Remote Sensing at its extreme :
the Inter-Disciplinary nature of Observational Radio Astronomy

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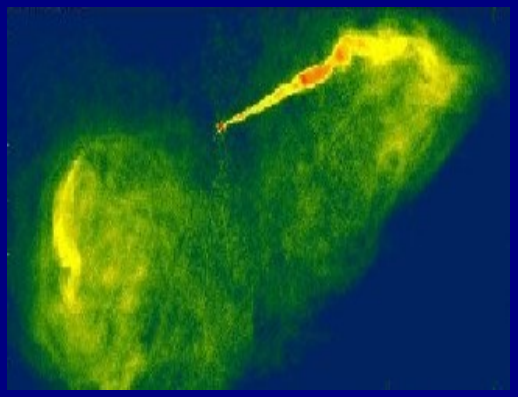
Astrophysics

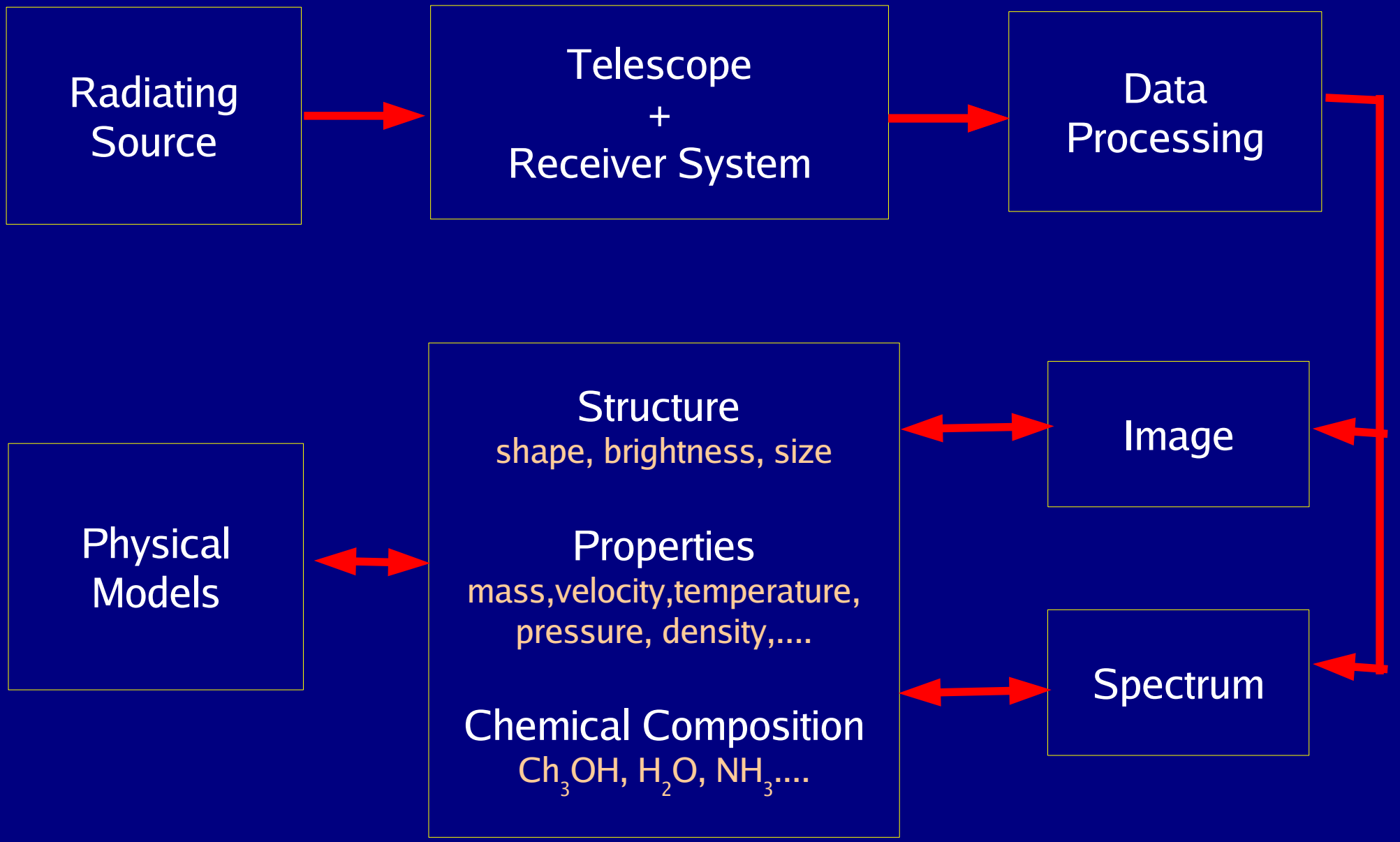


Instrumentation

Computing

... What's new ?

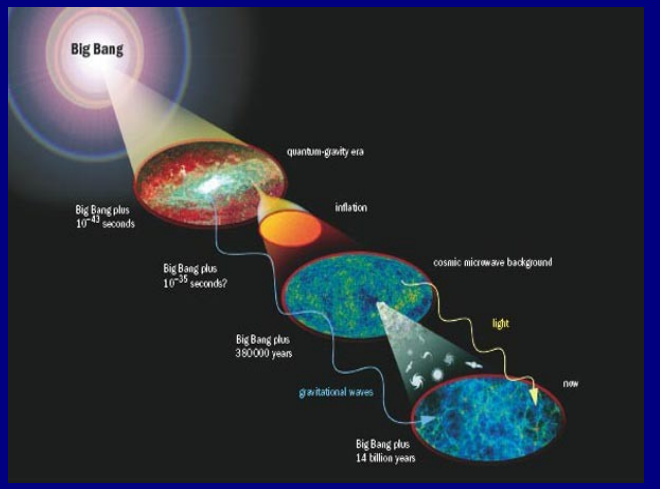
What is Astrophysics ?



Why do Astrophysics ?

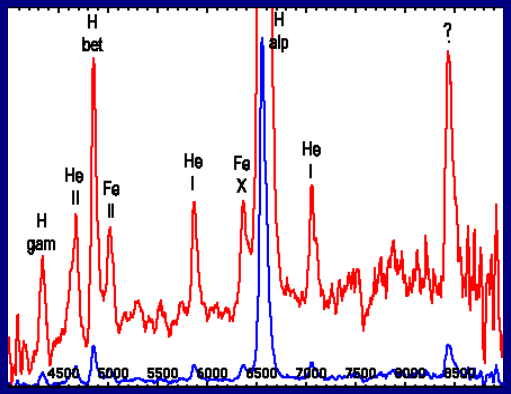
- Space is a unique laboratory to observe extreme physics in action

=> 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

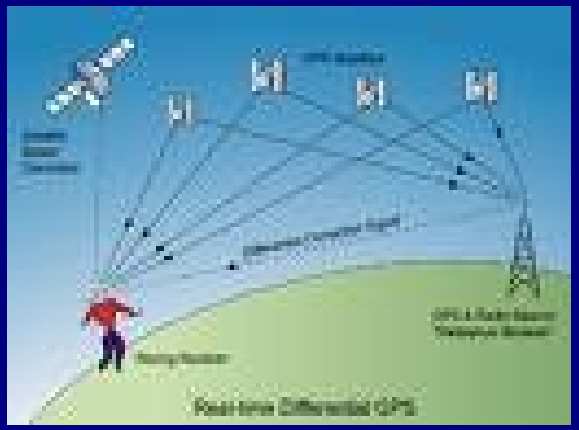


- Measuring the chemical composition of matter in space

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

Any practical use ?

- New Physics can feed back onto every-day life



=> Did you know that the GPS (Global Positioning Satellite) system could not have worked if Einstein's General Relativity had not been tested via astrophysics ?

(Ask Google : "GPS and Relativity")

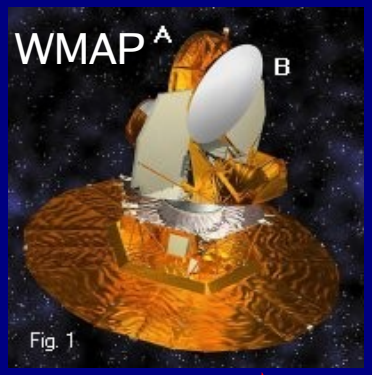
- Pushes technology to build better instruments (sensors)

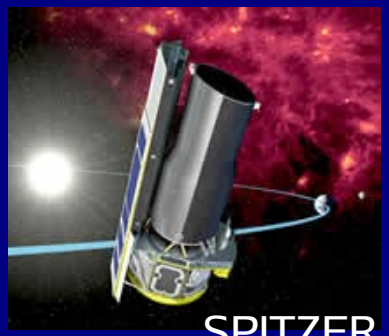
=> Electromagnetic waves from space are extremely weak

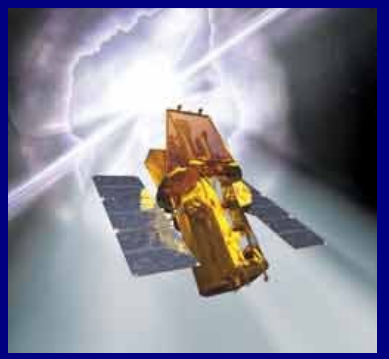
At radio frequencies, power is measured in units of "Jansky" (1Jy = 10^{-26} Watts/m^2Hz)

High frequencies : Build spacecrafts to get away from Earth's atmosphere
Low frequencies : Build very large ground-based detectors

Detectors at Multiple Wavelengths







Telescope Resolution

wavelength
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diameter

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)

Low Radio Frequencies
Longer Wavelengths
(50m - 0.5m)

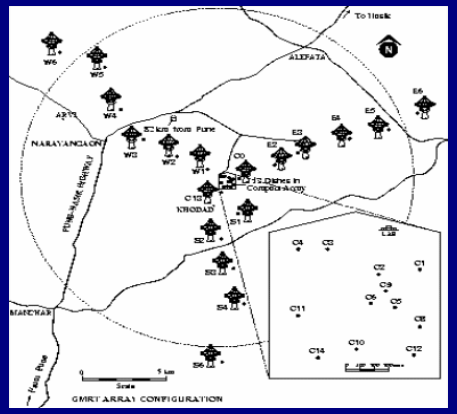
Cannot build larger dishes !!

Low Radio Frequencies : Interferometry

Artificially synthesize a large "dish" using many smaller ones...

Giant Meterwave Radio Telescope, 80km N of Pune, India
Operated by National Centre for Radio Astrophysics, T.I.F.R

150 MHz -> 1450 MHz, 30 dishes (45m each) spread across 27km



Array Configuration

Very Large Array, New Mexico, USA
Operated by National Radio Astronomy Observatory

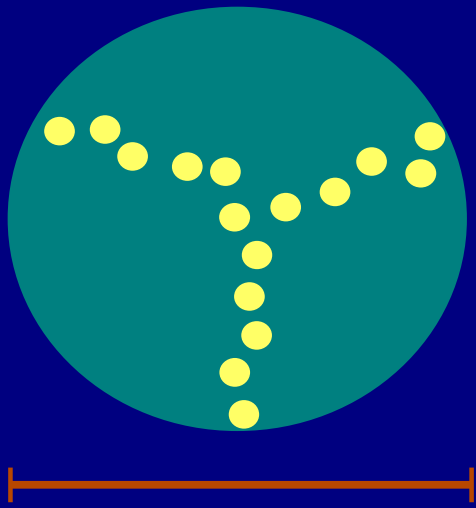
300MHz -> 22GHz, 27 dishes (25m each) spread across 30km

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

Single Dish

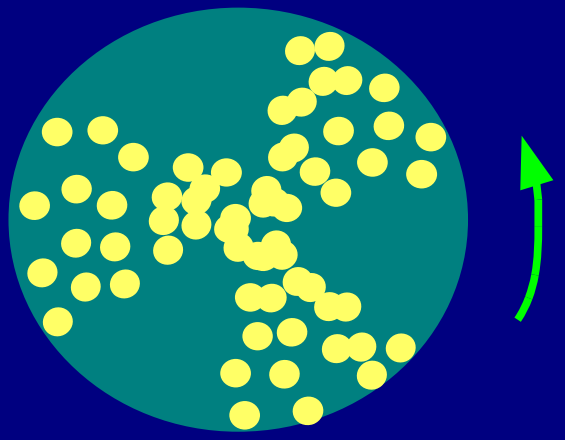
16 dishes, arranged in a "Y"

Synthesized aperture



Final diameter = Largest separation between antennas

As the Earth rotates...



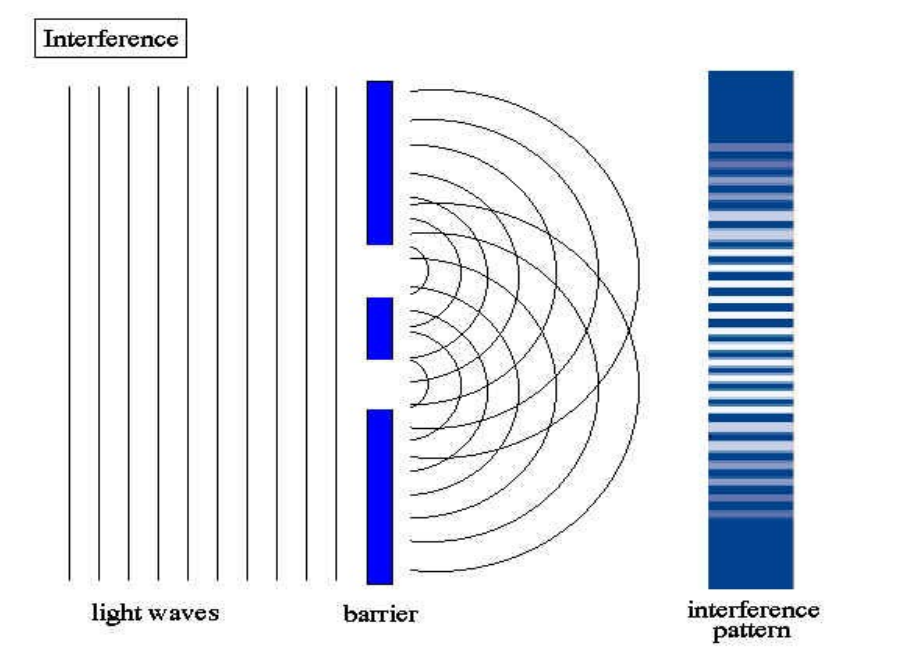
... the aperture fills up.

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

So how do you make it behave like one ?

... think about how an ordinary lens works.

Measure interference fringes



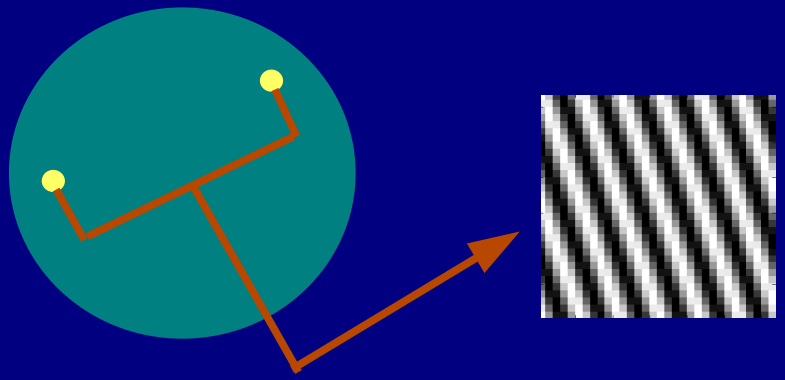
http://vsg.quasihome.com/interfer.htm

Young's Double-Slit Experiment

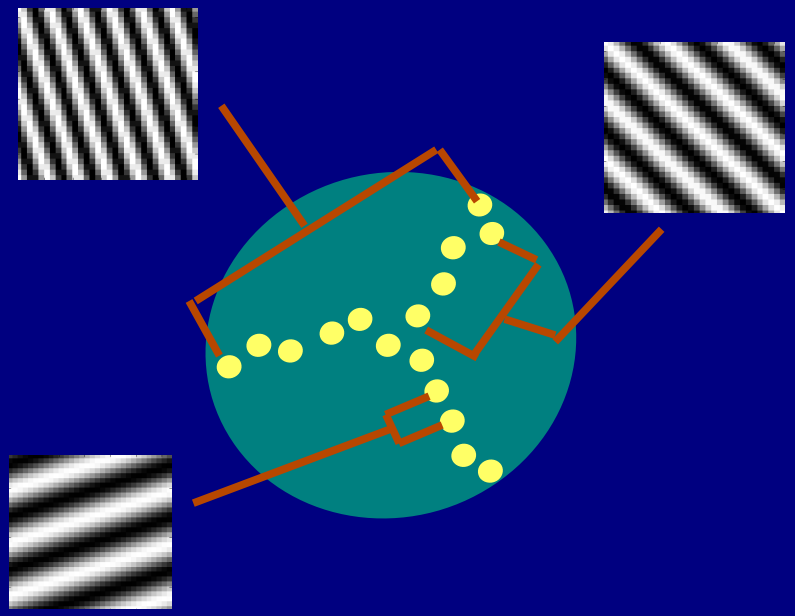
Distance between slits controls the wavelength of interference fringes

One dish == One slit

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



Fourier Synthesis

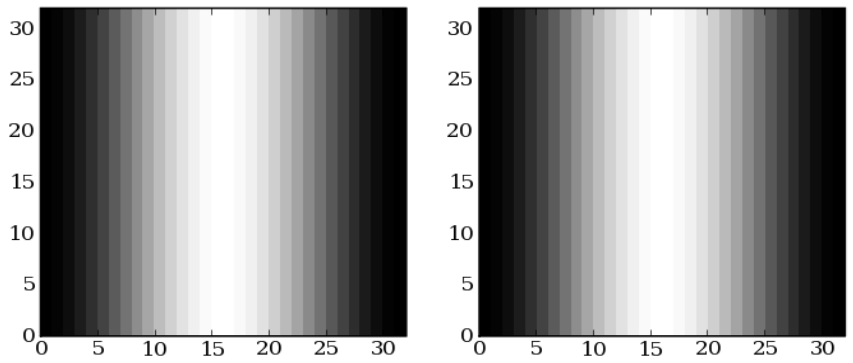


Measure and add up enough different fringes

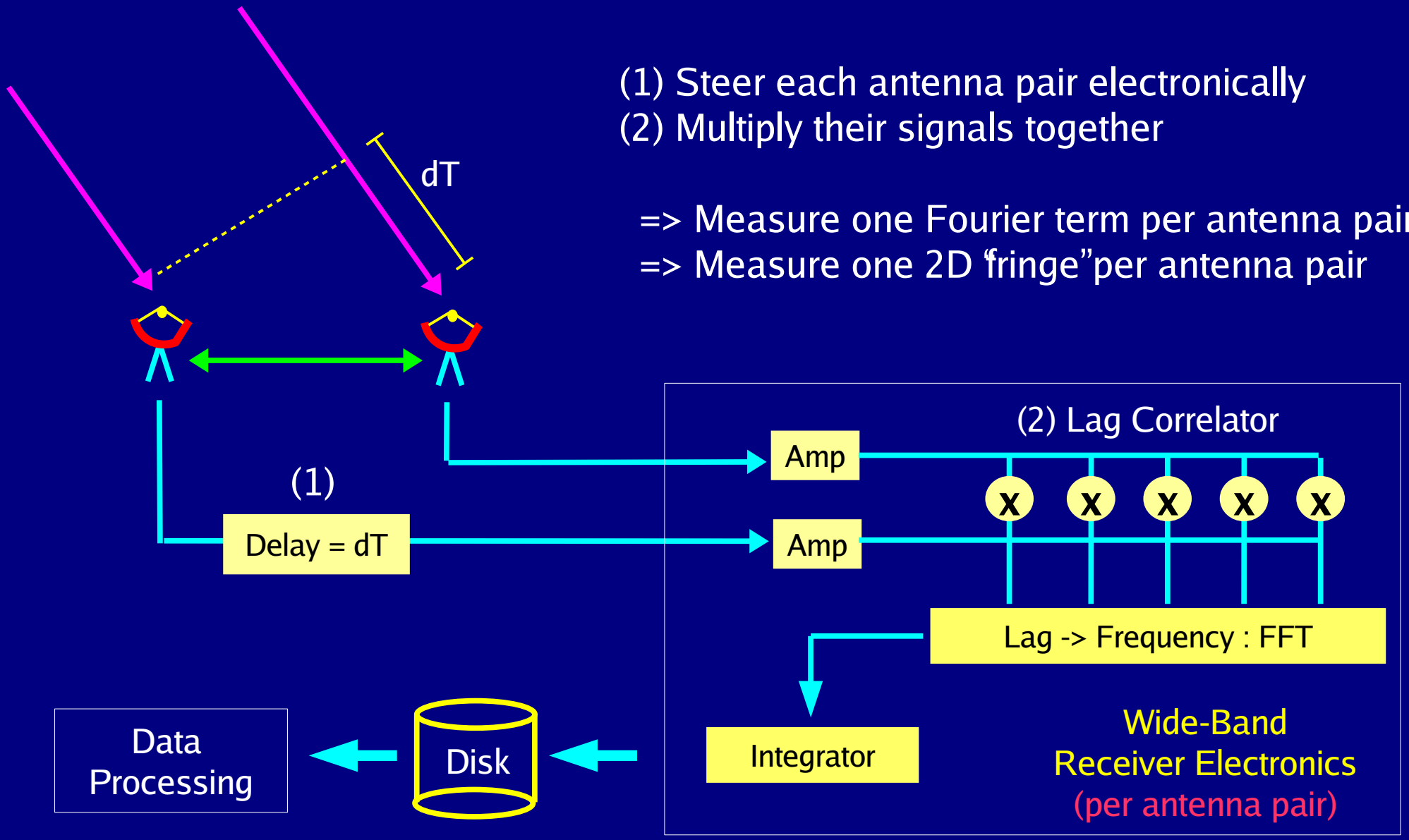
=> Good reconstruction of source structure

Fourier Transforms !!!

Form an image by adding together different Fourier terms.



Signal Processing



(1) Steer each antenna pair electronically
(2) Multiply their signals together

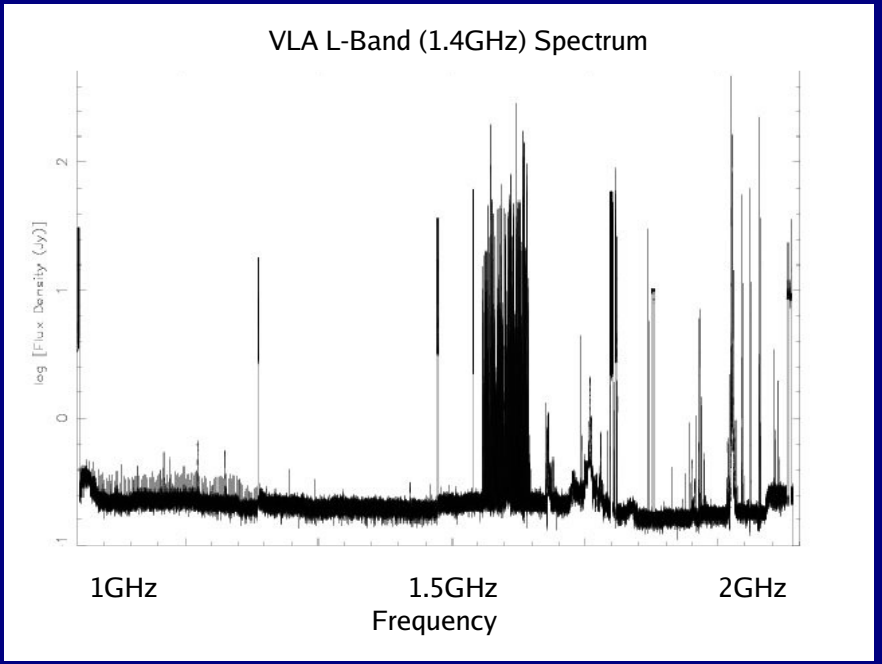
=> Measure one Fourier term per antenna pair
=> Measure one 2D "fringe" per antenna pair

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....



(2) Instrument Calibration

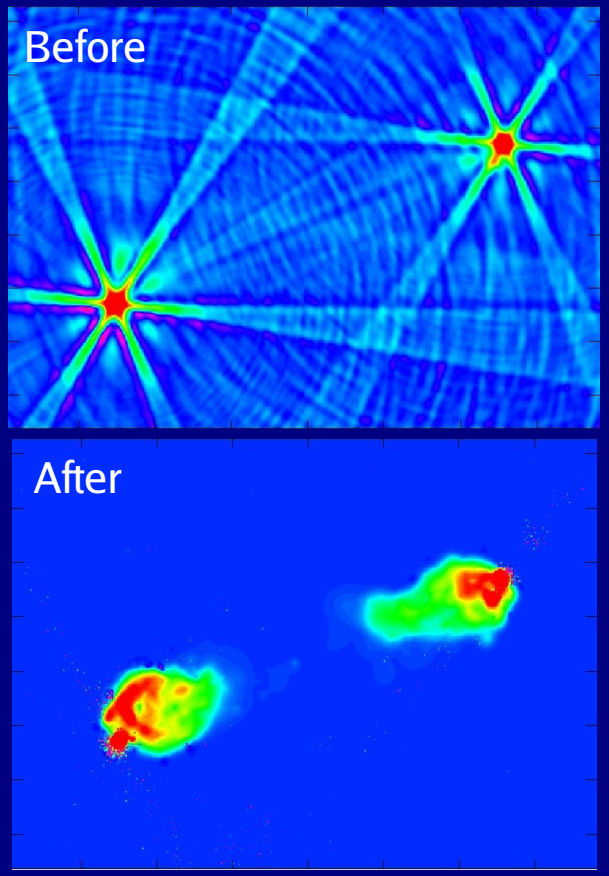
Fourier Optics applies only under some ideal conditions

=> Need to model instrumental effects and apply corrections to the data before creating an image.

Data Processing - 2

(3) Image Reconstruction

- Need to artificially interpolate between measured Fourier components to create the final image.



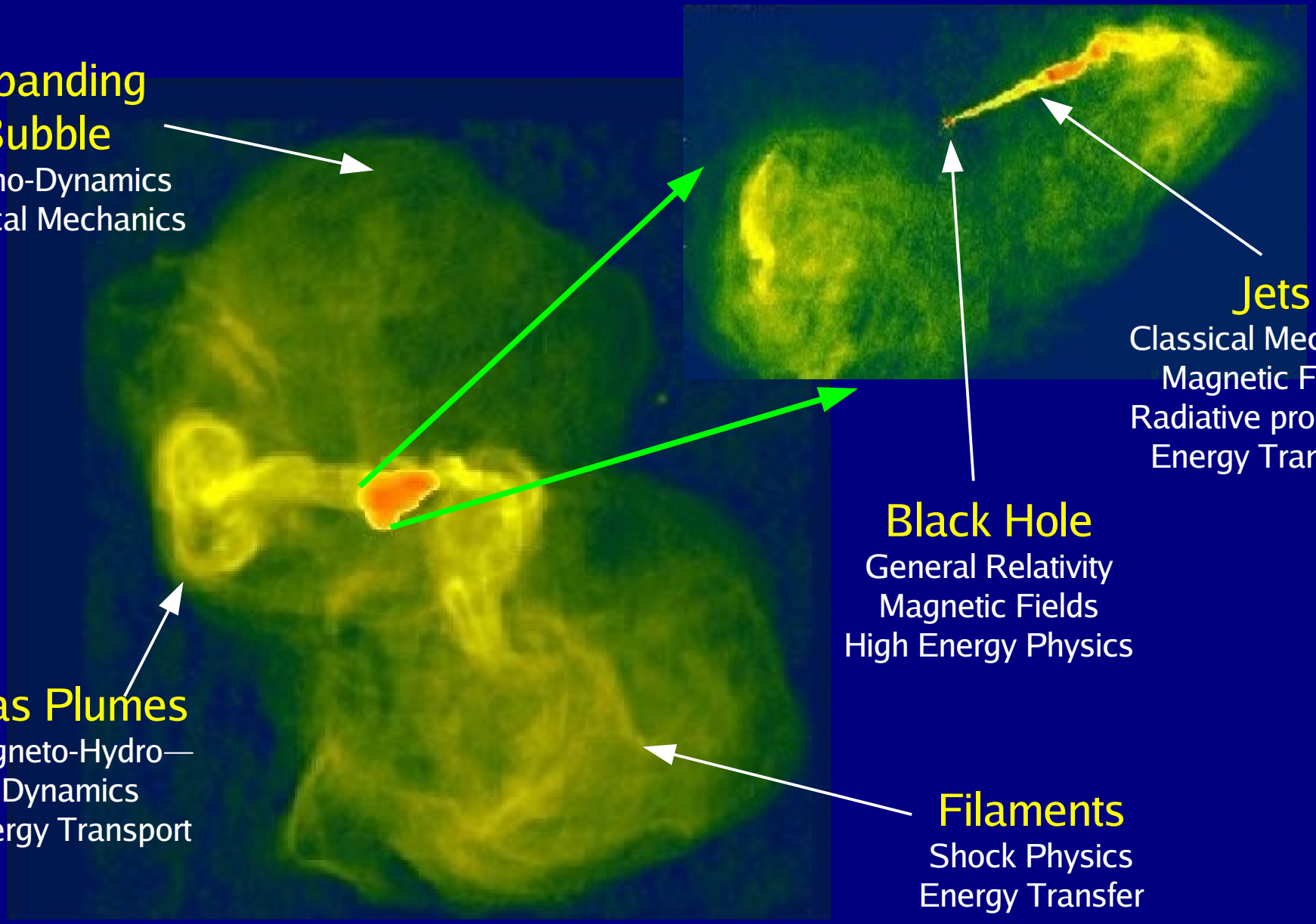
Steps (2) and (3) are done by

"non-linear model fitting".

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

Implementation requires various Performance Optimization strategies, and Parallelization to process very large data sets.

What can you do with these images ?



Expanding Bubble
Thermo-Dynamics
Classical Mechanics

Jets
Classical Mechanics
Magnetic Fields
Radiative processes
Energy Transport

Black Hole
General Relativity
Magnetic Fields
High Energy Physics

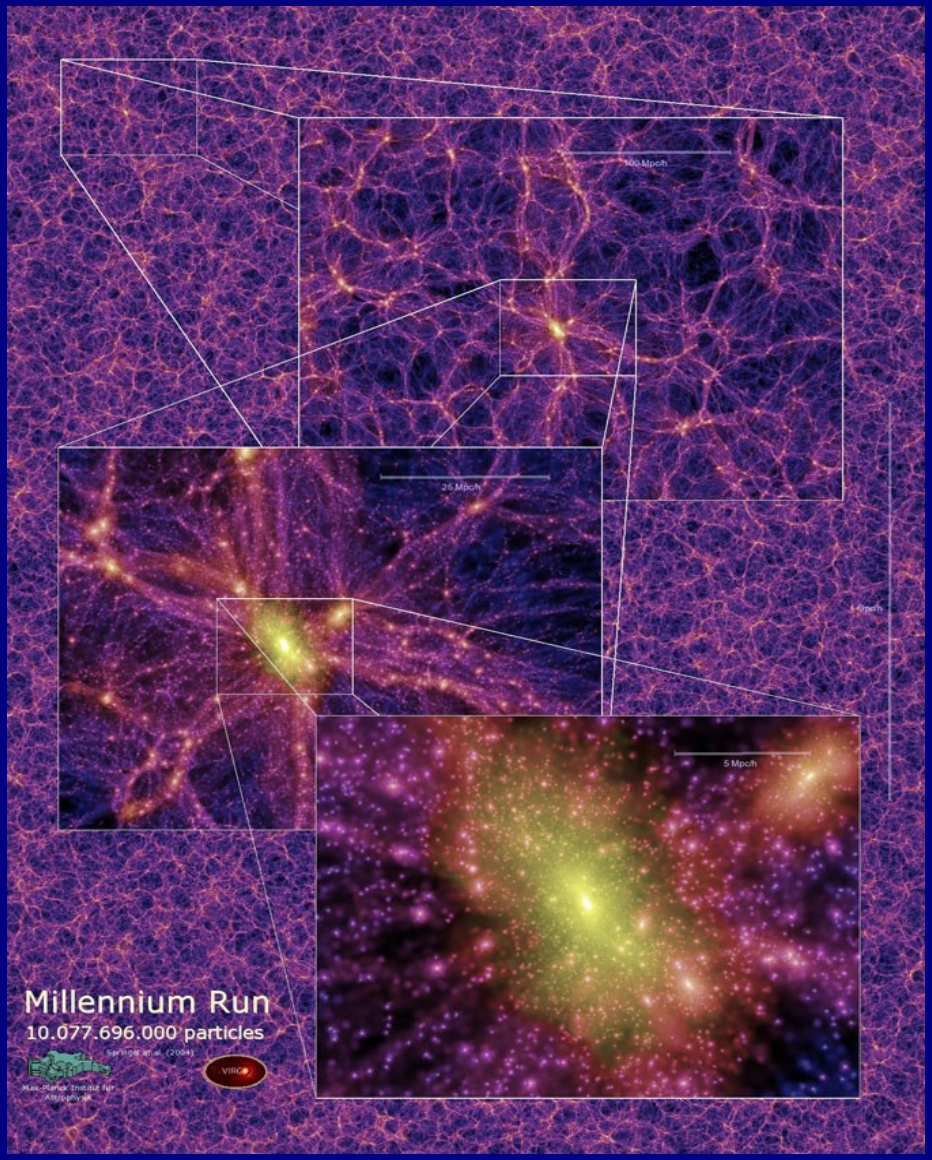
Gas Plumes
Magneto-Hydro—
Dynamics
Energy Transport

Filaments
Shock Physics
Energy Transfer

Images of M87 Radio Galaxy in the Virgo cluster
from F.Owen, NRAO

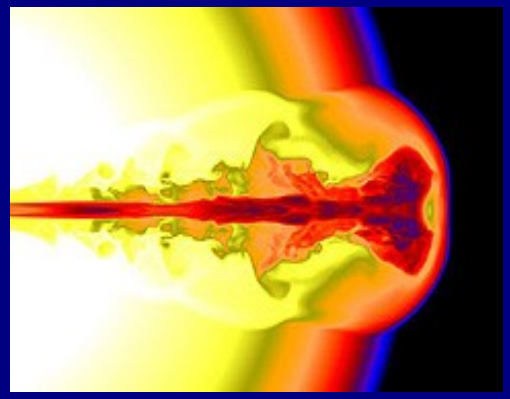
Simulations : Computational Physics

3D N-body simulations



Structure formation in the early universe
- Billions of points being tracked
- Computing time on a cluster : a month.

Magneto-Hydro-Dynamics



A Jet breaking through a star boundary at the start of a gamma-ray explosion.

Near-term Technical Challenges

- At least 3 independent very-low-frequency telescopes are being built, and existing ones are getting upgrades.

LWA

LOFAR

MWA

Research in antenna and feed design

- Reaching hardware limits => More analog+digital signal processing

"Dipole Arrays": much harder to model and characterize

- Many numerical modeling and image-reconstruction challenges

Data visualization, archiving, mining...

Visualization and editing

- Data-set size : 2GB now, and several TB soon.
- 3D visualization with interaction (virtual reality, "Cave"..)

Disk I/O and Archiving

- Current data rates : 10 GB/day now, and 1TB/hour soon.
- Cannot archive everything => Real-Time processing of several GB/sec.

Data mining

- Efficient query systems + distributed databases
- "Virtual Observatory"-> http://www.us-vo.org/index.cfm

High-Performance Computing - Parallelization, GPUs

How to learn more .....

- At BITS, be adventurous with electives !!
  - explore cross-disciplinary areas

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

- Attend summer school programmes
  - National Centre for Radio Astrophysics
  - Inter-University Centre for Astronomy and Astrophysics
  - Raman Research Institute
  - Indian Institute of Astrophysics
  - Indian Institute of Science

- Related commercial fields :
  - Remote Sensing –synthetic aperture radar, multi-wavelength imaging
  - Medical Imaging –CAT (computer aided tomography)

Some useful links...

- National Centre for Radio Astrophysics. : (NCRA/GMRT) : www. ncra.tifr.res.in
- Inter Univ.Centre for A & A (IUCAA) : www. iucaa.ernet.in
- National Radio Astro Observatory (NRAO) : www.nrao.edu
- Australia Telescope Nat. Facility (ATNF) : www. atnf.csiro.au
- Westerbork Synthesis Radio. Tel. (WSRT) : www. astron.nl/p/observing.htm
- National Virtual Observatory (NVO) : www. us-vo. org
- Radio JOVE : amateur radio :: www. radiojove.gsfc.nasa.gov/
- 2006 Synthesis Imaging Workshop Lectures www. phys.unm.edu/~kdyer/2006/lectures/
- Long Wavelength Array (LWA): lwa.nrl.navy.mil/
- Low Frequency Array (LOFAR) : www. lofar.org
- Murchison Widefield Array (MWA) : www. haystack.mit.edu/ast/arrays/mwa/

Wiki-Mapia (GMRT Central Square)
http:// www. wikimapia.org/#lat=19.0913&lon=74.049075&z=16&l=0&m=s&v=1