Radio Astronomy at the NCRA

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Radio Astronomy at NCRA – TIFR : Background

- One of the oldest radio astronomy group in the country – started by Prof. Govind Swarup in the early 1960s.
- Built the Ooty Radio Telescope in the late 1960s – still operational & producing international quality results (in fact, being upgraded with new receiver system!)
- Built the Ooty Synthesis Radio Telescope (1980s) – important step to the GMRT.
- Built the GMRT (Giant Metrewave Radio Telescope) in the 1990s – it is a world class instrument at low radio frequencies (50 to 1450 MHz)

NCRA as an organisation : overview

- A national centre of the TIFR, concentrating on research in radio astrophysics and related topics
- ~ 20 faculty members
- ~ 25 PhD students; ~ 10 PDFs
- ~ 125 technical staff -- major strengths in RF, OF, digital electronics, servo and mechanical…
- Runs two large radio astronomy facilities : ORT & GMRT

Radio Astronomy at NCRA – TIFR : current scope

- Radio Astronomy activities at NCRA can be broadly categorised as :
  - Research programs of staff members, many using the 2 in-house facilities : ORT and GMRT
  - Technology developments at these facilities, including upgrades
  - Participation in SKA and related activities
  - User community development and training programs

Main areas of research at NCRA

- Solar studies : solar radio emission, IPS, space weather…
- Galactic astronomy : including supernova remnants, interstellar medium, galactic centre, …
- Pulsars and related science : searching, timing, emission properties…
- Transients : GRBs, FRBs…
- Extragalactic astronomy : nearby, high redshift, AGNs, deep fields…
- Cosmology and the Early Universe : EoR, evolution of fundamental constants…

Radio Astronomy technology development at NCRA : overview

- Technology development activities at NCRA can be categorized as follows :

1. Receiver technology development for upgrades :
   - The ORT upgrade
   - The GMRT upgrade
   - Collaborations with international groups : e.g. CITA, CASPER…
   - Engagement with Indian industry : TCS, PSL, NVIDIA…

2. Technology development for SKA related activities
   - Lead role by the Indian SKA group for Telescope Manager work package of the SKA
   - Lower level of participation in Central Signal Processing and Signal & Data Transport work packages.

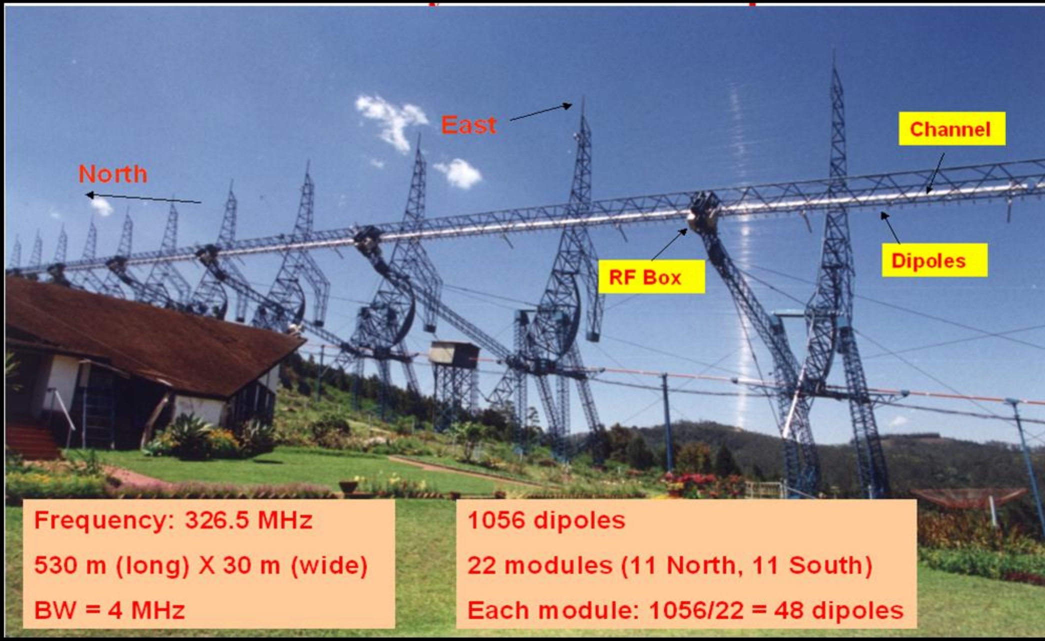
There are synergies between activities in 1. & 2.

NCRA major facilities : ORT & GMRT

- ORT : built in the late 1960s and still going strong !
- GMRT : built in the 1990s – international facility, many users; several important results.
- Both the ORT (age : 40 yrs) and the GMRT (age : 10 yrs) are undergoing major upgrades at present !

The Ooty Radio Telescope (ORT)

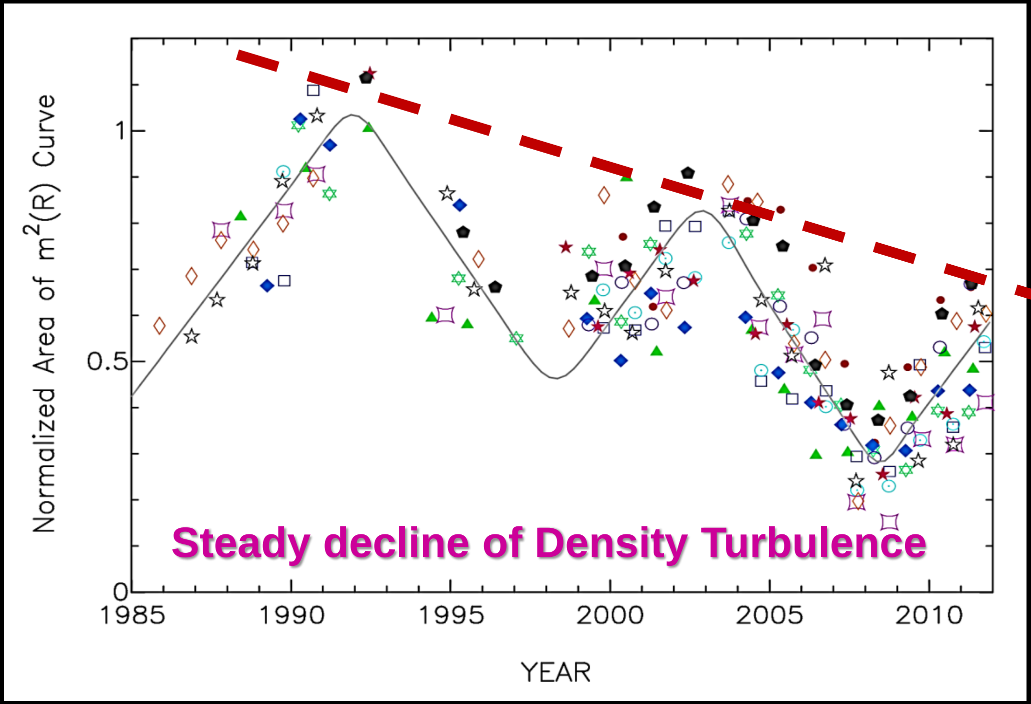
- ORT : 530 m long cylindrical paraboloid
- Operates at 325 MHz with bandwith upto ~ 40 MHz
- Many pioneering results in cosmology, pulsars, astrophysical plasmas over the years
- Presently being used primarily for solar wind , IPS studies + pulsars
- ORT IPS data being used by several institutions around the world (particularly for study of eruptive solar events)
- New pulsar receiver was installed around mid 2012 -- several new & interesting results



Results from ORT : Solar Cycle changes in the Solar Wind

- IPS observations over the years with the ORT show clear evidence for a steady decline in density turbulence (and hence mass flux) from solar cycles 22 to 24

- Indication of heading towards a "Maunder-type" minimum ?



Steady decline in density (mass flux) from solar cycle 22 to 24

Upgrade of the ORT

- A programmable digital receiver for the ORT
- NCRA – RRI – ISRO collaborative effort
- Aim is to digitise the RF signals at an early stage from the ORT dipoles / modules, do in-field processing and route the digital data via optical fibre to a central processing facility for analysis by an off-line software correlator.
- Being done in 2 phases :

phase 1 -- digitise each half-module o/p ➔ 44 signals (completed)
phase 2 -- digitise each 4 dipole set ➔ 256 signals (almost ready)

Parameter	Current	Phase-1	Phase-2
Bandwidth	4 MHz	18 MHz	40 MHz
FoV	2.3° x 2.2°	2.3° x 4.6°	2.3° x 27°
Sensitivity (τ = 1 s)	40 mJy	12 mJy	1 mJy

Science with the upgraded Ooty Radio Telescope

The upgraded ORT will be a versatile system for many astrophysical studies :

- Cosmological investigations of HI mass fluctuations using ORT
  - Bandwidth of ~20 MHz → volume of sky 7×10^6 Mpc^3
  - ~ 9 hours of continuous tracking
  - Large number of redundant baselines → improved calibration schemes
  - Should be able to detect spectrum of HI mass fluctuations in ~ 1000 hrs of integration
- Transient X-ray Binaries
  - It is important to monitor radio flux at low frequency (when ASTROSAT is in operation)
- Pulsars
- Spectral line studies
- Lunar occultation observations
- Simultaneous GMRT-ORT studies
- Space Weather Studies (Sun-Earth connection studies)

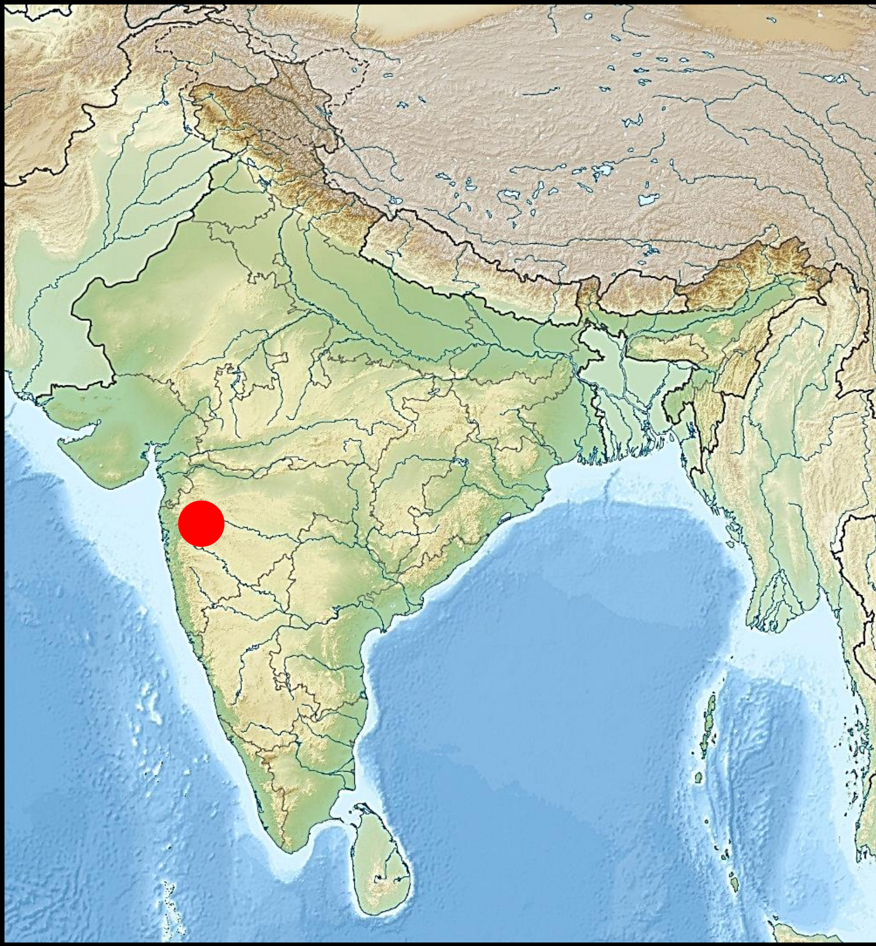
The GMRT

The GMRT : Brief History

- Motivation (early 1980s) : bridge the gap in radio astronomy facilities at low frequencies and address science problems best studied at metre wavelengths
- First concept : 1984 (started with large cylinders); evolved to 34 dishes of 45 metres by 1986
- Project cleared and funding secured by 1987
- Construction started : 1990; first antenna erected : 1992
- First light observations : 1997 – 1998
- Released for world-wide use : 2002

The GMRT : An Overview

- Located in the western part of India :
  - 80 km NE of Pune
  - 180 km E of Mumbai
  - Spread out over a 25 km diameter region
- Frequency range :
  - 130-170 MHz
  - 225-245 MHz
  - 300-360 MHz
  - 580-660 MHz
  - 1000-1450 MHz
  - max instantaneous BW = 32 MHz
- Effective collecting area (2-3% of full SKA) :
  - 30,000 sq m at lower frequencies
  - 20,000 sq m at highest frequencies
- Supports 2 modes of operation :
  - Interferometry, aperture synthesis
  - Array mode (incoherent & coherent)



The GMRT : An Overview

- 30 dishes, 45 m diameter each
  - 12 dishes in a central 1 km x 1 km region (central square)
  - remaining along 3 arms of Y-shaped array
  - baselines : ~ 200 m (shortest);
    ~ 30 km (longest)
- Frequency range :
  - 130-170 MHz
  - 225-245 MHz
  - 300-360 MHz
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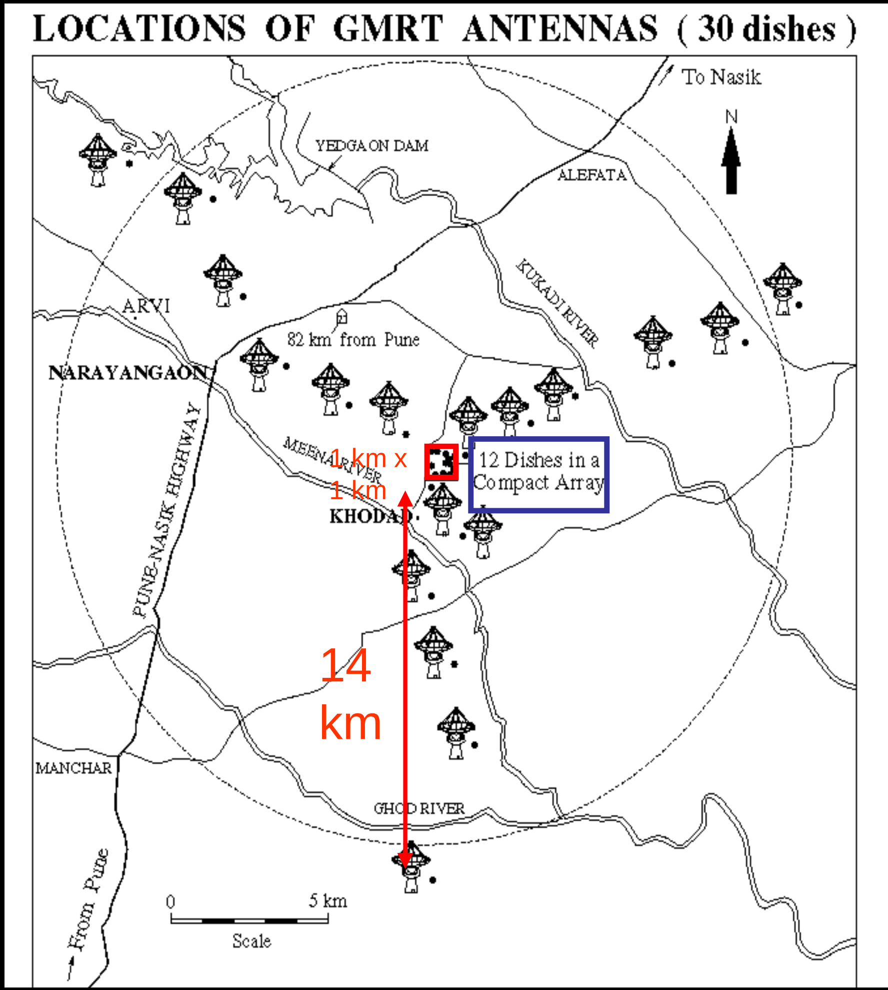


The Giant Metre-wave Radio Telescope

A Google eye view

The Giant Metre-wave Radio Telescope A Google eye view

The Giant Metre-wave Radio Telescope
Google eye view

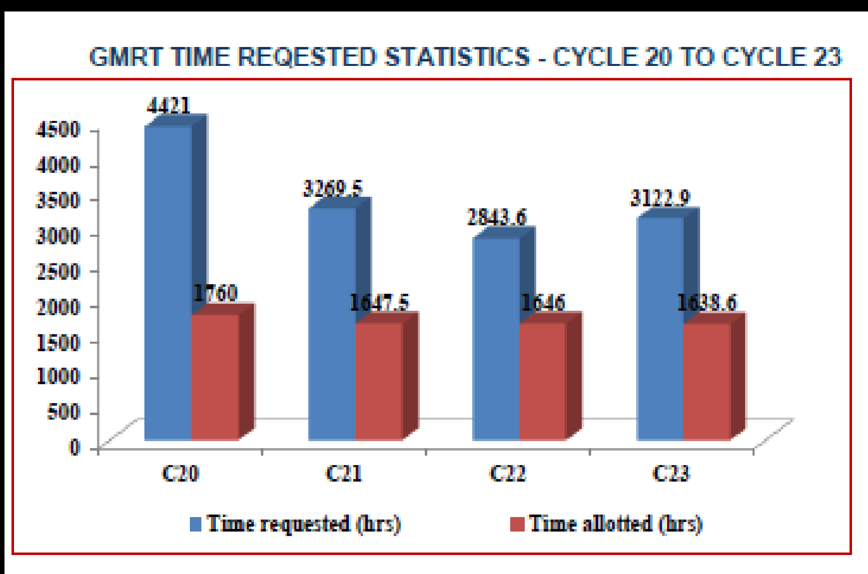
Dedication of the GMRT

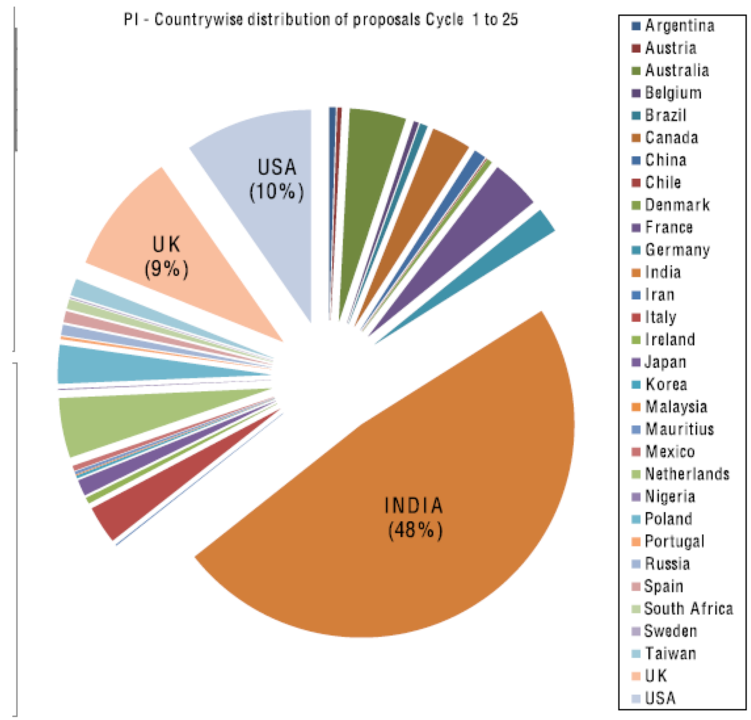
The Giant Metrewave Radio Telescope was dedicated to the World Scientific Community by the Chairman of TIFR Council, Shri Ratan Tata.

October 4, 2001

GMRT : Usage Statistics

- GMRT sees users from all over the world : distribution of Indian vs Foreign users is close to 45:55
- The GMRT has been typically oversubscribed by a factor of 2 or more





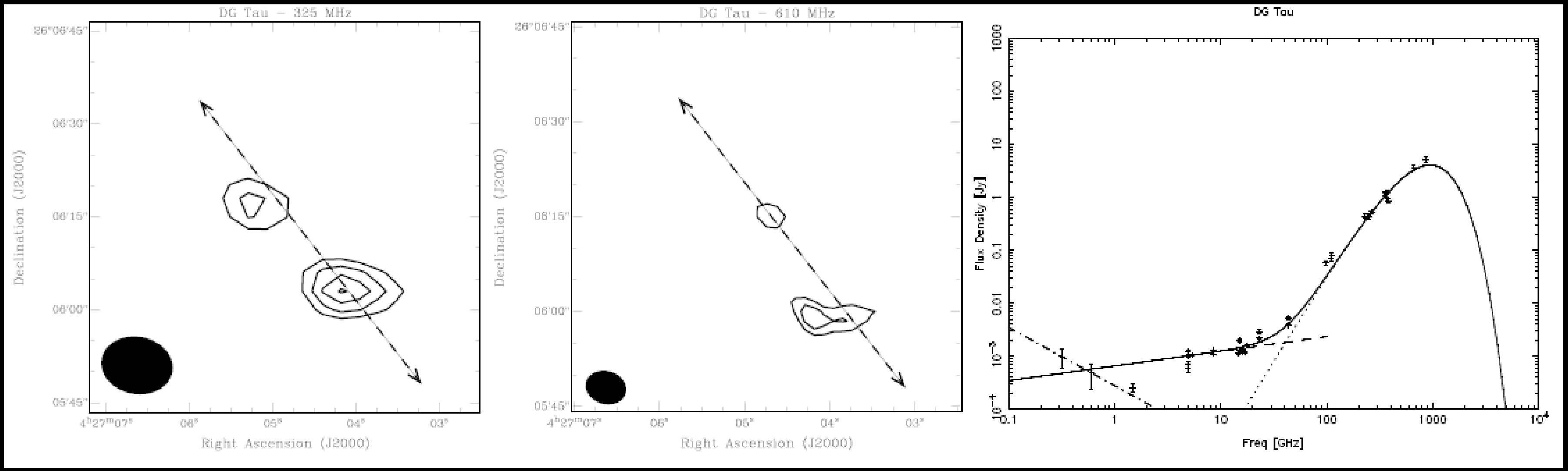
Country	Nos	Country	Nos	Country	Nos	Country	Nos	Country	Nos
Argentina	8	China	14	Iran	1	Mauritius	3	Russia	12
Austria	5	Chile	1	Italy	45	Mexico	6	Spain	13
Australia	67	Denmark	6	Ireland	7	Netherlands	71	South Africa	11
Belgium	6	France	59	Japan	19	Nigeria	1	Sweden	1
Brazil	9	Germany	30	Korea	3	Poland	46	Taiwan	20
Canada	47	India	758	Malaysia	1	Portugal	3	UK	145
								USA	152
Total Proposals Received					1570				

GMRT : Range of Science

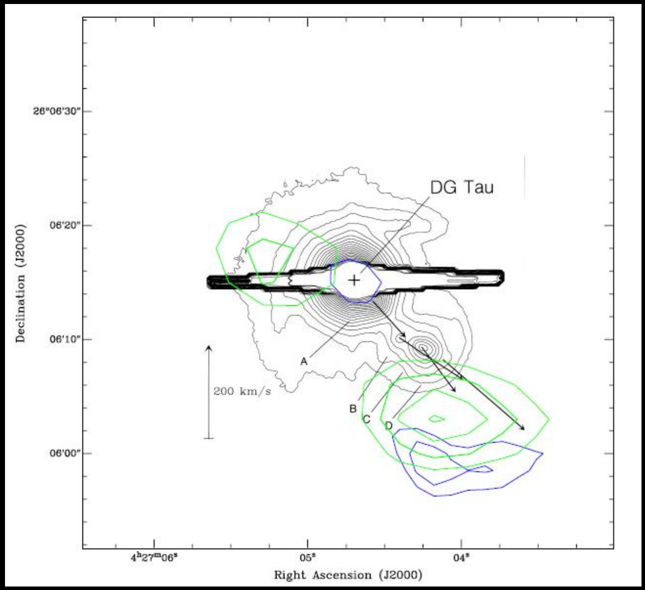
- The GMRT has been used for a wide range of studies :
  - Sun, extrasolar planets, YSOs -- some tantalising detections.
  - Pulsars : rapidly rotating neutron stars – many new results.
  - Other Galactice objects like supernova remnants, microquasars etc
  - Other explosive events like Gamma Ray Bursts
  - Ionized and neutral Hydrogen gas clouds (in our Galaxy and in other galaxies) -- from Damped Lyman systems to Dwarf galaxies…
  - Radio properties of different kinds of galaxies; galaxy clusters and haloes – lots of interesting results here.
  - Radio galaxies at large distances in the Universe -- interesting new objects reported, including spiral hosts…
  - Cosmology and the Epoch of Reionization – published upper limits.
  - All sky surveys such as the 150 MHz TGSS

Some unique results from the GMRT

First Radio Detections of YSOs

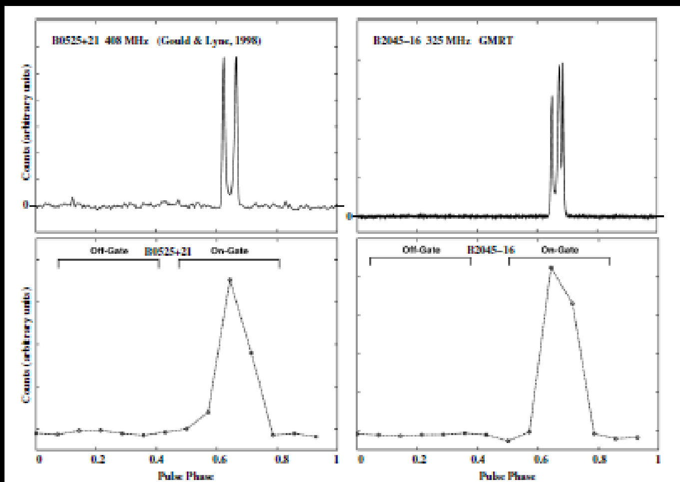


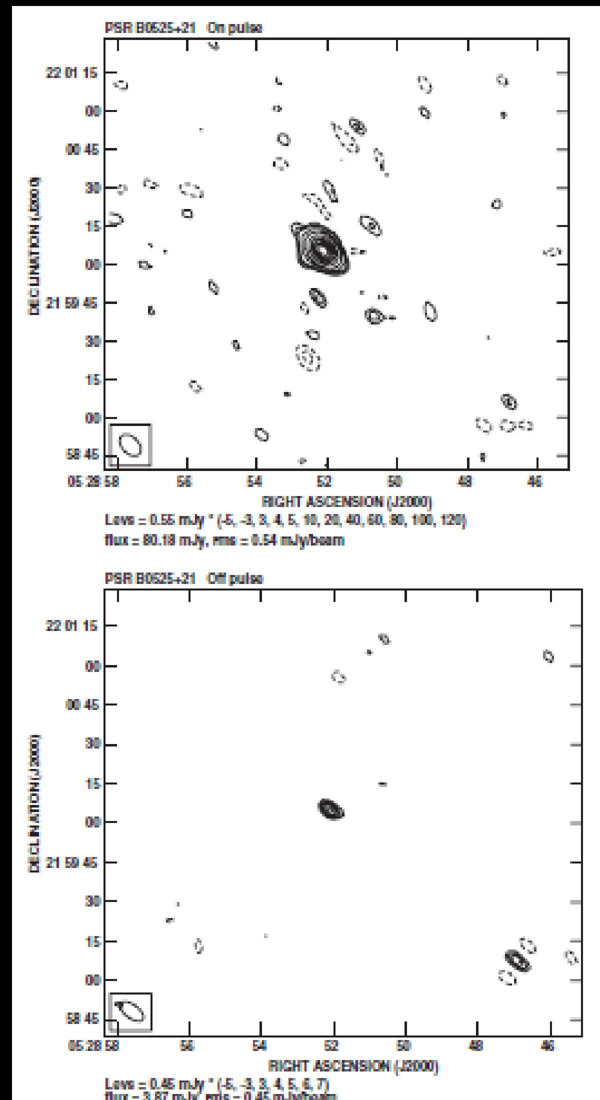
- (First) detection of 3 YSOs at 325 & 610 MHz
- First evidence for non-thermal radio emission in class II YSOs → synchrotron or gyro-sync ?
- DG Tauri : location of radio emission wrt proper motion → detection of bow shock

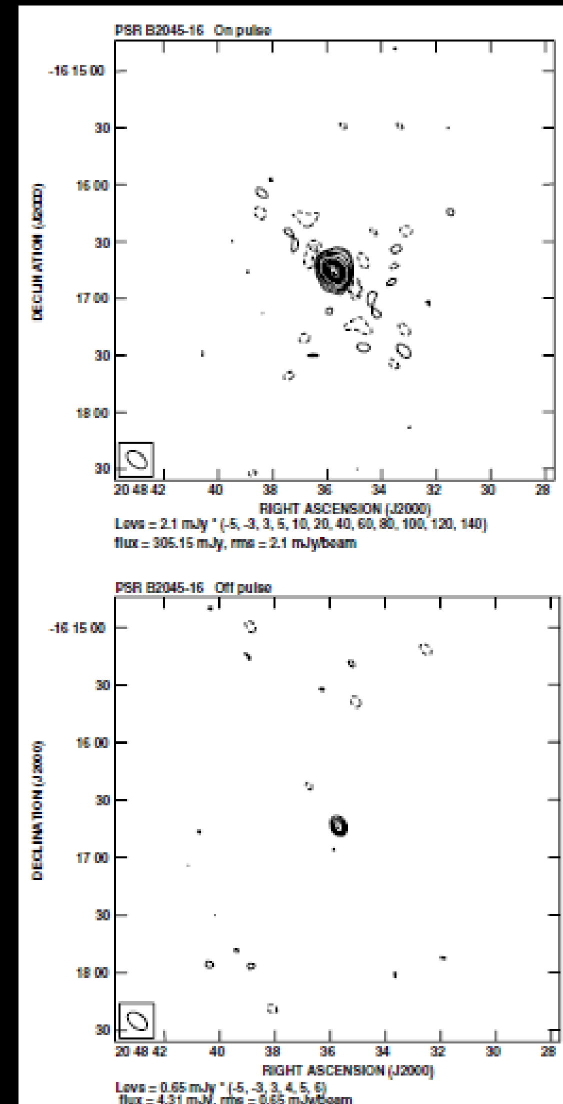


Ainsworth et al 2014

Off-pulse emission from pulsars





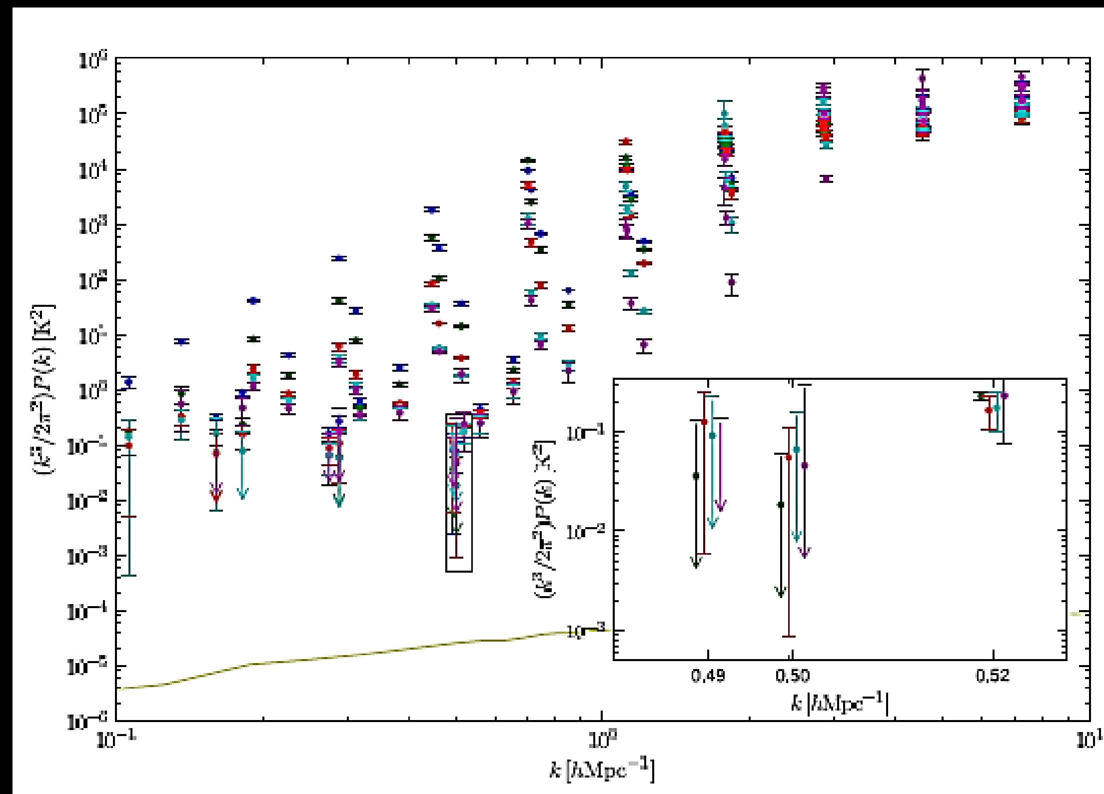


Using gated interferometer to make images for on-pulse and off-pulse regions for some well known pulsars

Basu, Athreya & Mitra (2011 & 2012)

EoR Experiment at the GMRT

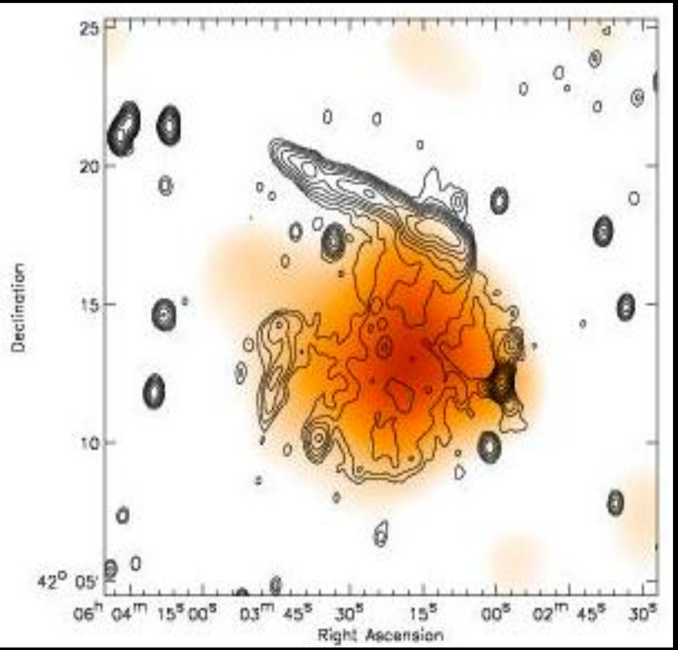
- EoR project at the GMRT led by Ue-Li Pen (CITA)
- Uses a field with a pulsar at the phase centre as the calibrator
- Works off a special mode of the software back-end with real-time pulsar gating
- First published results establish interesting new limits on EoR signal strength

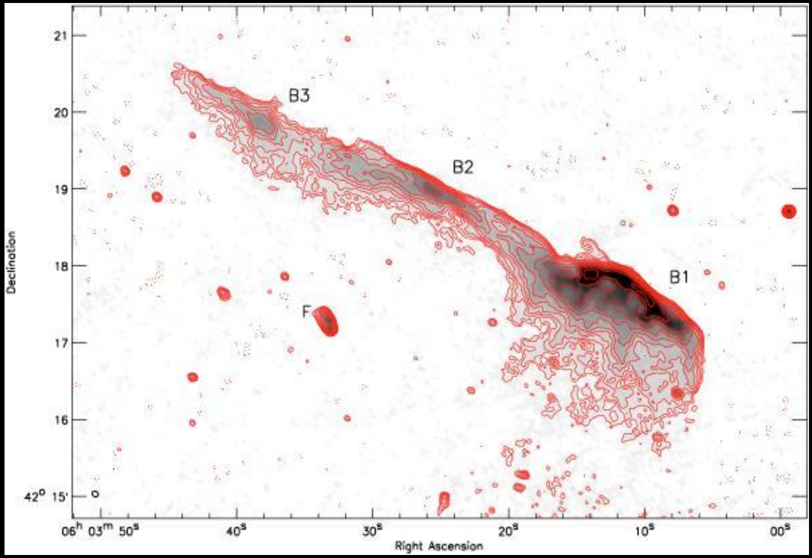


Paciga et al, 2011 & 2013

Relics in Clusters

- Easy to find radio relics in clusters with GMRT
- **Toothbrush Relic :** Evidence for a coherent linear 2 Mpc scale shock wave in massive merging galaxy cluster



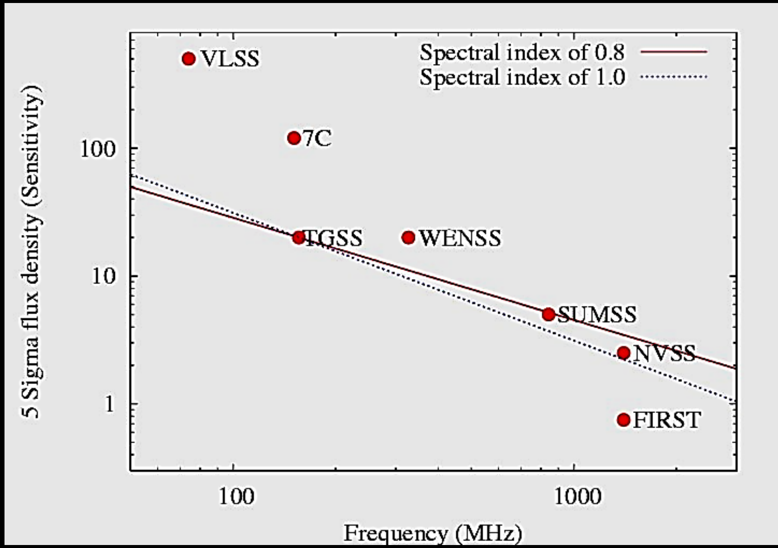


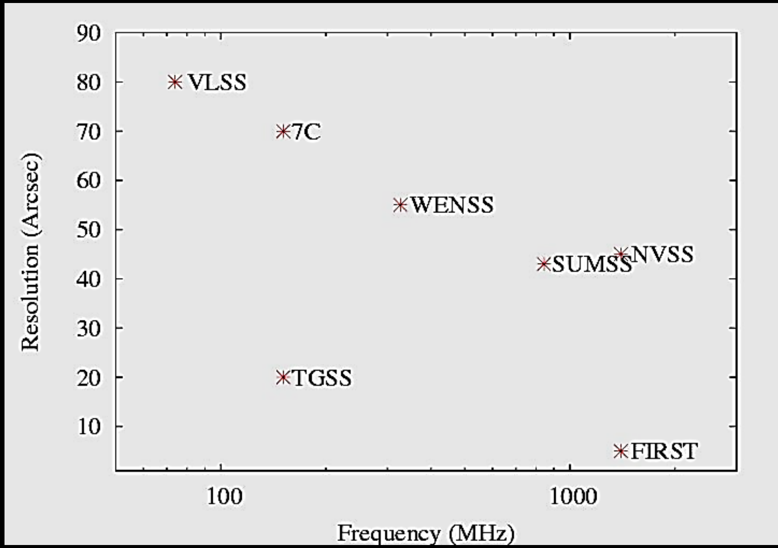
GMRT at 325 MHz

Van Weeren etal 2012

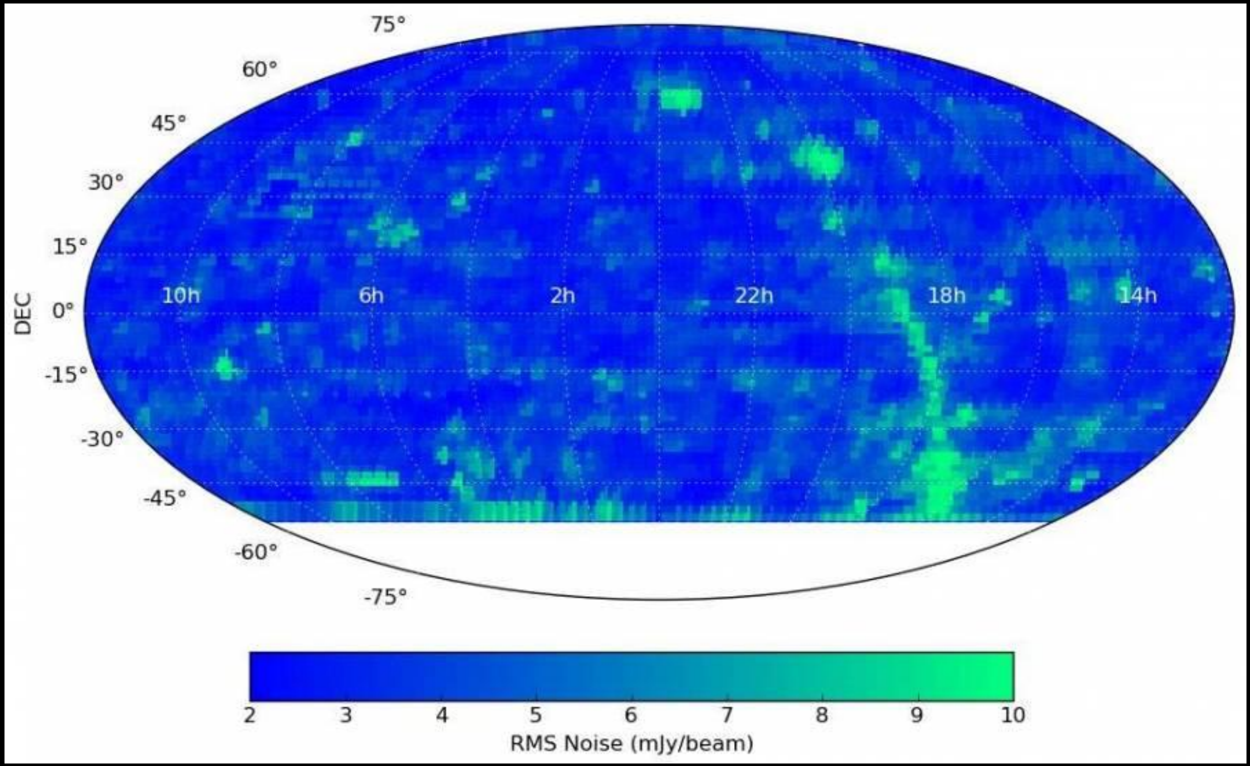
All Sky Surveys : TGSS

- All sky survey at 150 MHz
- Metrewave counterpart of NVSS (spectrally matched)
- 20” resolution (~ 5x better than NVSS)
- Median noise ~ 3.5 mJy/beam achieved
- 0.6 million sources already catalogued
- 5336 mosaic images of 5x5 sq deg





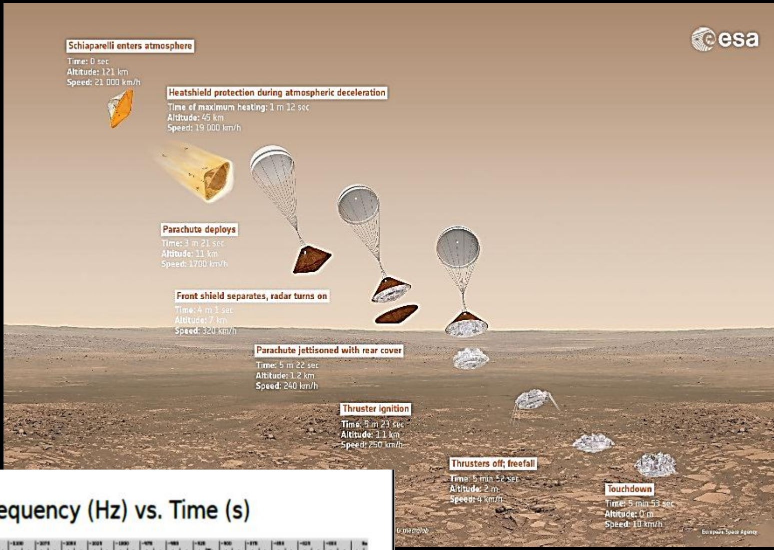
All Sky Surveys : TGSS

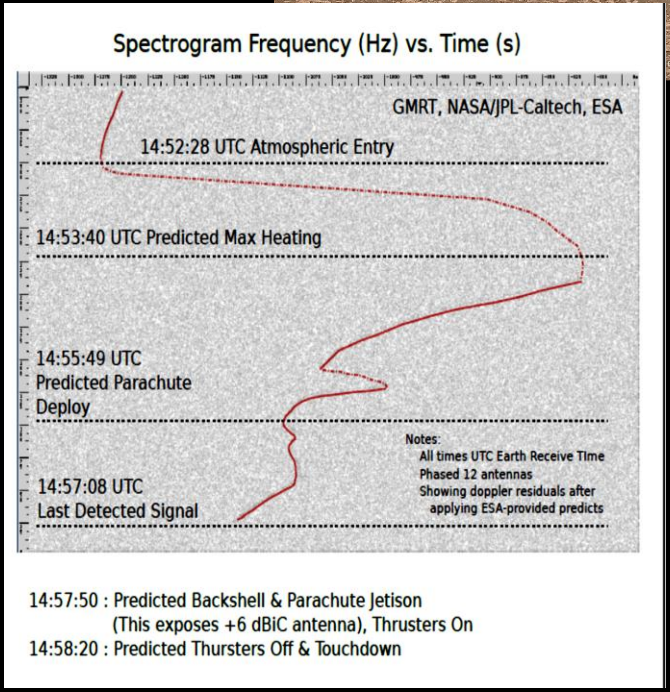


- Sky covered by the TGSS survey at 150 MHz : all sky > -53 dec.
- TGSS results and data products are proving very useful and popular – this is just what astronomers needed at low frequencies.

“Fringe” benefits with the GMRT : Tracking Space Probes !

- Ground support for ExoMars mission of ESA
- GMRT + NASA collaboration
- Faithfully tracked Schiaparelli Lander module of ExoMars through “8 mins of hell”
- ~ 3 W signal @ 401 MHz from Mars !





ExoMars/Schiaparelli/EDM
Entry, Descent, Landing (EDL)
Detection at GMRT, India
2016-10-19

Looking ahead : the upgraded GMRT

First concepts mooted : 2007-2008

Detailed work started : 2012

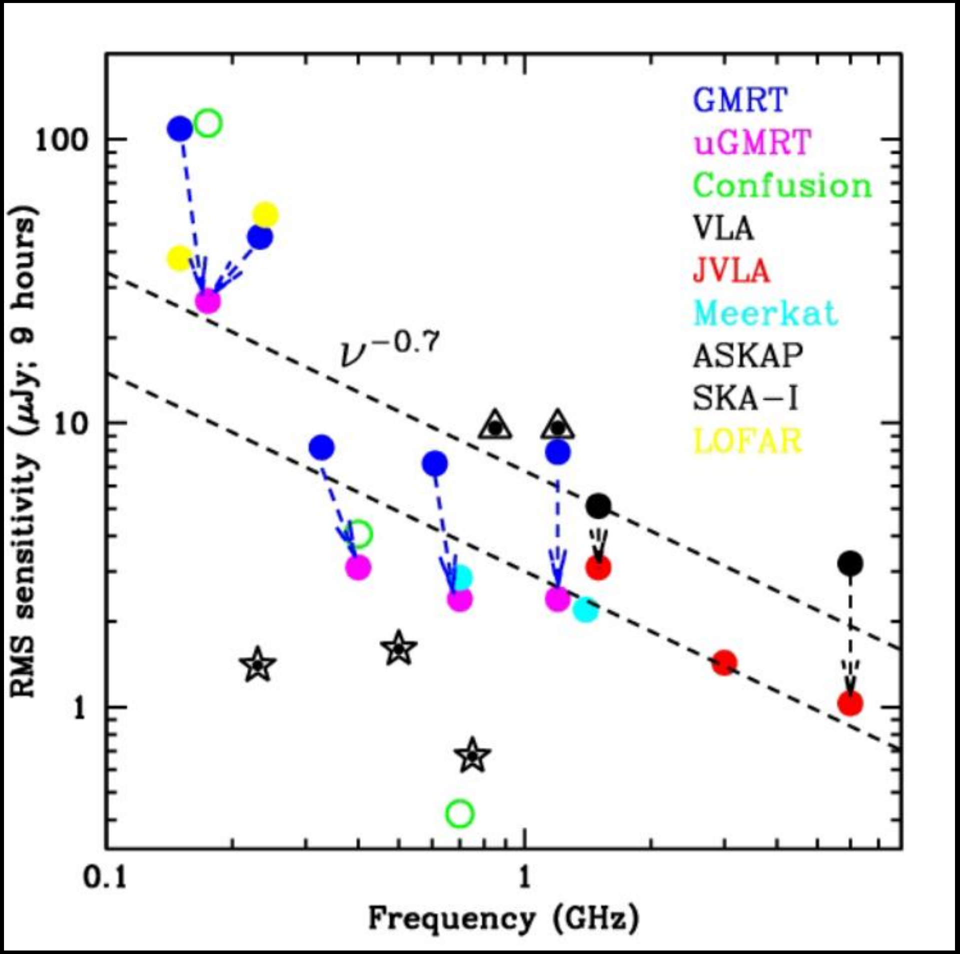
Now nearing completion

Looking ahead : the upgraded GMRT

- Main goals for the upgraded GMRT (uGMRT) were identified as :
  - Seamless frequency coverage from ~ 50 MHz to 1500 MHz, instead of the limited bands at present ➔ *design of completely new feeds and receiver systems with ~ octave bandwidths*
  - Improved dynamic range and G/Tsys ➔ *better technology receivers*
  - Increased instantaneous bandwidth of 400 MHz (from the present maximum of 32 MHz) ➔ *new digital back-end receiver*
  - Revamped servo system ➔ *brushless drives, new servo computer etc*
  - Modern, versatile control and monitor system ➔ *SKA contribution*
  - Matching improvements in offline computing facilities
  - Improvements in mechanical & electrical systems, infrastructure facilities
  - To be done without compromising availability of existing GMRT to users

uGMRT : Expected Performance

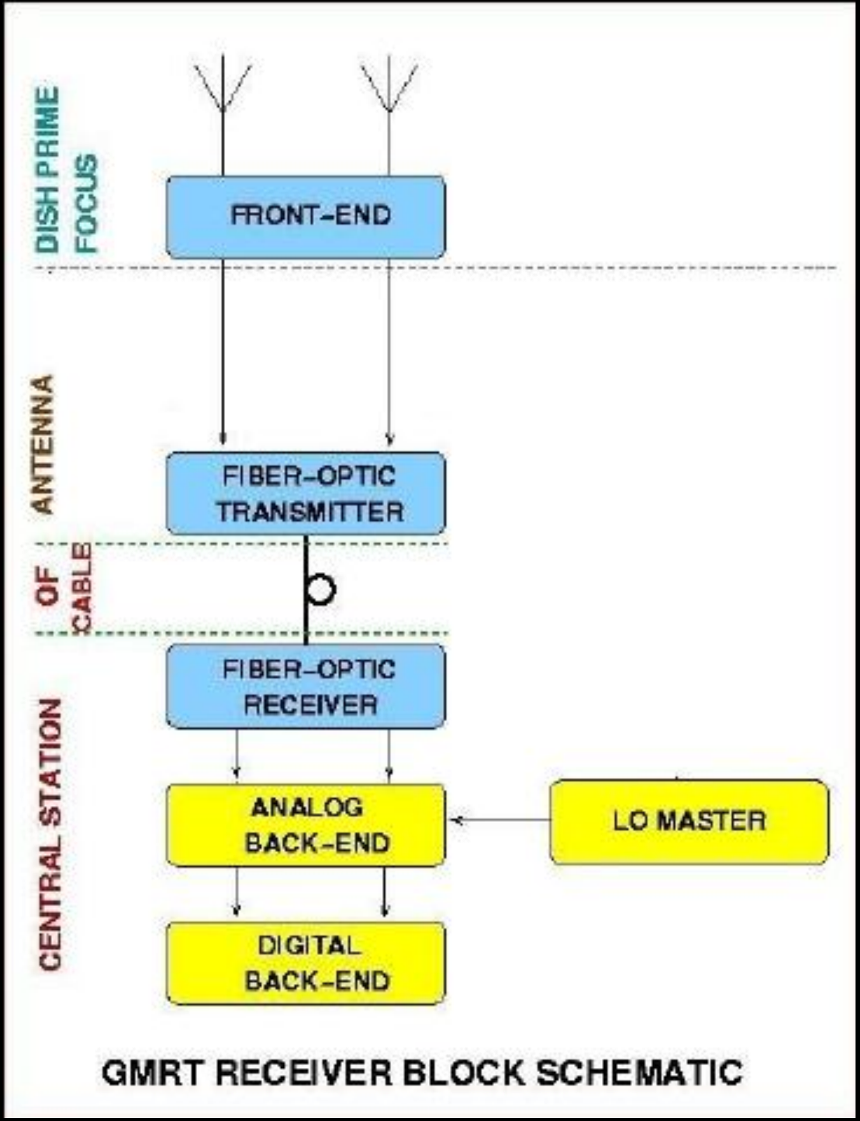
- Spectral lines : broadband coverage will give significant increase in the redshift space for HI lines + access to other lines
- Continuum imaging sensitivity will improve by factor of 3 or so.
- Sensitivity for pulsar observations will also improve by factor of 3.
- Only SKA-I will do better than uGMRT at centimeter and metre wavelengths



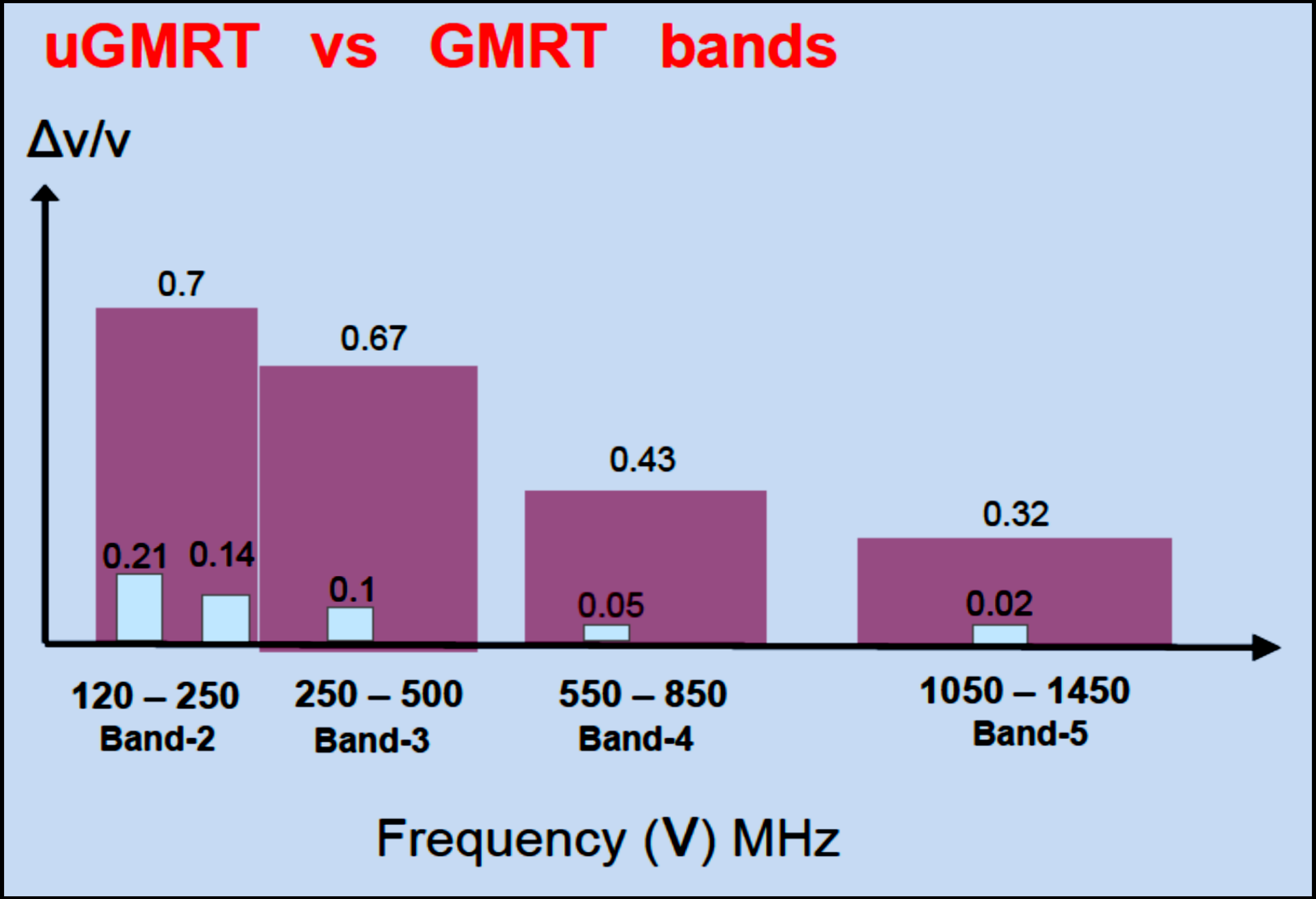
Expected sensitivity performance of the upgraded GMRT compared to other major facilities in the world, present and projected (courtesy : Nissim Kanekar, NCRA)

Overview of uGMRT Receiver System

- Broad-band feeds + FE (in octaves) :
  - 1000 – 1450 MHz (updating L-band)
  - 550 – 900 MHz (replacing 610)
  - 250 – 500 MHz (replacing 325)
  - 125 – 250 MHz (replacing 150)
- Modified optical fibre system to cater to wideband (50 to 2000 MHz) dual pol RF signals (while allowing existing IF signals)
- Analog back-end system to translate RF signals to 0 - 400 MHz baseband
- Digital back-end system process 400 MHz BW for interferometric and beam modes



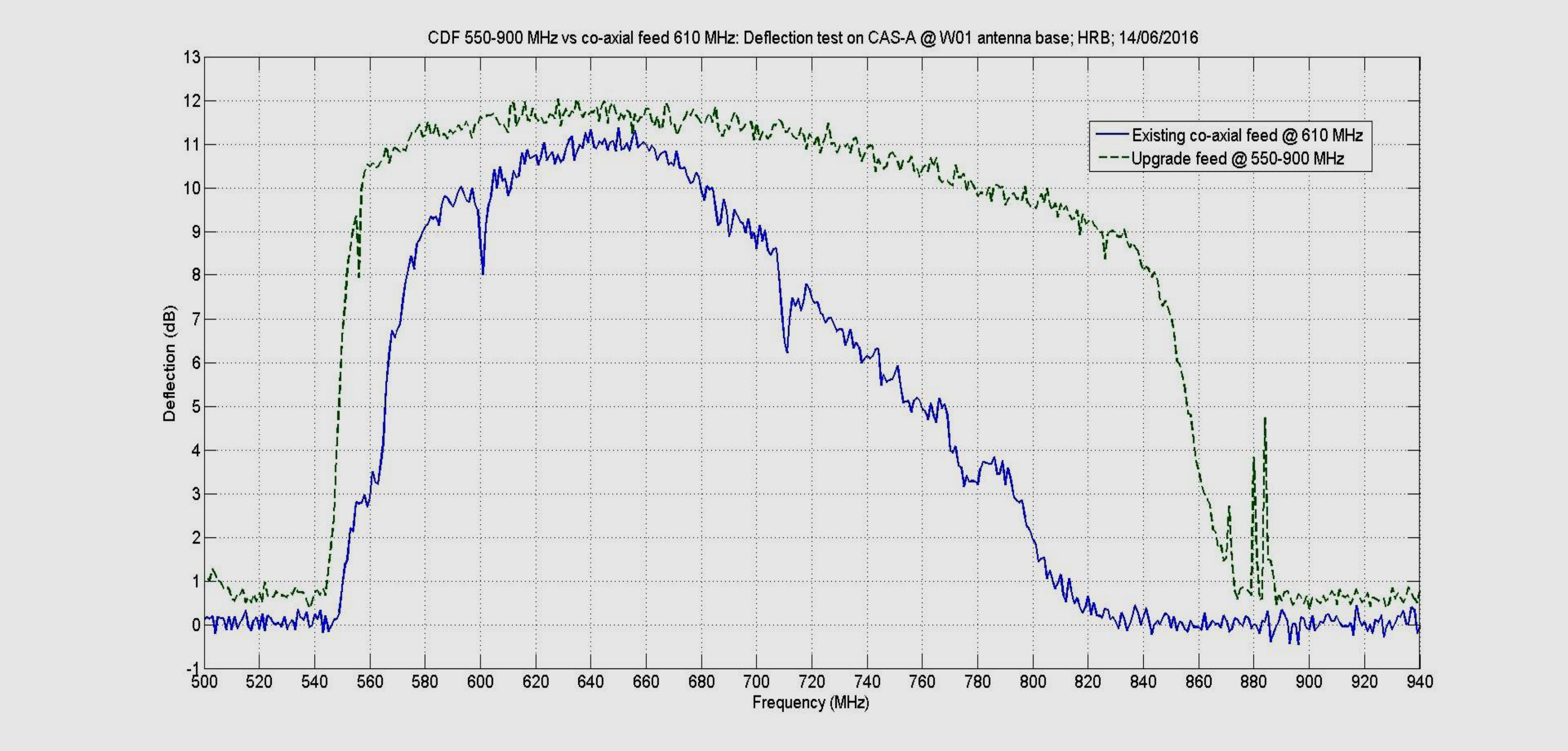
GMRT vs uGMRT : Frequency Coverage



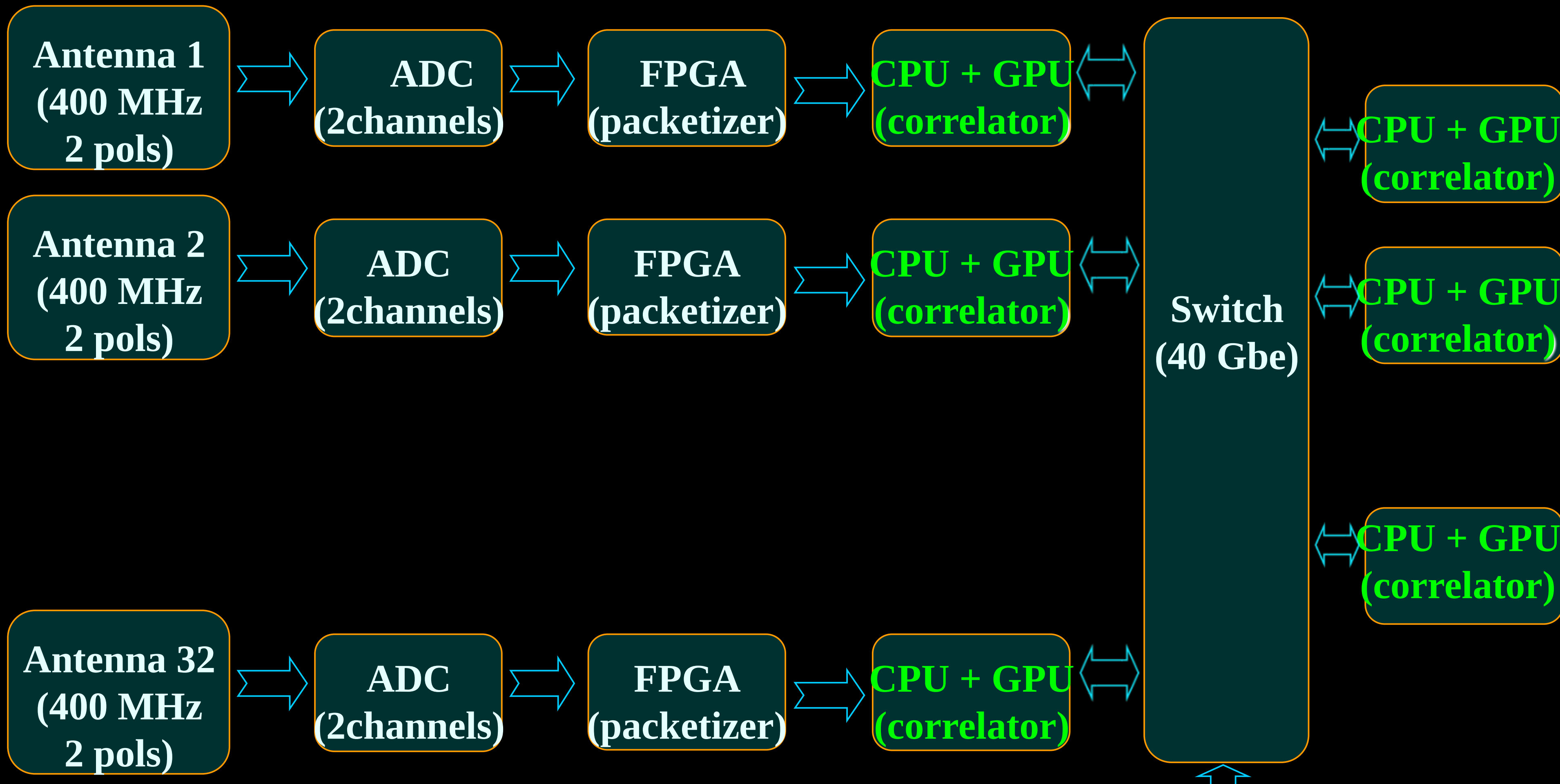
courtesy : Ruta Kale

Wideband front-ends for uGMRT : 550-850 MHz system – "Band 4"

- Performs better than existing feed at 610 MHz
- Nice, clean band with negligible RFI



uGMRT Digital Backend : Hybrid Design – FPGAs + GPUs



32 stations, 400 MHz BW, 16-32 K channels,
Full Stokes correlator + beamformer + pulsar rx.

Completion of uGMRT

uGMRT completion and release to users has been in multiple phases :

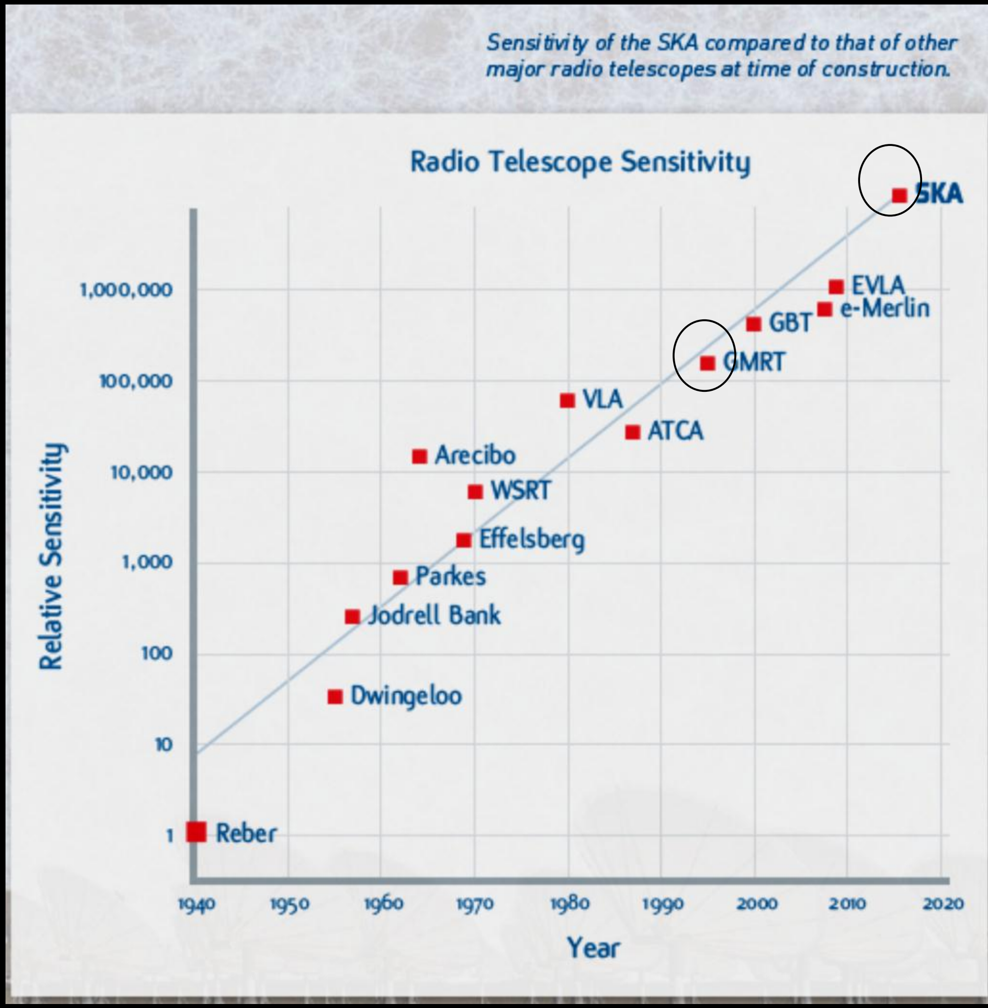
1. First release of 8 antenna trial system – way back in September 2013.
2. Release of 16 antenna system for internal users – September 2015.
3. Release of 16 antenna system in shared risk mode -- April 2016 .
4. Release of a 30 antenna system with 2 bands fully functional :
   Band-5 (1000-1450 MHz) & Band-3 (250-500 MHz) -- Oct-Nov 2016.
5. Next release : 30 antenna configuration with 3 bands completed
   (adding Band-4 : 550-850 MHz) -- October 2017.
6. Completion & formal inauguration of uGMRT : planned March 2018.

→ *Stay tuned !*

India and the SKA

The SKA is the future of Radio Astronomy

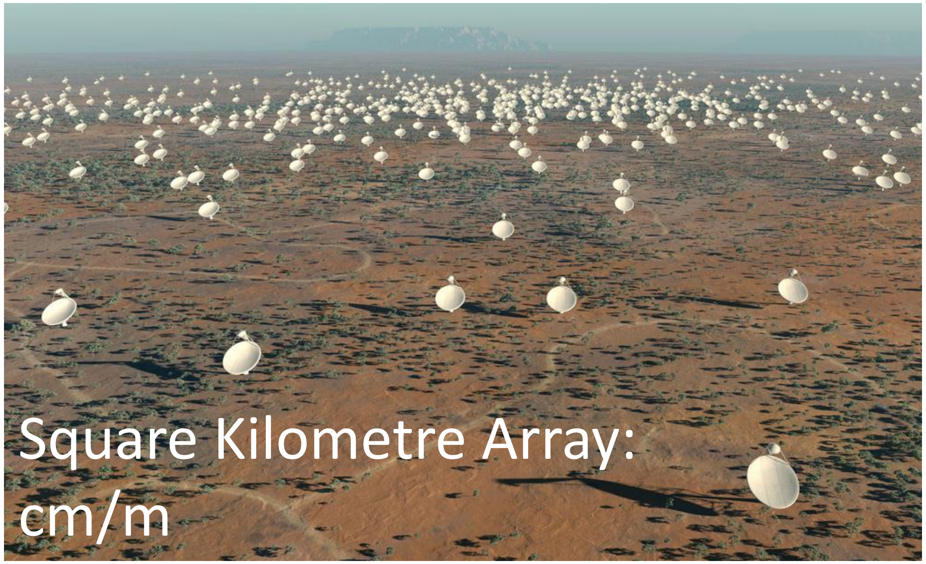
- The SKA is the most ambitious radio astronomy project
- Science with the SKA will be truly revolutionary !
- SKA will drive the growth of many new & cutting edge technologies : from electronics to supercomputing to software
- All the major radio astronomy nations are members
- Two phases :
  - SKA-I : ~ 10% of full SKA

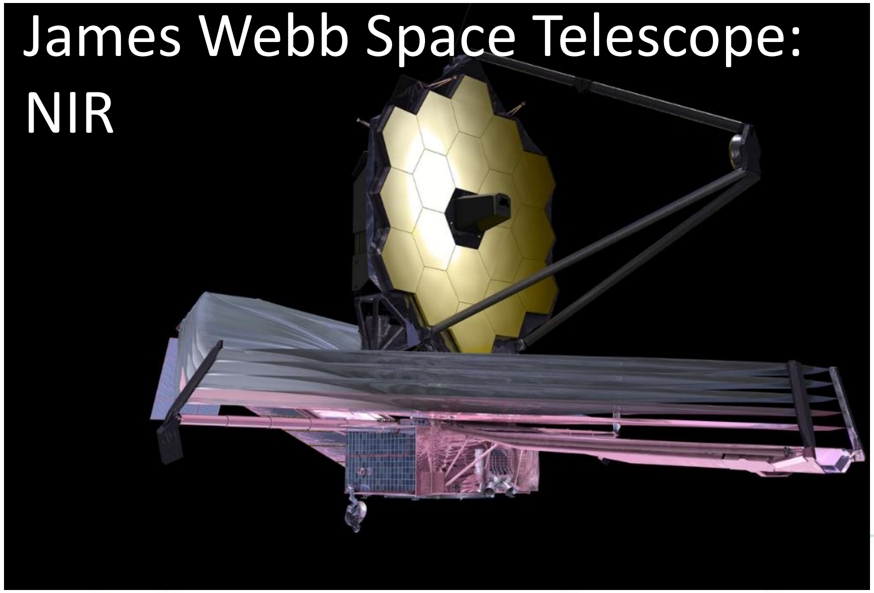


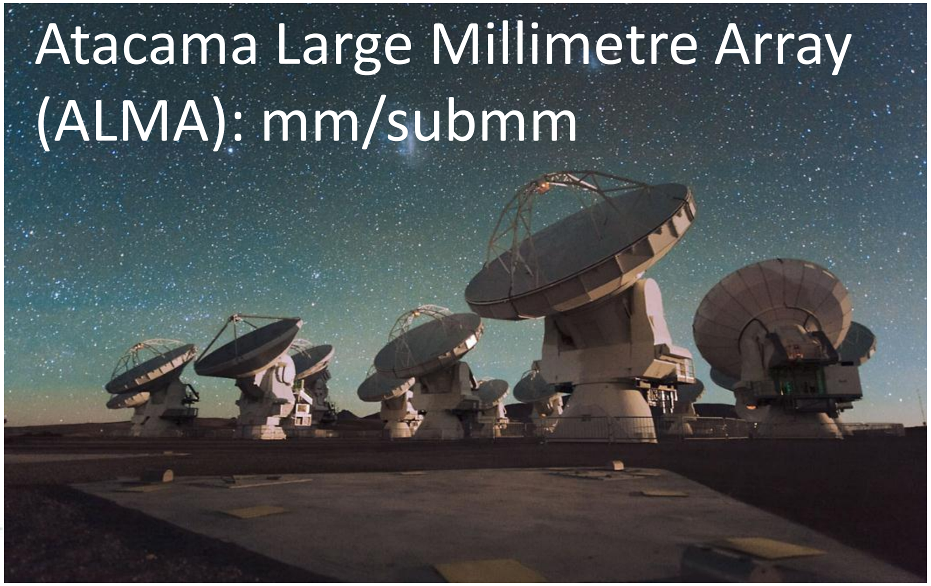
Radio telescope sensitivities over the years

SKA will be 50x better than today's best !

The SKA will be one of Great Multi-wavelength Observatories of the future decades

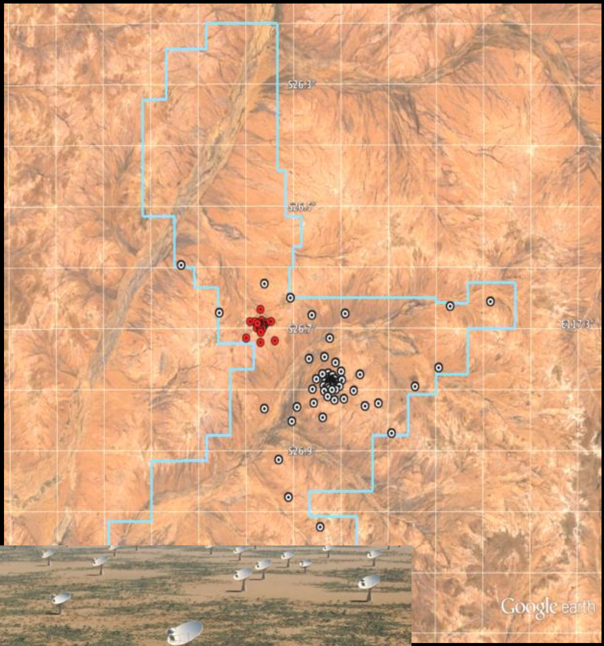






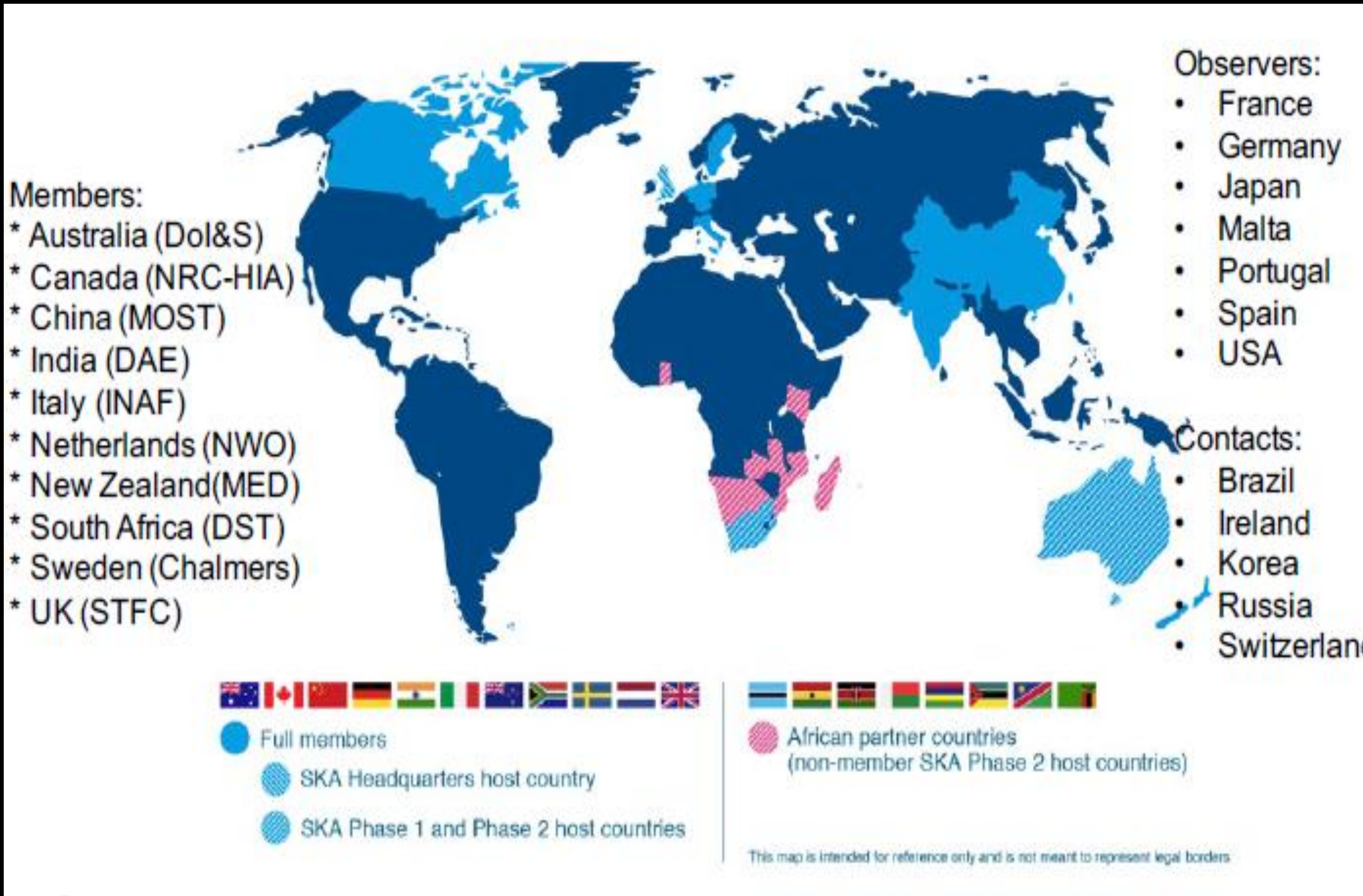
SKA Design & Technologies

- Receptor stations spread out over a region of 3000 km ; highly compact & dense central core region
- Multiple detector technologies to cover the large frequency range : dishes (high frequency), sparse & dense aperture arrays (low & mid frequencies)
- Extensive optical fibre network (petabits/sec) : > total internet traffic)
- State of the art low noise electronics & real-time signal processing
- Supercomputing capability (petaflops) for post processing requirements
- Complex telescope management structure



SKA-I : Design work packages

SKA-I : Members



Indian Participation in SKA : Overview

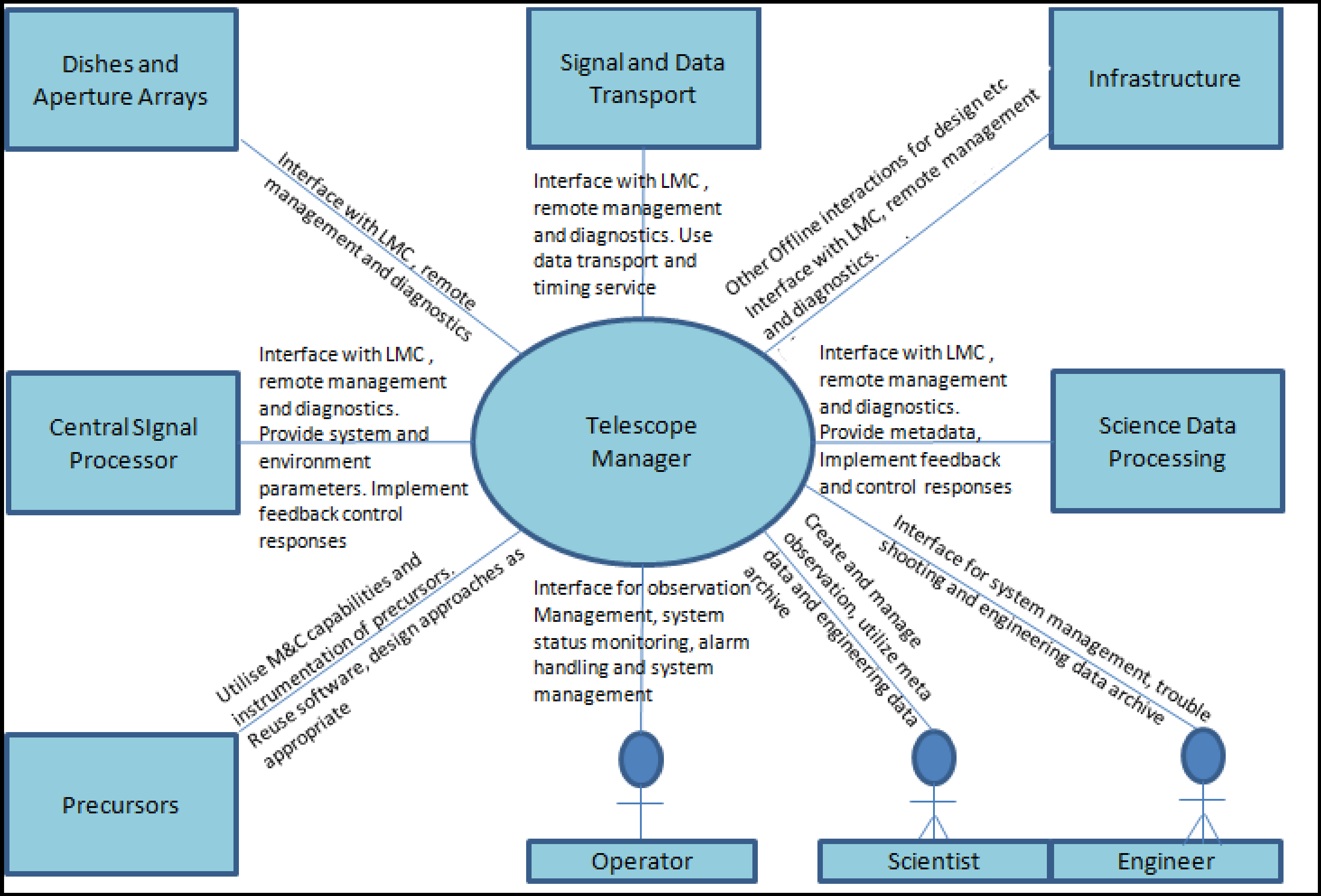
- India has been involved in the SKA Project since the early days of thinking & planning; and is a Full Member of the SKA Organisation.
- NCRA is the nodal organisation and DAE is the nodal ministry
- The GMRT has the status of a SKA pathfinder facility
- Main aspects of Indian participation in SKA, at present, are :
  - Participation in technical design phase of SKA-I (and plans for construction phase of SKA-I later on)
  - Involvement in SKA Pathfinders : technical and science aspects
  - Preparing for science with the SKA
  - Developing required technical and scientific manpower : training and outreach

TM Consortium : Partners & Roles

- LMC (INAF, Italy)
- Observation Management (UKATC , UK)
- Telescope Management (NCRA , India)
- Infrastructure (Engage SKA Consortium , Portugal)
- Project Management (NCRA, India)
- System Engineering (SKA SA, South Africa)
- Prototyping (NCRA , India)
- Review, support (CSIRO , Australia ; NRC-HIA, Canada)

The Telescope Manager Consortium is led by the Indian team (NCRA + partners from research institutes & industry) and includes members from 7 other countries. Each member plays a specific role in the consortium, contributing to one or more of the major activities.

Telescope Manager for the SKA



The Telescope Manager is the central brain + nervous system of the SKA telescope : it interacts with and controls every element of the observatory and plays the central role in carrying out the observations and managing the observatory resources.

SKA related activities : future plans

- Involvement in SKA Inter-Governmental Organisation (IGO) :
  - India is now a negotiating member in the ongoing IGO discussions
  - We hope to sign the treaty as a founding member of the SKA Observatory
- Complete the design work packages successfully :
  - Telescope Manager has completed PDR and is now well into CDR phase
  - Prototype TM system is being developed for the GMRT
- Participate in a significant manner in the construction activity
- Plan to have a SKA Engineering and Data Centre in India
- Development of SKA science related activities :
  - Continue participation in the SKA Science Working Groups
  - Enhance SKA science related activities in the country and build strong science groups
- SKA India Consortium of interested organizations has been set-up to coordinate all these activities.

Thank You