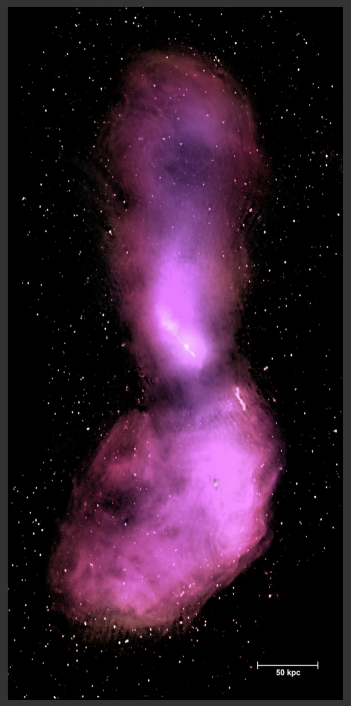
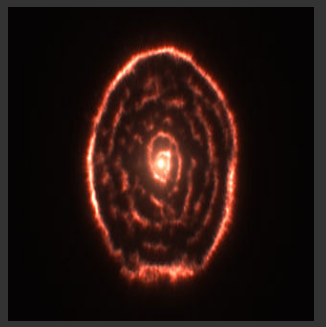
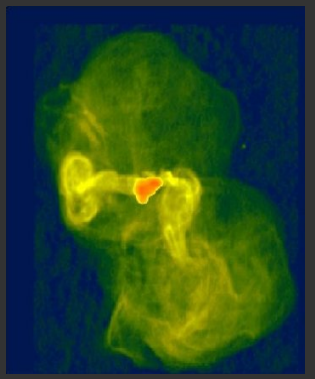
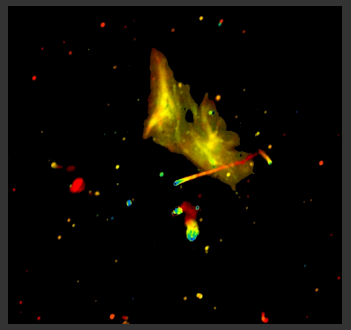
A radio eye on the Universe

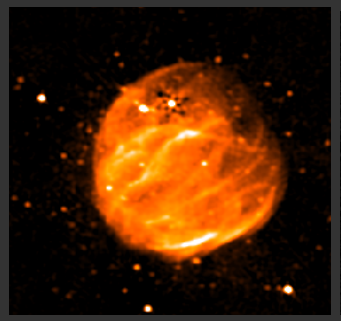


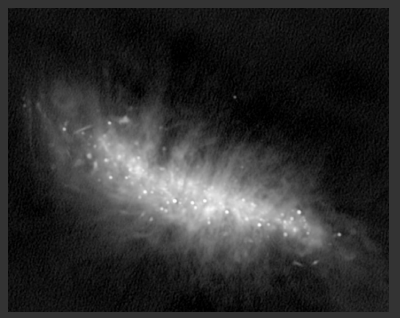
- Building a radio camera
- Making images of the radio sky
- Areas of technical research
- Future of this field





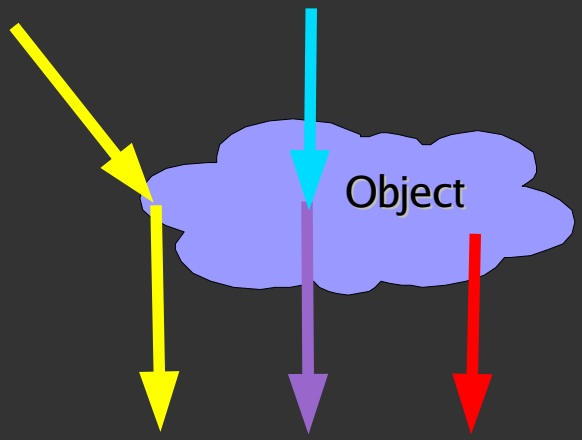




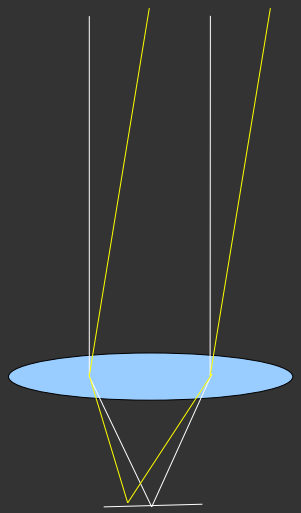


Urvashi Rau
National Radio Astronomy Observatory, USA.
18 Nov 2012, BITS-Goa

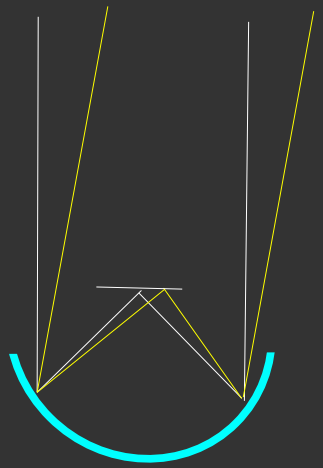
Making an image of an object



Electromagnetic Radiation



Lens
(Refractor)



Dish
(Reflector)

A lens (or dish) focuses parallel rays onto a detector in the focal plane

Make an image (a grid of pixels) by

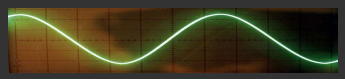
- Using a multi-pixel detector
- Pointing in different directions

Smallest separation between directions

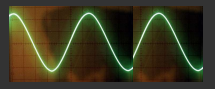
=> Resolution (diffraction limit)

= Wavelength / Diameter

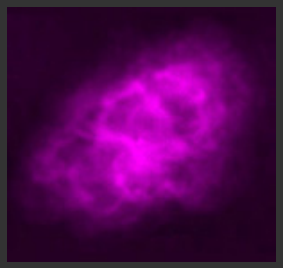
The Electromagnetic Spectrum



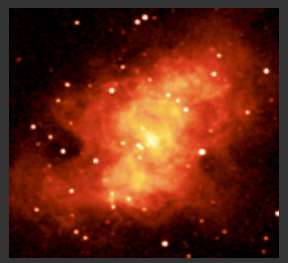
10^{6}	10^{4}	10^{2}	1	10^{-2}	10^{-4}	10^{-6}	10^{-8}	10^{-10}	10^{-12}	10^{-14}	wavelength (m)
ULF		Radio		Micro Wave	Infra red	Visible	Ultra violet	X-Ray		Gamma Ray	
10^{2}	10^{4}	10^{6}	10^{8}	10^{10}	10^{12}	10^{14}	10^{16}	10^{18}	10^{20}	10^{22}	frequency (Hz)



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

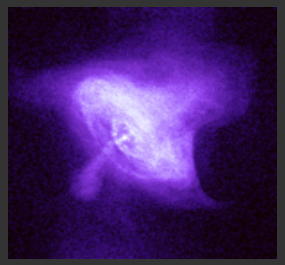


Radio

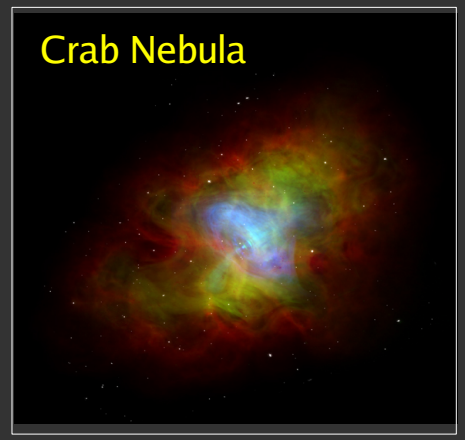


Infra-Red

Optical (visible)



X-ray

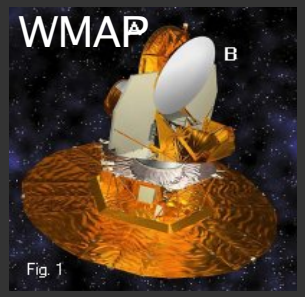


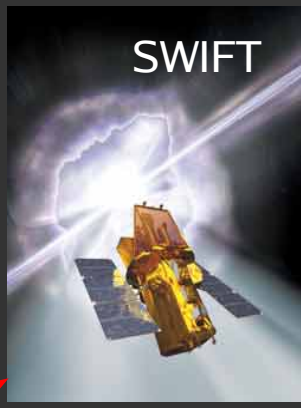
=> Want to make images at all wavelengths

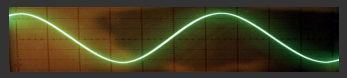
..... with the same level of detail.

$$\text{Resolution} = \frac{\text{Wavelength}}{\text{Diameter}}$$

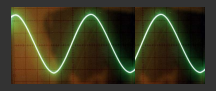
Detectors at Multiple Wavelengths





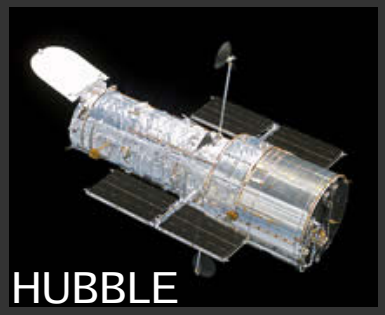


10^{6}	10^{4}	10^{2}	1	10^{-2}	10^{-4}	10^{-6}	10^{-8}	10^{-10}	10^{-12}	10^{-14}	wavelength (m)
ULF		Radio		Micro Wave	Infra red	Visible	Ultra violet	X-Ray	Gamma Ray		
10^{2}	10^{4}	10^{6}	10^{8}	10^{10}	10^{12}	10^{14}	10^{16}	10^{18}	10^{20}	10^{22}	frequency (Hz)



Longer Wavelengths
(50m - 0.5m)

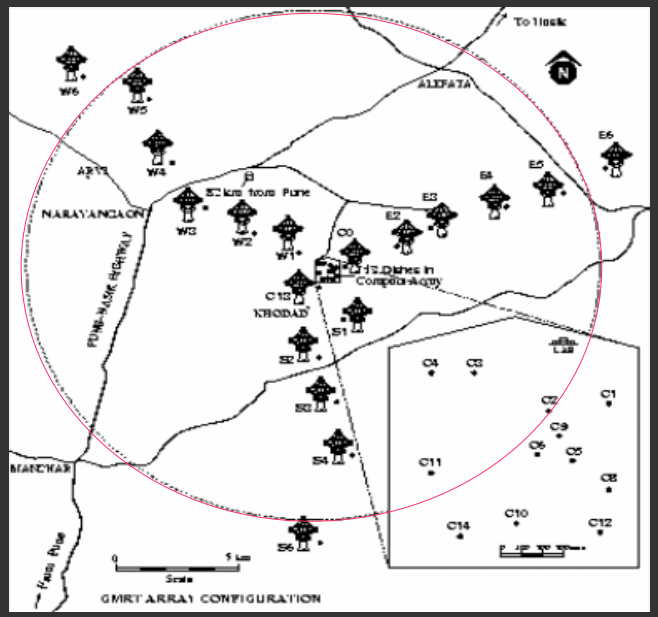
Cannot build larger dishes !!



Building a really large detector

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

Very Large Array



Giant Meterwave Radio Telescope

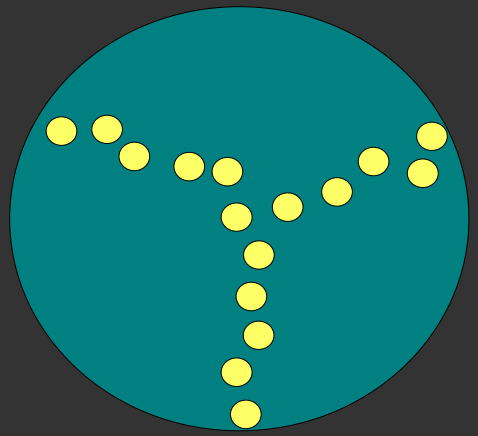
... this is called ‘Aperture Synthesis ‘

... used in many Remote Sensing applications.

Synthesize a large "dish"...

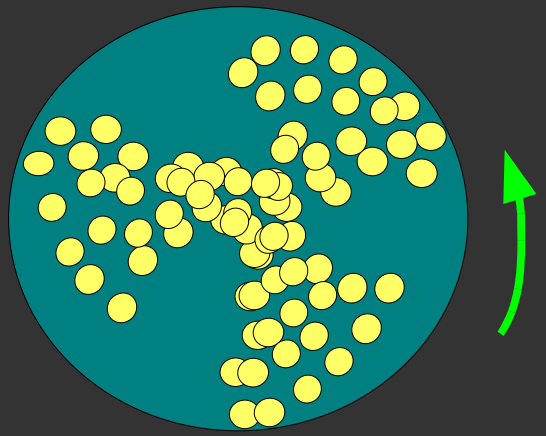
Single Dish

Synthesized aperture



Final diameter = Largest separation between dishes

As the Earth rotates...



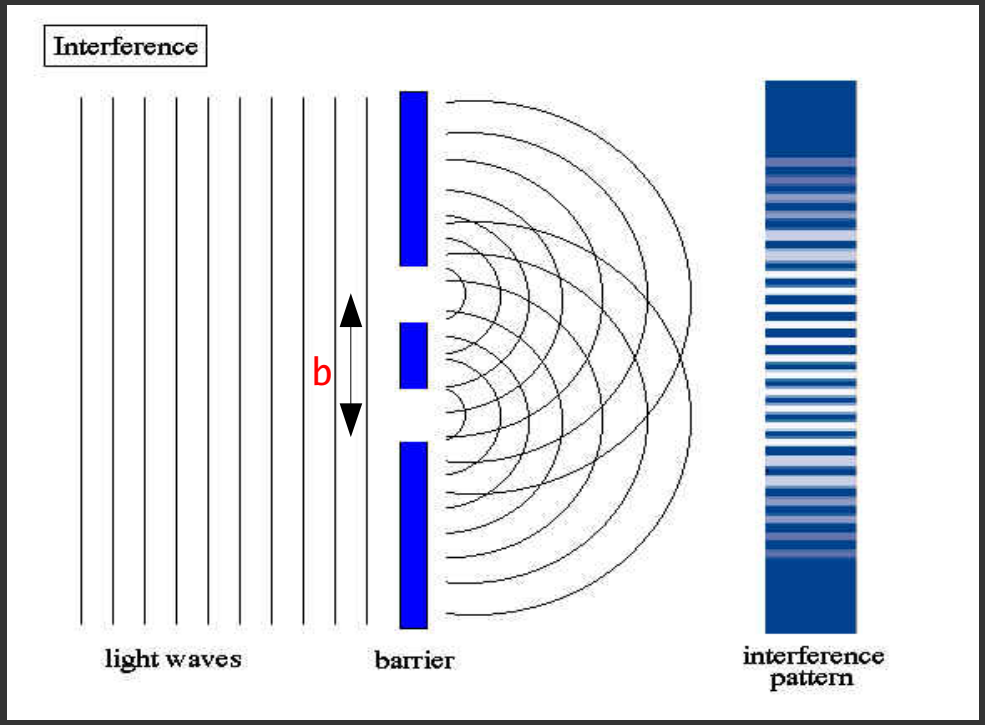
... the aperture fills up.

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

So how do you make it behave like one ?

... imitate the Physics of a lens.

Measure interference fringes

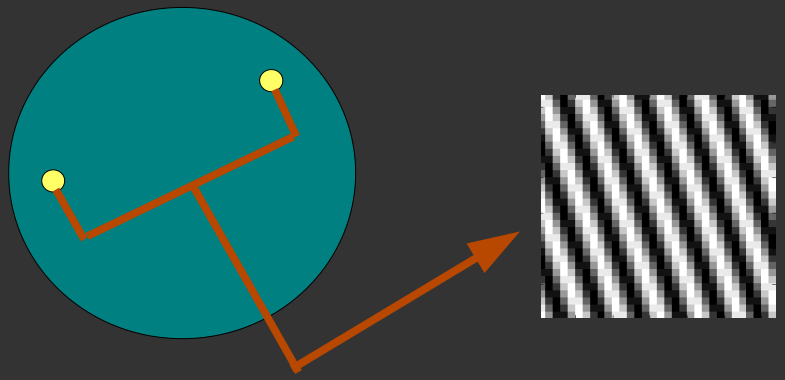


Young's Double-Slit Experiment

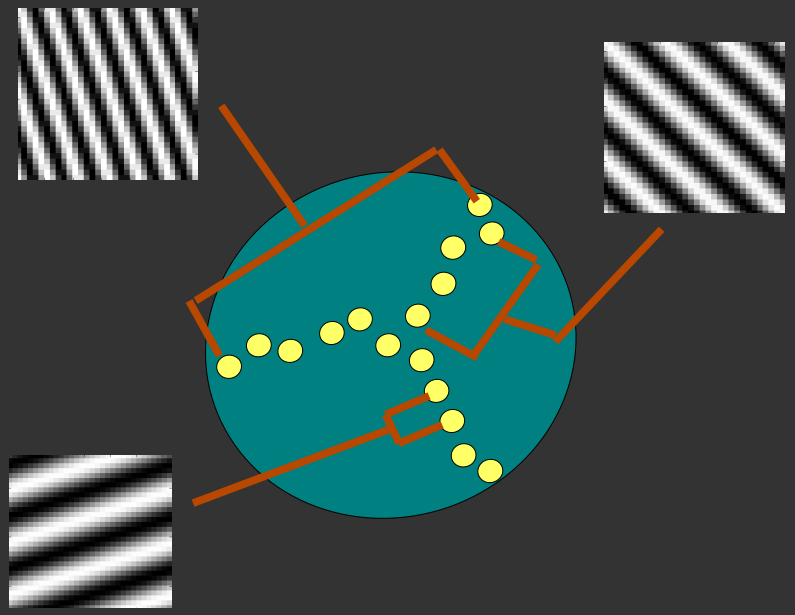
Distance between slits controls the wavelength of interference fringes

One dish == One slit

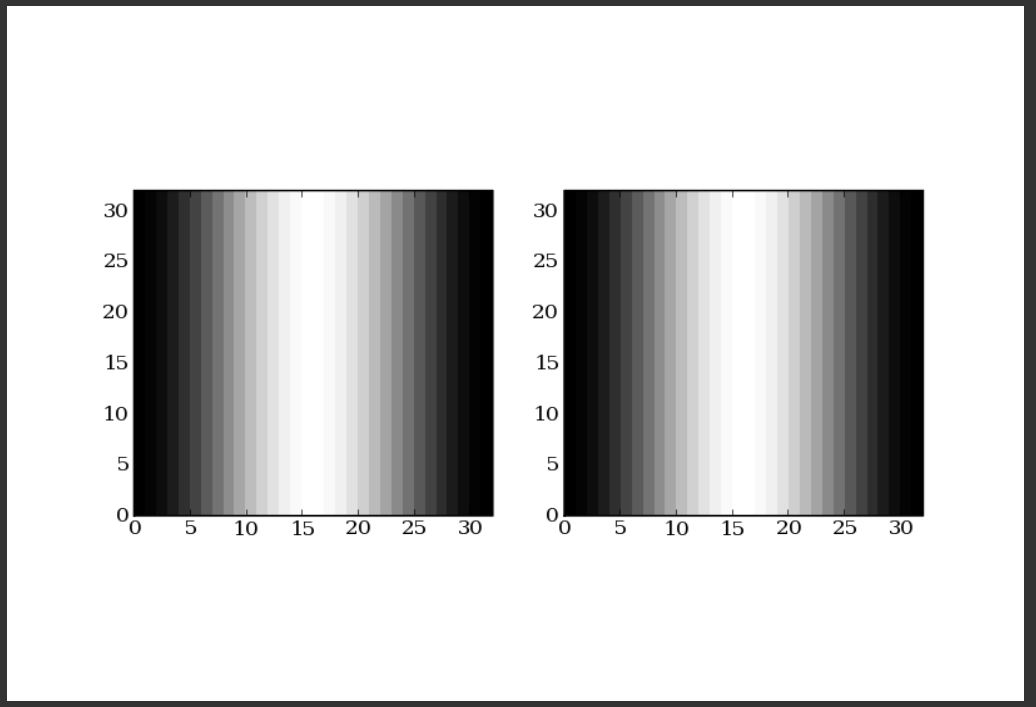
=> Each pair of antennas measures a different 2D fringe.



Fourier Synthesis



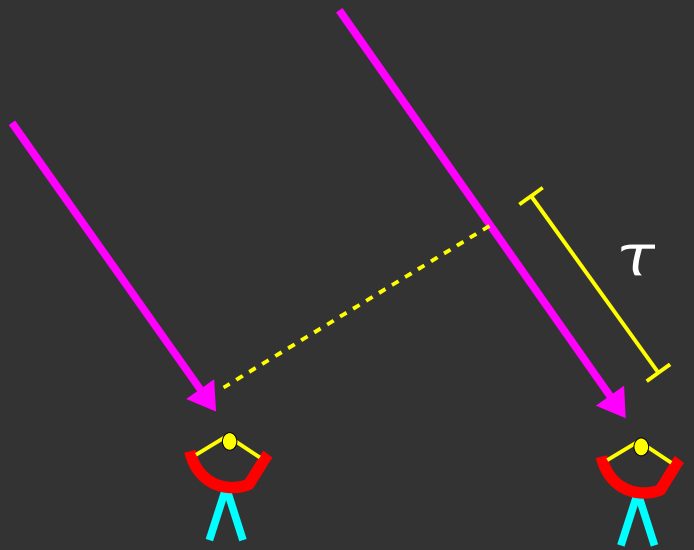
Fourier Transforms !!!



Measure and add up
enough different fringes

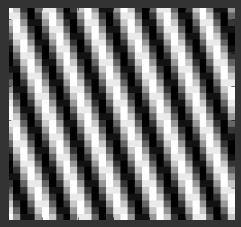
=> Good reconstruction
of the image

Signal Processing

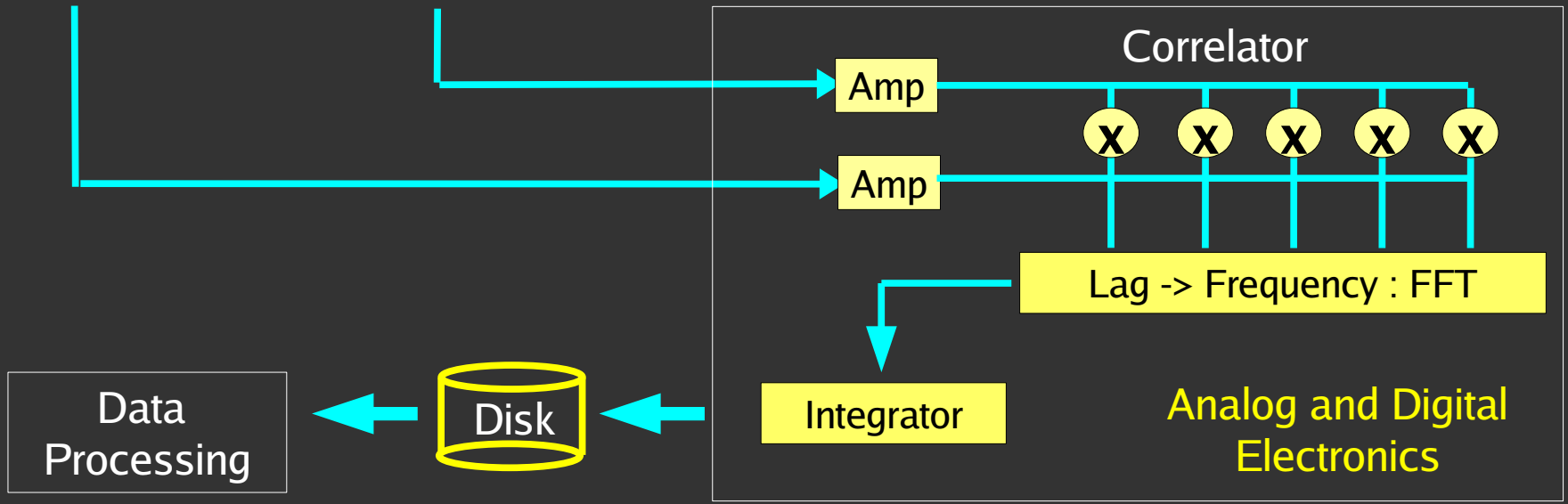


Each Pair of Antennas :

=> Measures one 2D "fringe"



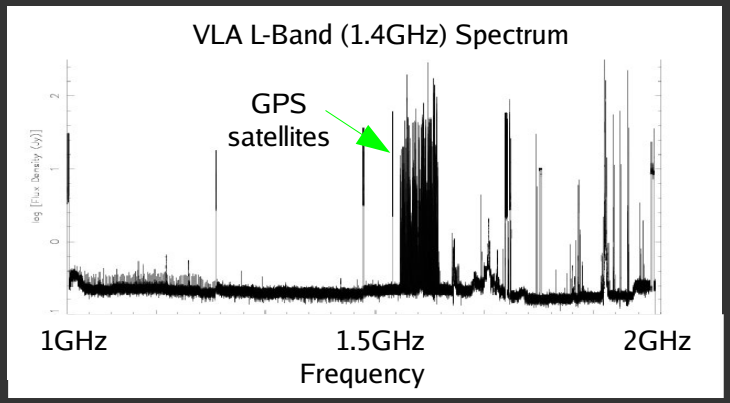
"fringe spacing", "orientation", "amplitude", "phase"



Data Processing

(1) Editing :

Some data are corrupted by man-made signals
=> Need to identify and remove bad data

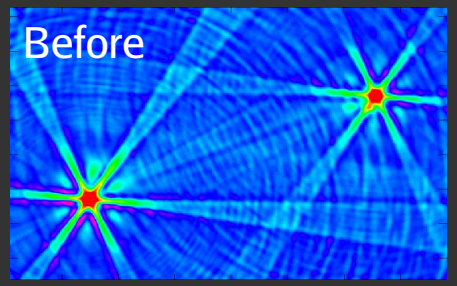


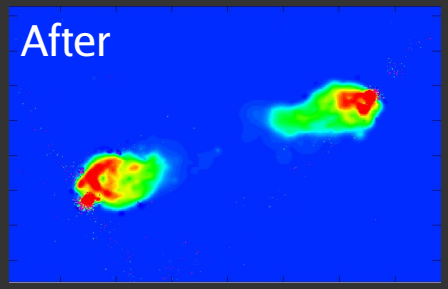
(2) Calibration :

Fourier Optics applies only under ideal conditions
=> Need to model instrumental effects and apply corrections.

(3) Image Reconstruction :

Only some Fourier terms are measured.
=> Need to estimate the others...

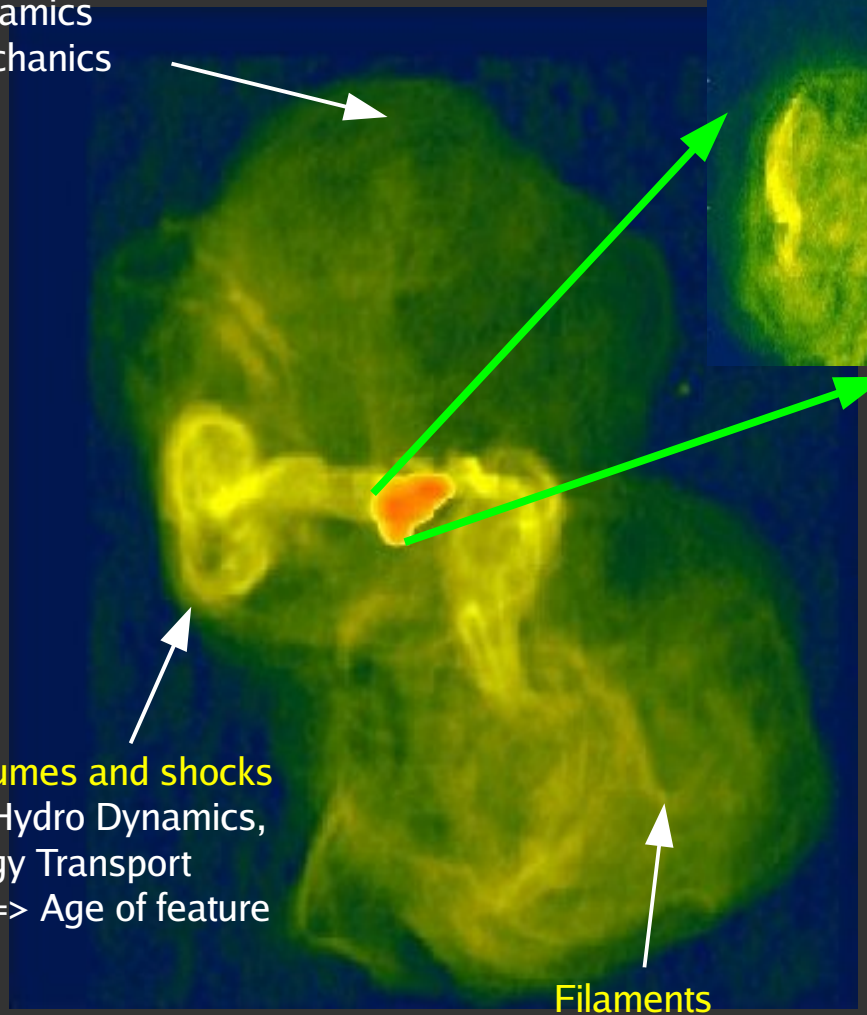




Uses concepts from Numerical Analysis, Optimization Techniques, Computational Physics, Fourier Transforms, Fourier Optics, Statistics, Digital Filters....

Extreme Physics in action

Can study processes that cannot be re-created on Earth

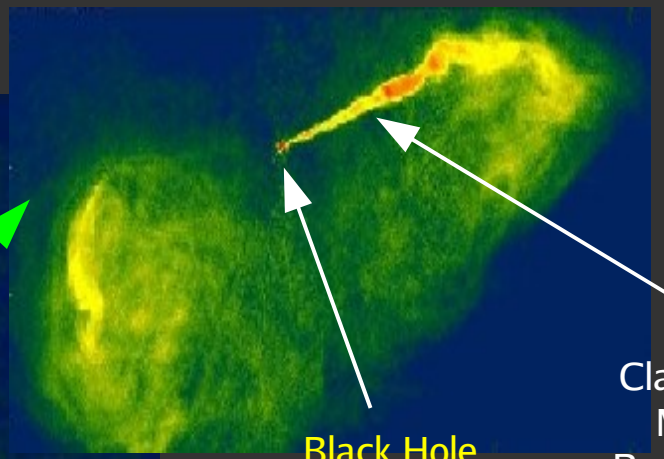


Expanding Plasma Bubble
Thermo-dynamics
Classical Mechanics

A Radio Galaxy
in the
Virgo Cluster

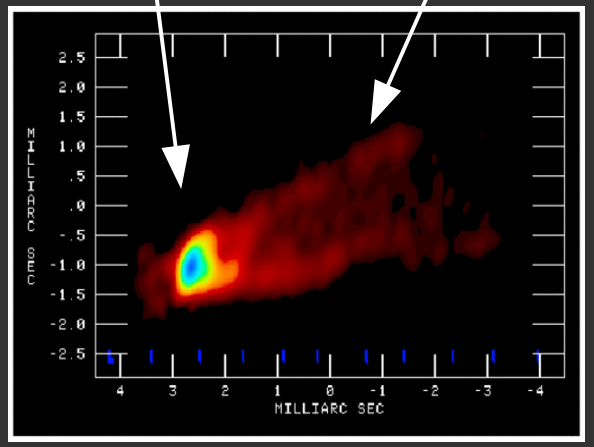
Plasma plumes and shocks
Magneto Hydro Dynamics,
Energy Transport
Spectrum => Age of feature

Filaments
Shock Physics
Energy Transfer



Black Hole
General Relativity
Magnetic Fields
High Energy Physics

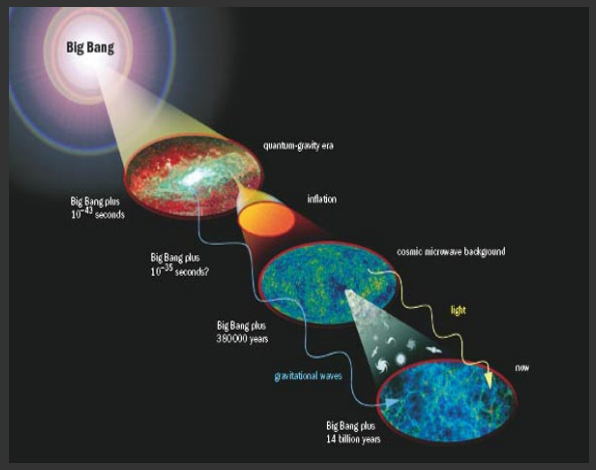
Jets
Classical Mechanics,
Magnetic Fields,
Radiative Processes,
Energy Transport



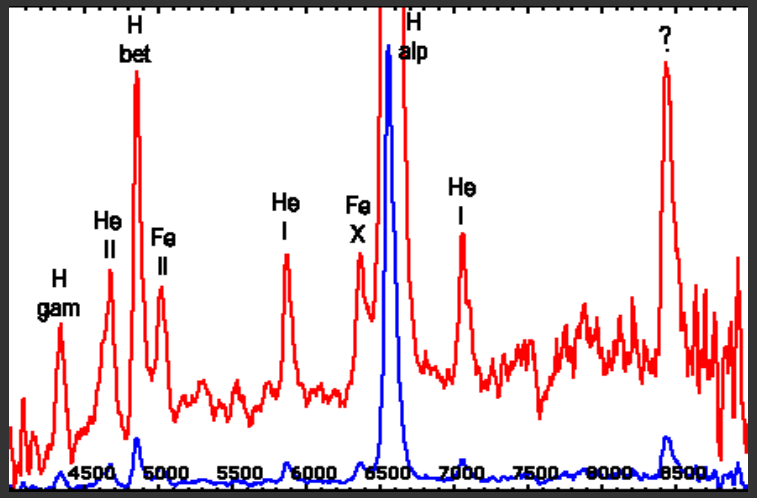
Cosmology

Looking farther away == Looking back in time

=> Can probe the history and evolution of the universe



Chemistry



Measuring the chemical composition of matter in space

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

=> Doppler shifts indicate physical movement.

Storming Aurora....

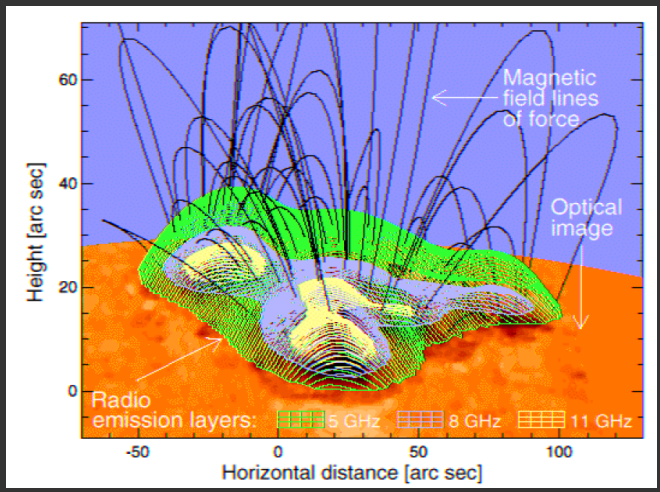
Space Weather –Solar flares send plasma flying towards the Earth

This can harm satellites in its path.

=> Need to understand and predict such flares

Magnetic fields on the sun's surface and in the plasma are best studied at radio wavelengths.

Can even get 3D information !



An interdisciplinary field of research

Physics and Optics :
- The working of a lens, the signature of physical processes

Instrumentation :
- Design and construction of detectors, sensors, receivers

Analog and Digital Signal Processing :
- Signal acquisition and validation, real-time processing

Numerical Mathematics :
- Algorithms for data analysis and image reconstruction

Computer Science :
- High-performance computing, database management





Other applications : Geographical Information Systems, Medical Imaging, Non-destructive Testing, Ground-penetrating Radar, Satellite Radar, ...

This work happens at : Radio Observatories, Many Universities, Govt. Research Labs, Companies like General Electric, Phillips, Siemens, ...

(Some) Radio Telescopes of the World...

How to learn more at BITS.....

- Be adventurous with electives and projects !
  - Explore cross-disciplinary areas

- Get core-coursework in multiple disciplines (dual-degree).
  - Physics / Math + EEE / Instrumentation / Comp.Sc

- Attend summer schools and internships
  - National Centre for Radio Astrophysics, TIFR, Pune (www.ncra.tifr.res.in)
  - Inter-University Centre for Astronomy and Astrophysics, Pune (www.iucaa.ernet.res.in)
  - Raman Research Institute, Bangalore (www.rri.res.in)
  - Indian Institute of Astrophysics, Bangalore (www.iiap.res.in)
  - Indian Space Research Organization, Bangalore (www.isro.org)
  - National Remote Sensing Agency, Hyderabad (www.nrsa.gov.in)

Explore, explore and explore some more until you figure out what fascinates you the most. BITS is a great place to do this.