# Radio Waves and the Universe; from Big Bang to Black Holes

Govind Swarup
Formerly Centre Director,
National Centre for Radio Astrophysics,
Tata Institute of Fundamental Research
Pune 411007
gswarup29@gmail.com

## Slide 1

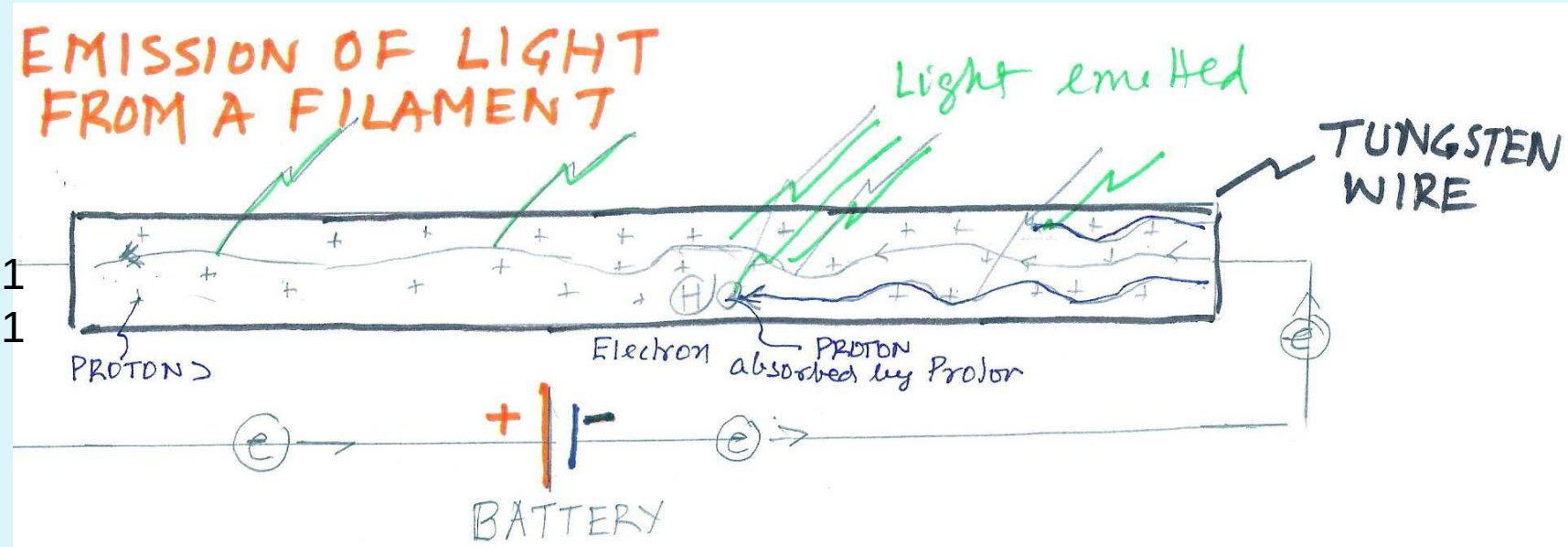
**MSOffice1** , 26-Apr-09

# Radio Universe: Plan of the Talk

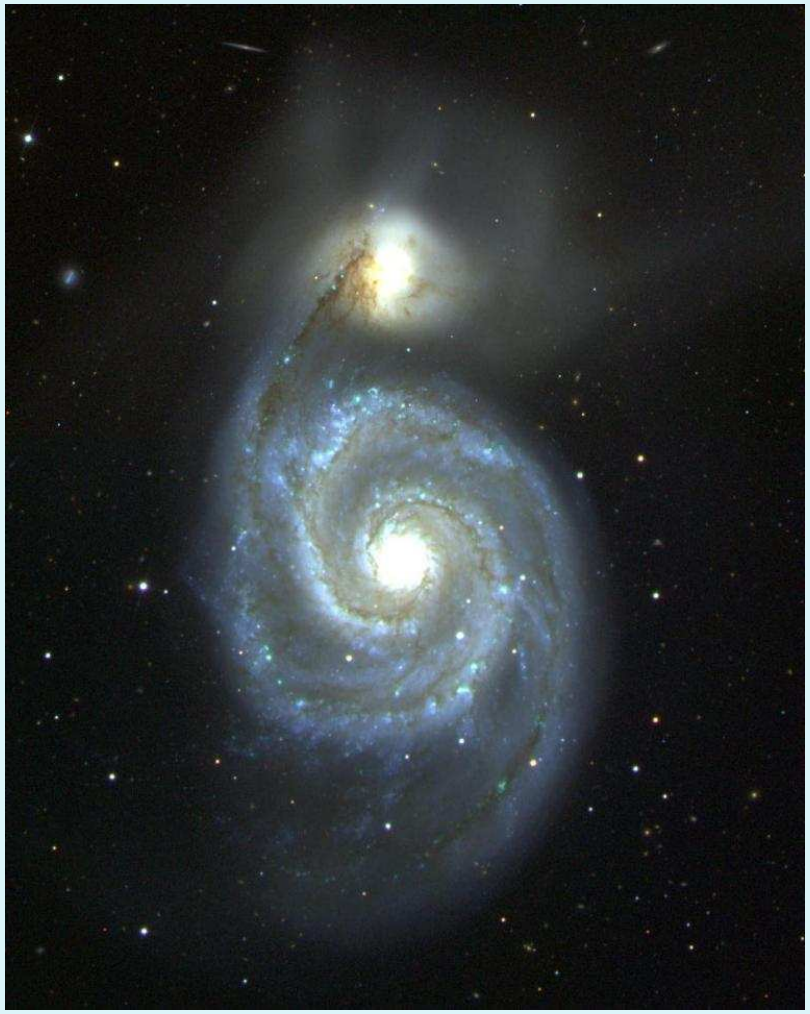
- • What are Radio waves
- Great Discoveries in Radio Astronomy
- Radio Galaxies , Quasars and Black holes
- Big Bang Model and Precision Cosmology
- Radio Telescopes
- GMRT and few recent results
- Key Questions Today
- Next Generation of Radio Telescopes
- Conclusion

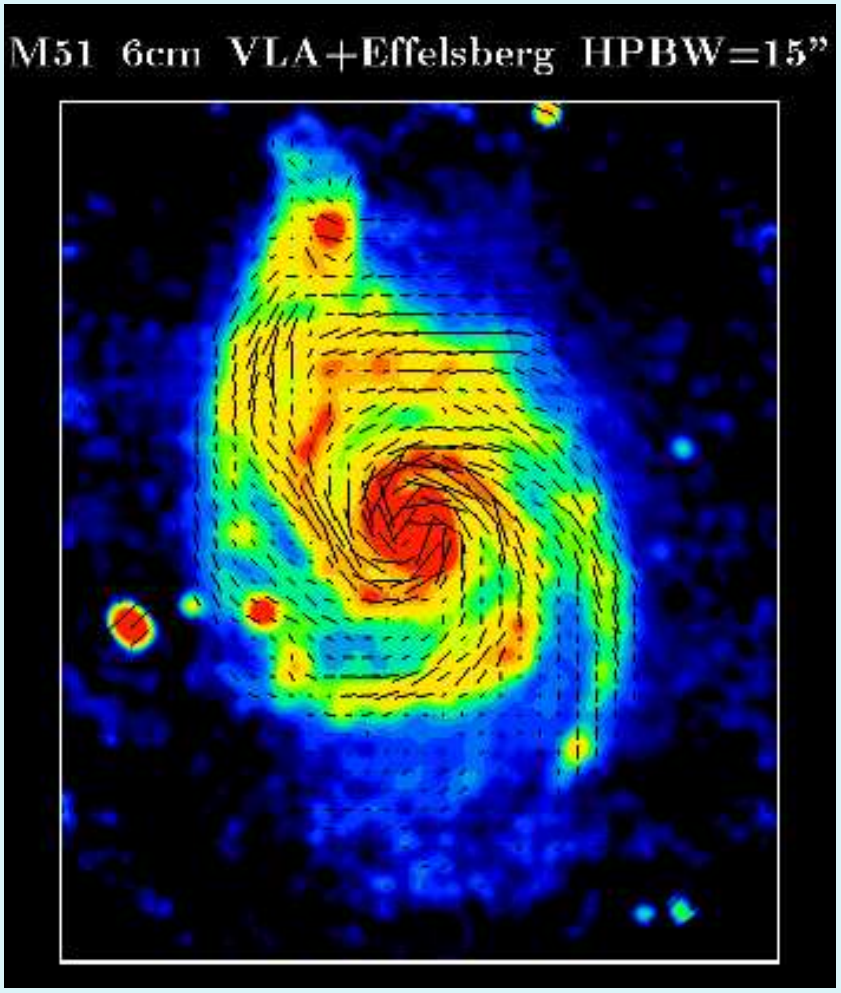
# Radio Waves from the Universe

- Radio waves like light are electromagnetic radiation.
- It is known that any charged particle when accelerated or de-accelerated gives rise to electromagnetic radiation...
- Hot bodies give rise to electromagnetic radiation when electrons suffer collisions or near collisions with protons.
- **Radio waves of extremely high power arise when electrons with relativistic velocities radiate in the presence of magnetic fields: radio galaxies, quasars, supernova remnant.**




ELECTROMAGNETIC WAVES ARISE WHEN A CHARGED PARTICE SUCH AS ELECTRON GETS ACCELERATED OR DE ACCELEATED






Left: Nearby Galaxy M51 in Visible light

Right: Radio Emission by accelerated electrons. Bars show magnetic field lines

# Some of the great discoveries made in the radio window are:

**Radio Galaxies and Quasars**

Massive Black Holes in the centre of the active galaxies (Galactic Nuclei)

**Microwave background**
**2.7 k Radiation**

**Big Bang origin of the Universe**

**Molecules in Space**
★Over 100 Molecules discovered
(Ammonia, Alcohol, Water, OH, HCN, CO, etc.)
★ Star Formation
★ Ingredients of Organic Life

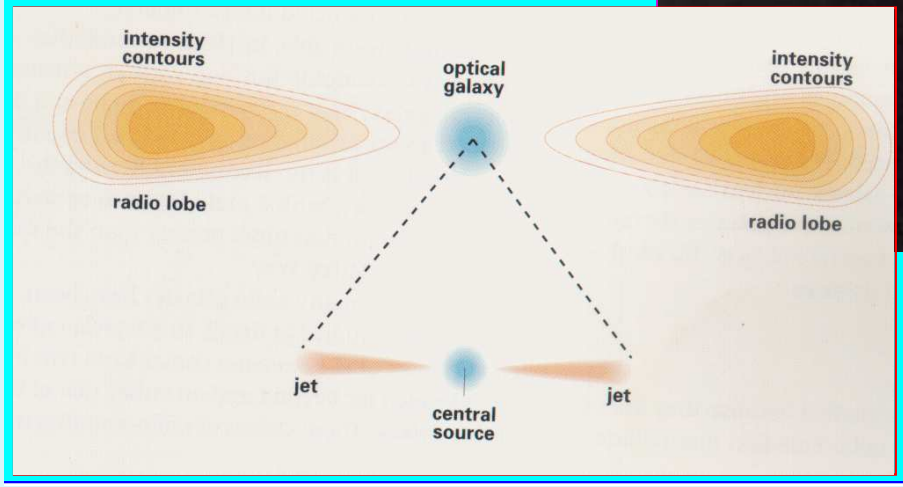
★ **Gravitational lensing**

★ **Rotation Curves**

Dark Matter in the Universe

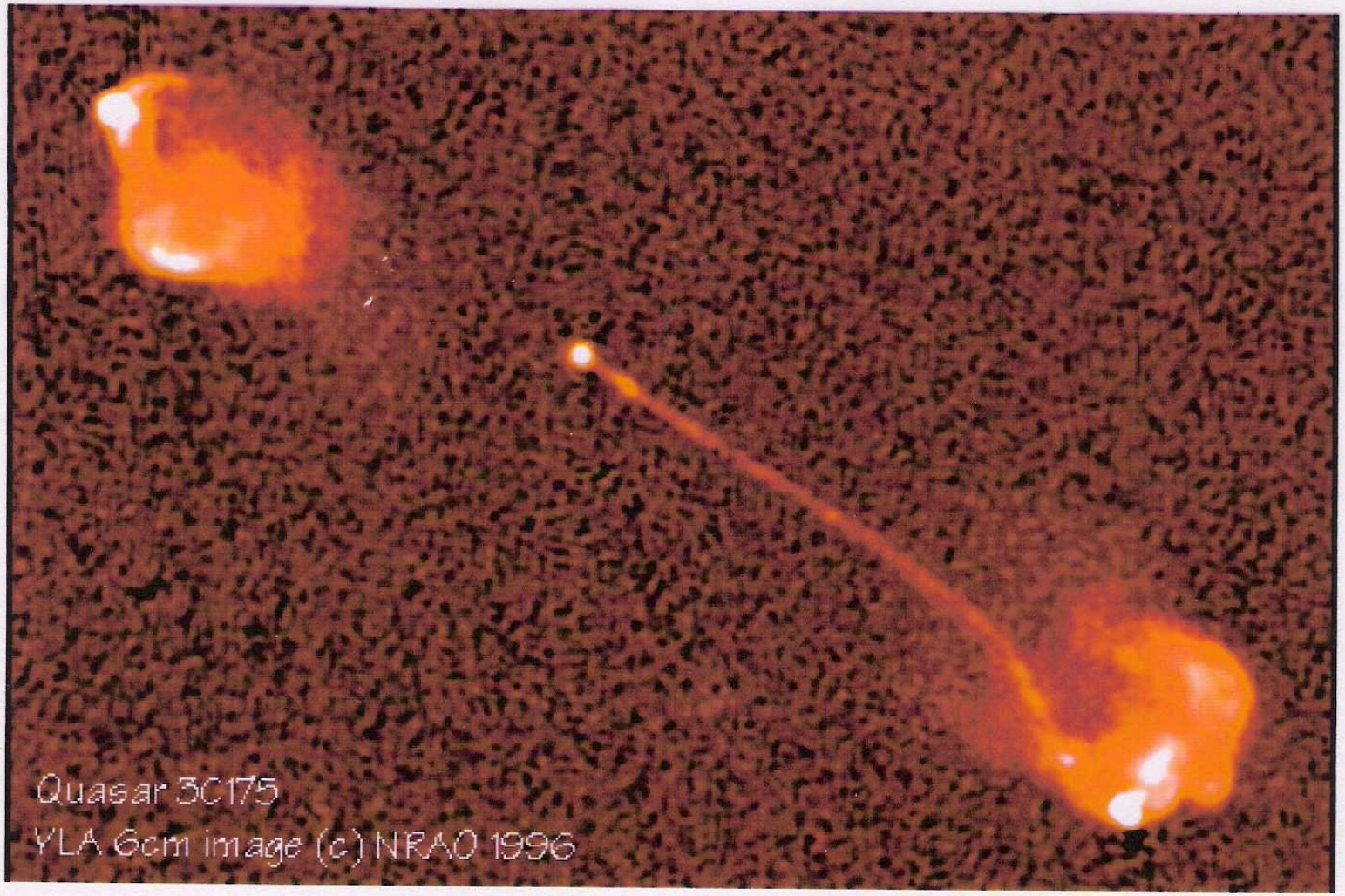
**Pulsars**
(Pulsating radio sources)

★ Provides tests of the General Theory of Relativity


intensity contours
optical galaxy
intensity contours
radio lobe
radio lobe
jet
central source
jet

# Quasar 3C175 : VLA

4.9 GHz, 0".35 FWHM

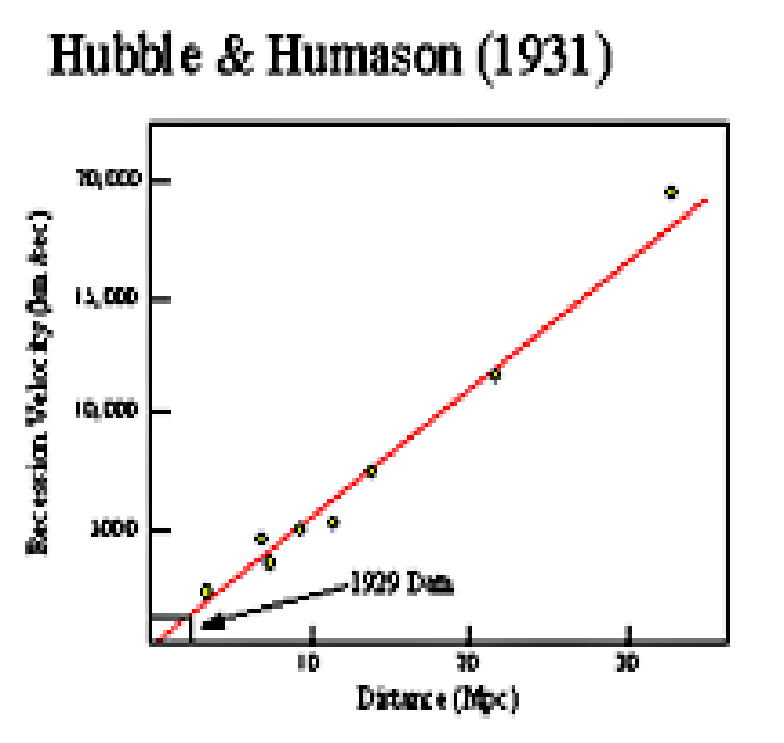


# Black Holes

- In order to explain the occurrence of extremely energetic radio galaxies, it was suggested in 1960s that at the centre of these objects lies a massive body.
- Extensive observations during the last 40 years have shown that “black holes” with mass of millions of solar mass do exist at the centre of almost all galaxies in the Universe, of which only a few give rise to radio galaxies and quasars.

# Hubble's Law

- **In 1929 Hubble made a remarkable discovery.**
- ***Farther away is a galaxy located , faster it is moving away from us***
- **Conclusion: Universe is Expanding**



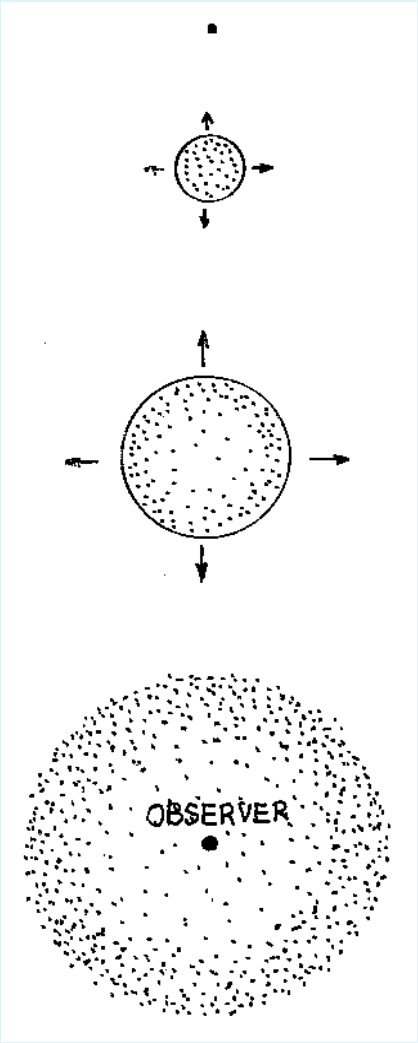
# Evolution of the Universe *(Big Bang Model)*

T=0

T=t1

T=$t_2$

T=$t_3$
Now

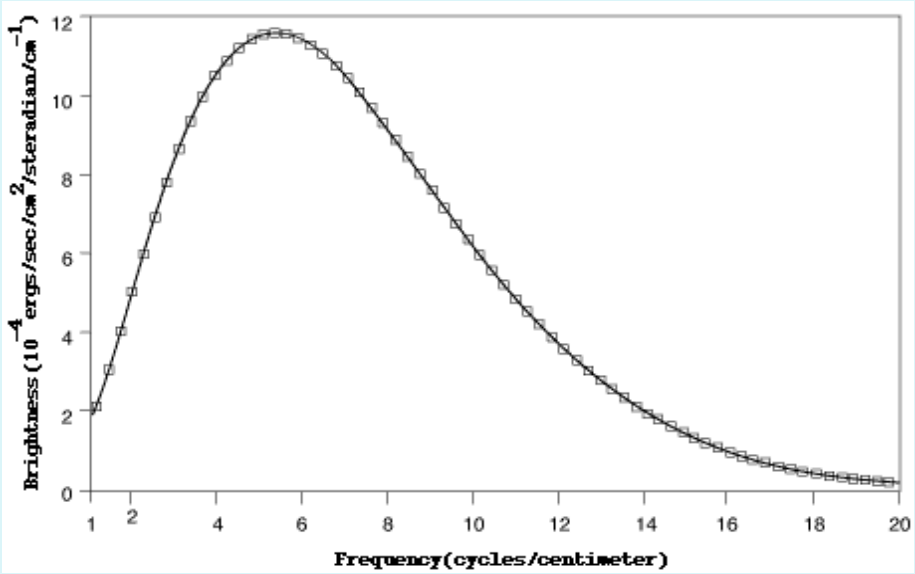


## Ooty Radio Telescope: 530m long and 30m wide with its long axis parallel to that of the earth

During 1970's ORT provided angular sizes of about 1000 radio sources with arcsec resolution using method of lunar occultation PROVIDING independent evidence of the big bang model

# Cosmic Microwave Background Radiation (CMBR)

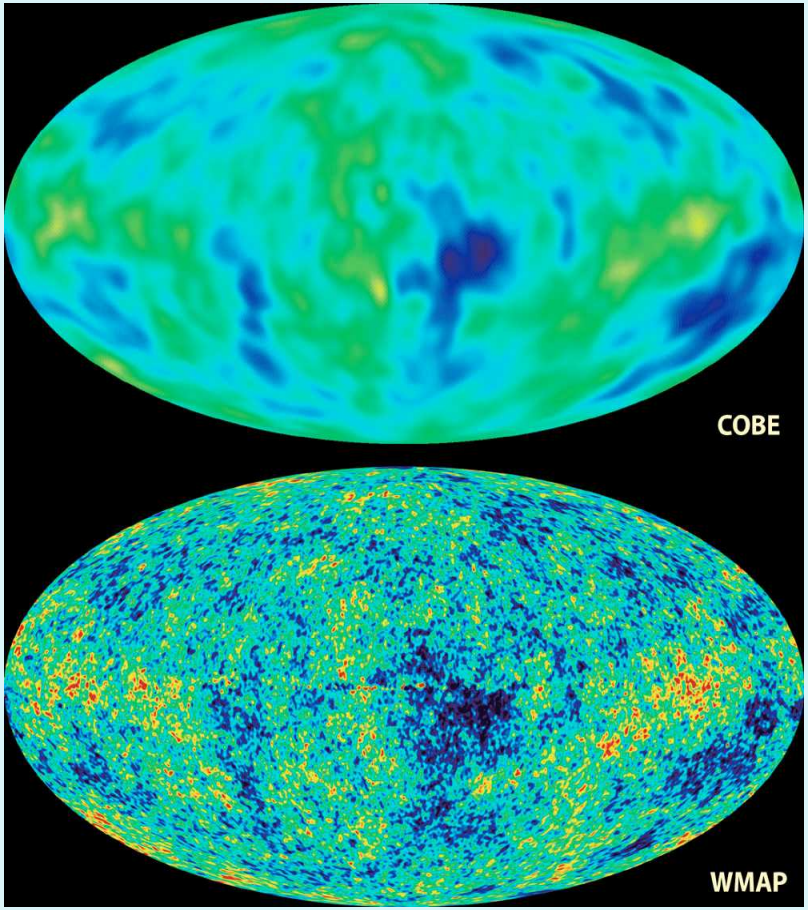
- In 1965 Penzias & Wilson made a remarkable discovery that there exists a cosmic microwave background radiation across the sky, corresponding to the blackbody temperature of about 2.7K.
- During 1990s the COBE satellite designed by John Mather and colleagues showed CMBR to be a perfect blackbody radiation.



# Formation of Galaxies and cluster in the Universe

Fluctuations were detected by COBE (1992) and WMAP Satellite in (2002) in the Microwave Background radiation of about 1 part in $10^5$

These are the seeds of irregularities in distribution of matter in the early universe, giving rise later to the formation of galaxies by gravitational collapse?

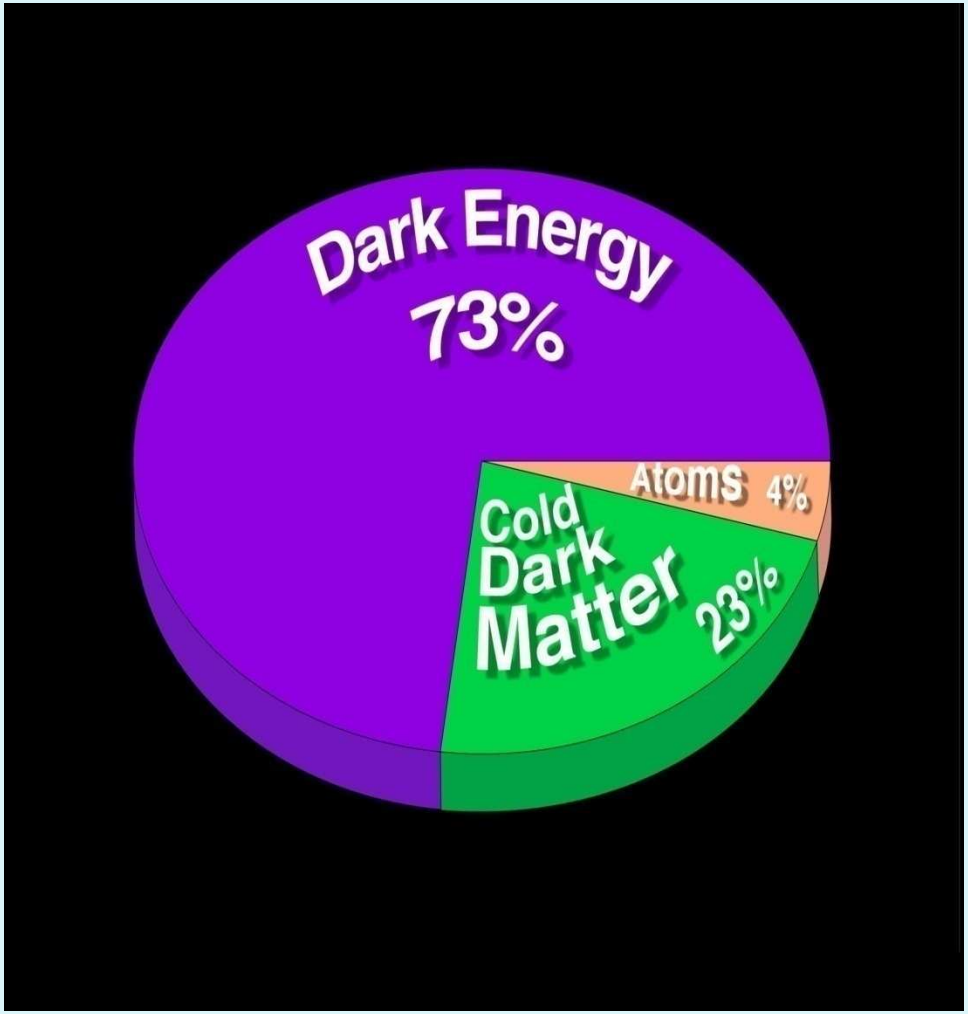


# Precision Cosmology

Observations of distant supernovae remnants, SN I have shown that universe is **accelerating** in the presence of dark energy, similar to the cosmological constant of Einstein's GTR.

- Great observational challenges :cold dark matter (axions, photinos, neutralinos)

➢ Dark energy also influences "large scale structure"



# Formation of Elements in the Universe and Black Holes when massive stars collapse.

- In the beginning, at ~ few minutes, ~75% Hydrogen, HI, and 25% Helium,He, form, when the Universe has temperature of billions of degrees.
- HI cools and stars and galaxies form.
- Nuclear burning taking place at centre of stars forming elements, C, S, etc
- Stars suddenly collapse when nuclear fuel runs out resulting in a white dwarf, or neutron star and black hole if star is many time more massive than the Sun
- Over 1500 pulsars and MICRO-QUASARS have been discovered in our Galaxy.

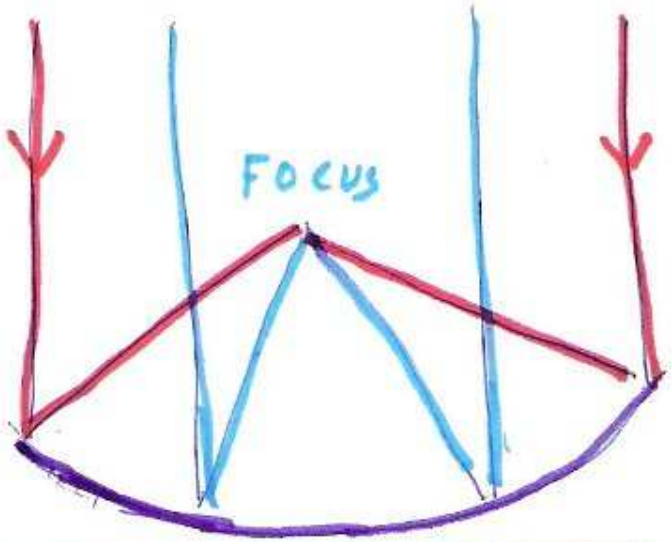
# Radio Astronomy & Cosmology

- According to big bang model, galaxies form by gravitational collapse of neutral hydrogen (HI) condensates.
- HI gives rise to line emission at a wavelength of 21cm, which gets red-shifted to meter wavelengths with the expansion of the Universe.
- This is one of the prime motivation for the construction of the Giant Metrewave Radio Telescope (GMRT) in India

# Radio Telescopes

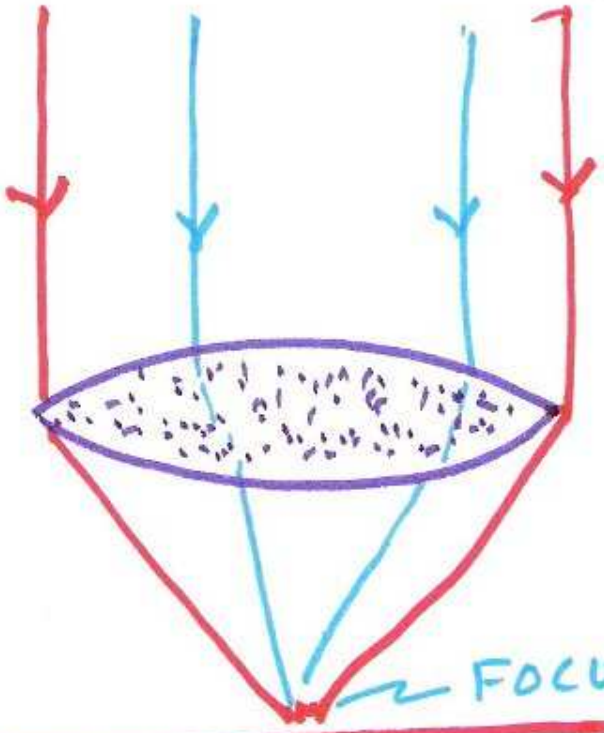
- Resolution of a radio telescope is given by ~ λ /D radians, where λ = wavelength and D is the aperture diameter.
- To get arcmin to arcsec resolutions, astronomers have built
  - Single dishes at cm, mm λs.
  - **Radio Interferometers at mm, dm, and metre wavelengths that are used as Earth's Rotation**
    - **Synthesis Telescope**

RAYS FROM STAR




PARABOLIC DISH

ALL RAYS HAVE EQUAL PATH FROM STAR TO FOCUS

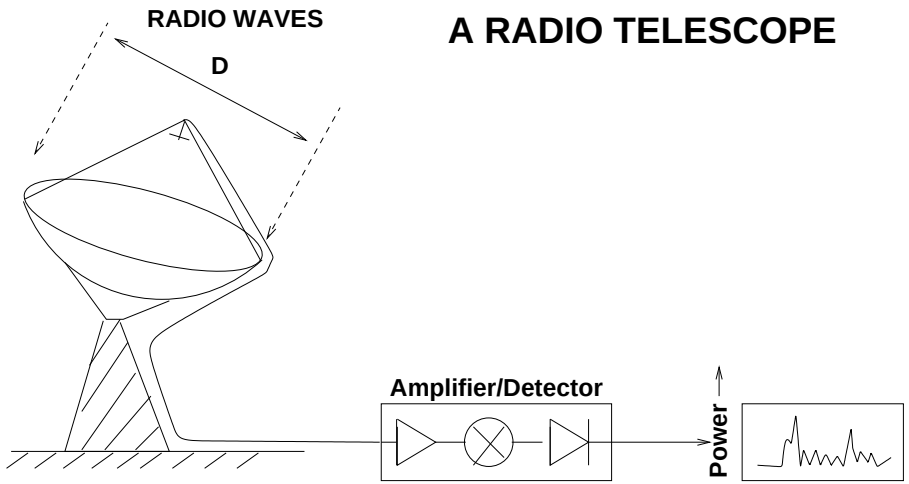



OPTICAL LENS

ALL RAYS REACH FOCUS SAME TIME BECAUSE VELOCITY OF LIGHT IN GLASS IS SLOWER THAN IN AIR

# Radio Telescopes

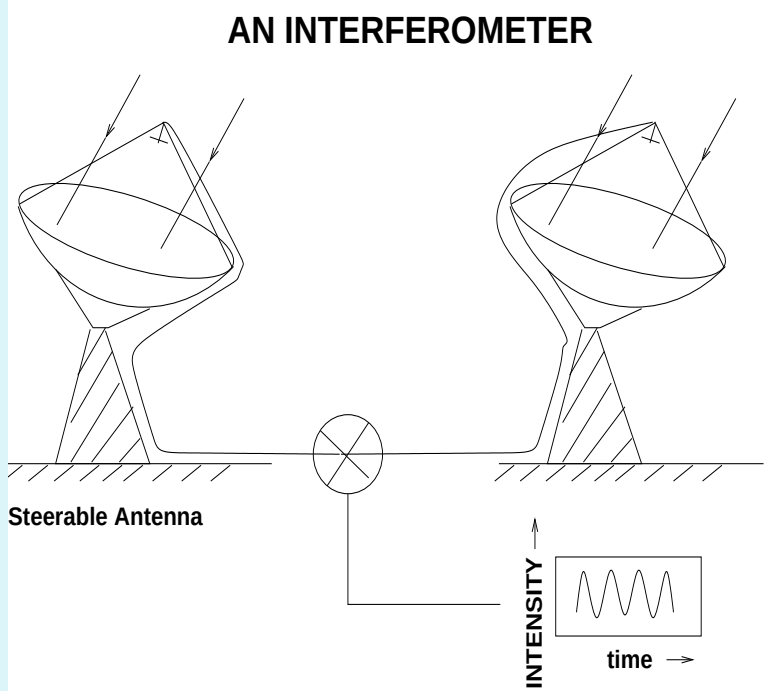
**A SIMPLE RADIO TELESCOPE CONSISTS OF AN ANTENNA, A RECEIVER AND A RECORDER**




RESOLUTION = Antenna Beam $= \lambda / D$

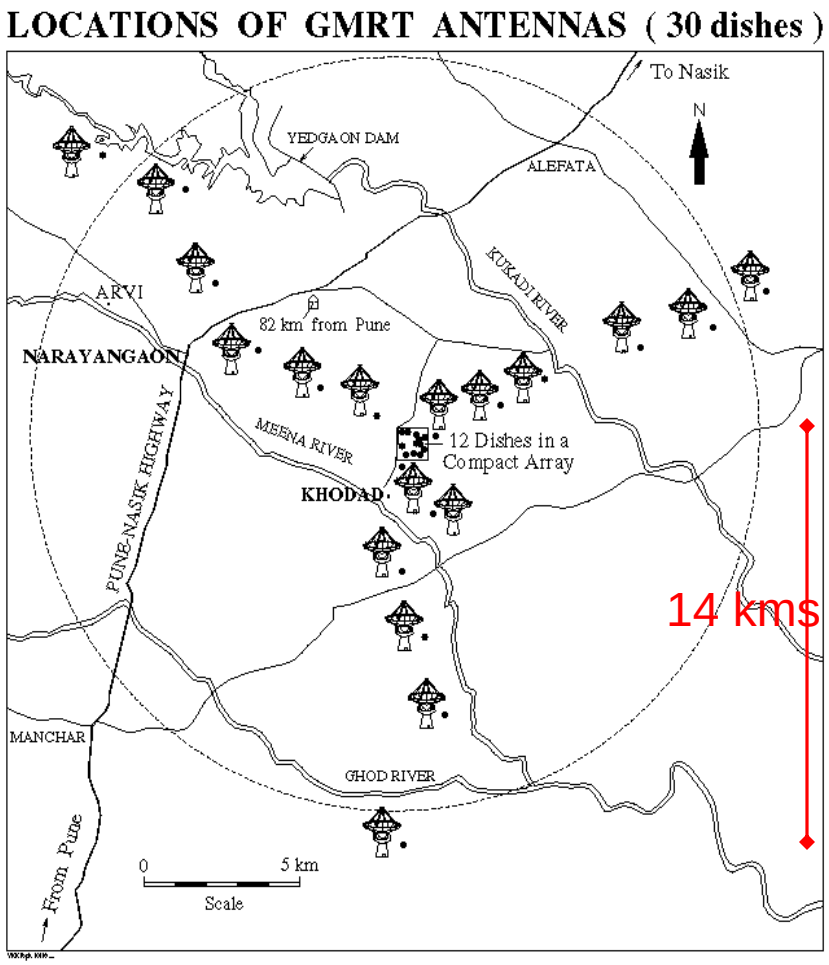
**TO GET ONE ARCSEC RESOLUTION AT A WAVELENGTH OF ONE METRE (300 MHZ) WE NEED D=200KM!**

**FOR OBTAINING HIGH ANGULAR RESOLUTION SCIENTISTS USE RADIO INTERFEROMETERS**




**An Interferometer measures one FOURIER COMPONENT OF THE RADIO IMAGE**

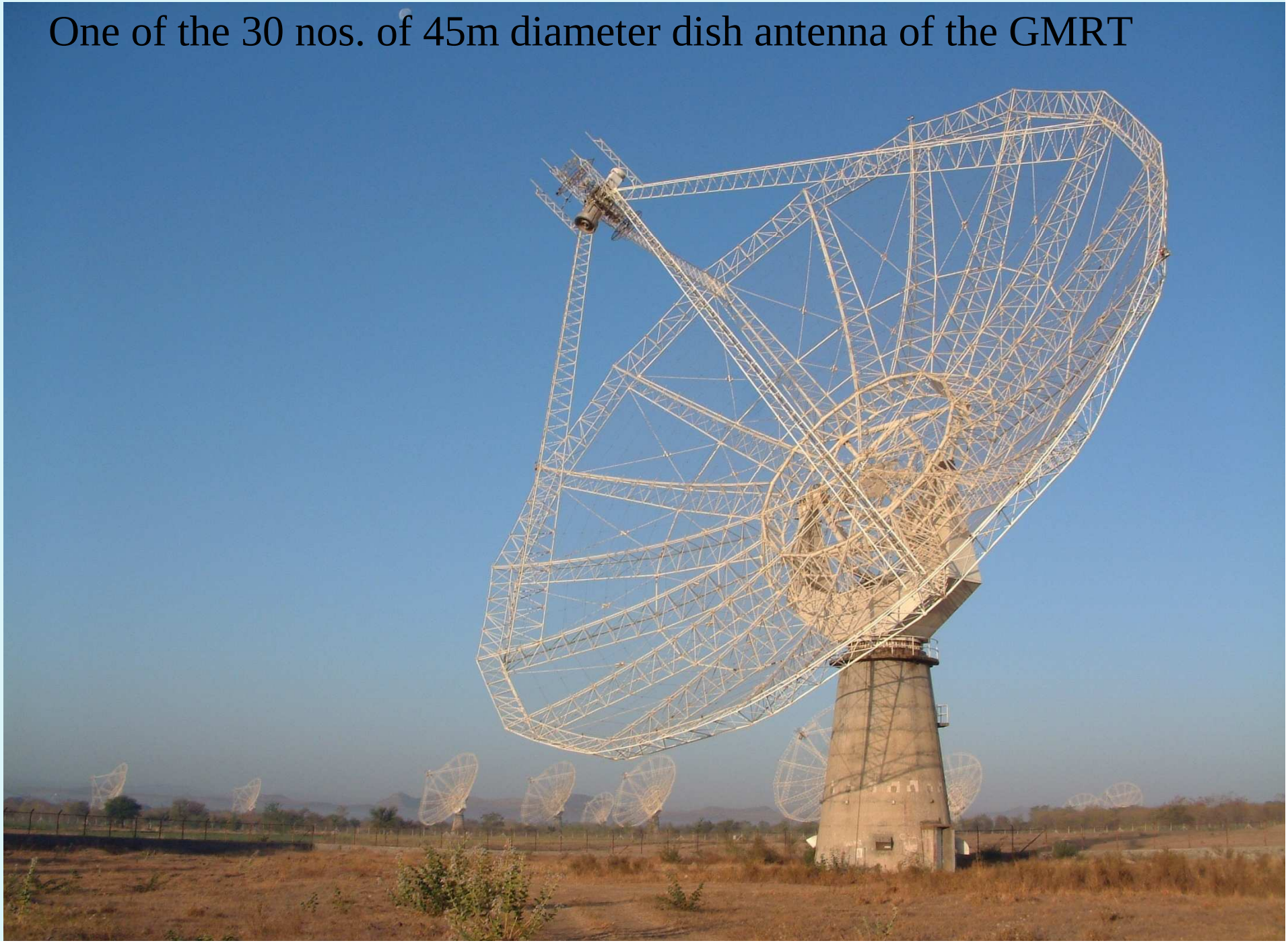
# GIANT METREWAVE RADIO TELESCOPE




GMRT consists of 30 dishes of 45m diameter each, *located in an array of about 25 km in extent. With the rotation of the earth, the Y array rotates with respect to stars. In* 10 hours of observations we get maps as if made with a 25 km dish !

GMRT is the largest radio telescope in the world, operating from about ~130 MHz to 1430 MHz

One of the 30 nos. of 45m diameter dish antenna of the GMRT



# GMRT is a versatile instrument

(it is being used by about 100 astronomers from India and more than 200 astronomers from ~ 20 countries, based on best proposals

**Solar system**: Jupiter, Sun

**Our Galaxy:**

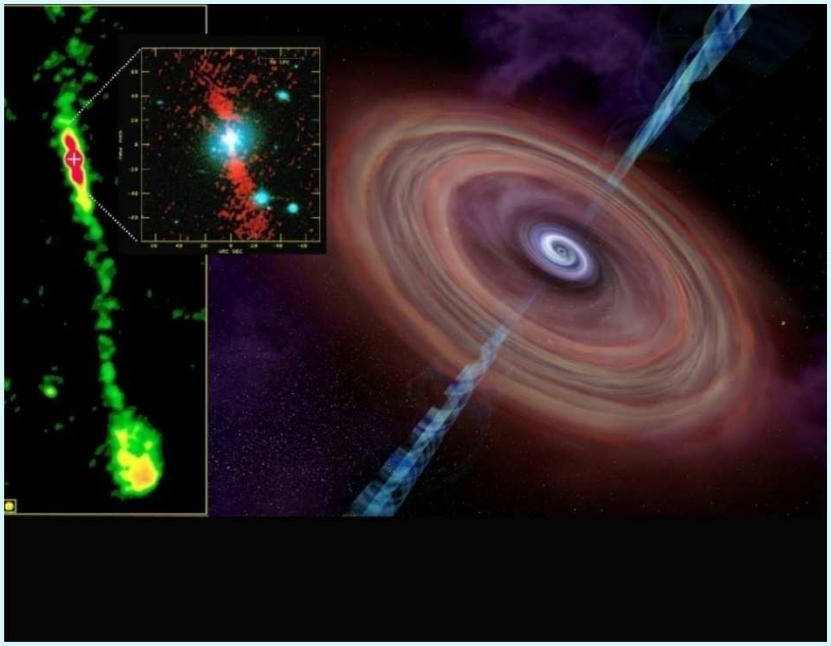
- ★ Pulsars, Supernova remnants, Micro-quasars, γ-ray & X-ray sources, HII regions; HI studies, Galactic Centre, Recombination Lines

**Nearby Galaxies**: Clusters of Galaxies (Halos/ Relics)

**Radio Galaxies & Quasars**

**Damped Ly-a systems**; Associated HI absorption

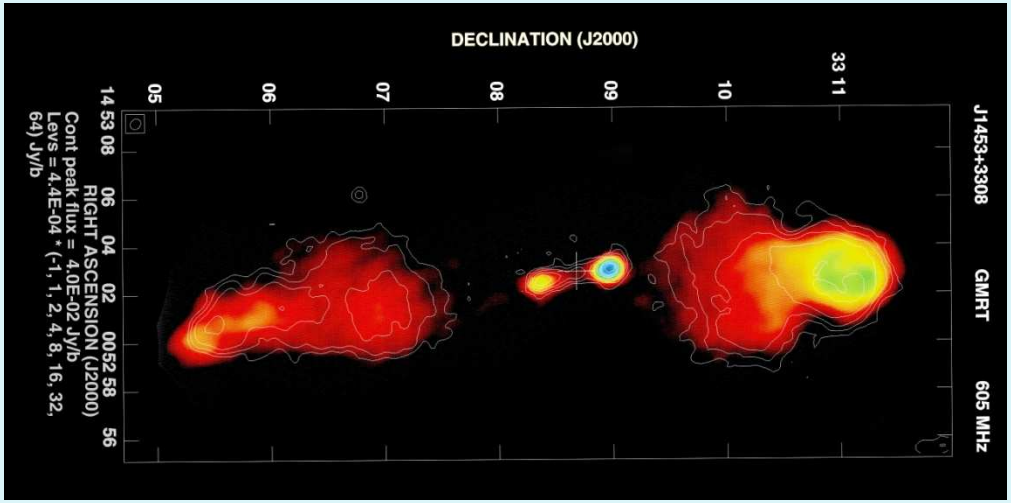
**Search for HI proto-clusters, Reionization epoch**



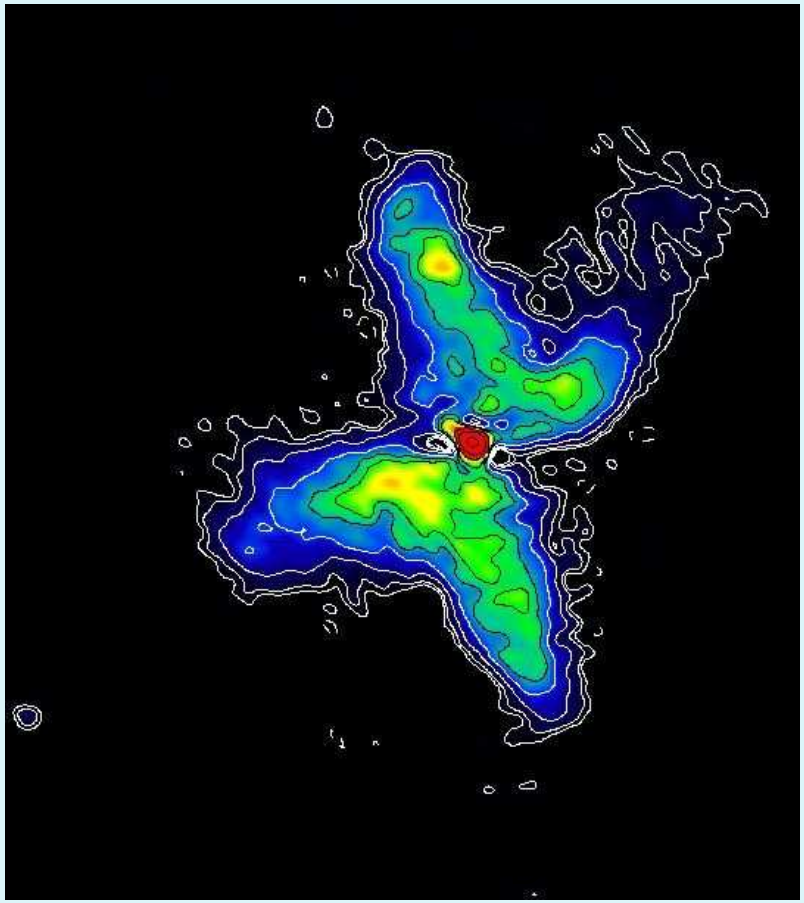
Radio galaxies: few examples.

GMRT radio image of a very large one sided jet discovered by Bagchi et al. (2007)

GMRT radio map of a Double Double Radio Galaxy (Saikia et al. (2006).

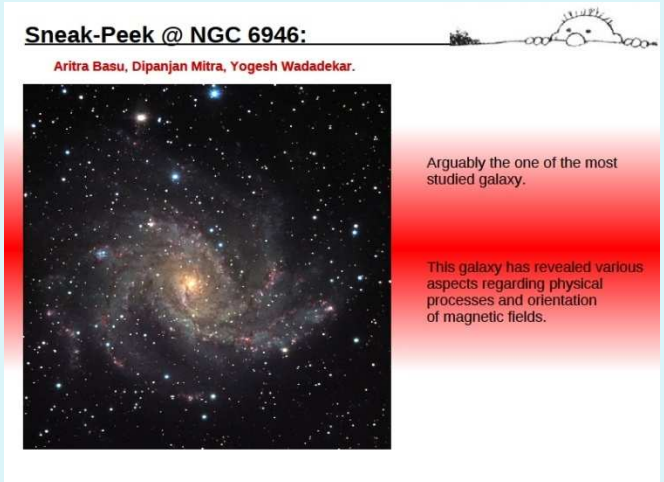


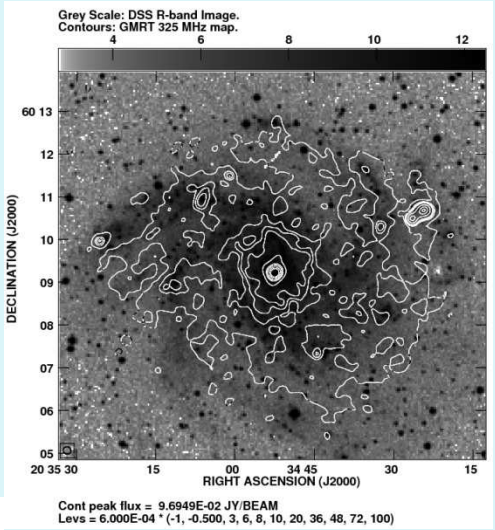
# RADIO GALAXIES

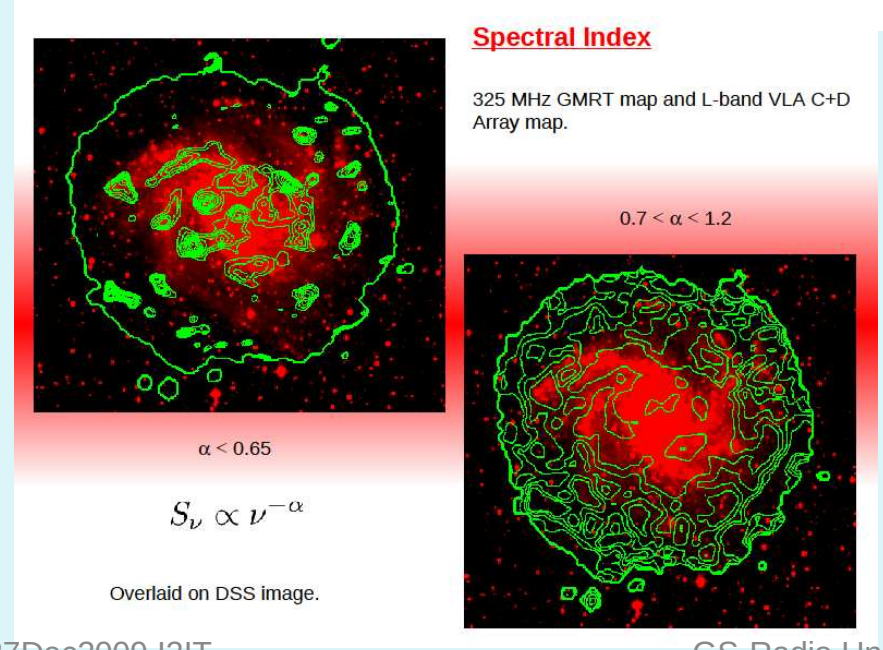


**An X-shaped Galaxy mapped by GMRT at 615 MHz indicating merger of a minor galaxy resulting in the re-orientation of the spin axis of the parent Active Galaxy**

Nearby Galaxies: Pilot survey has been done recently using the GMRT at 325 MHz for Spirals and Elipticals ( and using huge data that is publicly available ranging from X-rays, optical, infra-red to cm. wavelengths)




Spectral index variation across NGC 6946 based on GMRT observations at 325 MHz and VLA observations at 1420 MHz.

(Aritra Basu, Dipanjan Mitra & Ishwara Chandra in prep.)

# GMRT Discovery of a new pulsar in a supernova remnant

**Recent discovery of a young pulsar in the supernova remnant G21.5-0.9 .**

Period 61.96 ms;
characteristic age ~ 4800 yrs.

**Second highest spin-down luminosity (second only to the Crab Pulsar).**

Chandra's X-Ray image is shown in the Top left panel. Pulsar is located near the centre OF THE NEBULA.

(Gupta, Mitra, Green & Acharyya 2005)

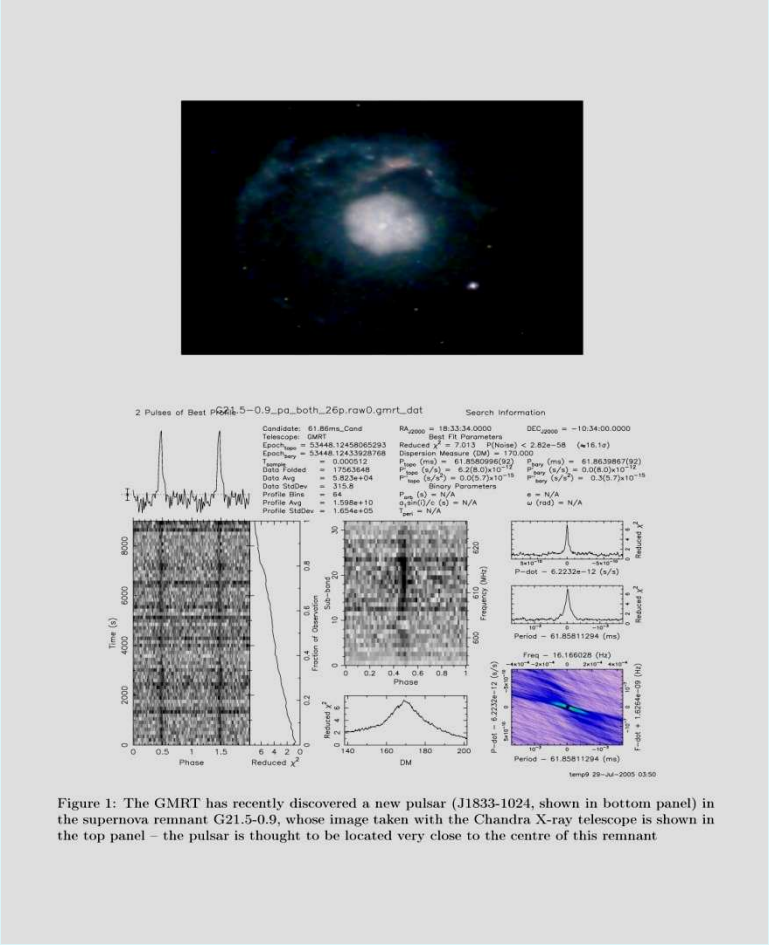
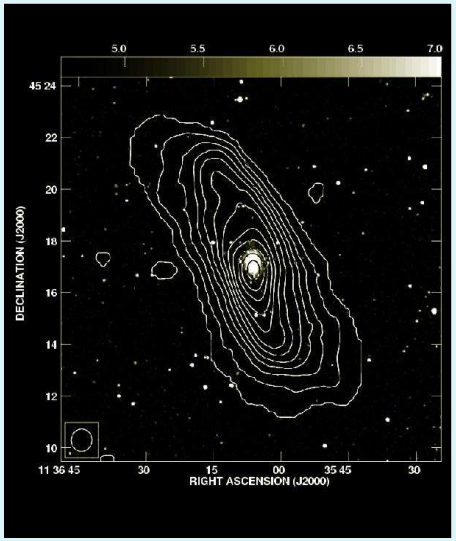
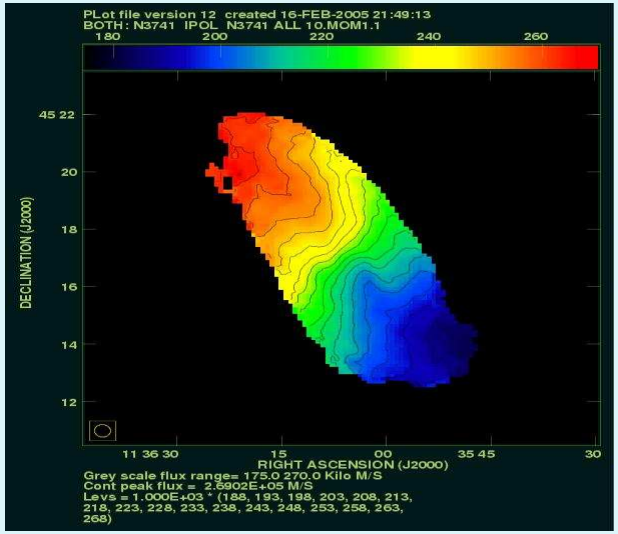


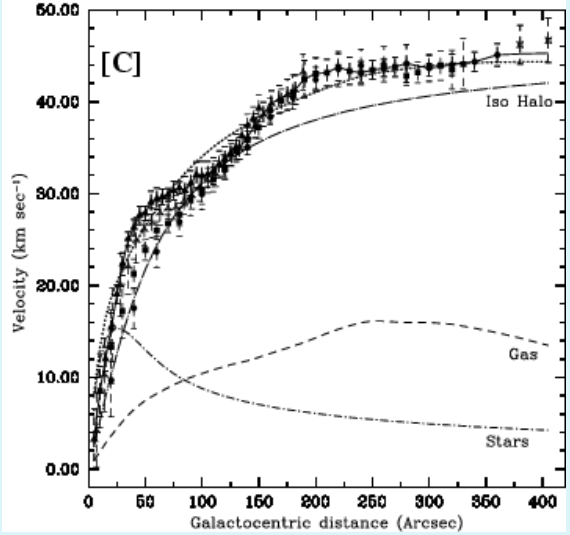
Figure 1: The GMRT has recently discovered a new pulsar (J1833-1024, shown in bottom panel) in the supernova remnant G21.5-0.9, whose image taken with the Chandra X-ray telescope is shown in the top panel – the pulsar is thought to be located very close to the centre of this remnant

# GMRT observations of HI in ~ 25 Dwarf galaxies have been made to understand their kinematics.

Begum et al. A&A, 433, L1 (2005)




Rotation Curve

HI disk extends to ~ 8.3 times Holmberg radius. Kinematics are very regular – no sign of tidal or other disturbances.

Rotation curve measured to ~ 38 optical disk scale lengths.

$M_{dyn}/L_B$ ~ 107 – one of the "darkest" galaxies known. Does it also have a small baryon fraction?

NGC 3741 $M_B$ ~ -13.1

# Search for UHE Cosmic Rays and UHE neutrinos using the GMRT (Sirothia, Panda & Swarup)

•Recent observations of ~ 20 events of Ultra high energy (UHE) Cosmic rays, UHECR, by AUGER at energies >~ $5x10^{19}$ eV is a great mystery.

•Such high energy particles are likely to have extragalactic origin from AGNs, Gamma Ray bursts or massive particles predicted by particle physicists.

•Accelerated protons interact with CMB photons or those from AGNs and give rise to UHE neutrinos. Many large scale terrestrial experiments are being carried out to search for UHE neutrinos.

•The UHE neutrinos interact with the regolith of the Moon and give rise to nano-sec duration pulses by Cerenkov emission. We have recently made observations with the GMRT for possible detection of UHE Cosmic Rays and UHE neutrinos > $10^{22}$ eV by observing towards the MOON. We have recorded raw voltages from all the 30 antennas of the GMRT and will point phased beams towards various AGNs .
(Swarup and Panda 2008: Astro-phSP0805.4304v1)

# Geometry for lunar CR or neutrino cascade event

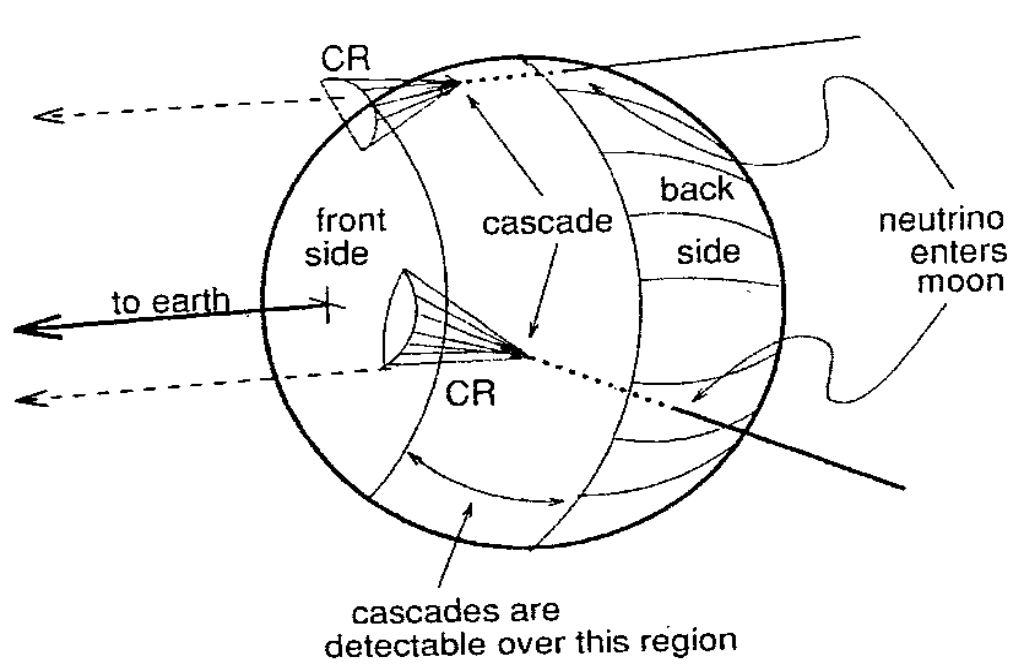



Fig.Geometry for CR or neutrino cascade event generating Cerenkov radiation of radio waves in the lunar regolith by Askarian effect

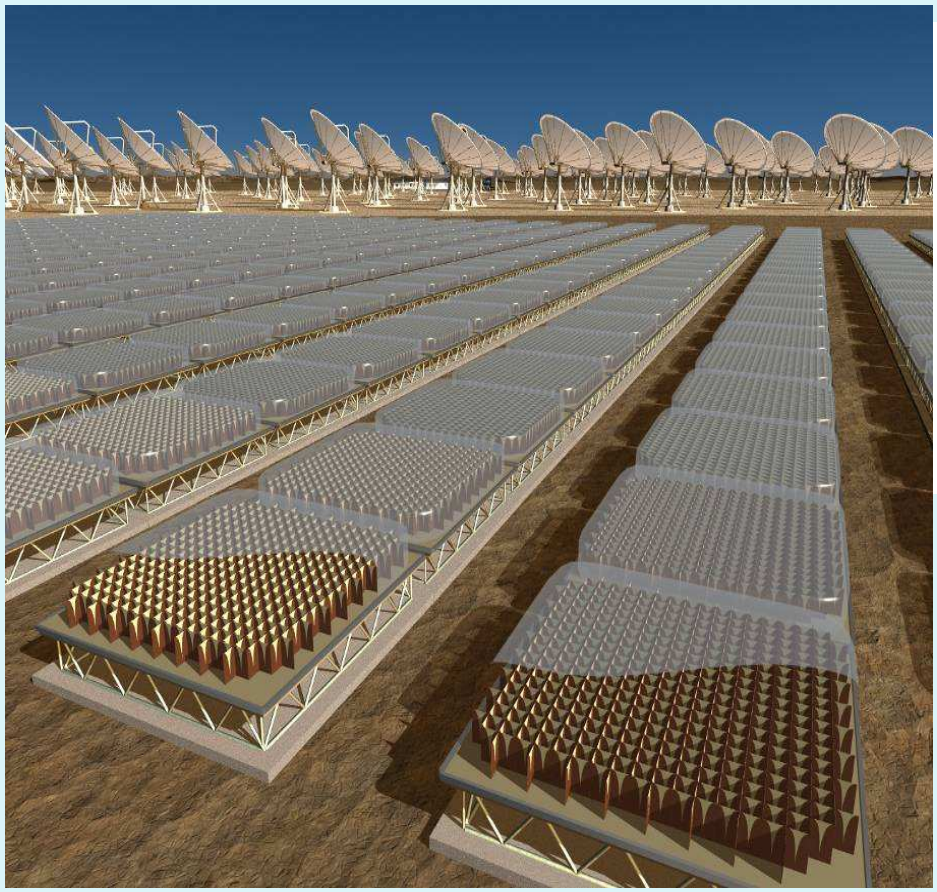
# Many Key Questions Today

1. Origin and evolution of the Universe
2. Formation of Galaxies
3. Was Einstein right?
4. Origin of Magnetic Field
5. Are we Alone?

# New challenges for the Electronics system of the GMRT

- 1. Wide band focal plane antenna system
- 2. Room temperature low noise amplifiers
- 3. Increase bandwidth from 32 MHz to 400MHz: new IF system, multi-wavelength optical fibre system
- 4.New 400 MHz hardware-software correlator.

# Next decade: Square Kilometer Array (SKA): a very challenging project in astronomy



100 times more powerful than any existing radio telescope to be built during *2***012 to 2020, by 17 countries:** Australia, China, **India**, South Africa, UK, Netherlands, Italy, Canada, USA, Argentina, Brazil….

**Thousands of SKA antennas to be located in a 3000 km array**

# Life in the Universe: Are we alone?

# GMRT and SETI

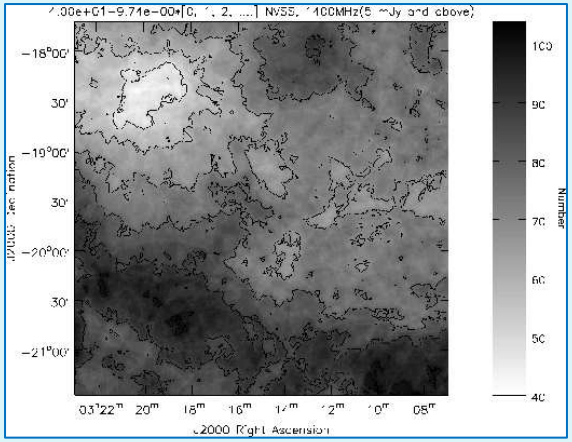
# SETI

- GMRT has recently started a programme for SETI observations for detecting leakage radiation from any extra-terrestrial intelligence (ETI) transmitters (Gajjar et al.)

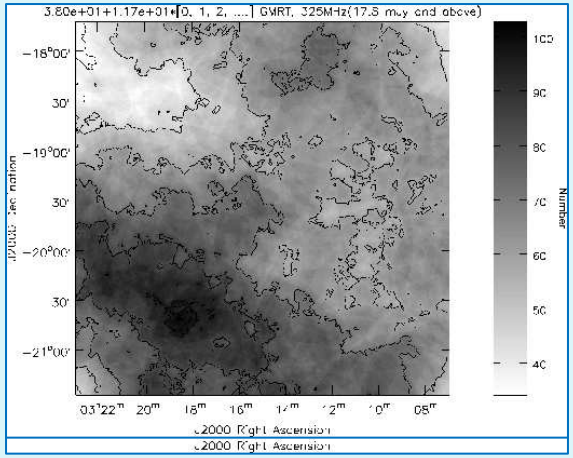
- The proposed Square Kilometer Array (SKA) will allow studying extra-solar terrestrial planet formation and search for possible ETI from millions of stars.


Era of discoveries through radio window is likely to continue for decades to come.
Thank you

# Extreme Cold Spot in the Cosmic Microwave Background Radiation



Radio source density at 1420 MHz (NVSS)



Radio source density at 325 MHz (GMRT)

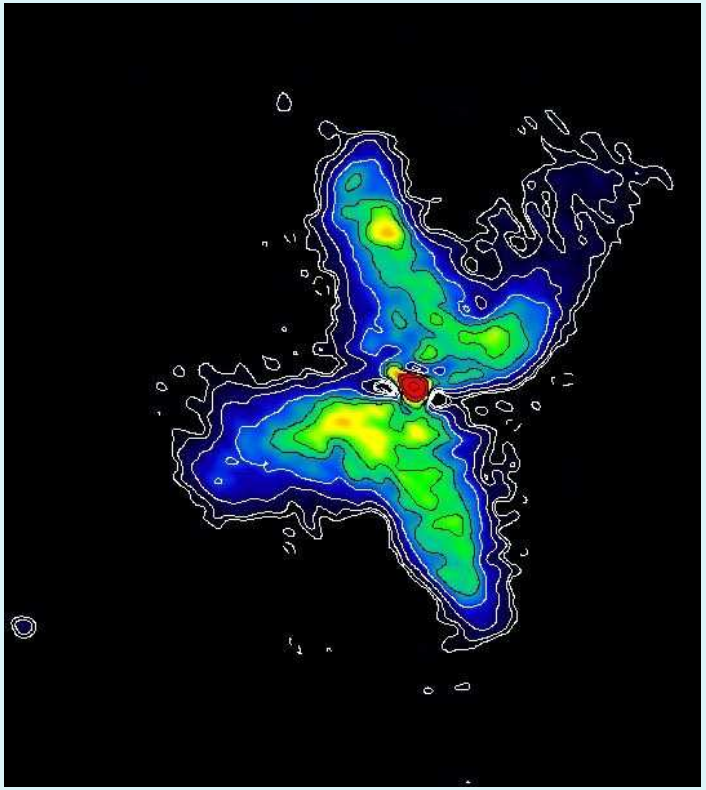
• Vielva et al (2004) noted an Extreme Cold Spot in the CMBR. Rudnick et al. (2007) noted deficiency of radio sources in the NVSS catalogue at 1420 MHz and ascribed it to the Integrated Sachs-Wolfe effect by a VOID of ≥ 100 Mpc! . GMRT observations have been made with higher resolutions at 325, 610 and 1280 MHz . Preliminary observations made at 325 MHz have confirmed the observed deficiency of radio sources (Sirothia, Swarup and Shukla, LFRU, 2009).

• Challenge is to search for a possible void in the redshift space. Based on the GMRT catalogue and Pan-Starr observations by Greg Aldering at Berkeley, AAT authorities in Australia have allotted 7 nights of spectroscopic observations using AAOmega for ~ 3000 objects in Dec. 2009 (Aldering, Shukla, Swarup, Sirothia, Silk, Bremmer, Colless, Sharp).

# Conclusion

- Early Universe provides a fascinating and challenging play field to theoretical physicists, e.g. implications of quantum gravity, GUT, string theory, etc.
- Astronomical observations have provided strong support to the Big Bang Model.
- Five Key Questions form the thrust for new generation of radio telescopes, such as LOFAR, SKA, E-VLA, U-GMRT
- Laboratory searches for Dark matter candidates are crucial and also wide field observations for determining the pressure of the dark energy.
- Golden age of Astronomical Discoveries likely to continue for long: great opportunity for young scientists and engineers in India to work at the frontiers of science and technology.

X-shaped Galaxies: about dozen of these have been mapped using the GMRT at multiple frequencies order to understand evolution of radio galaxies.



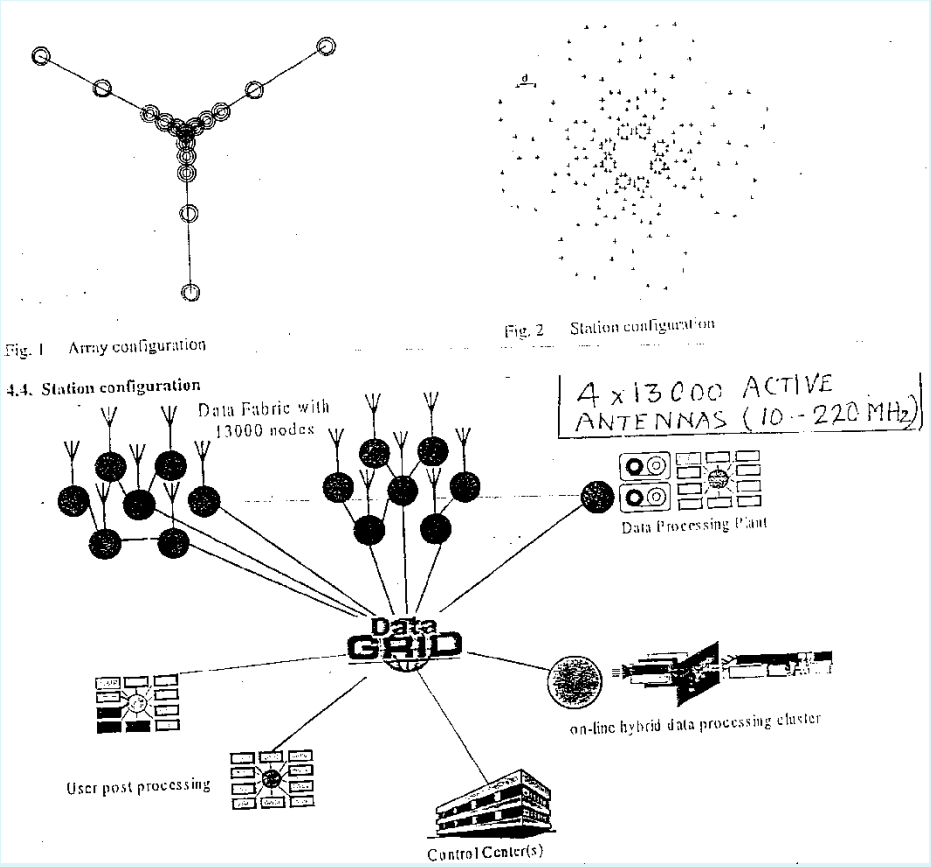
3C315 map by D,V. Lal 2005

An X-shaped Galaxy mapped by GMRT at 615 MHz indicating merger of a minor galaxy resulting in the re-orientation of the spin axis of the parent Active Galaxy. (Lal & Rao 2005).

About 50 X-shaped sources have been mapped and investigated in detail by various workers. The nature of X-shaped sources is a matter of considerable debate: it has been proposed that they provide evidence for black hole mergers/spin reorientation, and therefore constrain the rate of strong gravitational wave events (Merritt &Ekers 2002).

Lal et al. arXiv-0904.2725, 2009, Lal, D.V. & Rao, A.P. 2007, MNRAS, 374, 1085

# A Software Radio Telescope **LOFAR:** Low Frequency Array. (Epoch of Reionization)




- Frequency coverage ~10 to 300 MHz
- Tens of thousands of active antennas ($l << \lambda$)
- Thousands of frequency channels (10,000)
- Massive use of VLSI, Optical fibre and standard data processing units for 40 terra-flops of data.

LOFAR is being developed by NFRA, Netherlands: by 2010. MIT/Berkeley,RRI and Australian groups are also planning (Milluera project); NAL in USA (LWA project)


THANK YOU

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