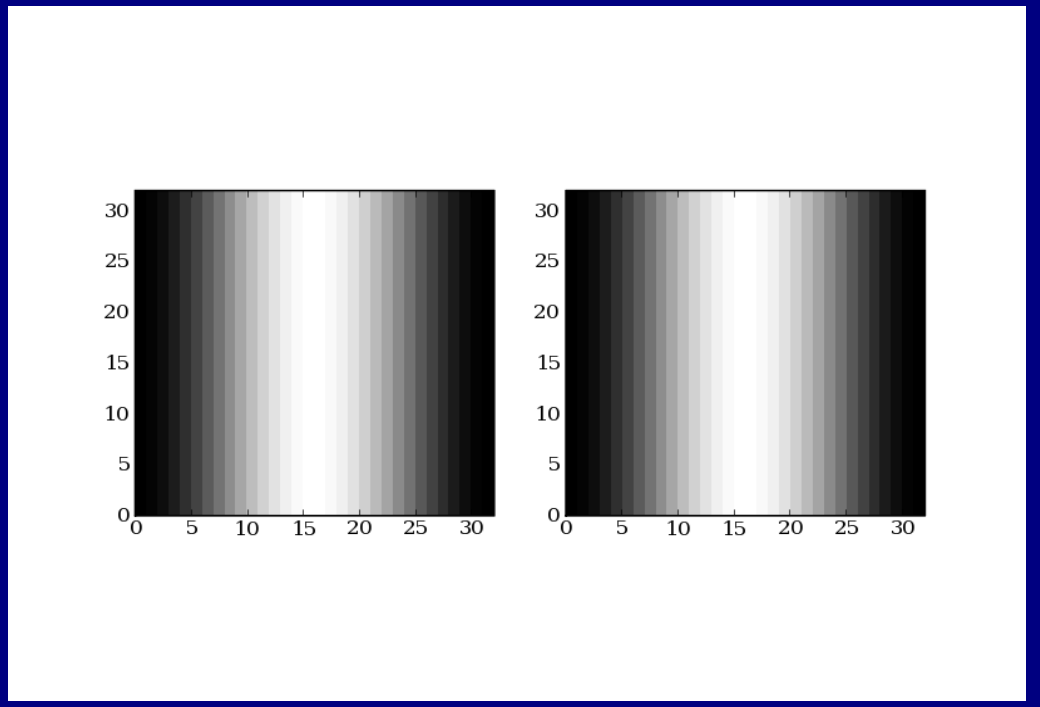
=> Each pair of antennas measures a different 2D fringe.



Fourier Synthesis



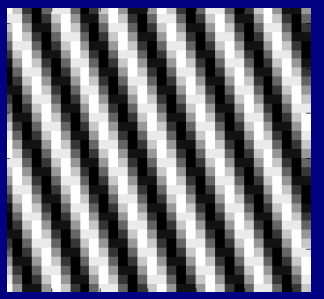
Fourier Transforms !!!



Measure and add up
enough different fringes

=> Good reconstruction
of the image

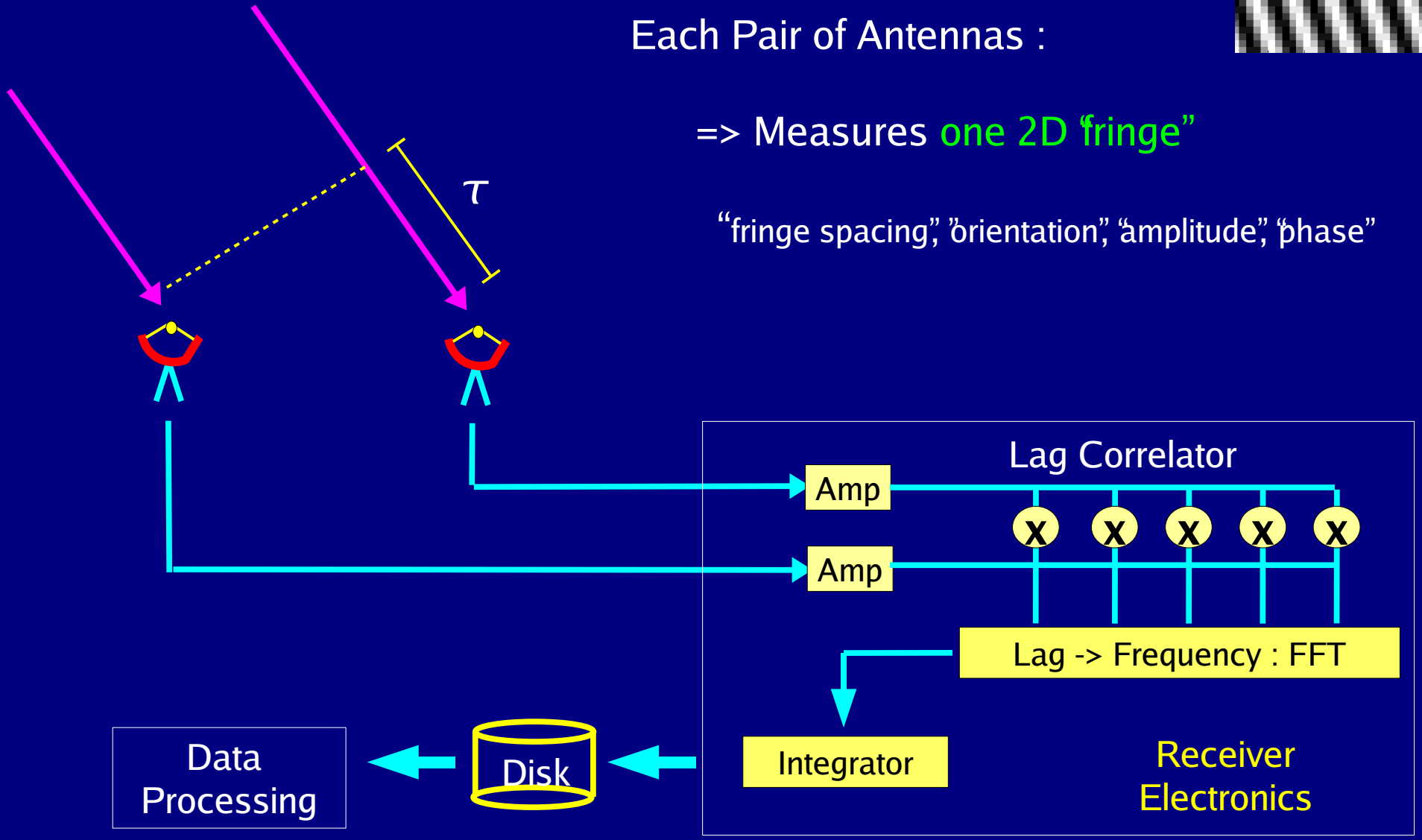
Signal Processing



Each Pair of Antennas :

=> Measures one 2D "fringe"

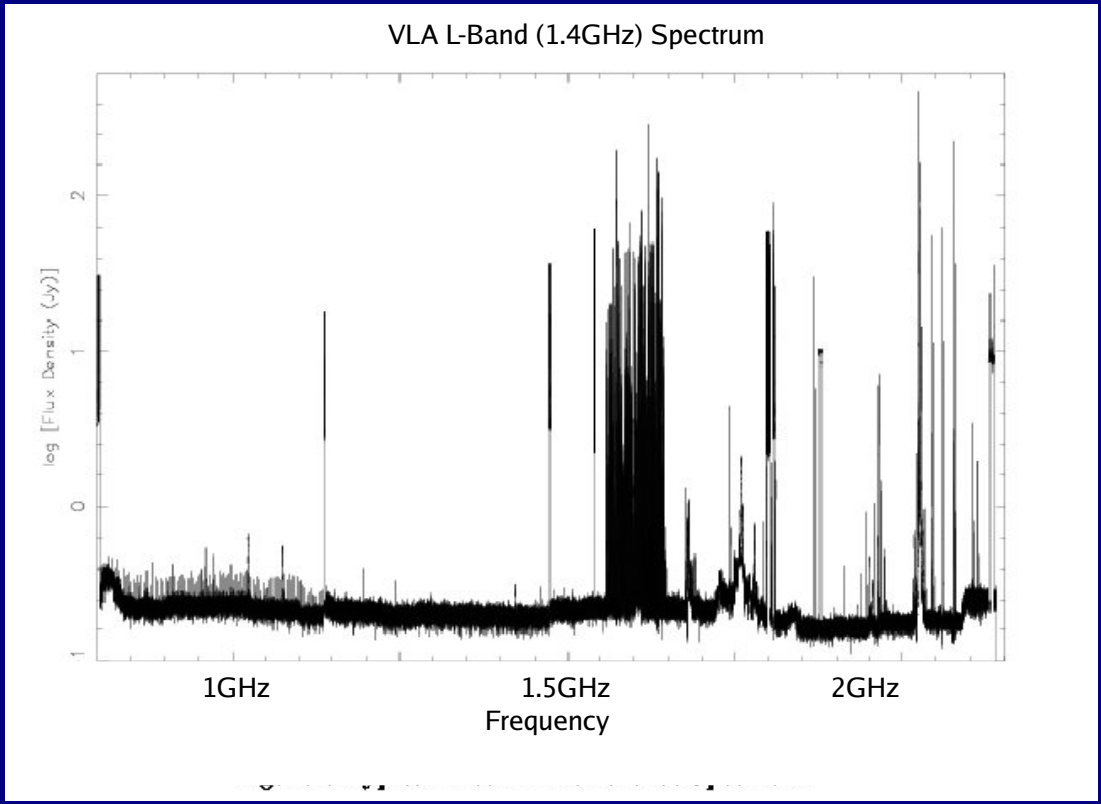
"fringe spacing", "orientation", "amplitude", "phase"



Data Processing - 1

(1) Editing

=> Need to Identify
and remove "bad data".



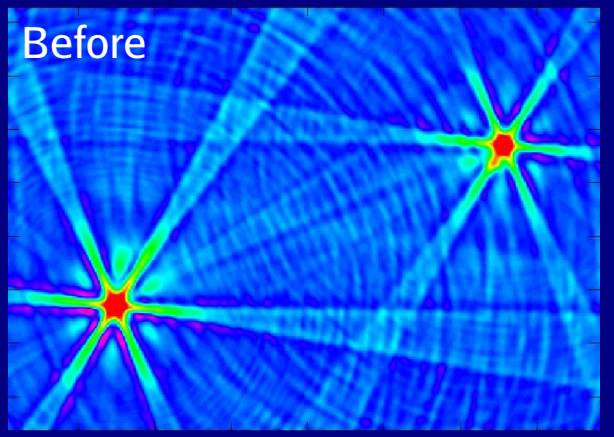
Stray signals : TV, Air-Traffic-Control, Radio stations,
Cell phone services, satellite communication signals, etc....

Data Processing - 2

(2) Instrument Calibration

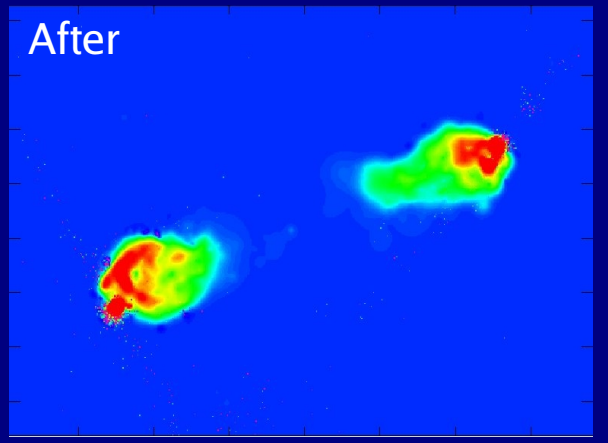
Fourier Optics needs ideal conditions

=> Need to model and remove instrumental effects



(3) Image Reconstruction

Artificially interpolate between measured Fourier terms to create the final image.



Steps (2) and (3) are done by "non-linear model fitting".

New Telescopes !

LWA, New Mexico, USA

LOFAR, The Nederlands

MWA, Australia

PAPER, Green-Bank (USA),
Murchison, Australia

At even longer wavelengths,
even single dishes cannot be built.

" Dishes"are built electronically from "dipoles "...

A Career in Astrophysics ?

Physics

- Interferometry, Astrophysics of objects in space ...

Instrumentation :

- Antennas, detectors, sensors, receivers ...

Signal and Image Processing :

- Signal Processing, Numerical Math ...

Computer Science :

- High-performance computing ...