The GMRT : a look at the Past, Present and Future

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URSI GASS Montreal 2017

NCRA • TIFR

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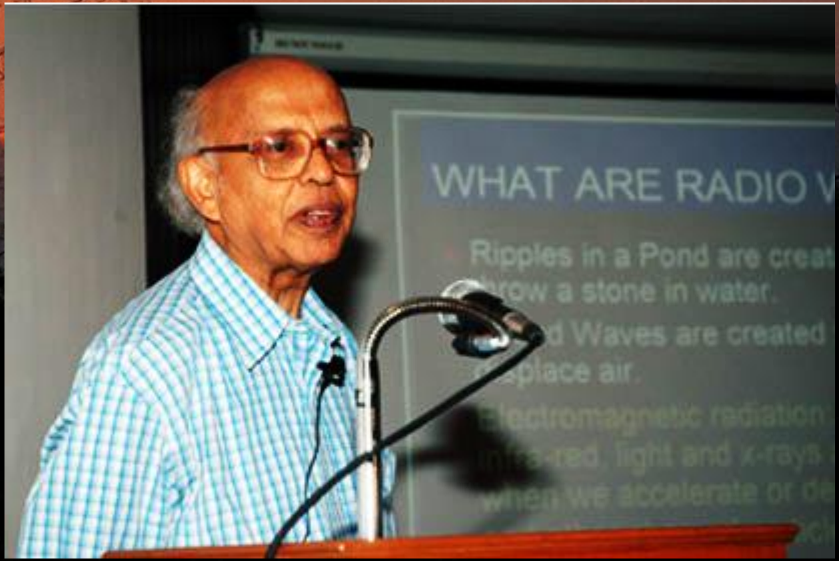

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Overview of today's talk

- Part I : the GMRT -- a historical perspective
- Part II : the GMRT -- current status
- Part III : future -- the upgraded GMRT

Some history

- It is the early 1980s… the VLA has recently become operational
- Radio astronomy has shifted from the low frequencies, where it was born, to higher frequencies (cm and higher wavelengths) -- obvious reasons
- Note, however, techniques like self-cal have been shown to work

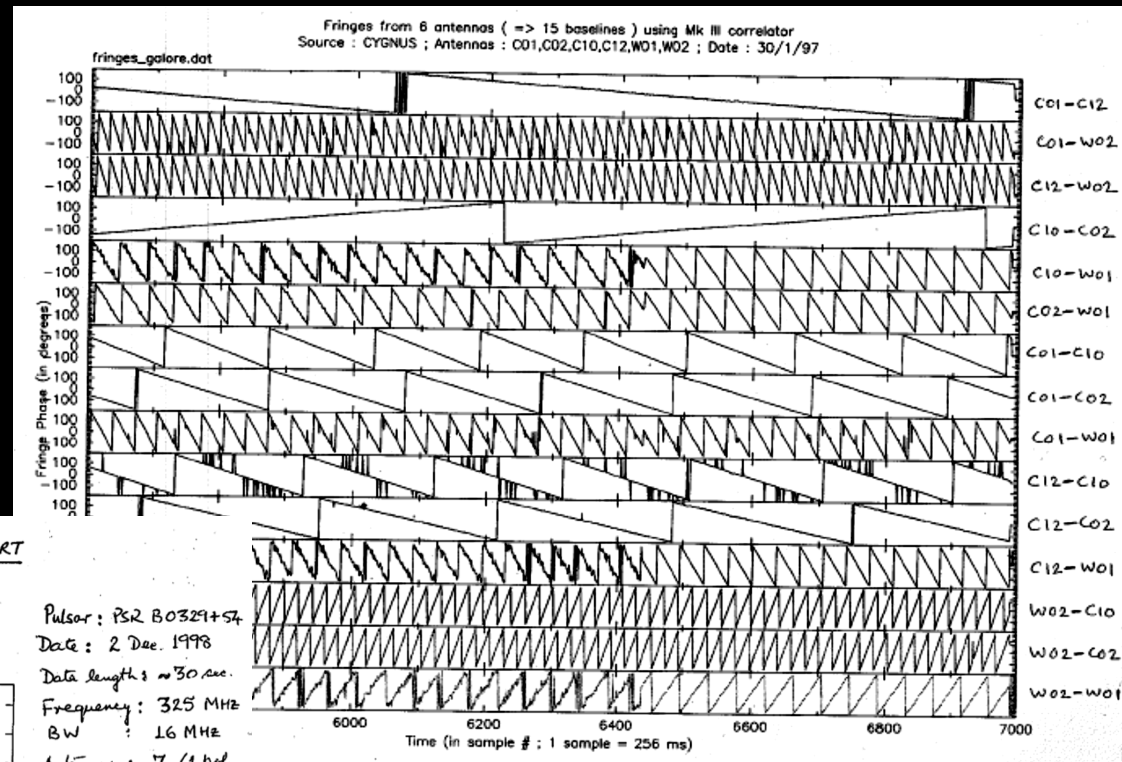
- In India, the radio astronomy group at the Tata Institute, under the leadership of Govind Swarup, is looking for the next big challenge… They have already :
  - Built the Ooty Radio Telescope in the late 1960s – still operational & producing international quality results (in fact, currently being upgraded with new receiver system!)
  - Built the Ooty Synthesis Radio Telescope (1980s) – short-lived but valuable learnings
  - Built up considerable experience in low frequencies (metre wavelengths)

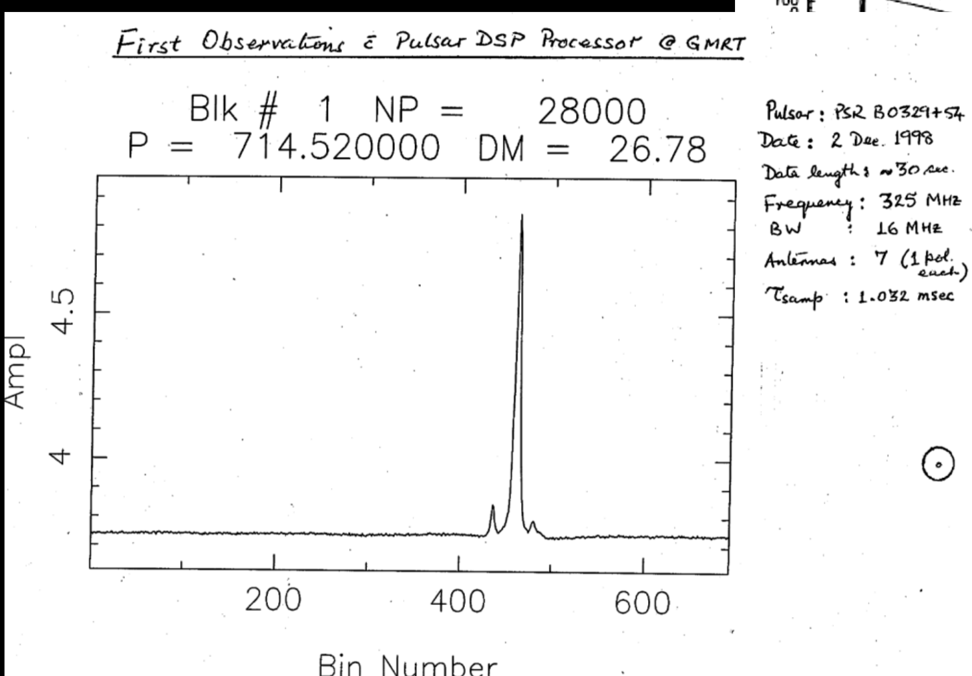
Birth of the GMRT

- Motivation : 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 : turning it ON

Jan 1997 : First fringes with the prototype GMRT correlator





Dec 1998 : first light pulsar observation with the GMRT

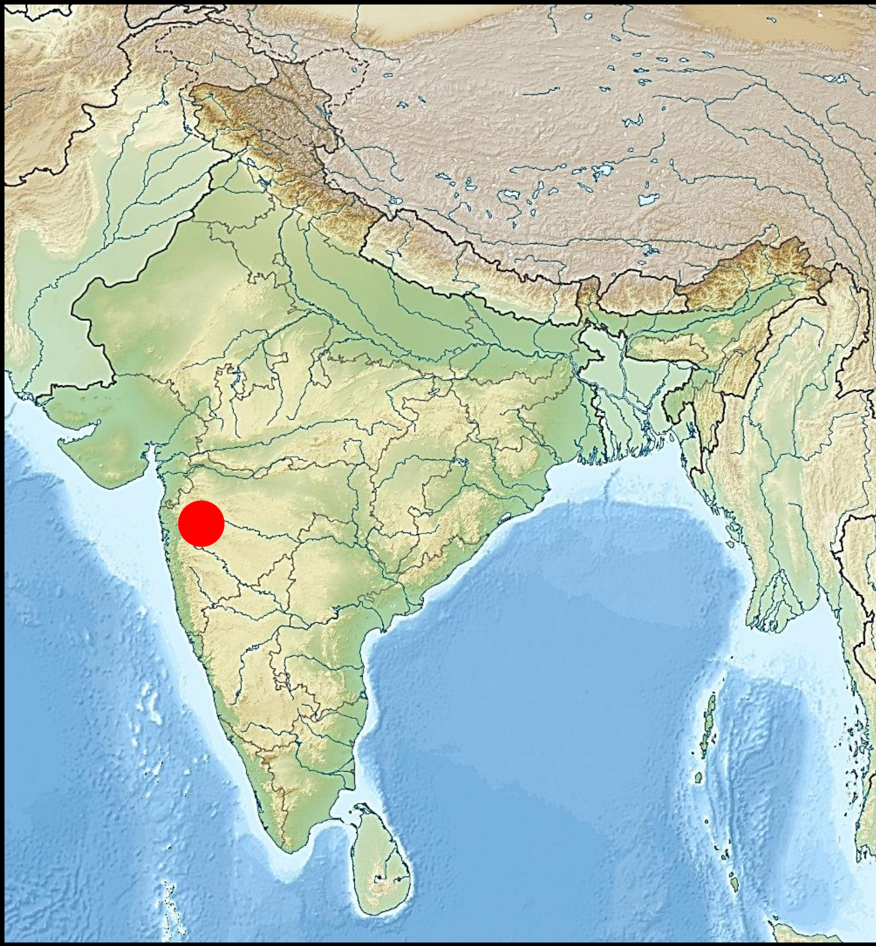
Dedication of the GMRT

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

October 4, 2001

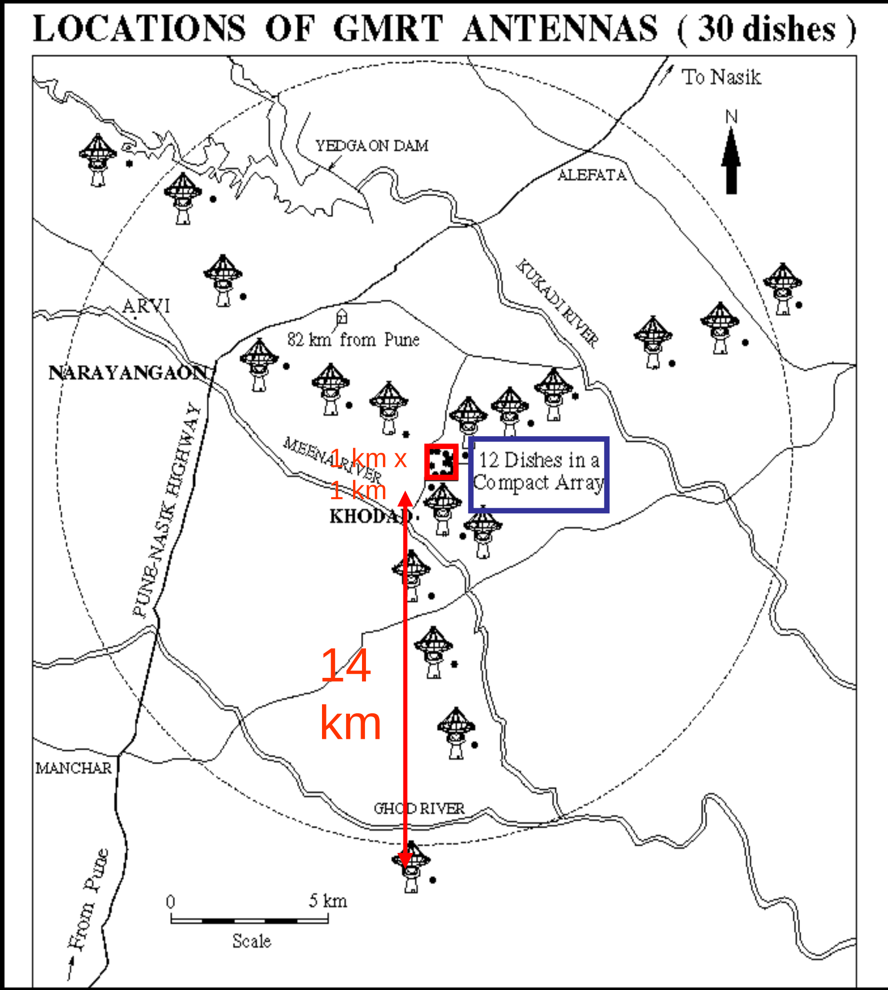
The GMRT : An Overview

- 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

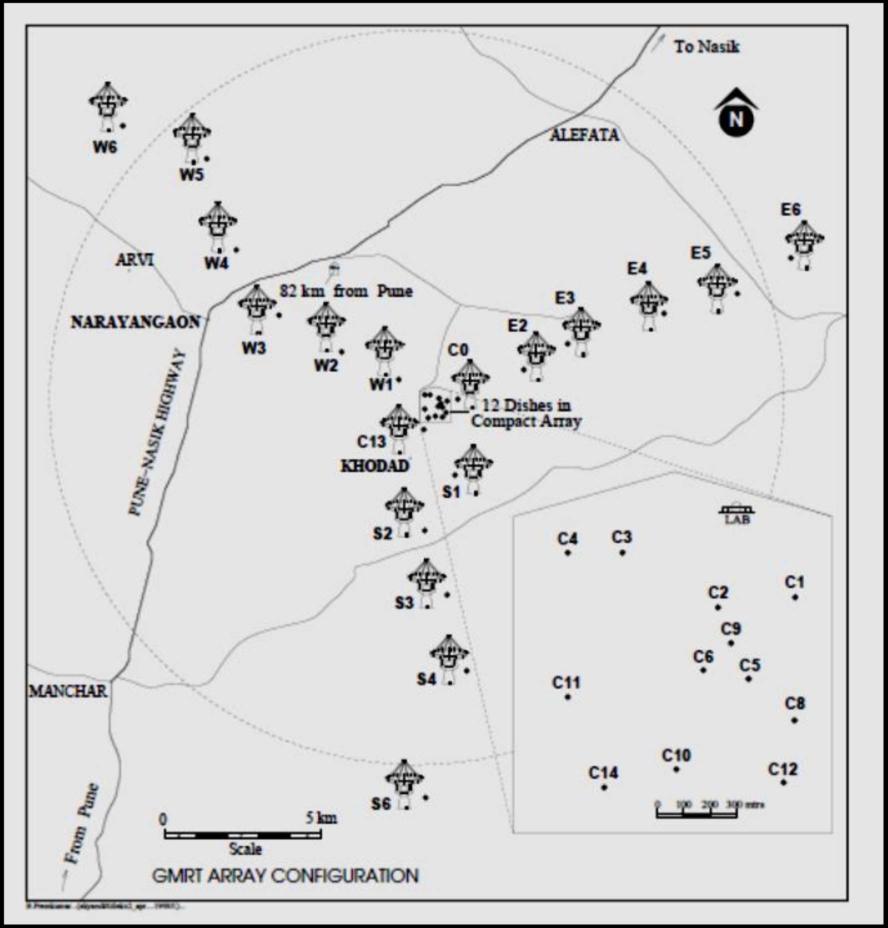
- 30 dishes, 45 m diameter each
  - 12 dishes in a central 1 km x 1 km region (central square)
  - remaining along 3 arms of Y-shaped array
  - baselines : ~ 200 m (shortest);
    ~ 30 km (longest)
- Frequency range :
  - 130-170 MHz
  - 225-245 MHz
  - 300-360 MHz
  - 580-660 MHz
  - 1000-1450 MHz
  - 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
  - Beamformer (incoherent & coherent)



The GMRT : Some (historically) unique features

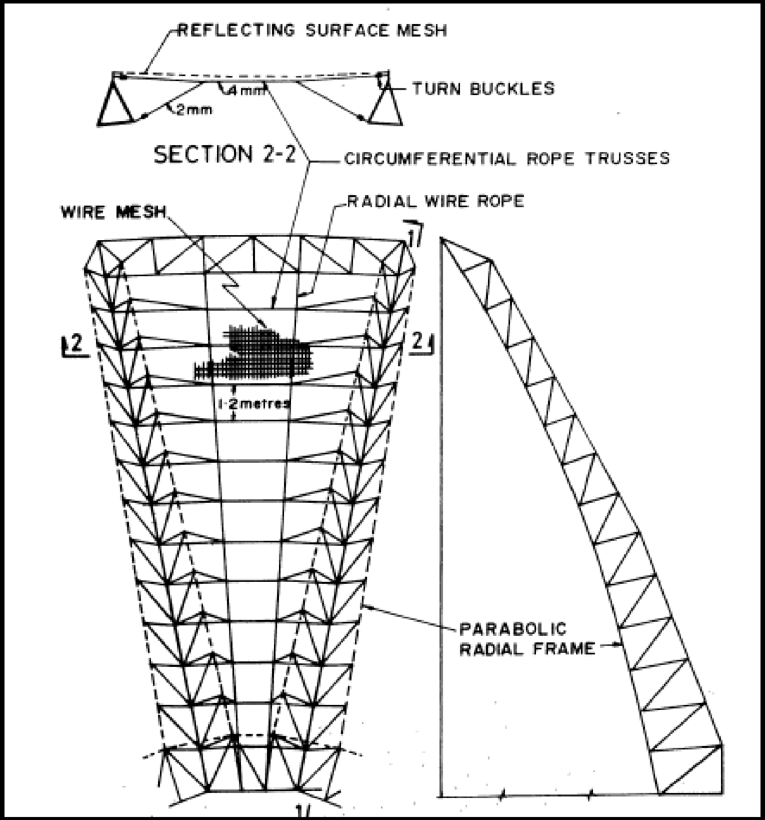
GMRT unique features : array layout

- Hybrid : central compact array (1 x 1 km) + Y-shaped arms -- optimized sensitivity to compact & extended sources -- commonly used concept now-a-days



GMRT unique features : “SMART” design antennas

- SMART : Stretched Mesh Attached to Rope Trusses (aka “the Indian rope trick”)
- Graded mesh sizes from inner to outer parts of reflector – optimized wind loading
- Very light weight 45-m dish : only ~ 110 tonnes of moving parts !



GMRT unique features : choice of receiver bands

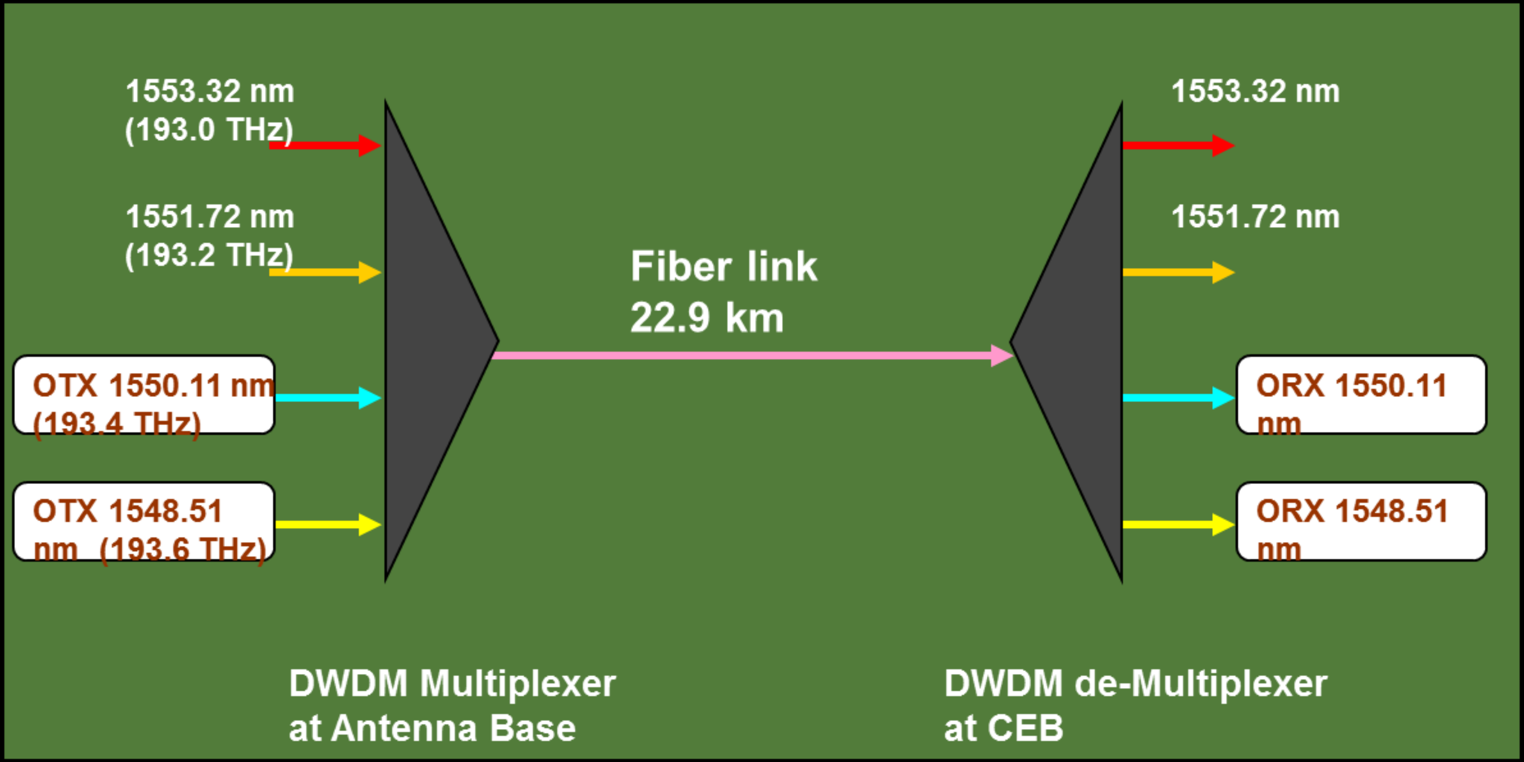
- L-band downwards, chosen to optimize study of redshifted HI
- Simultaneous dual-frequency feed : 235 + 610 MHz

5 bands of operation	300 – 360 MHz
120 – 180 MHz	580 – 650 MHz
225 – 245 MHz	1000 – 1430 MHz

Feeds are placed on a rotating turret at prime focus of the dish

GMRT unique features : use of optical fibre

- One of the first interferometers to use optical fibres over large distances
- Dual fibres to each antenna for receiving RF / IF signals and for M&C link
- Buried 1 m under ground, over distances ~ 20 km -- some challenges here !
- Has worked very well, after some initial hiccups and learning curve

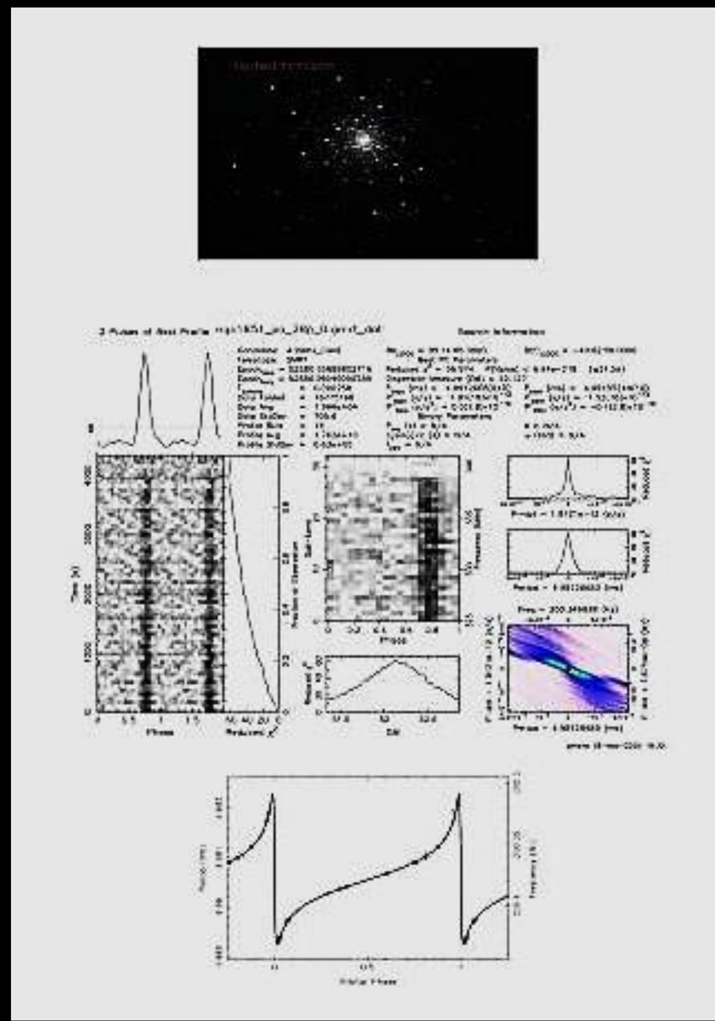


GMRT unique features : beamformer mode

- One of the first interferometer arrays to support simultaneous beamformer operation – incorporated into the basic design
- Two modes of beamformer : incoherent and coherent summation of signals from all 30 antennas – useful for different applications e.g. pulsar survey vs targeted studies
- Simultaneous pulsar observations and imaging observations possible from day #1

Interferometry + Beamformer : localization of newly discovered pulsars

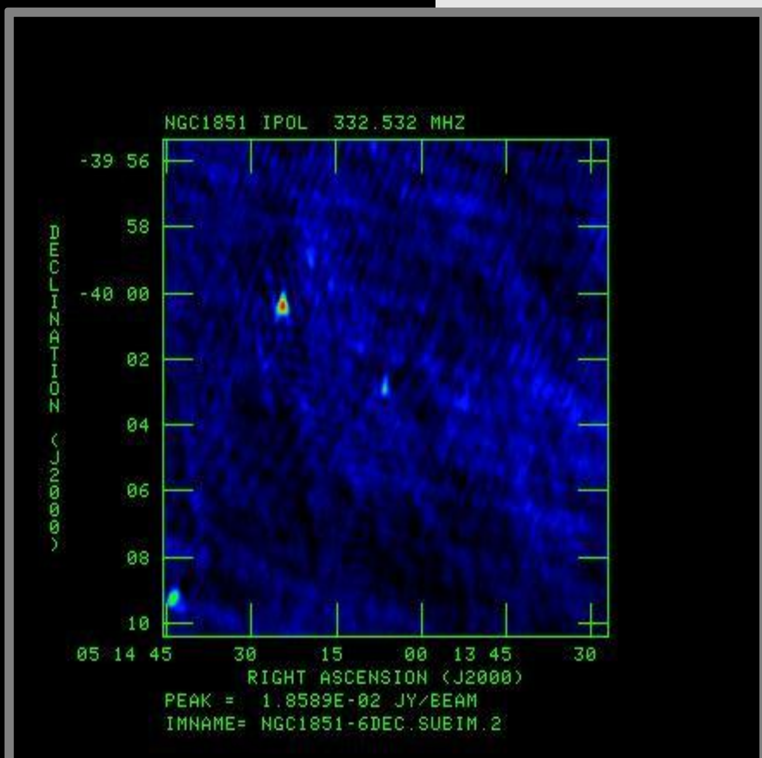
- Search for pulsars in globular clusters using phased array mode
- Discovered highly eccentric binary millisecond pulsar in NGC 1851



Freire, Gupta, Ransom & Ishwar-Chandra (2004)

Interferometry + Beamformer : localization of newly discovered pulsars

- Central core of the GMRT used in phased array mode to cover the target
- Simultaneous interferometric imaging reveals the position of new pulsar !



GMRT radio map of NGC1851

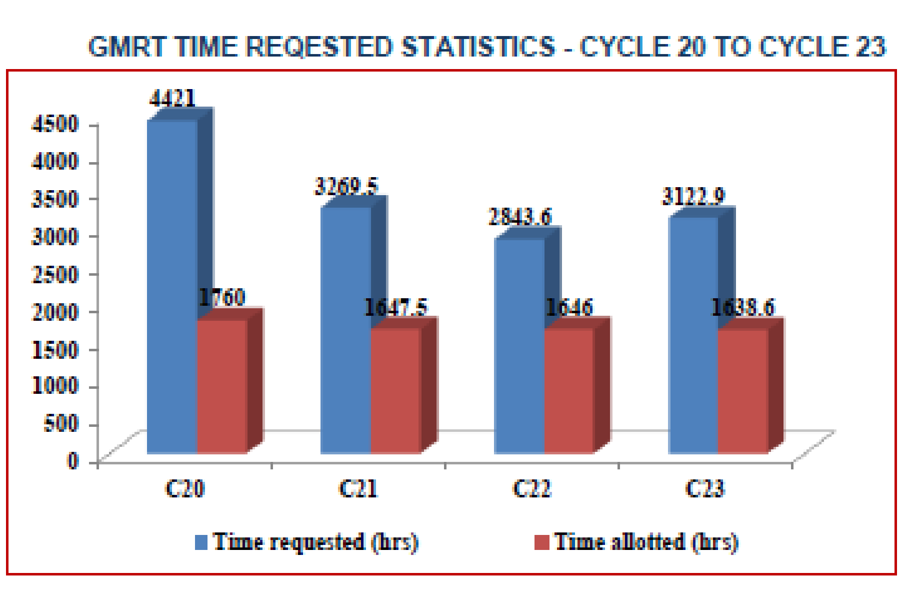
Optical image of NGC1851

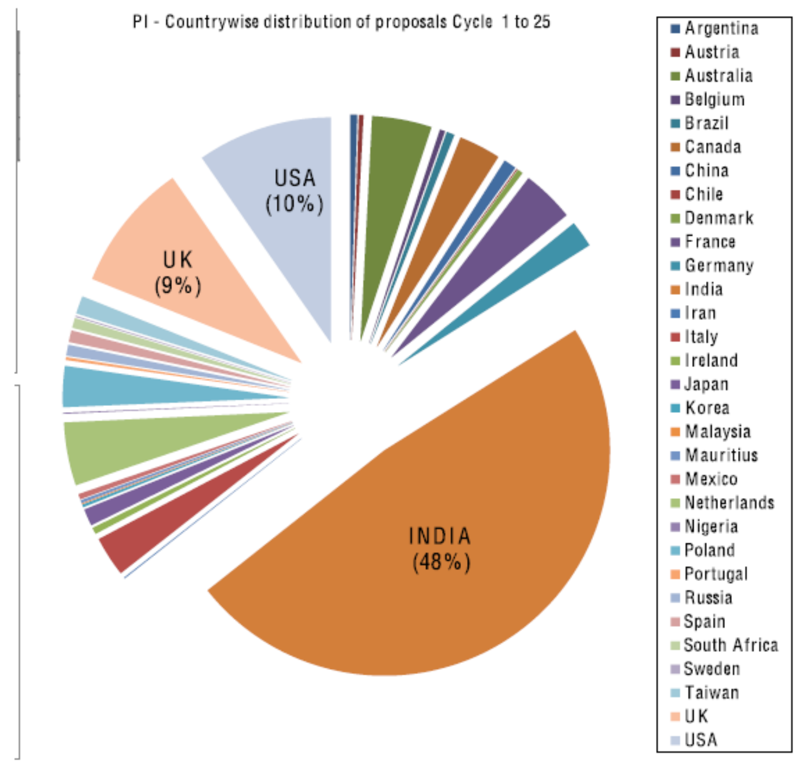
Freire, Gupta, Ransom & Ishwar-Chandra (2004)

The GMRT today

GMRT : Usage Statistics

- GMRT sees users from all over the world : distribution of Indian vs Foreign PIs is close to 50:50
- The GMRT is 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 & Epoch of Reionization – first published upper limits.
  - All sky surveys such as the 150 MHz TGSS

Some unique results from the GMRT

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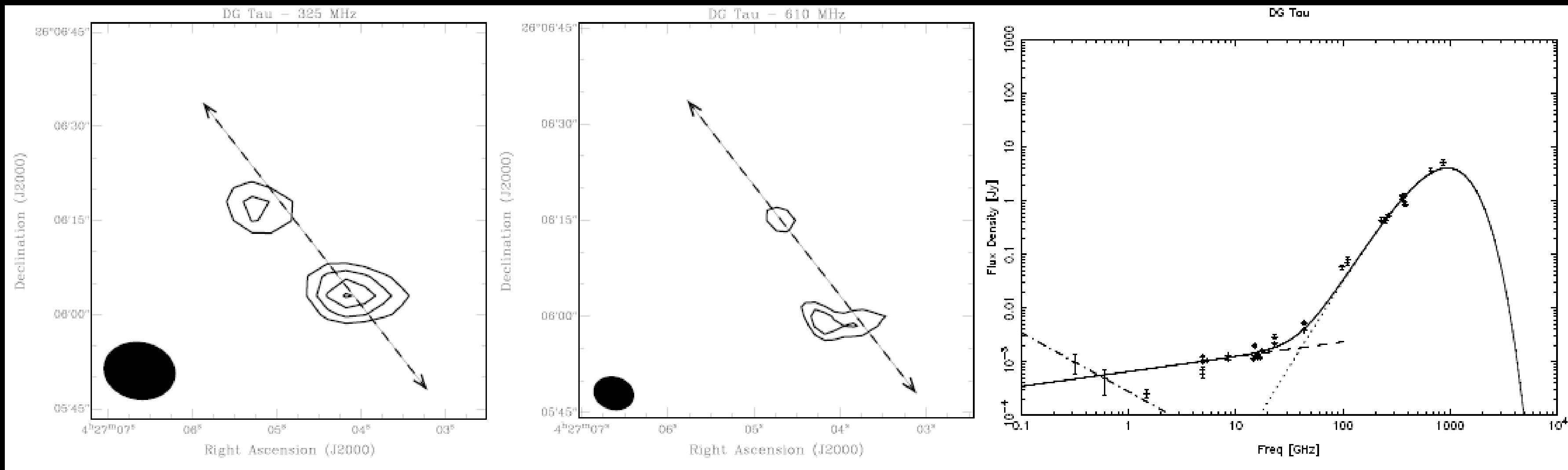
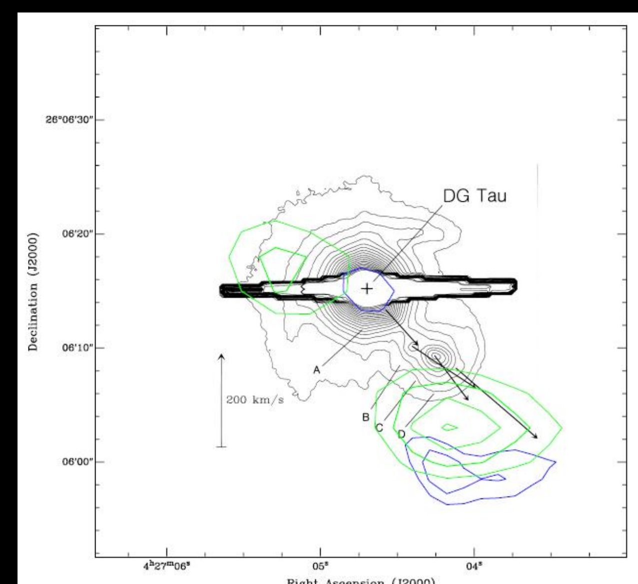
First Radio Detections of YSOs

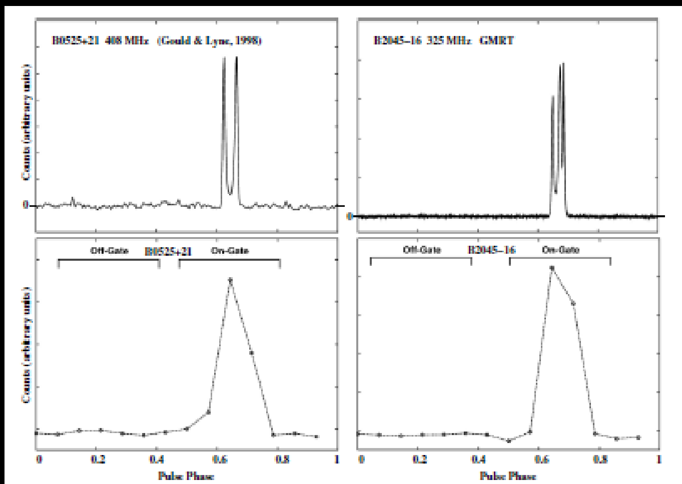


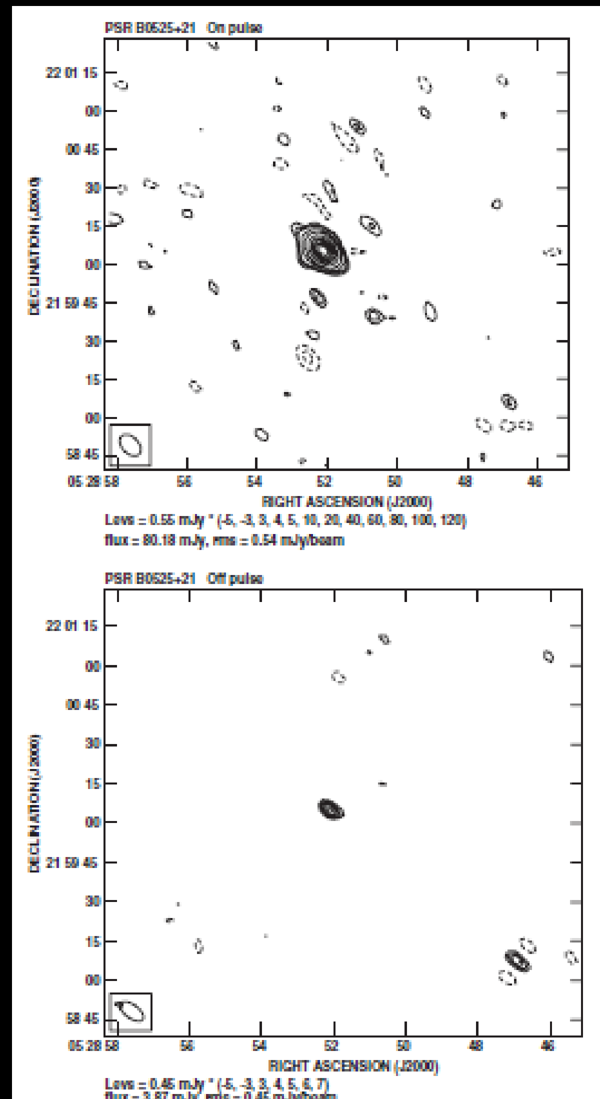
- (First) detection of 3 YSOs at 325 & 610 MHz
- First evidence for non-thermal radio emission in class II YSOs → synchrotron or gyro-sync ?
- DG Tauri : location of radio emission wrt proper motion → detection of bow shock

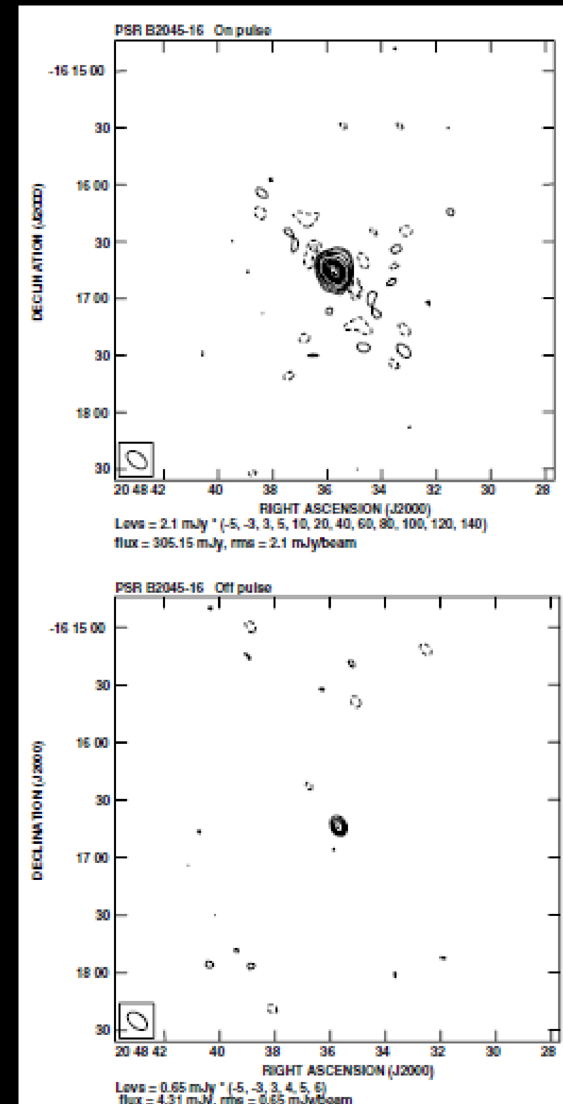


Ainsworth et al 2014

Off-pulse emission from pulsars





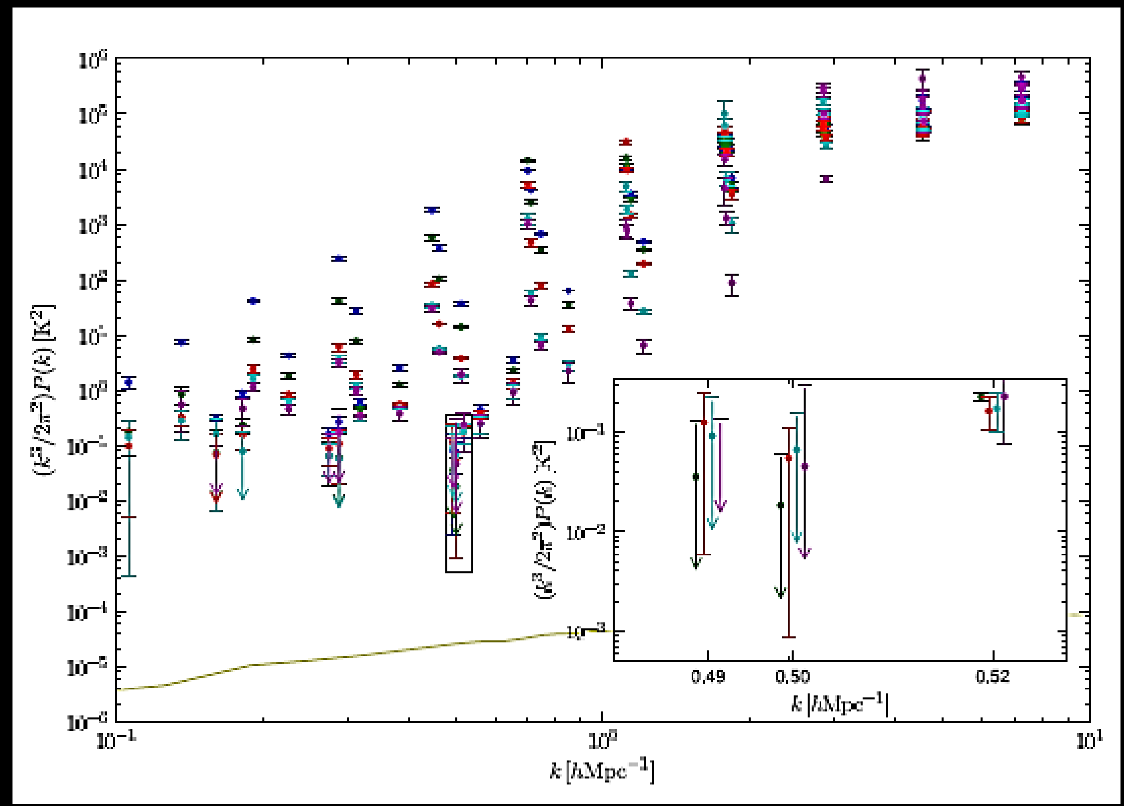


Using gated interferometer to make images for on-pulse and off-pulse regions for some well known pulsars

Basu, Athreya & Mitra (2011 & 2012)

EoR Experiment at the GMRT

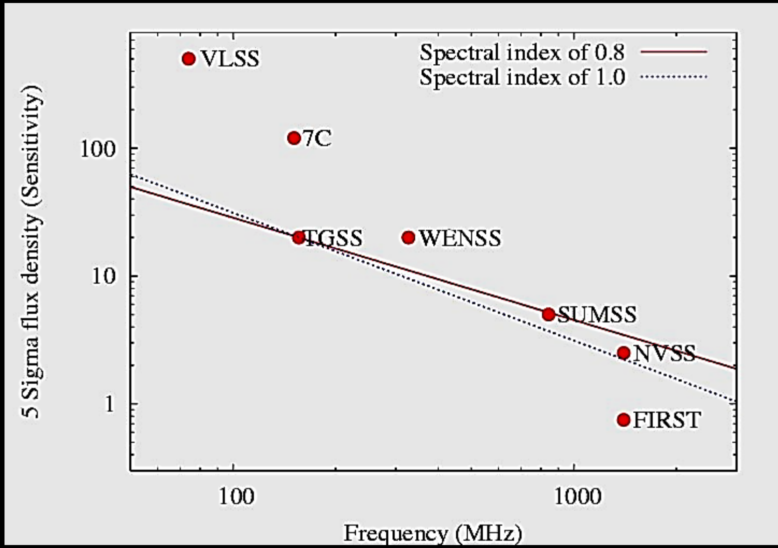
- EoR project at the GMRT led by Ue-Li Pen (CITA)
- Uses a field with a pulsar at the phase centre as the calibrator
- Works off a special mode of the software back-end with real-time pulsar gating
- First published results establish interesting new limits on EoR signal strength

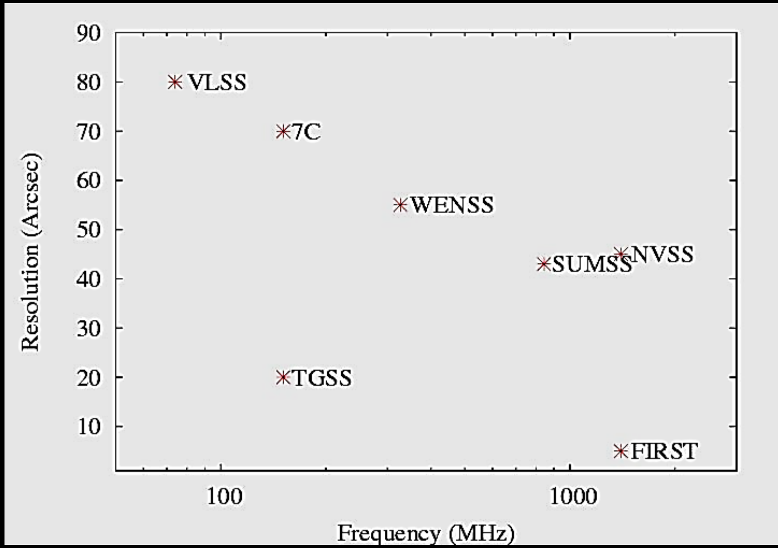


Paciga et al, 2011 & 2013

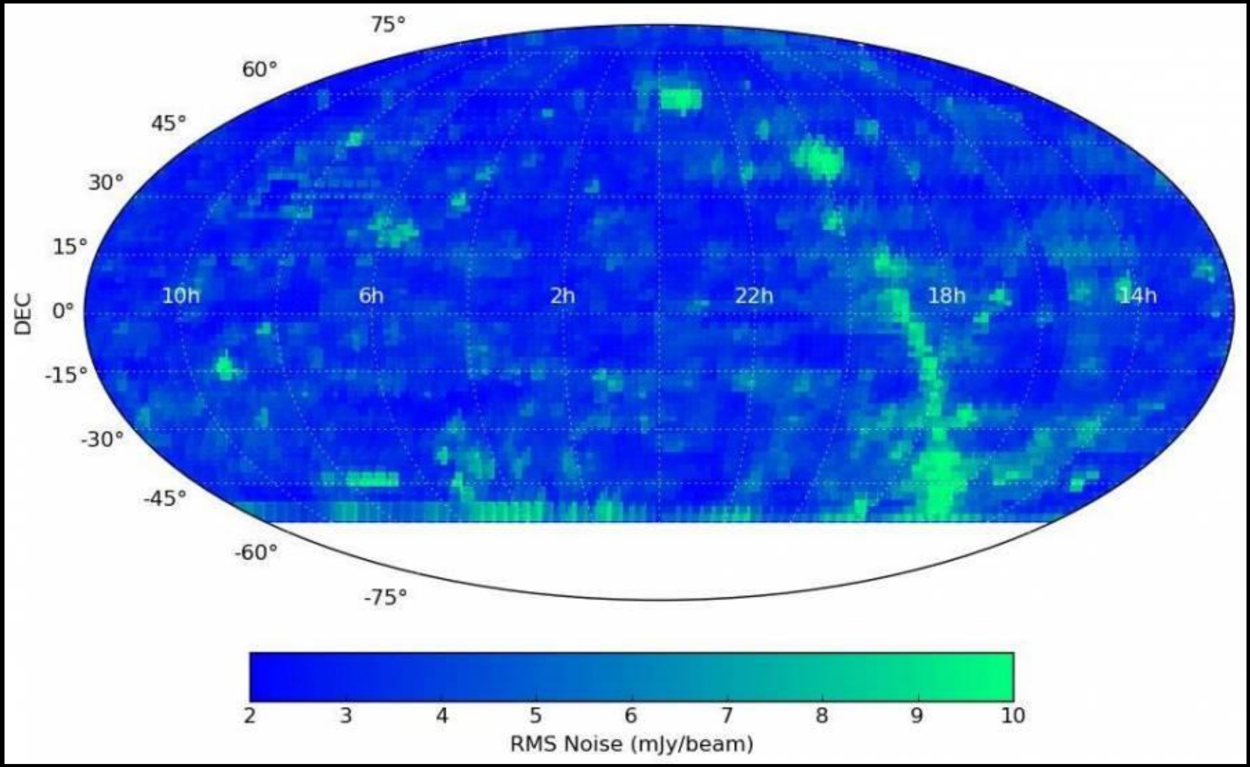
All Sky Surveys : TGSS

- 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.

Intema et al 2016

Looking ahead : the upgraded GMRT

First concepts mooted : 2007-2008

Detailed work started : 2012

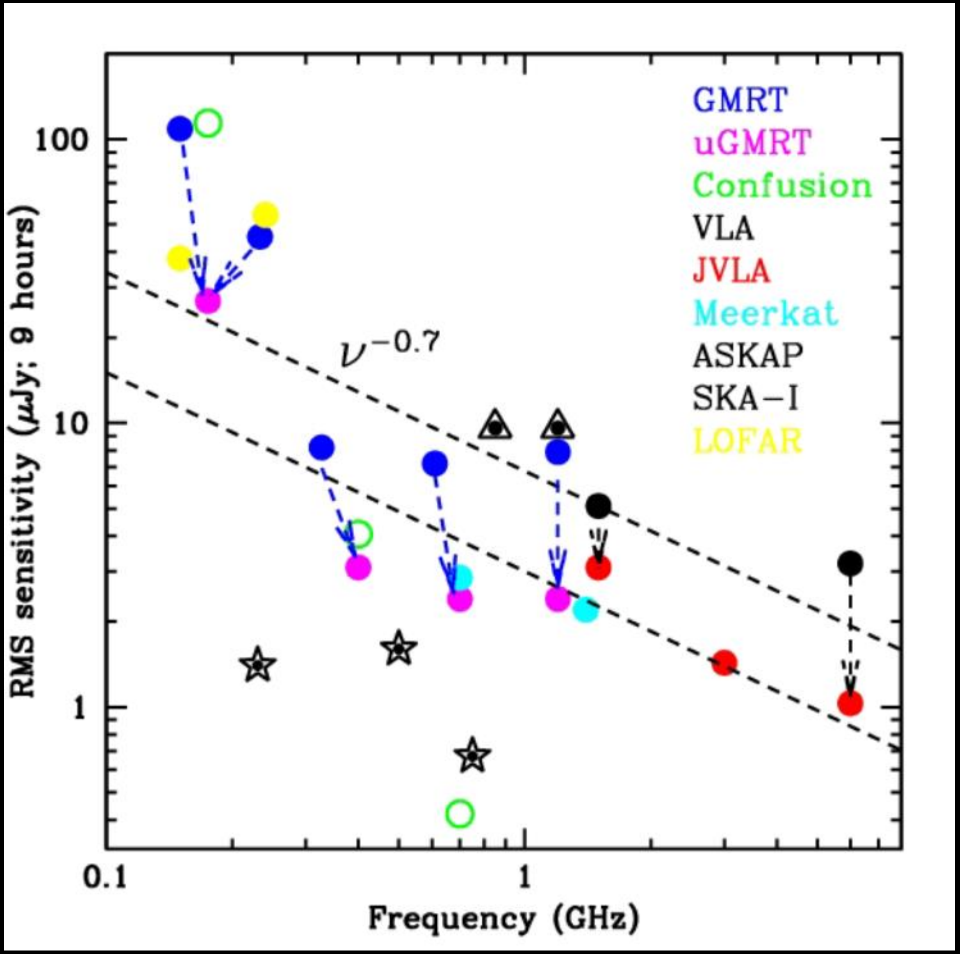
Now nearing completion

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

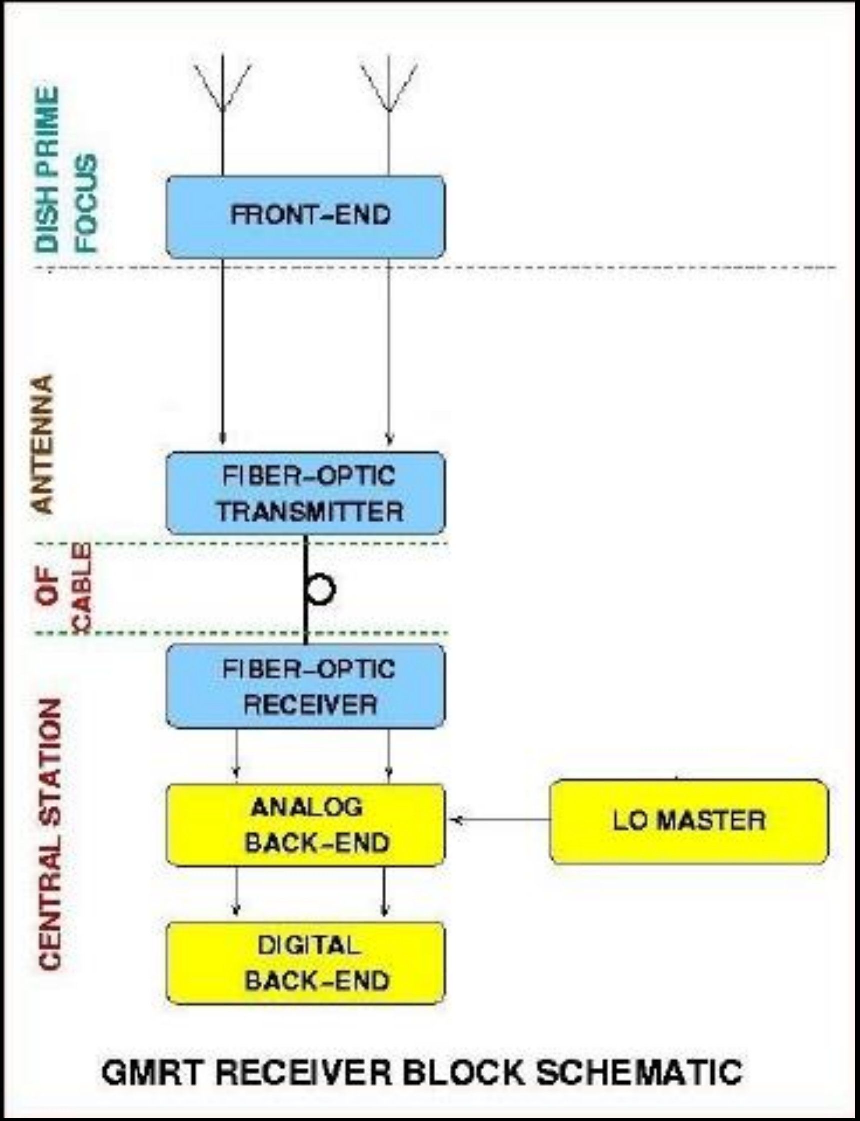
- Spectral lines : broadband coverage will give significant increase in the redshift space for HI lines + access to other lines
- Continuum imaging sensitivity will improve by factor of 3 or so.
- Sensitivity for pulsar observations will also improve by factor of 3.
- Only SKA-I will do better than uGMRT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



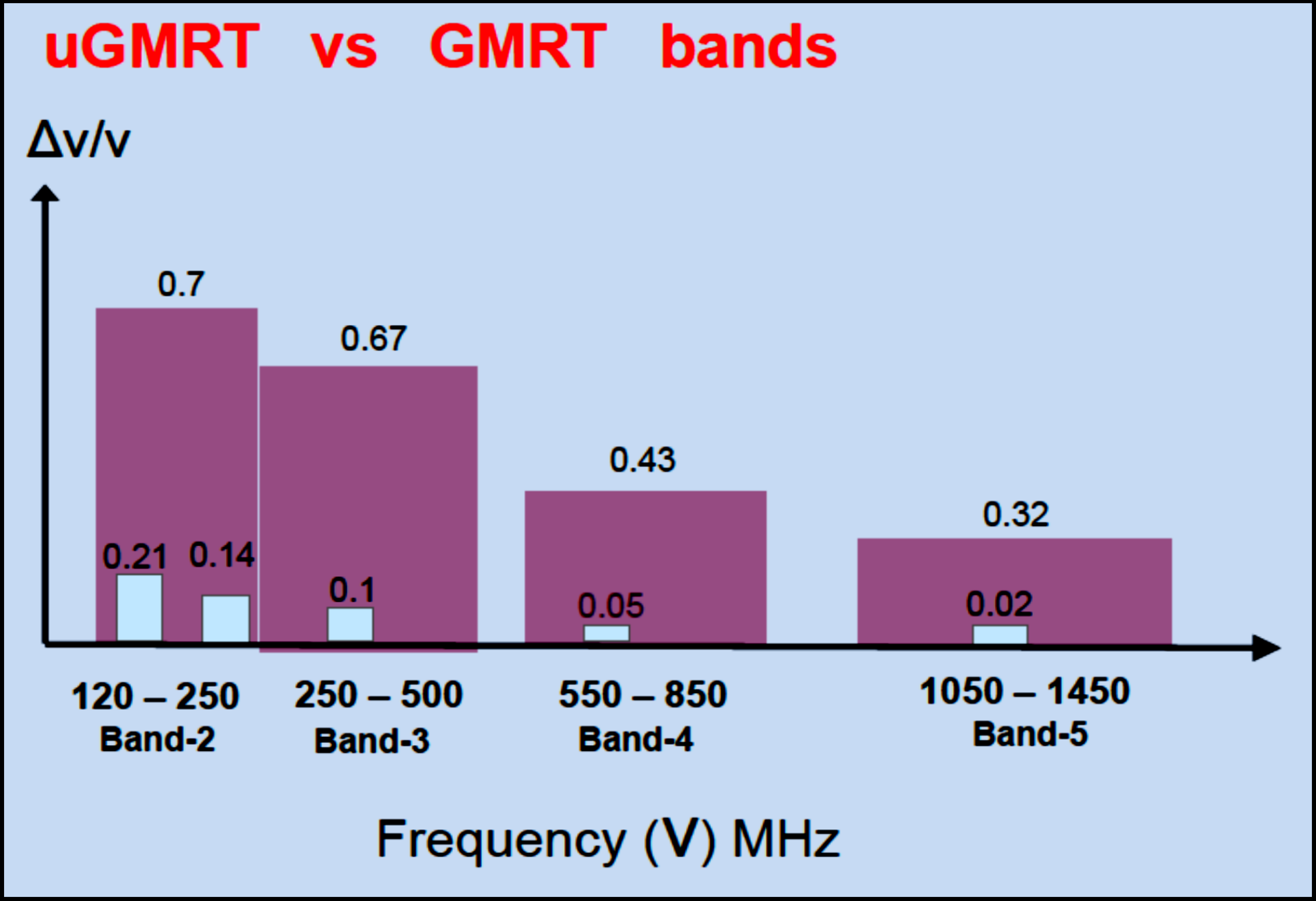
Expected sensitivity performance of the upgraded GMRT compared to other major facilities in the world, present and projected (courtesy : Nissim Kanekar, NCRA)

Overview of uGMRT Receiver System

- Broad-band front-end (in octaves) :
  - 1000 – 1450 MHz (updating L-band)
  - 550 – 850 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



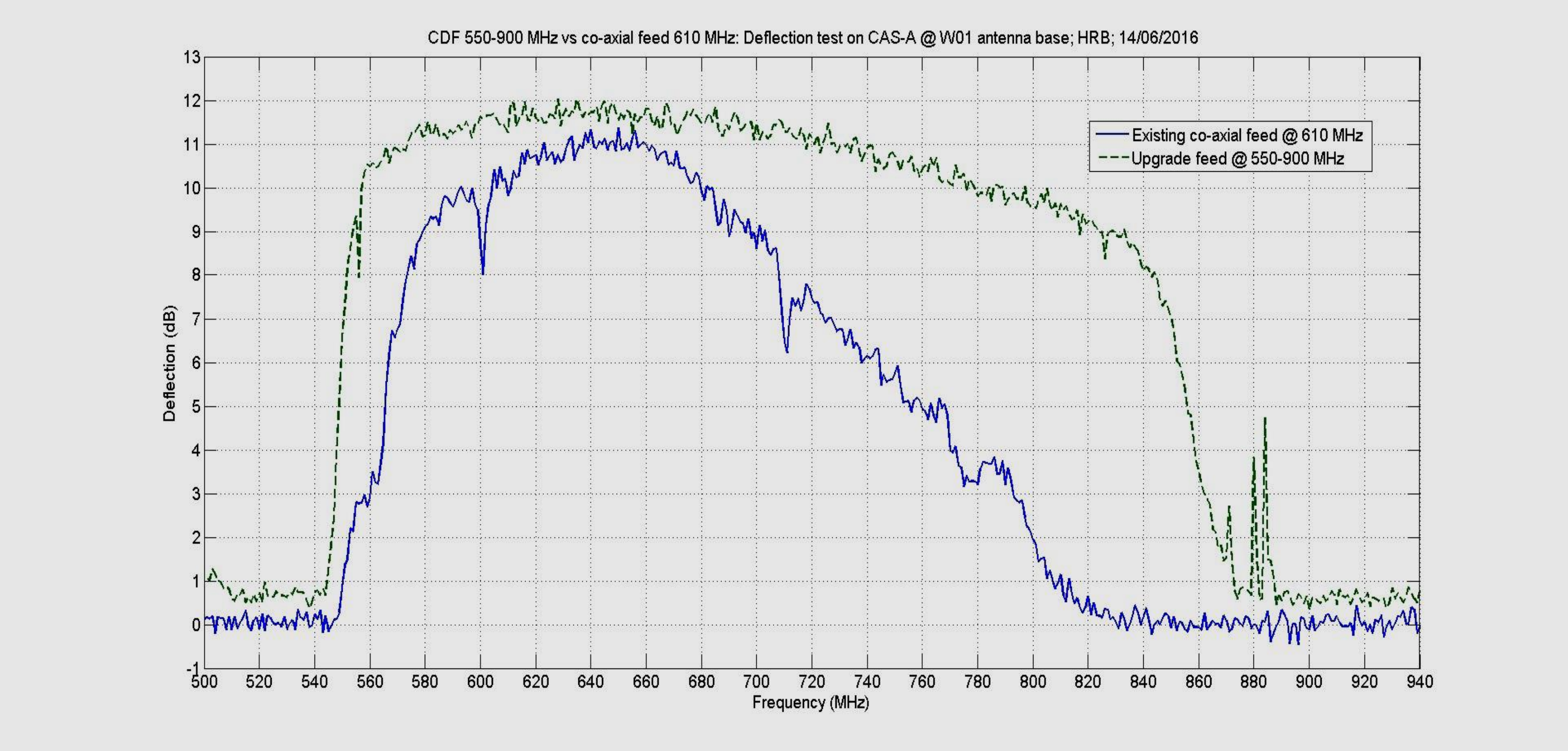
GMRT vs uGMRT : Frequency Coverage



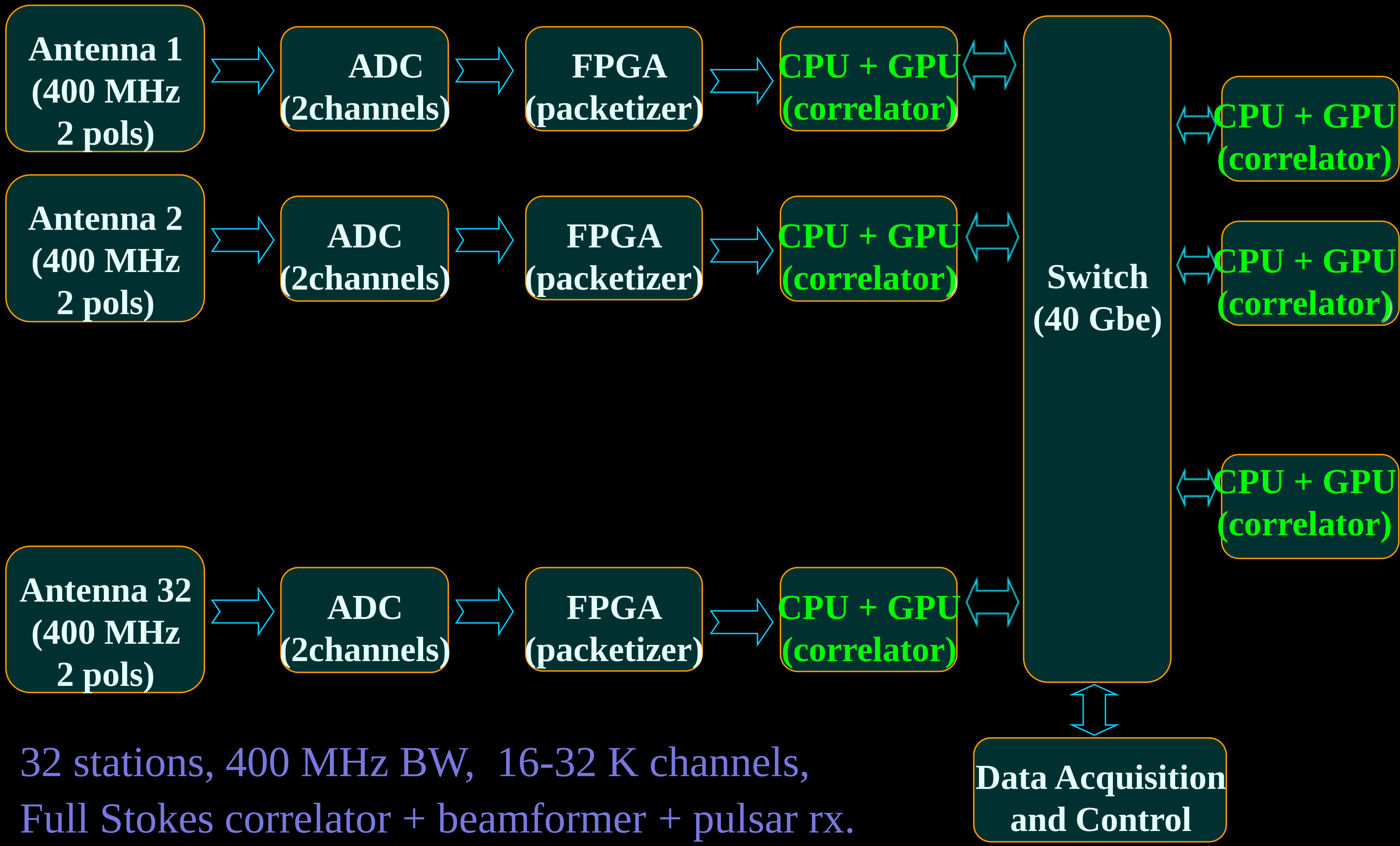
courtesy : Ruta Kale

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



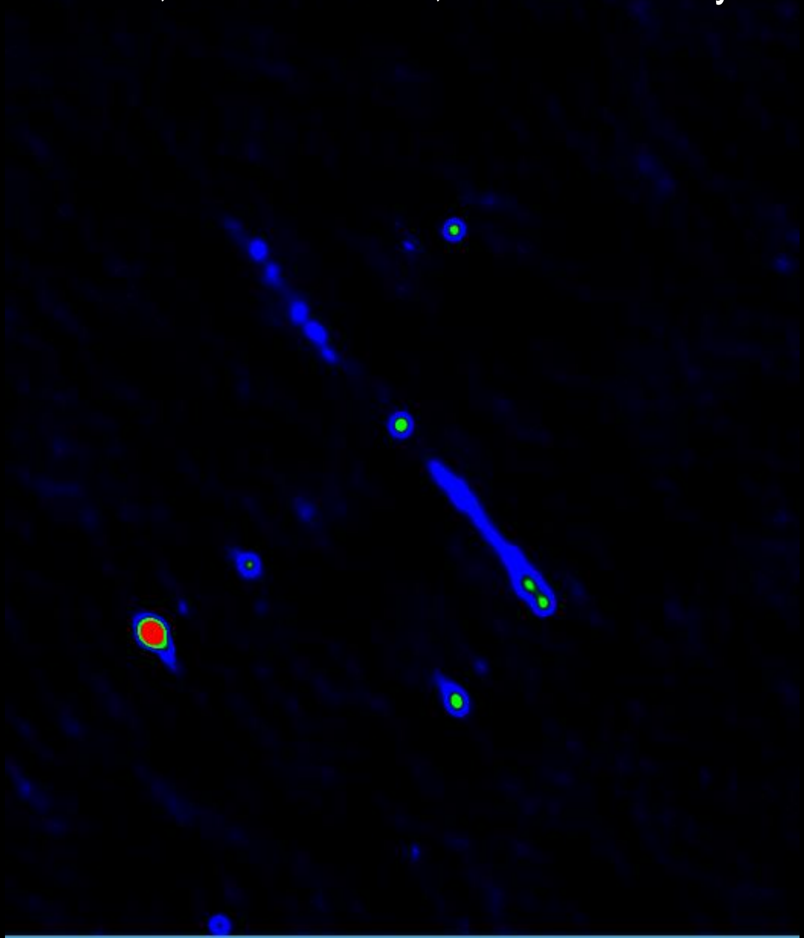
32 stations, 400 MHz BW, 16-32 K channels,
Full Stokes correlator + beamformer + pulsar rx.

Towards a working uGMRT…

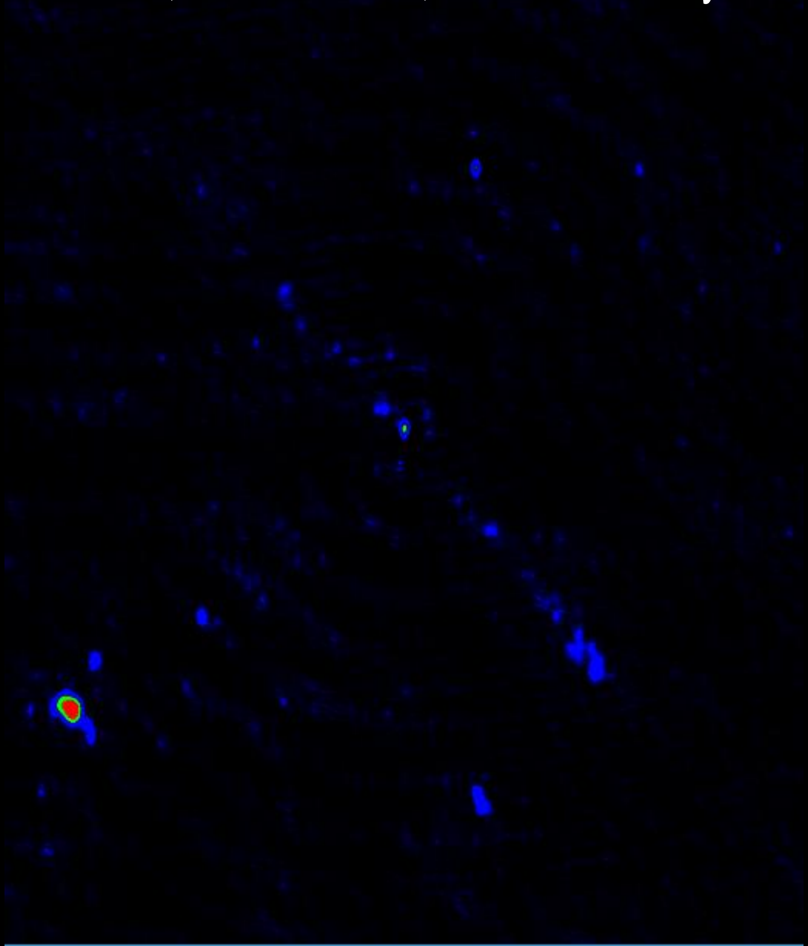
uGMRT : Early Sample Results

Imaging with the 400 MHz bandwidth mode at Lband

GWB: 2 hrs, BW: 250 MHz, rms=30 microJy/beam



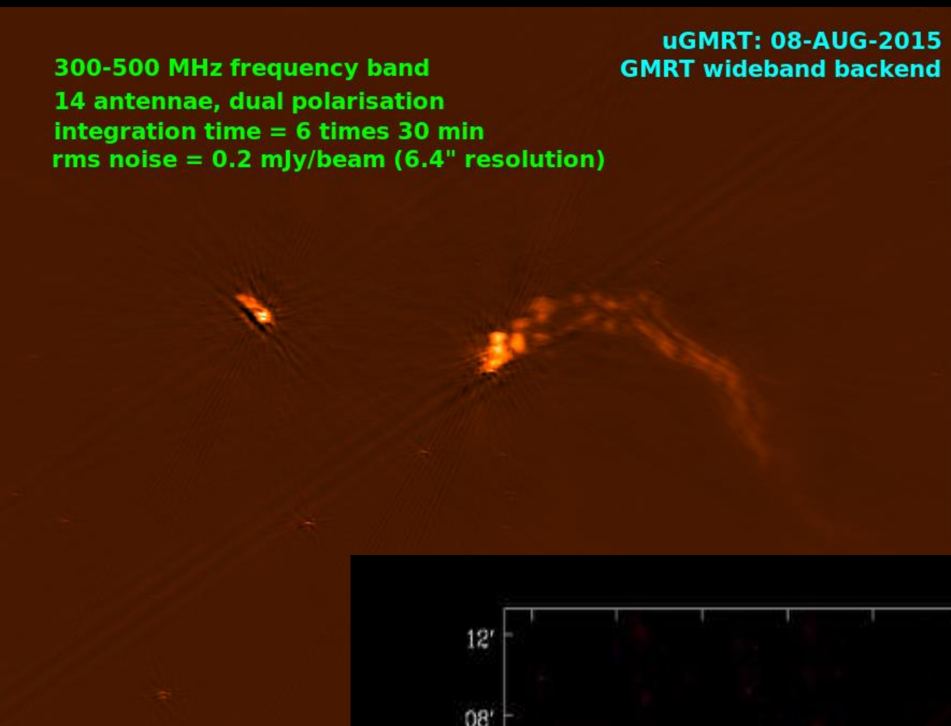
GHB: 4 hrs, BW: 14 MHz, rms=55 microJy/beam

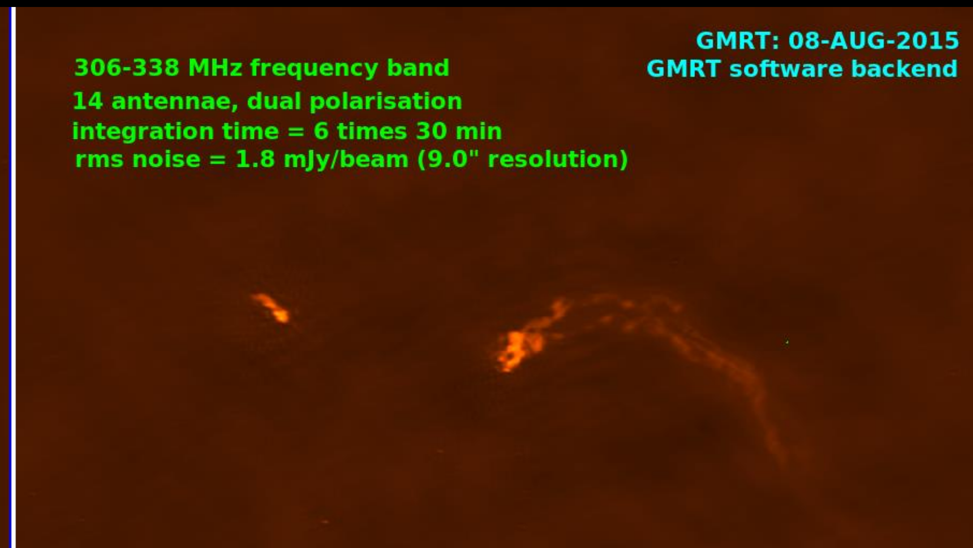


courtesy : C.H. Ishwara-Chandra + Binny Sebastian

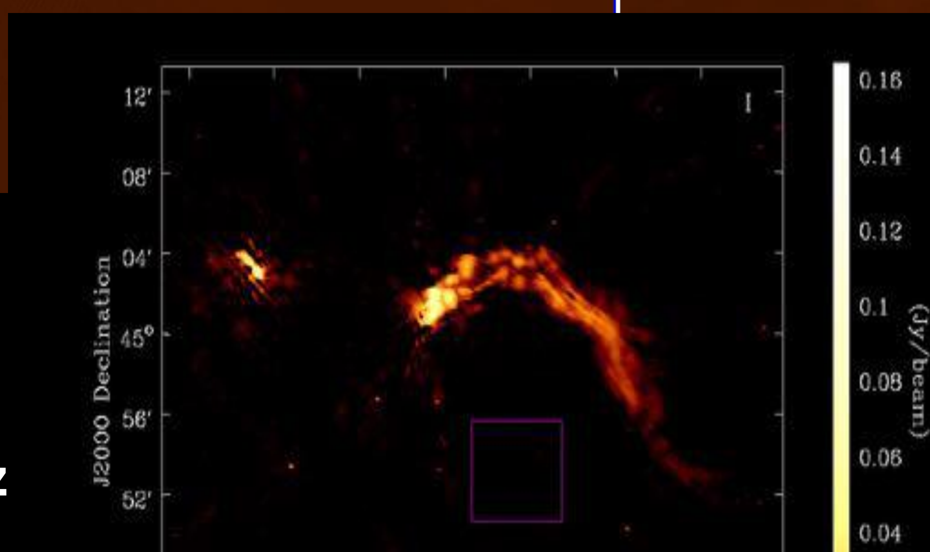
uGMRT : Early Sample Results

3C129 imaged with the uGMRT system using 14 antennas, 300-500 MHz





courtesy : Dharam Vir Lal + Binny Sebastian



- 80 microJy
- 3 hours
- 14 antennas
- 300-500 MHz

- Calibration in AIPS
- Imaging in CASA
- W-projection
- MS-MFS

Wideband Pulsar Observations

Millisecond pulsar J0613-0200

300-500 MHz band

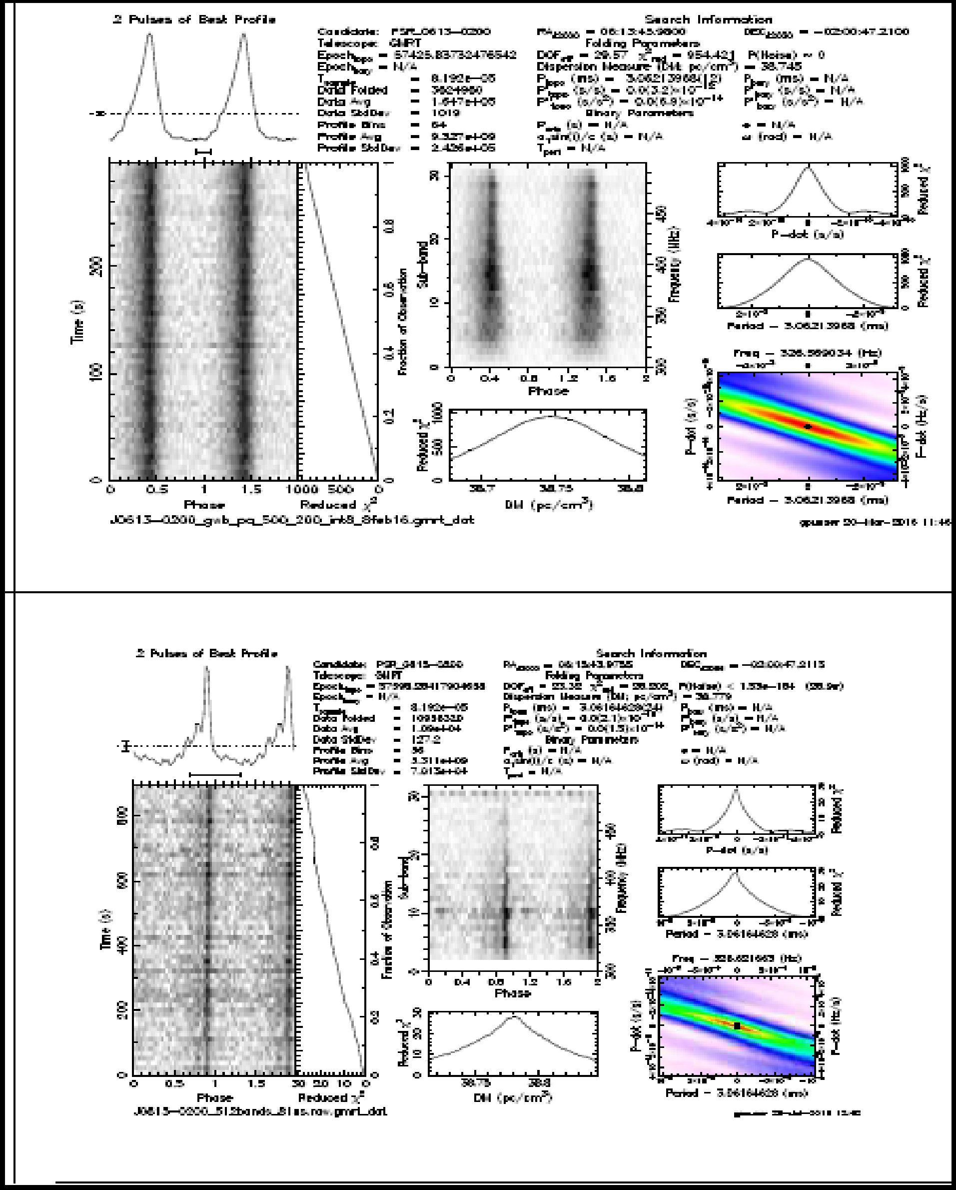
Phased array with ~ 12 antennas

Upper panel :

incoherent dedispersion

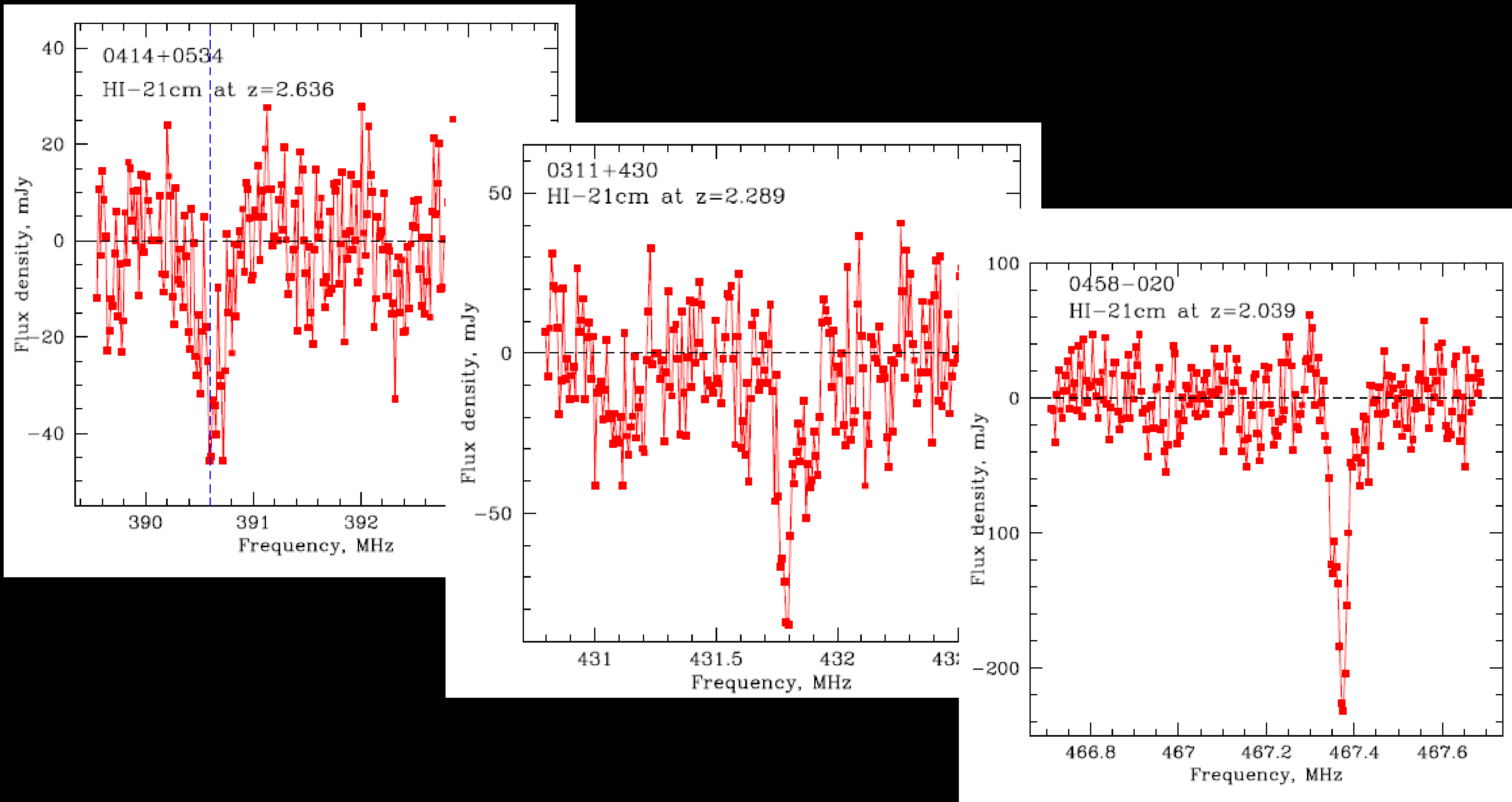
Lower panel :

coherent dedispersion



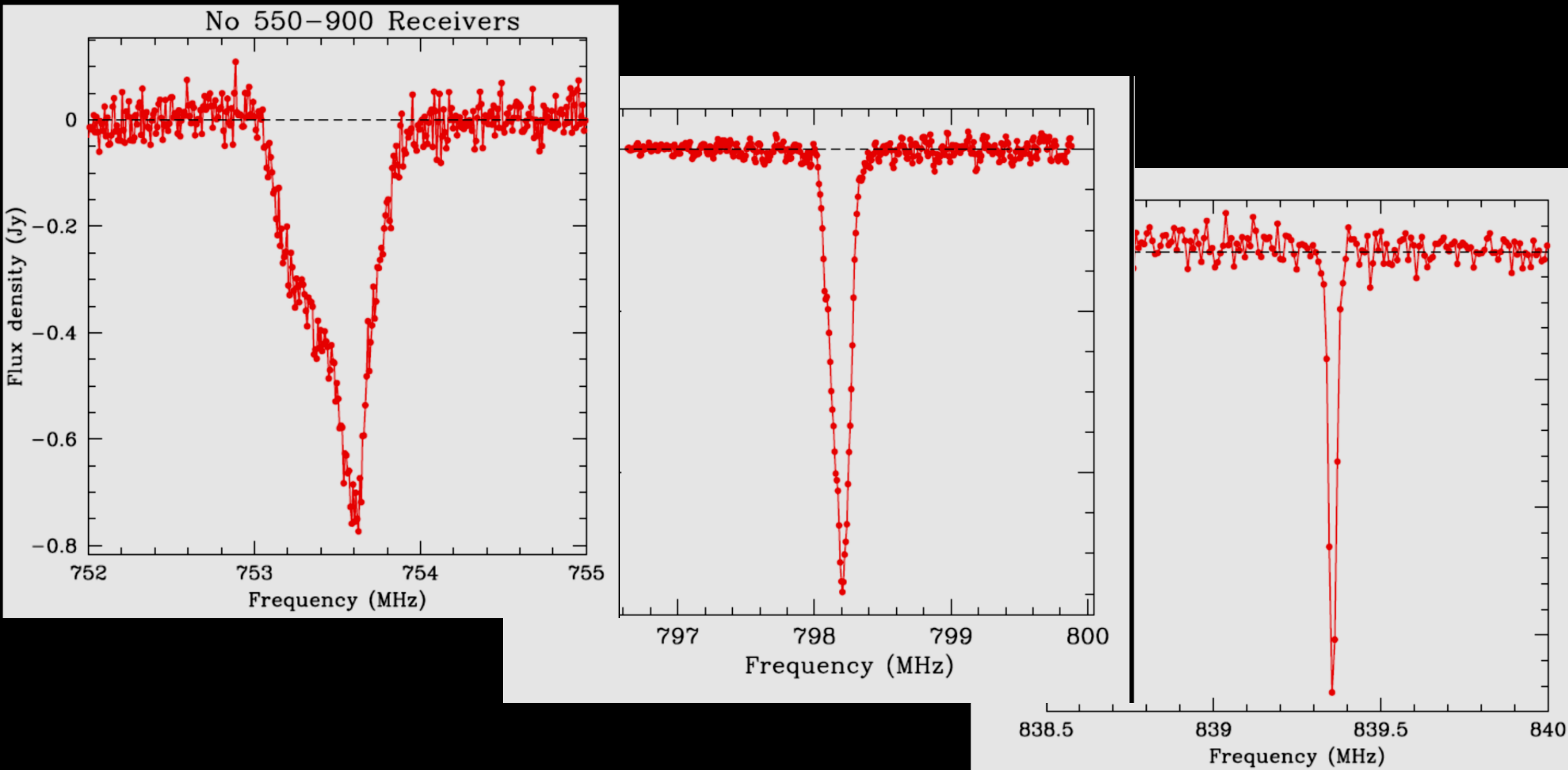
courtesy : Kishalay De & Y. Gupta

Upgraded GMRT : opening new windows – Band 3 (250-500 MHz)



First light results : spectral lines from different sources, at different red shifts in the 250-500 MHz band (Nissim Kanekar)

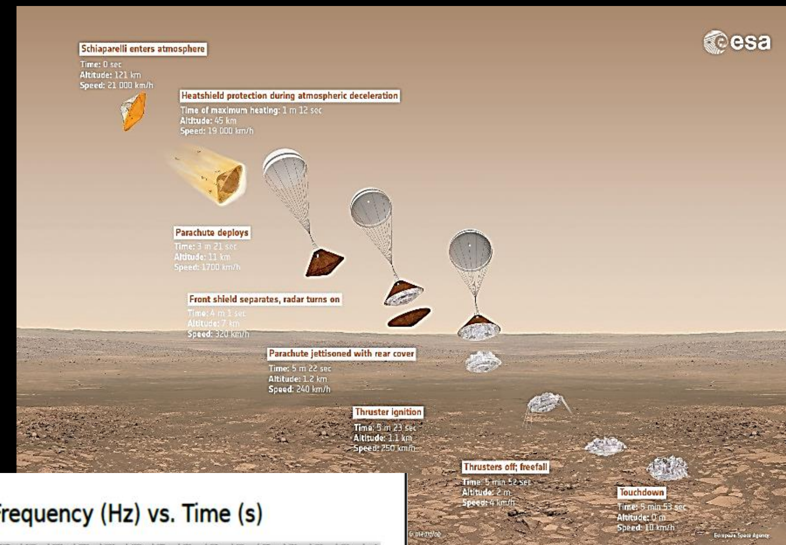
Upgraded GMRT : opening new windows – Band 4 (550-850 MHz)

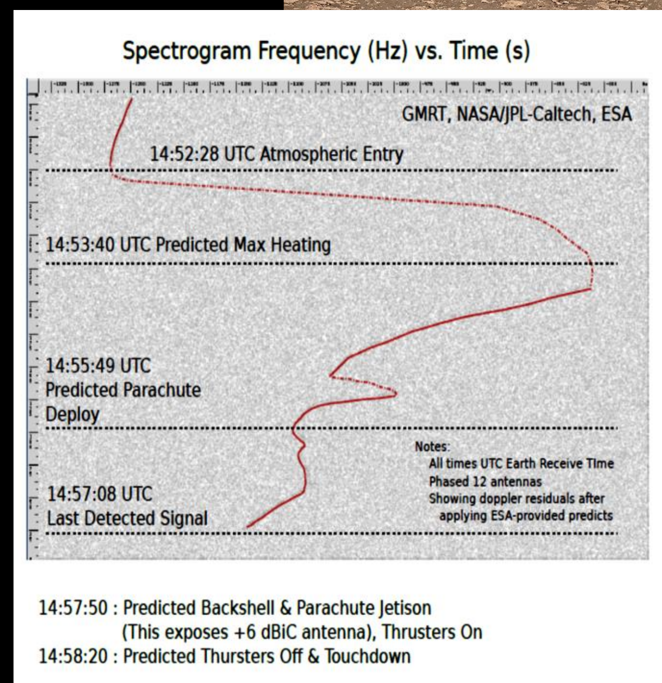


First light results : spectral lines from different sources, at different red shifts in the 550-850 MHz band (Nissim Kanekar)

"Fringe" benefits with the uGMRT : 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

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 !*

Thank You