The upgraded GMRT : Status and Future Plans

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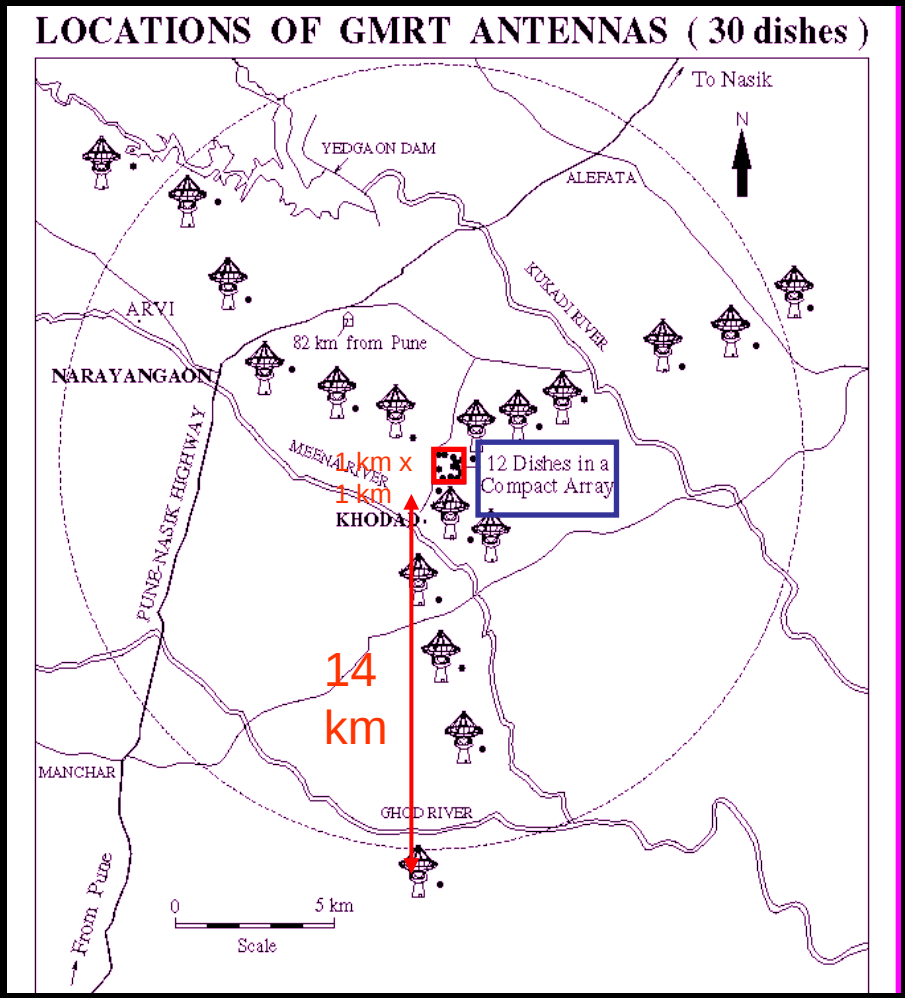
Part I : The *original* GMRT (legacy GMRT)

Conceived of in the 1980s
Built during the 1990s
Operational since 2001

- Major low frequency radio facility (~ 100 to 1500 MHz) – the largest in the world in this range
- Located in western part of India, about 80 km from Pune

The *original* 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 (of original GMRT) :
  - 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 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)



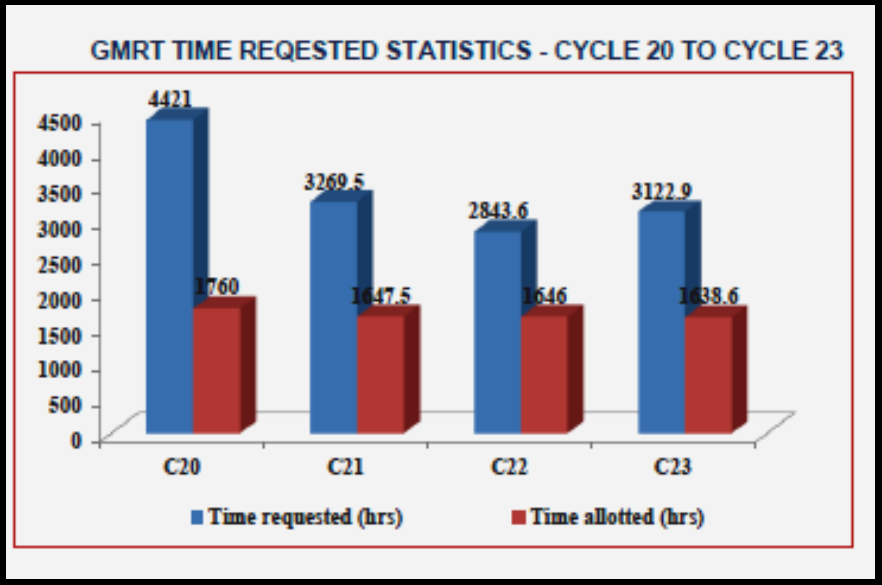
Inauguration of the legacy GMRT

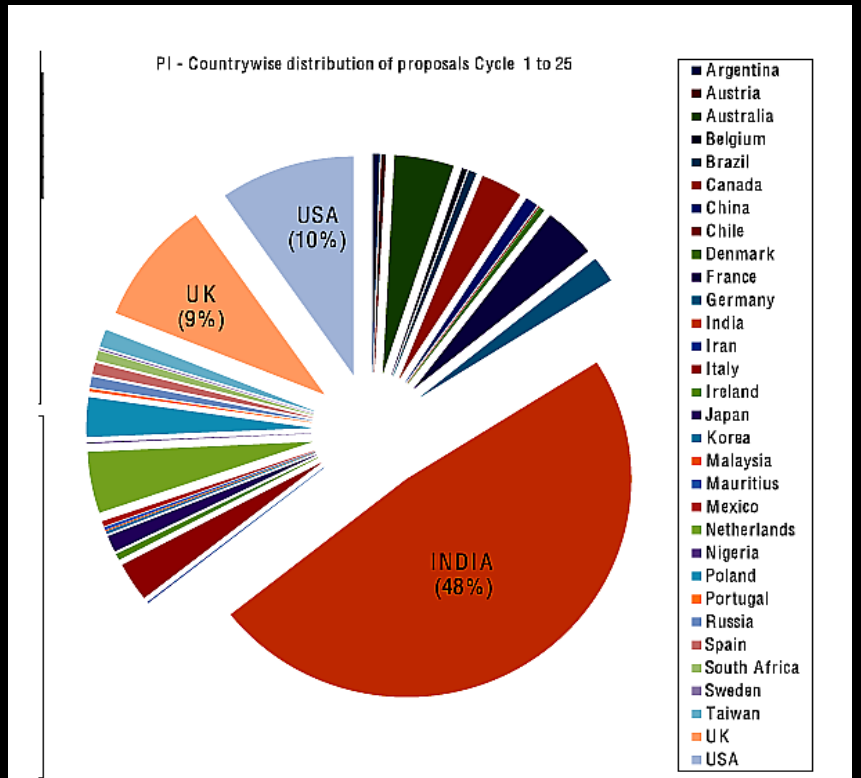
- The GMRT was built during the 1990s
- It was made available to the global scientific community from early 2002

Dedication of the GMRT : October 4, 2001

GMRT : Usage Statistics

- GMRT sees users from all over the world : distribution of Indian vs Foreign users is close to 50:50
- The GMRT is 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 is a powerful instrument to probe several astrophysical objects and phenomena :

- The Sun, extrasolar planets
- Pulsars : rapidly rotating neutron stars
- Other Galactic objects like : supernova remnants, microquasars etc
- Other explosive events like Gamma Ray Bursts
- Ionized and neutral Hydrogen gas clouds (in our Galaxy and other galaxies)
- Radio properties of different kinds of galaxies; galaxy clusters
- Radio galaxies at large distances in the Universe
- Cosmology and the Epoch of Reionization
- All sky surveys such as the 150 MHz TGSS

…and many interesting new results have been produced

Part II : The upgraded GMRT

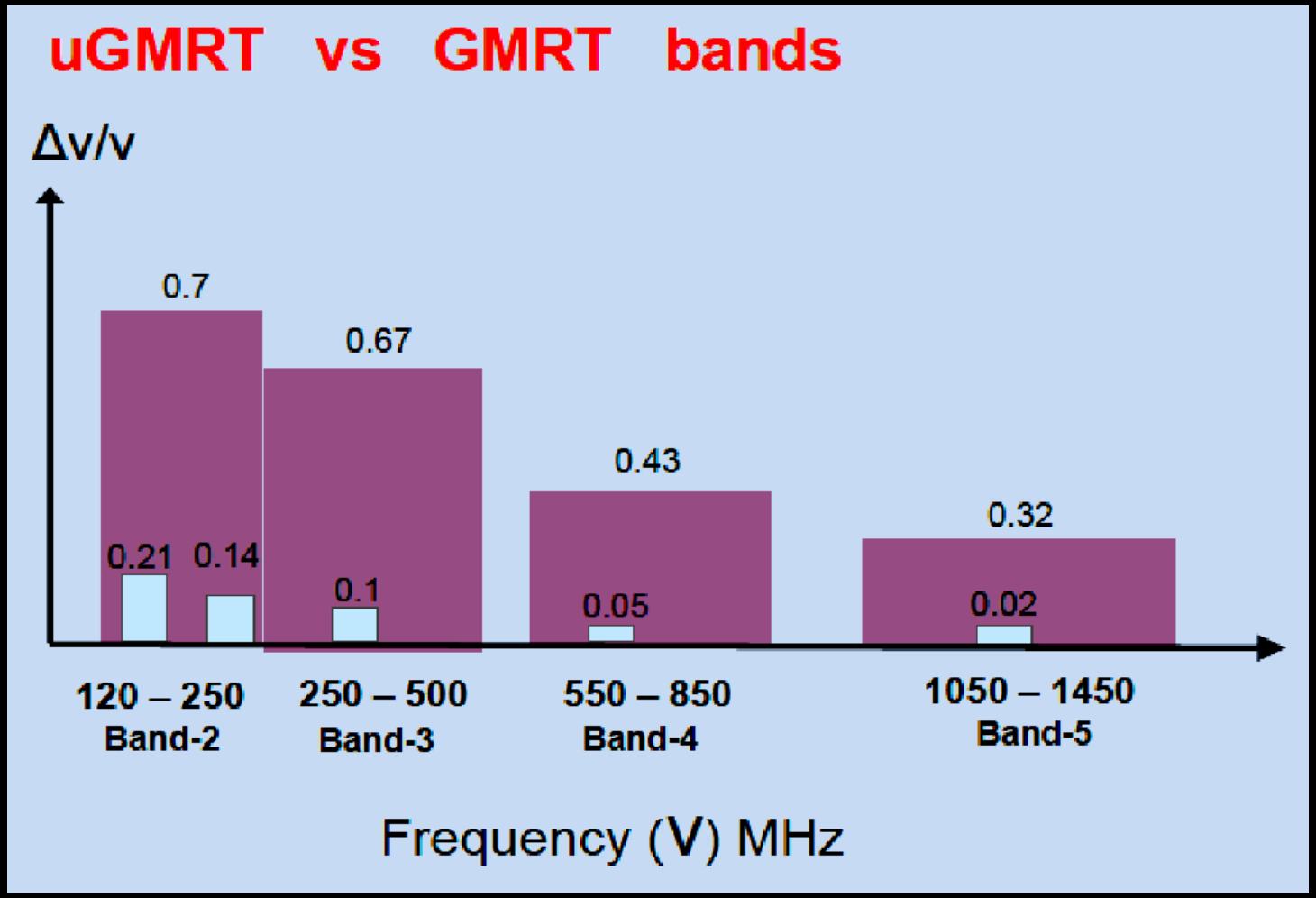
First concepts mooted : 2007-2008
Detailed work started : 2012
Now completed

Next Generation : The uGMRT

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

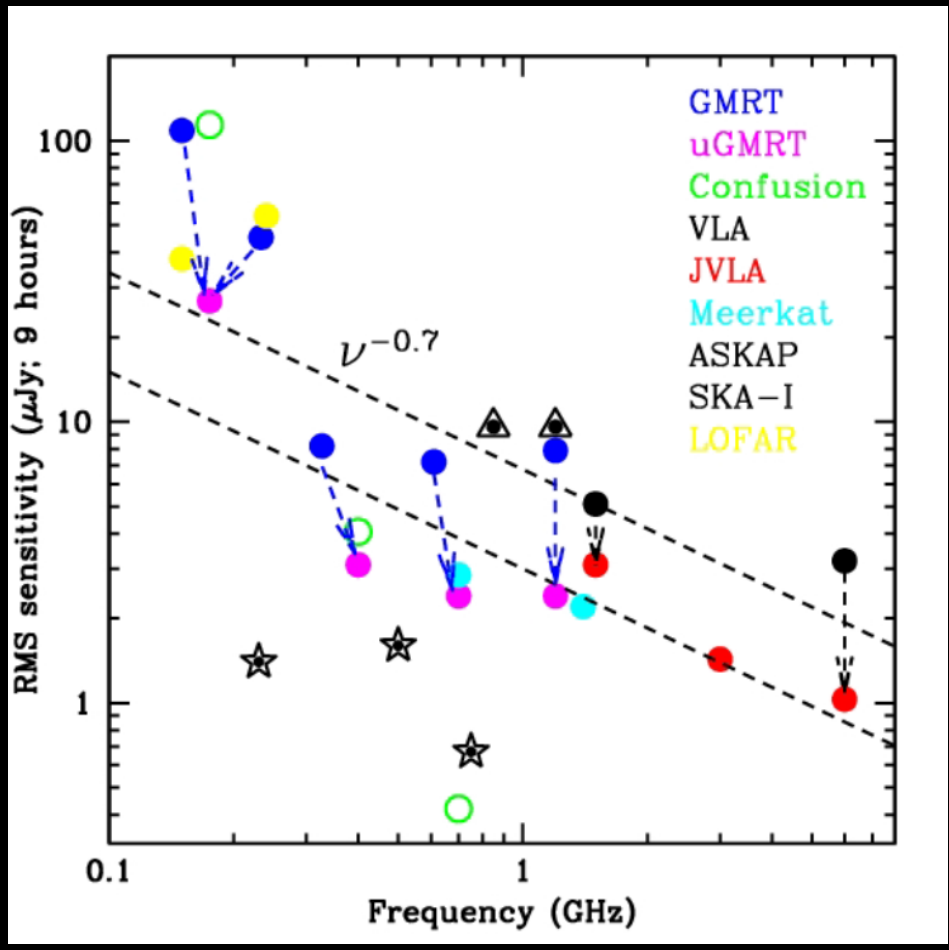
GMRT vs uGMRT : Frequency Coverage



courtesy : Ruta Kale

uGMRT : Expected Performance

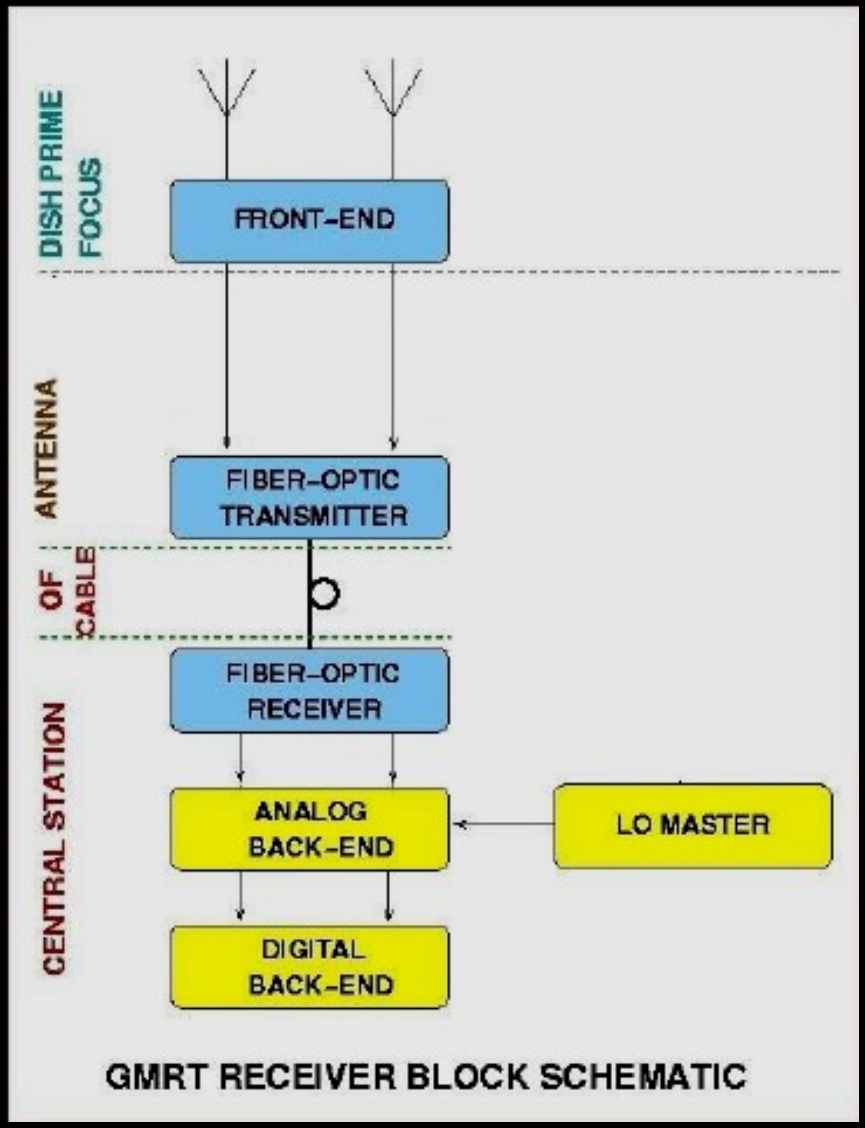
- Spectral lines : broadband coverage will give significant increase in the redshift space for HI lines + access to other lines
- Continuum imaging sensitivity will improve by factor of 3 or so.
- Sensitivity for pulsar observations will also improve by factor of 3.
- Only SKA-I will do better than uGMRT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

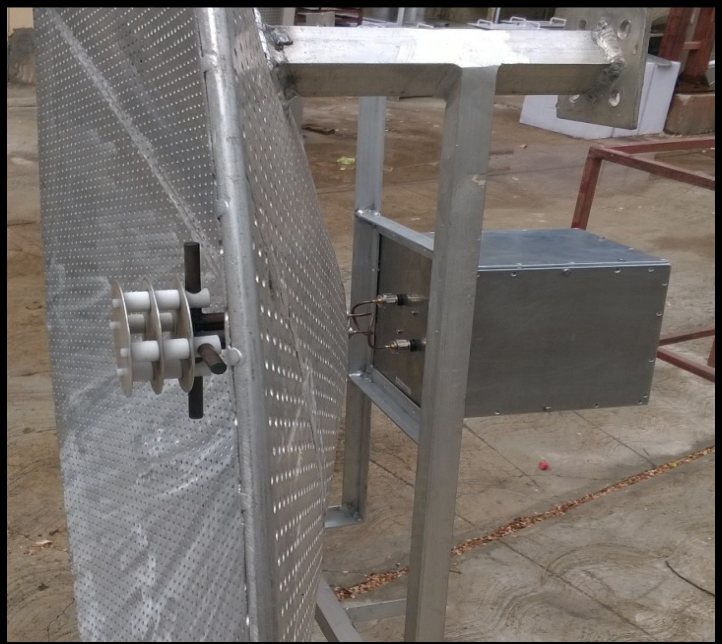
Overview of uGMRT Receiver System

- Broad-band feeds + FE (in octaves) :
  - 1000 – 1450 MHz (updating L-band)
  - 550 – 850 MHz (replacing 610)
  - 250 – 500 MHz (replacing 325)
  - 120 – 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 to process 400 MHz BW for interferometric and beam modes

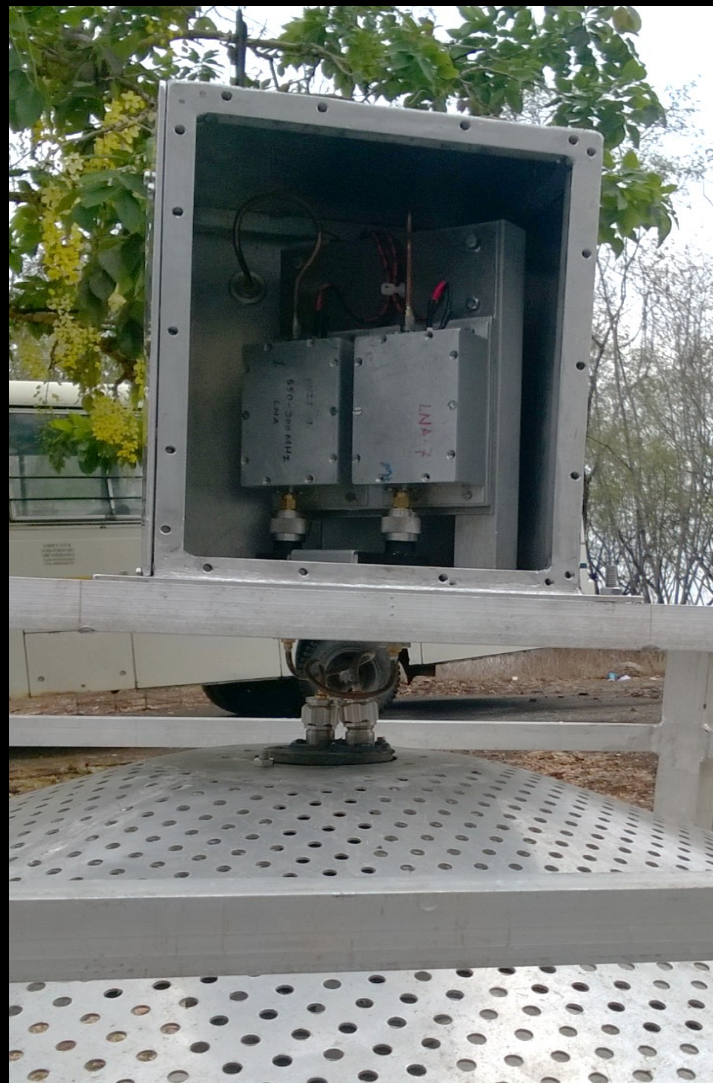


Wideband feeds + FE for uGMRT : 550-850 MHz system – “Band 4”

- Replaces existing 235/610 MHz system
- Front-End system split into two parts :
- Polariser + LNA is right next to feed (to minimize the loss)
- Rest of the FE electronics is in the regular box

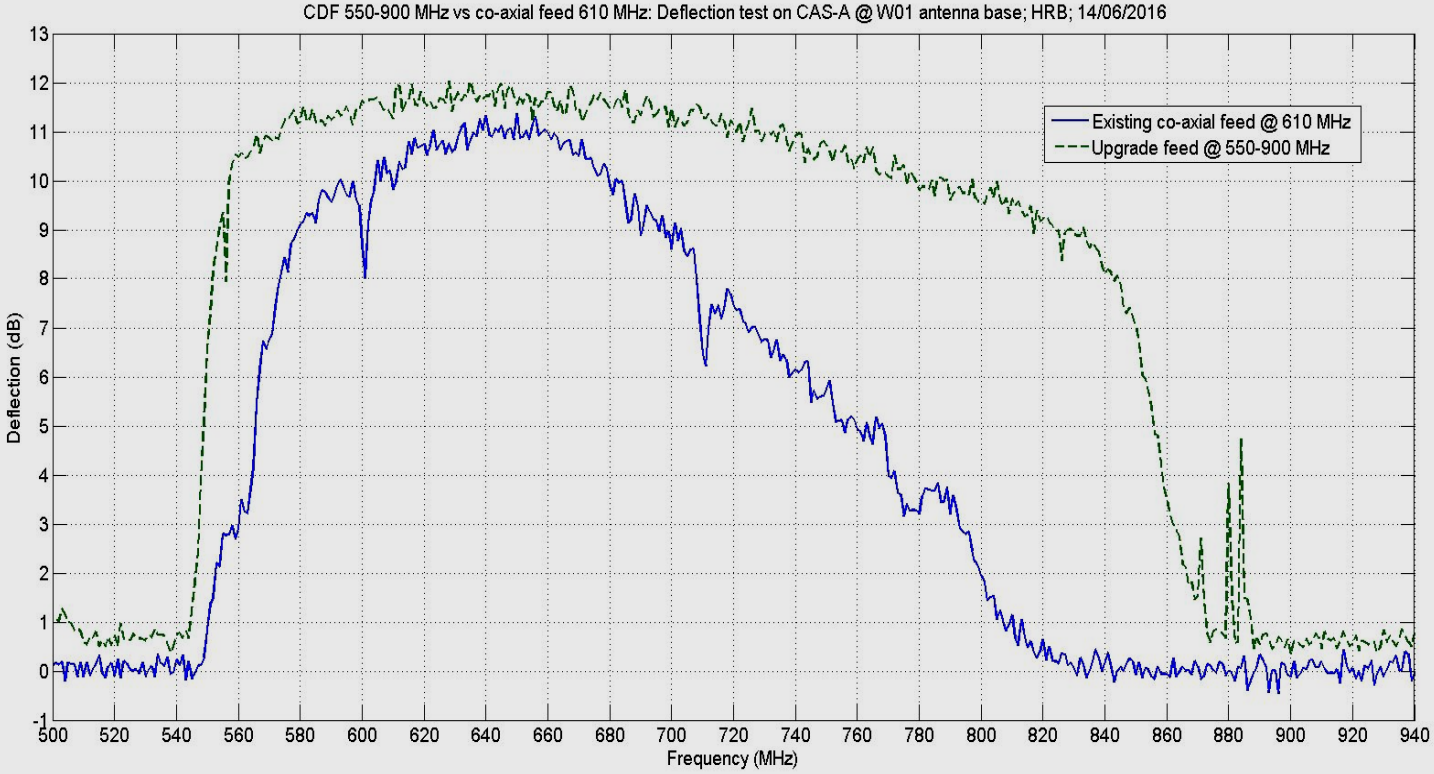


Cone Dipole feed (for 550-850) alongwith polarizer and LNA



Wideband feeds + FE for uGMRT : 550-900 MHz system – “Band 4”

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



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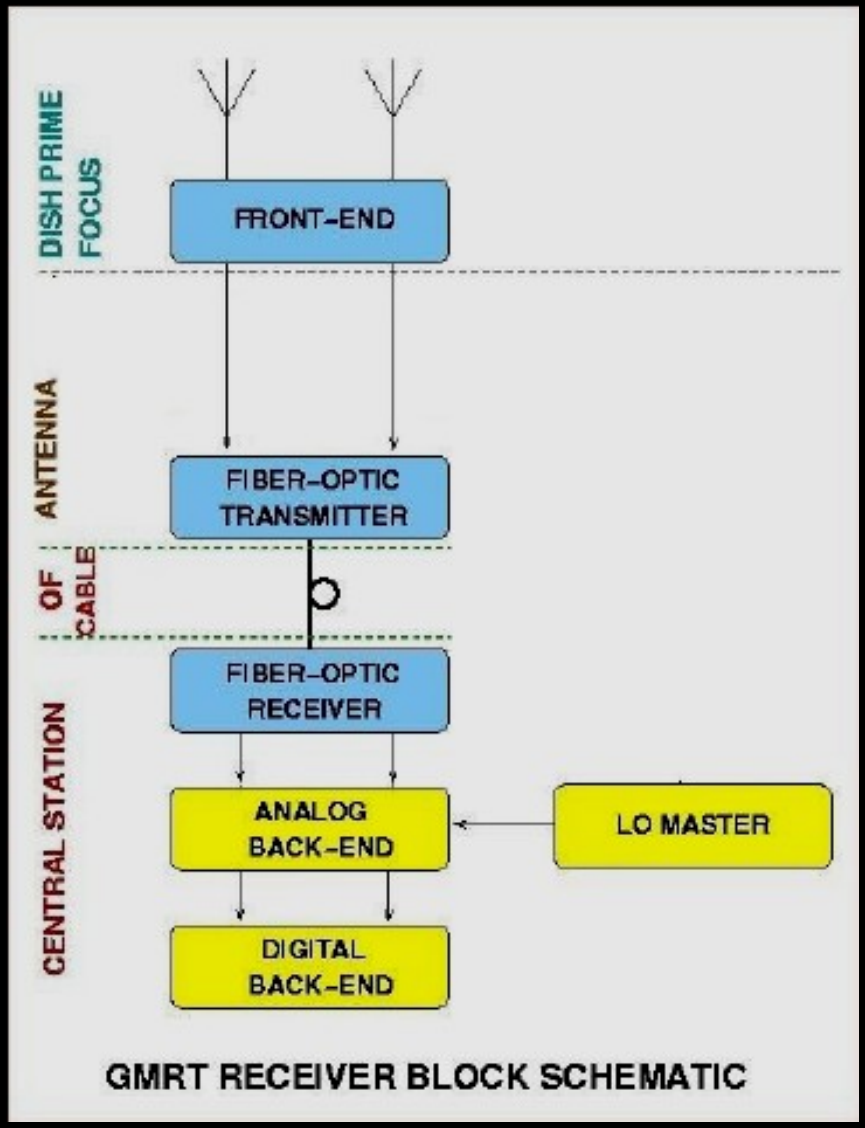
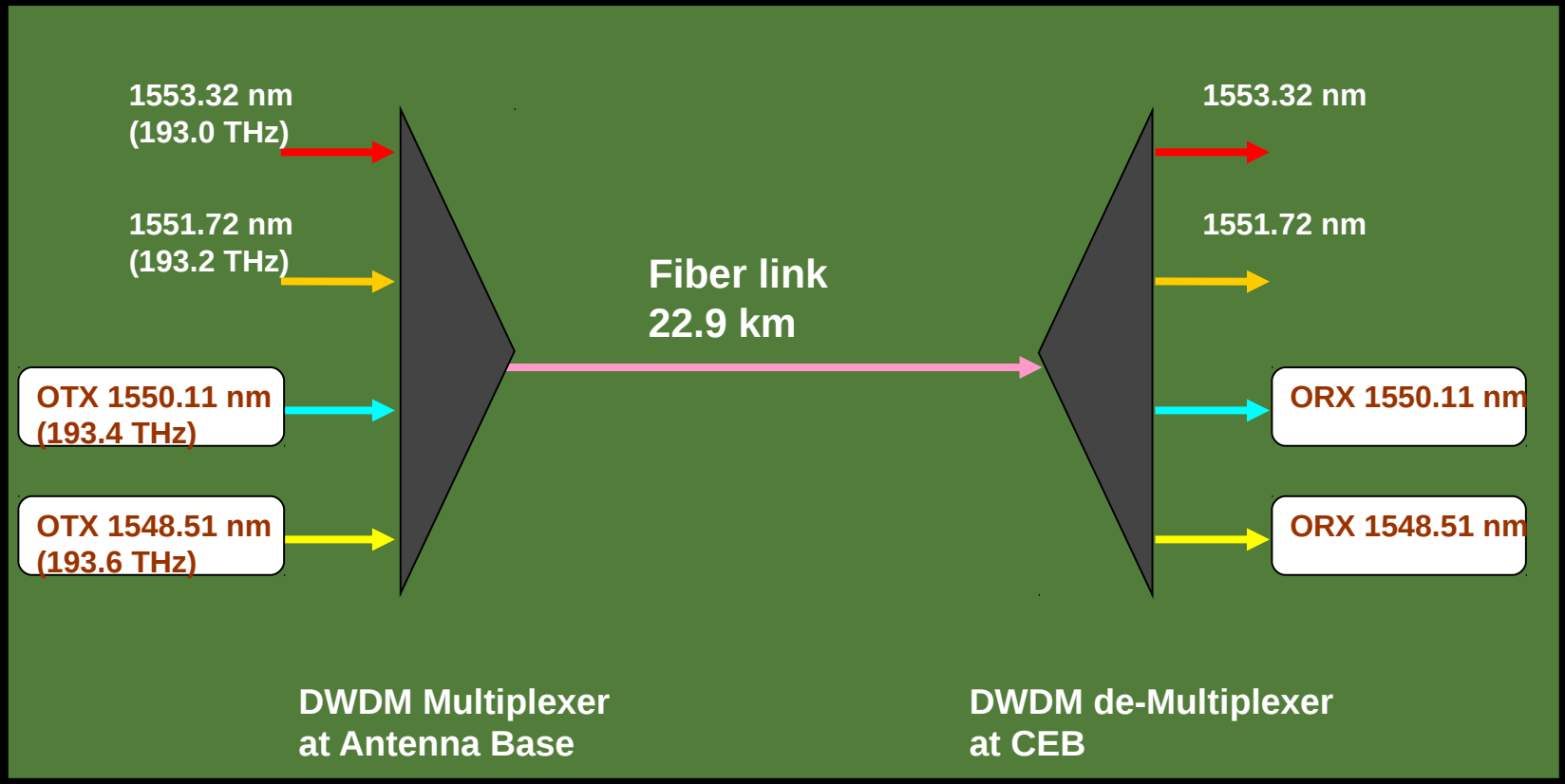


GMRT RECEIVER BLOCK SCHEMATIC

GMRT Upgrade : Optical Fibre Systems

- DWDM based, broad-band (2.5 GHz), analog optical fibre transmission scheme; features : 20 dB S/N; 40 dB dynamic range
- Brings back 2 broad-band RF channels + existing IF channels ; also supports new and existing control and monitoring schemes



GMRT Upgrade : Optical Fibre Systems

Completed installation for all 30 antennas in September 2015 and working well

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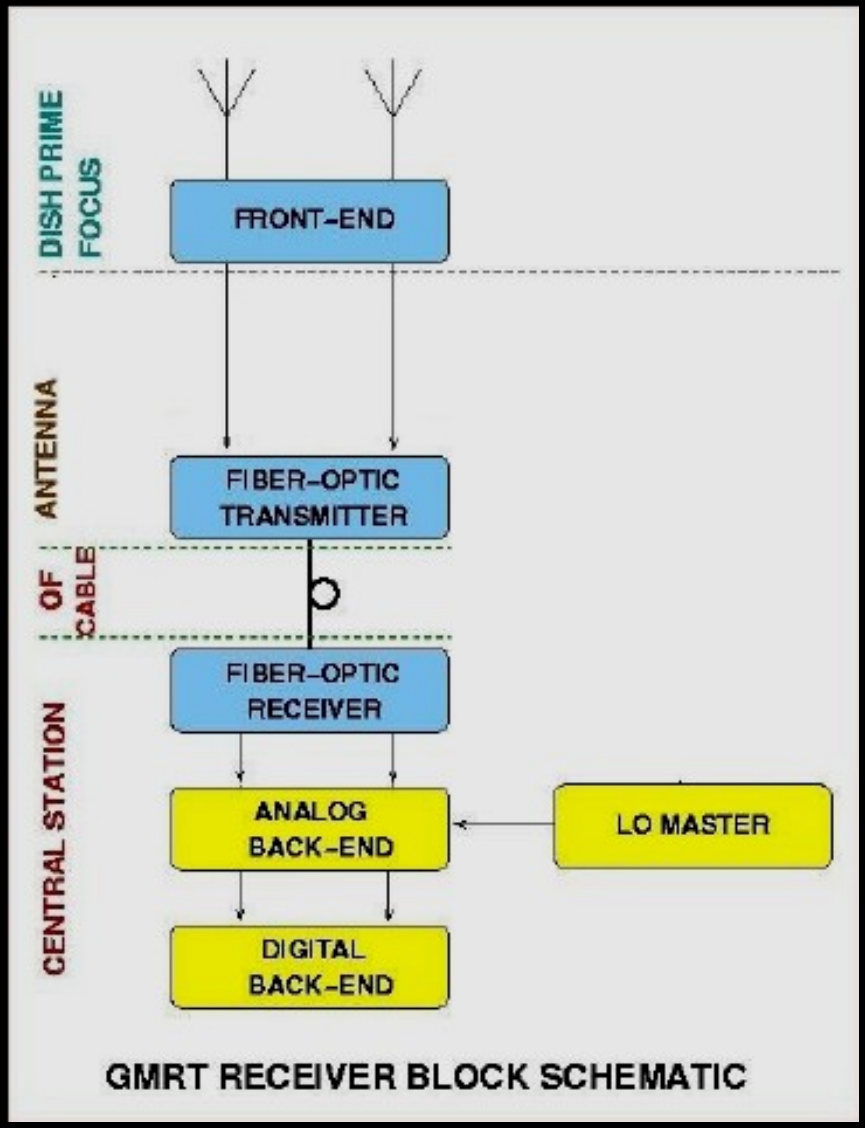
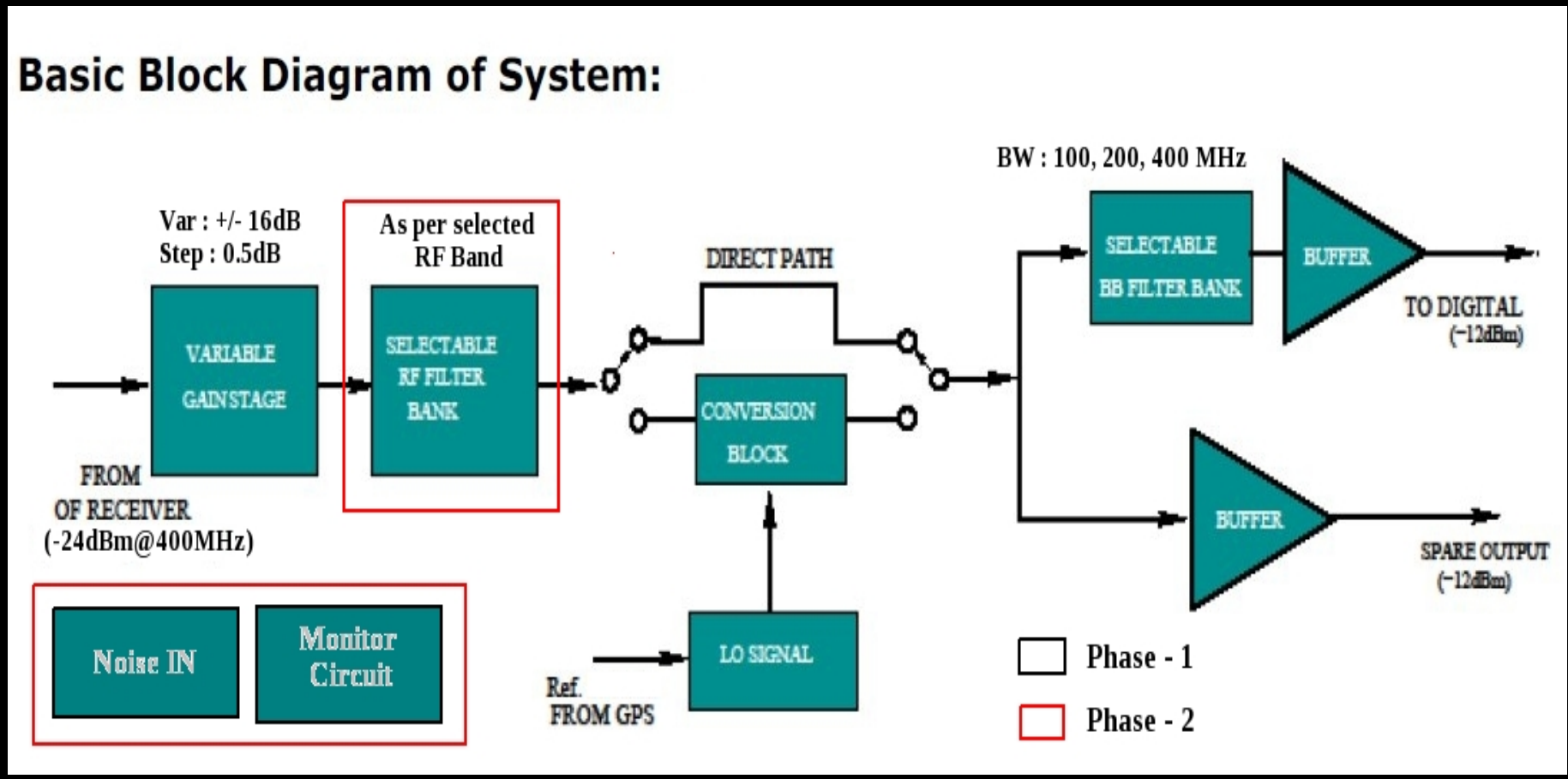


uGMRT : Analog Backend

- Receives wideband RF signals from OF system output
- Converts to baseband signals of 100, 200, 400 MHz BW after appropriate signal conditioning (amplification, filtering etc)



uGMRT : Analog Backend Status

- Phase-I 30-antenna system installation completed in 2017; peripheral units installed as part of phase-II in 2018

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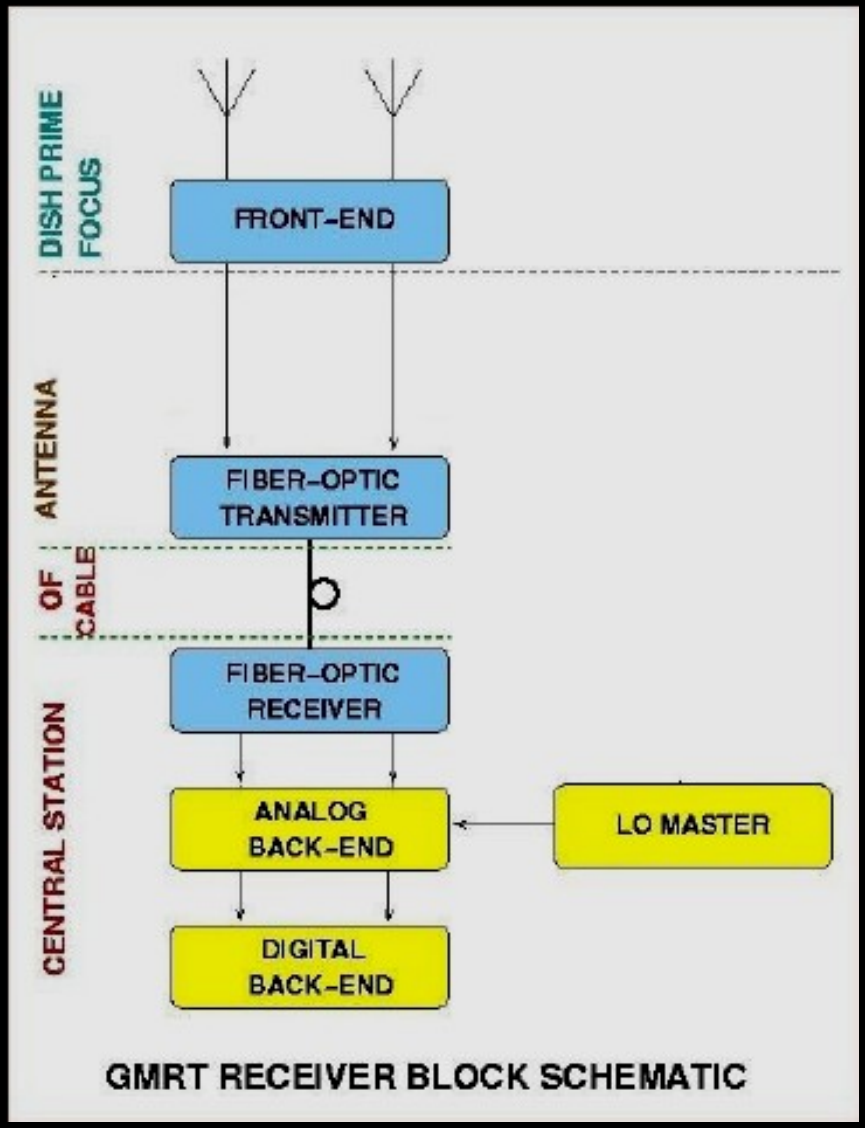
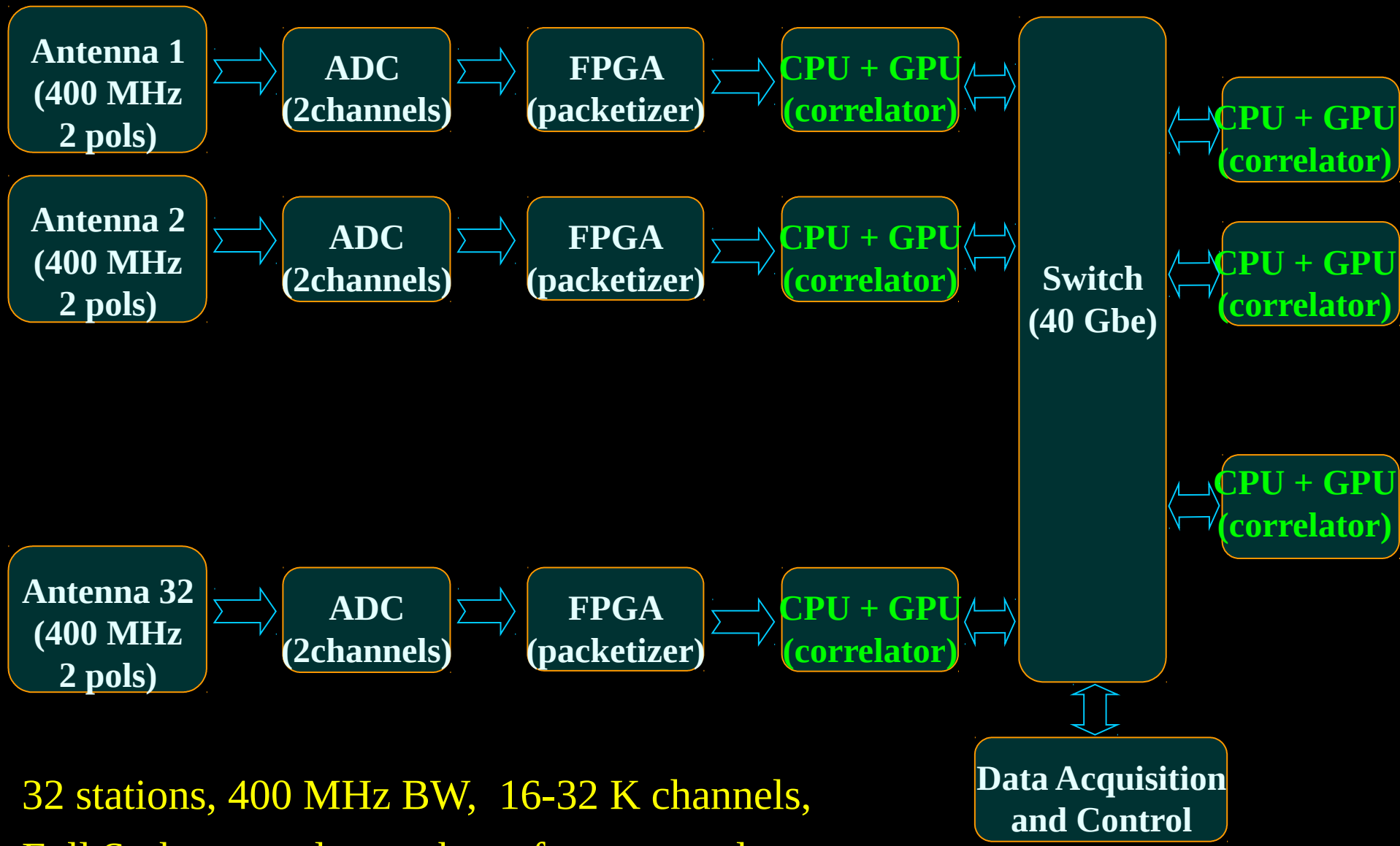


GMRT RECEIVER BLOCK SCHEMATIC

uGMRT Digital Backend : Hybrid Correlator Design



32 stations, 400 MHz BW, 16-32 K channels,

Full Stokes correlator + beamformer + pulsar rx.

uGMRT Digital Backend : Final 30-antenna system

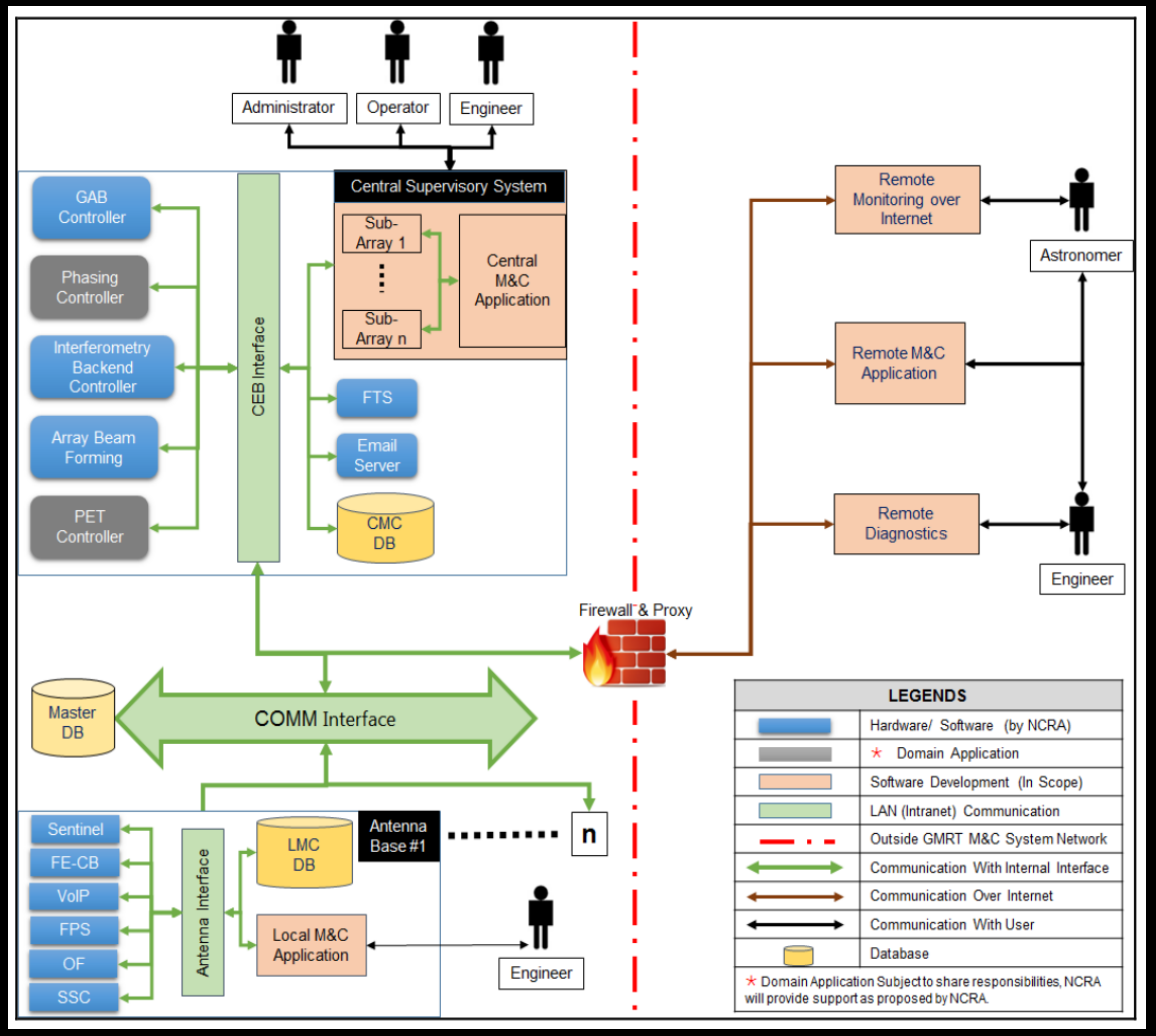
32 stations, 400 MHz BW, 16-32 K channels,

Full Stokes correlator + beamformer + pulsar rx.

Completed early 2018 and working fine

Next Generation Monitor & Control System for uGMRT

- Hardware and local interfaces : in-house
- High level software : in collaboration with TRDDC / TCS + PSL
- Uses TANGO platform
- Now ready for release
- Being developed as a SKA-prototype for the Telescope Manager

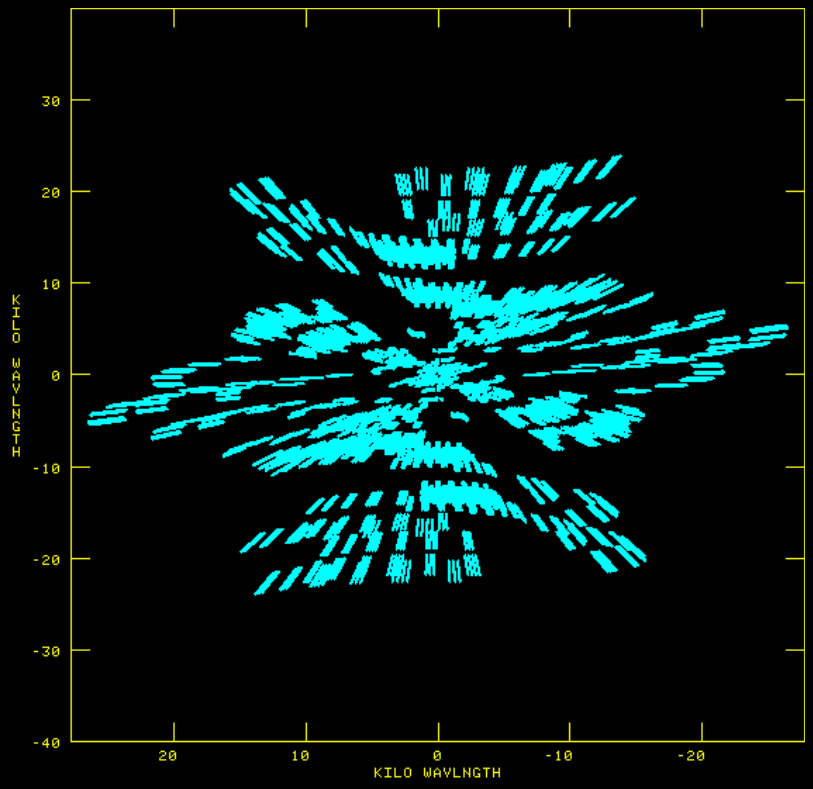


Towards a working uGMRT…

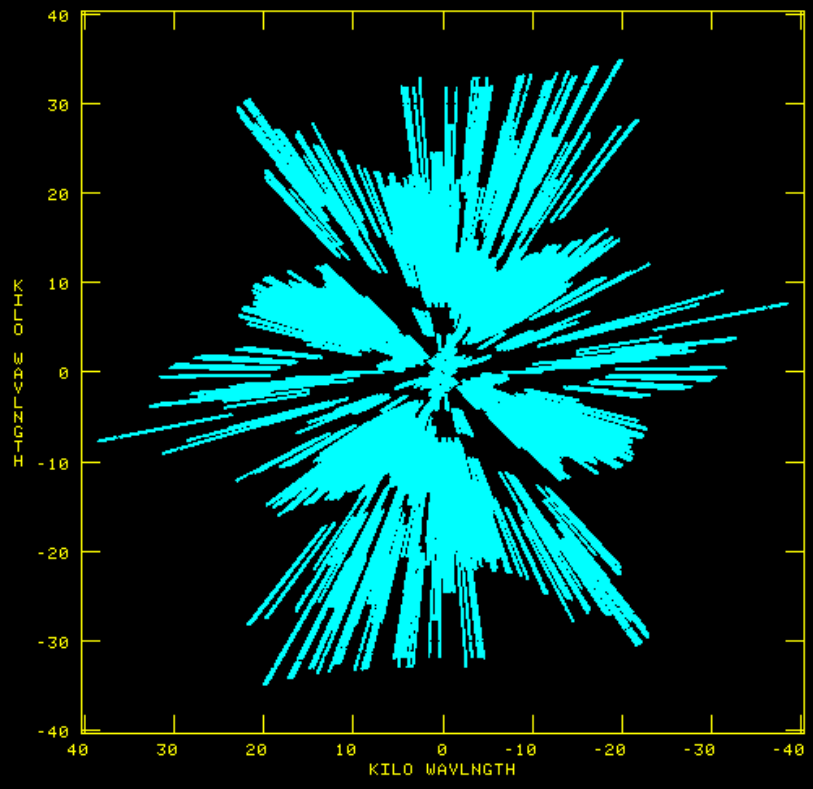
Improved imaging with uGMRT

- Large bandwidth of observations leads to improved uv-coverage and hence better imaging quality

Legacy GMRT : 325 +/- 16 MHz

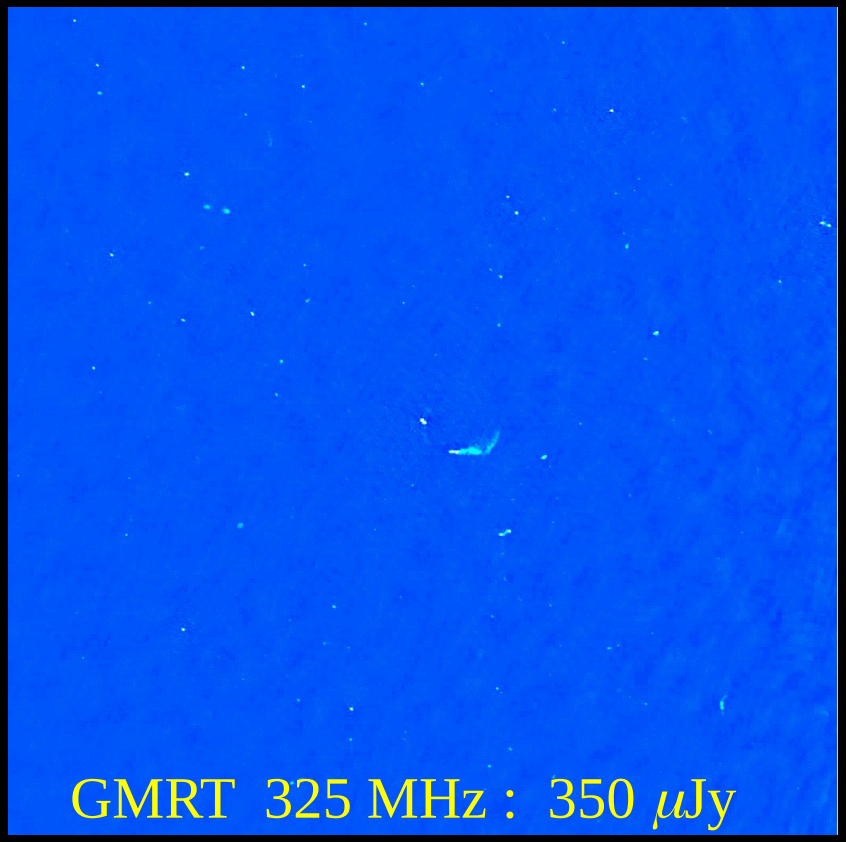


Upgraded GMRT : 400 +/- 100 MHz

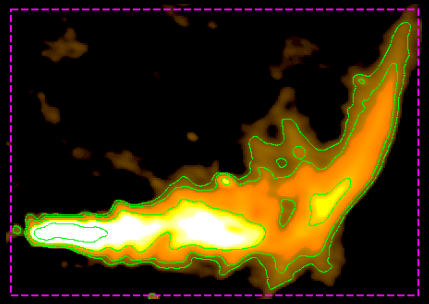


Courtesy : D.V. Lal

Improved imaging with uGMRT



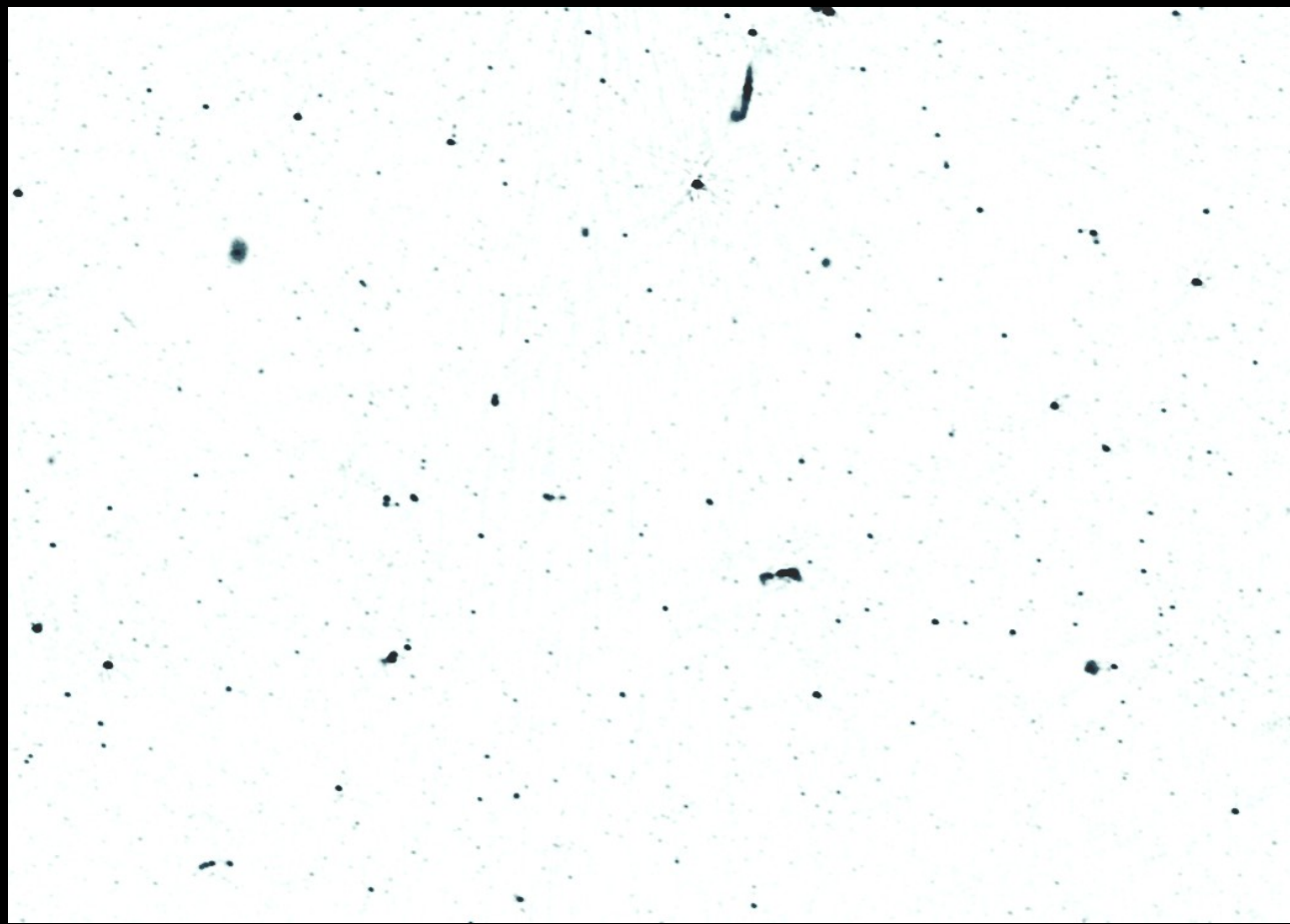
- 10x lower noise RMS in uGMRT image for similar observing times
- Could detect 30 radio galaxies in the Coma cluster, some for the first time



Courtesy : Lal & Ishwar-Chandra

Deep field imaging with the uGMRT : XMM-LSS at Band-3 (300-500 MHz)

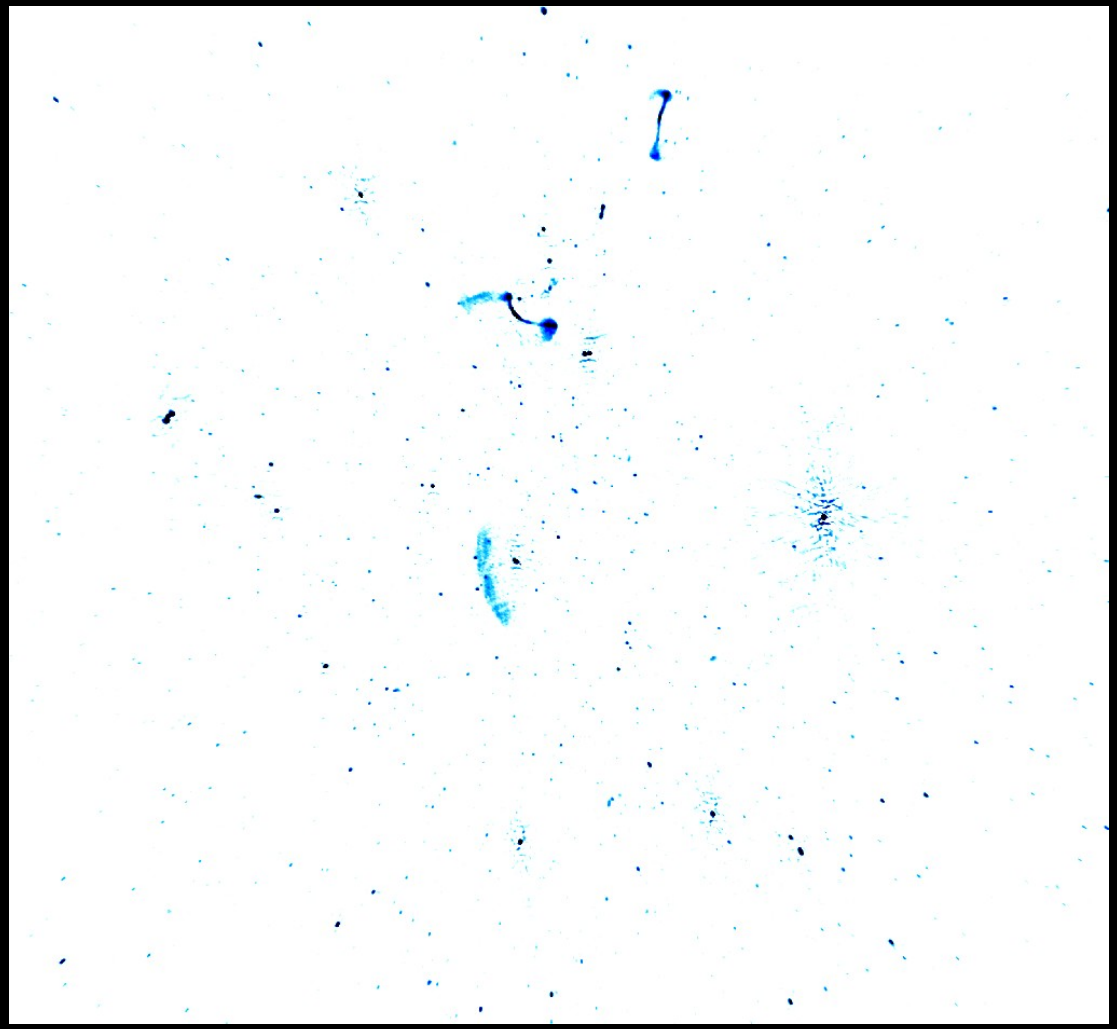
- Deepest ever (most sensitive) image made at 400 MHz by any telescope !
- 200 MHz BW
- 20 hrs on-source time
- 6.7”x5.8” resolution
- 14 microJy / beam noise
- Over 1600 sources per sq deg !



Ishwar-Chandra & collaborators

Deep imaging with the uGMRT : Abell 521 at Band-4 (550-850 MHz)

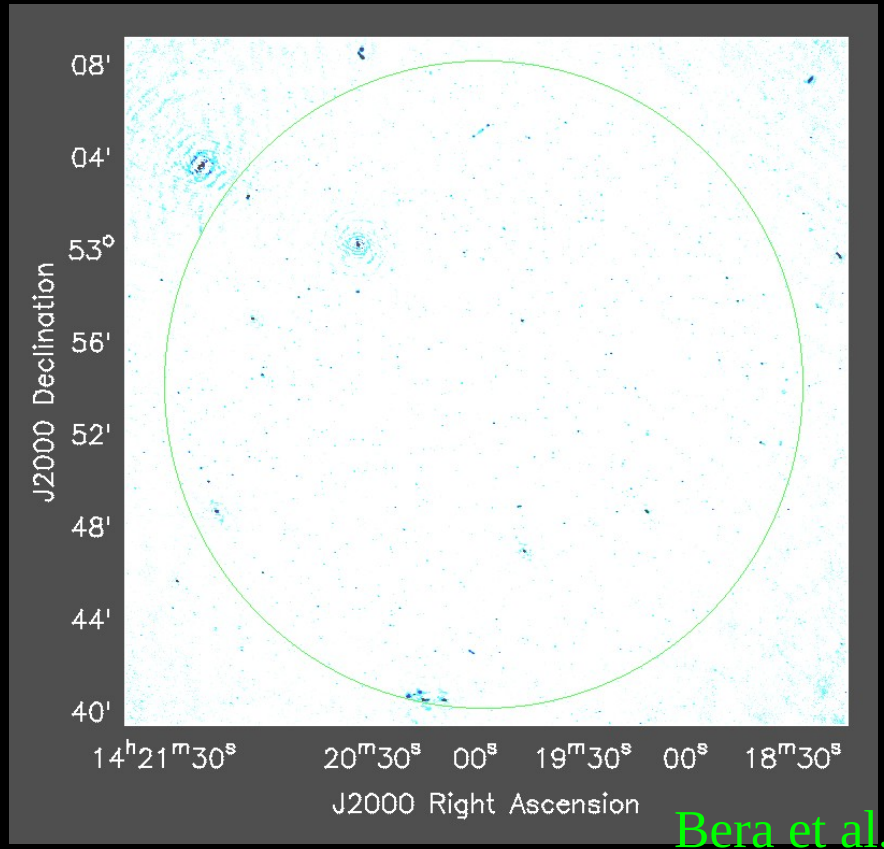
- Deepest image at Band-4 so far
- 10 microJy / beam noise !
- Arc like shock relic
- Faint central radio halo
- Radio lobes of some of the galaxies – new detections

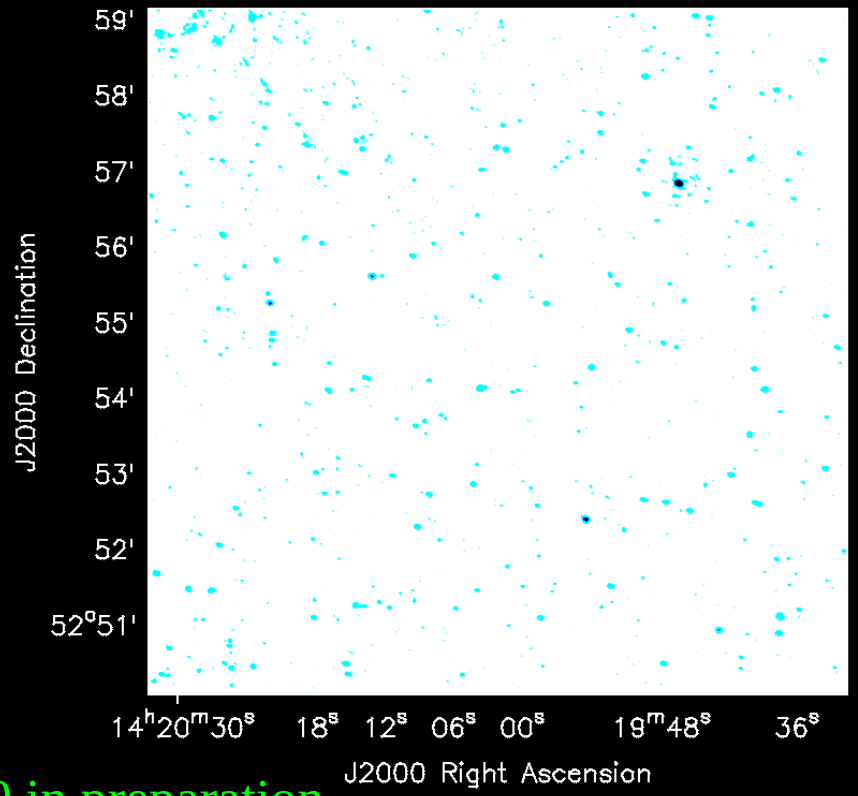


Kale & collaborators, 2019

Deep fields with the GMRT : Best image at Band-5 (1000-1460 MHz)

- Recent result from L-band (1000 – 1460 MHz) study of the Extended Groth Strip (EGS) field with the uGMRT
- Reached noise level of 2.3 microJy in ~ 110 hrs of on source observing
- Deepest image of the EGS ! deepest image with the uGMRT so far !!
- 2nd deepest image at L-band EVER (only JVLA has one deeper) !!!





Bera et al, 2019 in preparation

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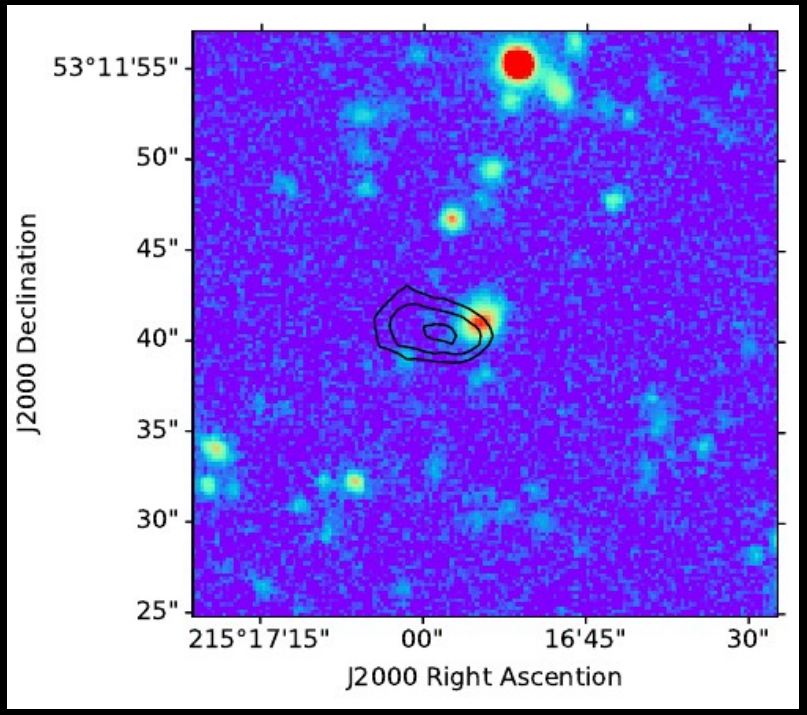
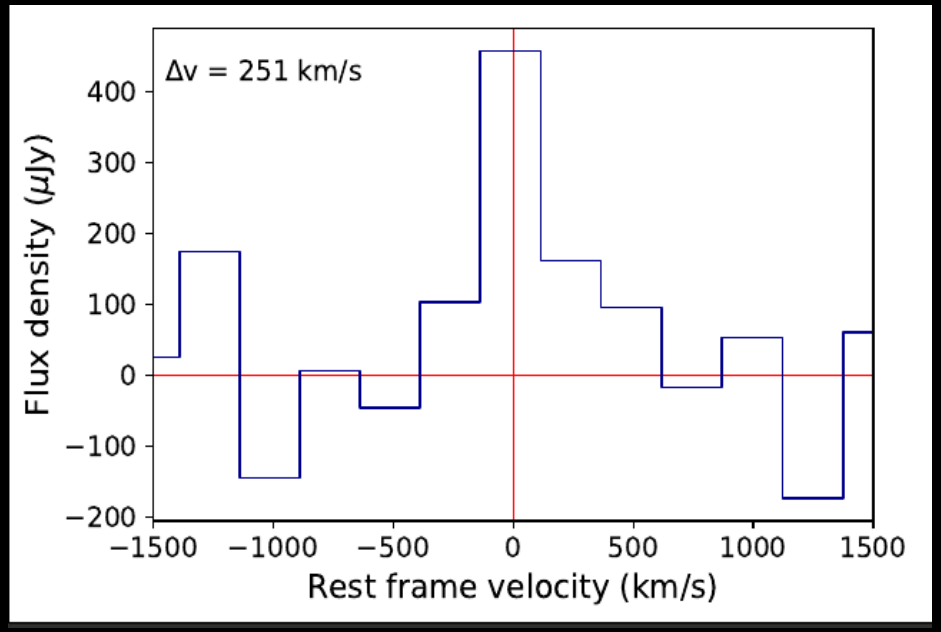
- Reached noise level of 2.3 microJy in ~ 110 hrs of on source observing
- Deepest image of the EGS ! deepest image with the uGMRT so far !!
- 2nd deepest radio image at L-band EVER (only the JVLA has one deeper) !!!
- Discovery of 2 galaxies in HI in emission at redshifts of 0.324 and 0.387 – latter is THE highest redshift for detection of HI emission to date !



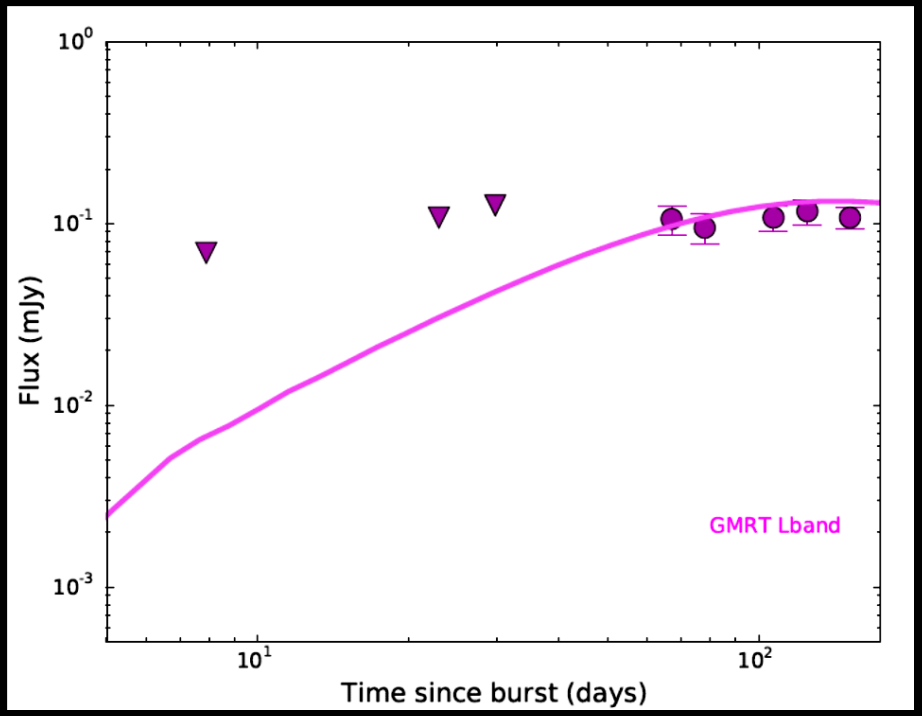


Bera et al, 2019 in preparation

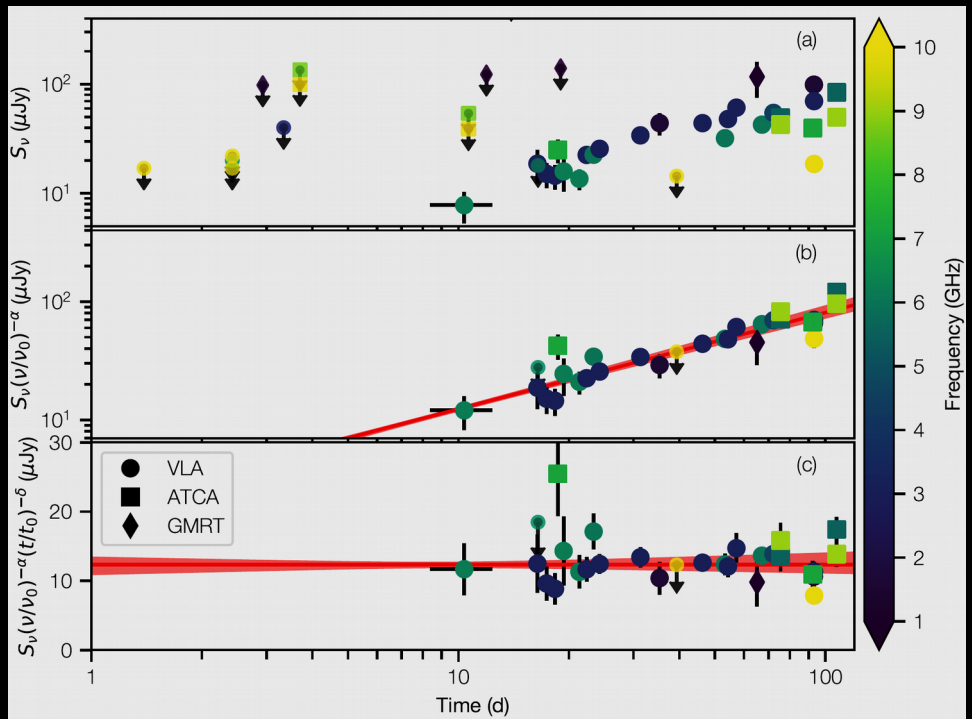
GW170817 : neutron star merger event with the uGMRT

- uGMRT played an important role in the multi-messenger observations of the GW event of 17 Aug 2017.

- Two groups followed the source with the uGMRT – helped constrain the models for the structure of the event.

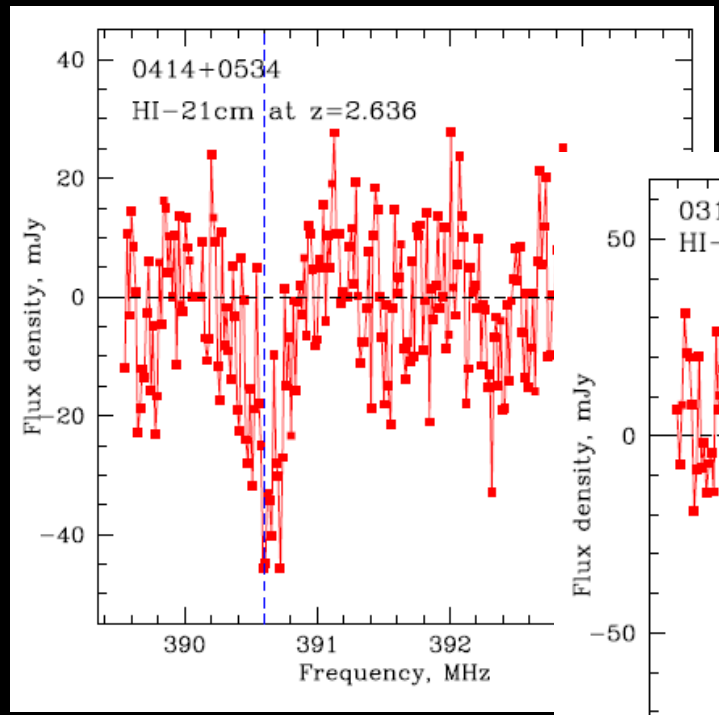


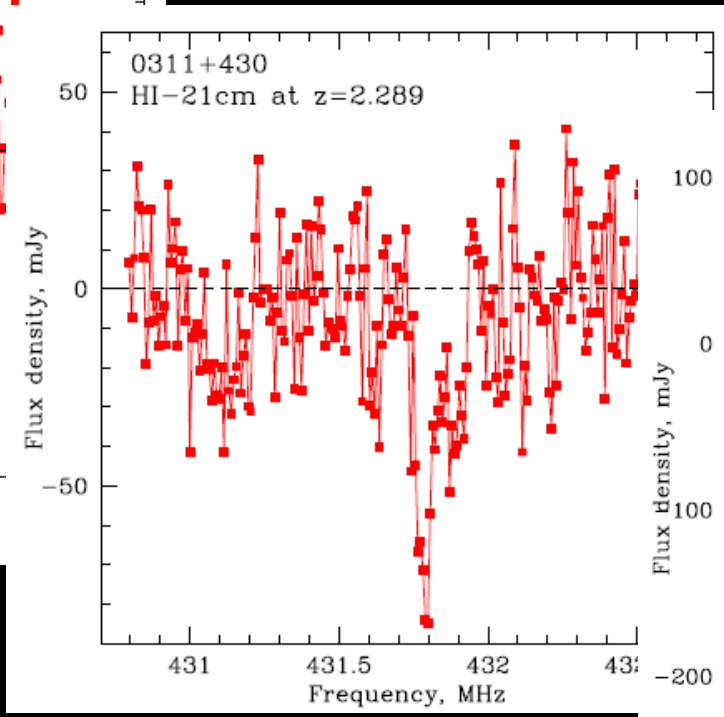
Resmi et al 2018

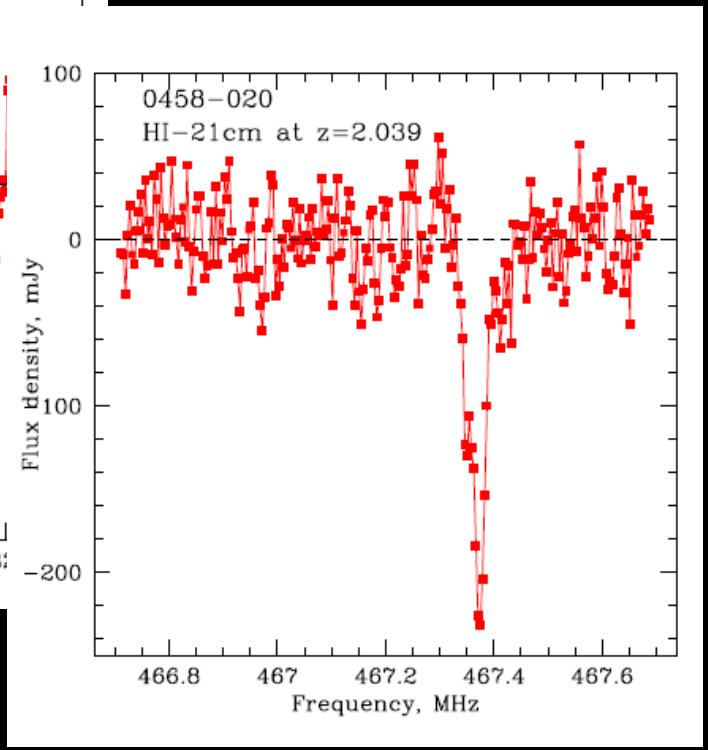


Hallinan et al 2017

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

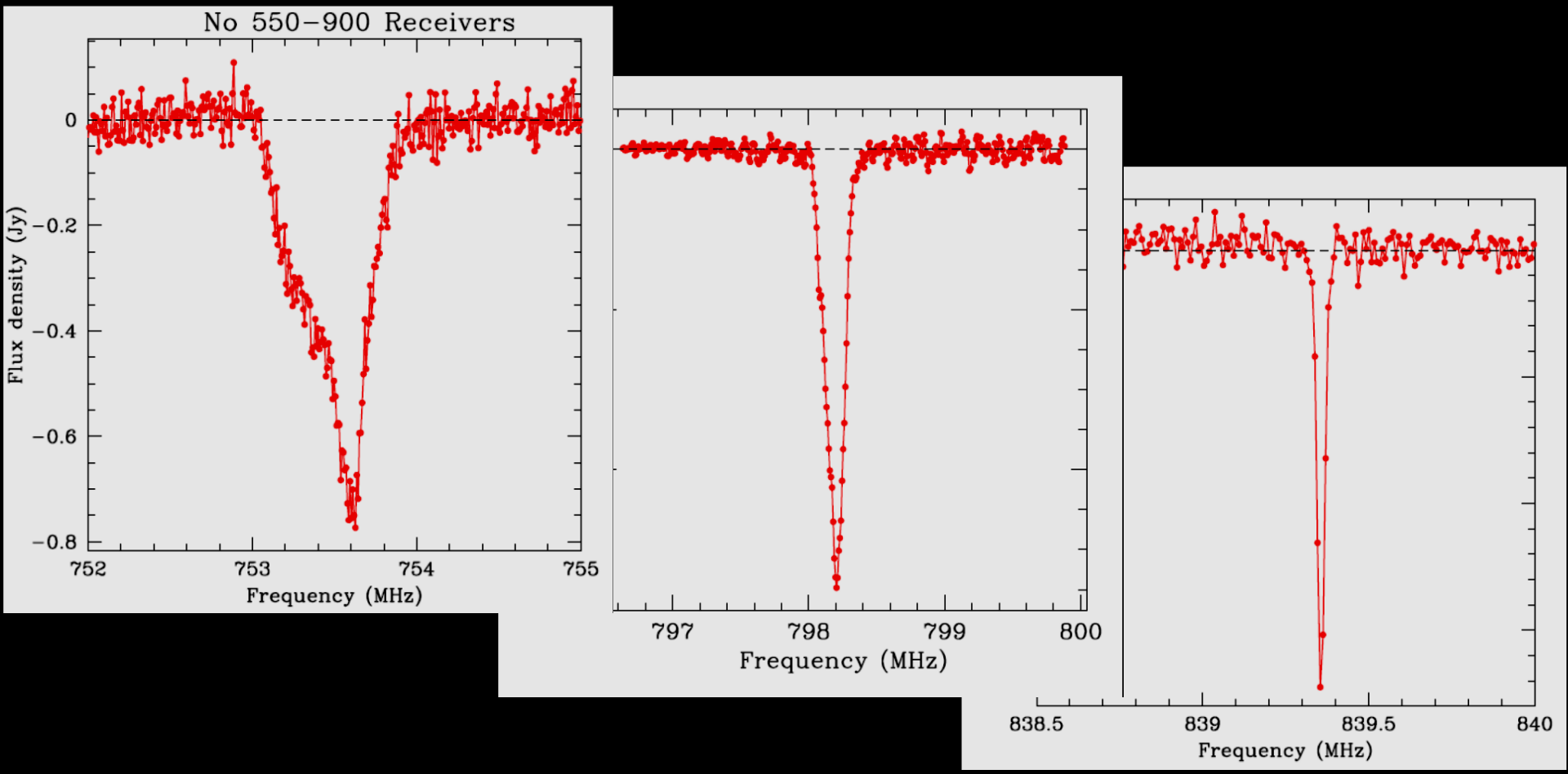






First light results : spectral lines from different sources, at different parts of the 250-500 MHz band (Nissim Kanekar)

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

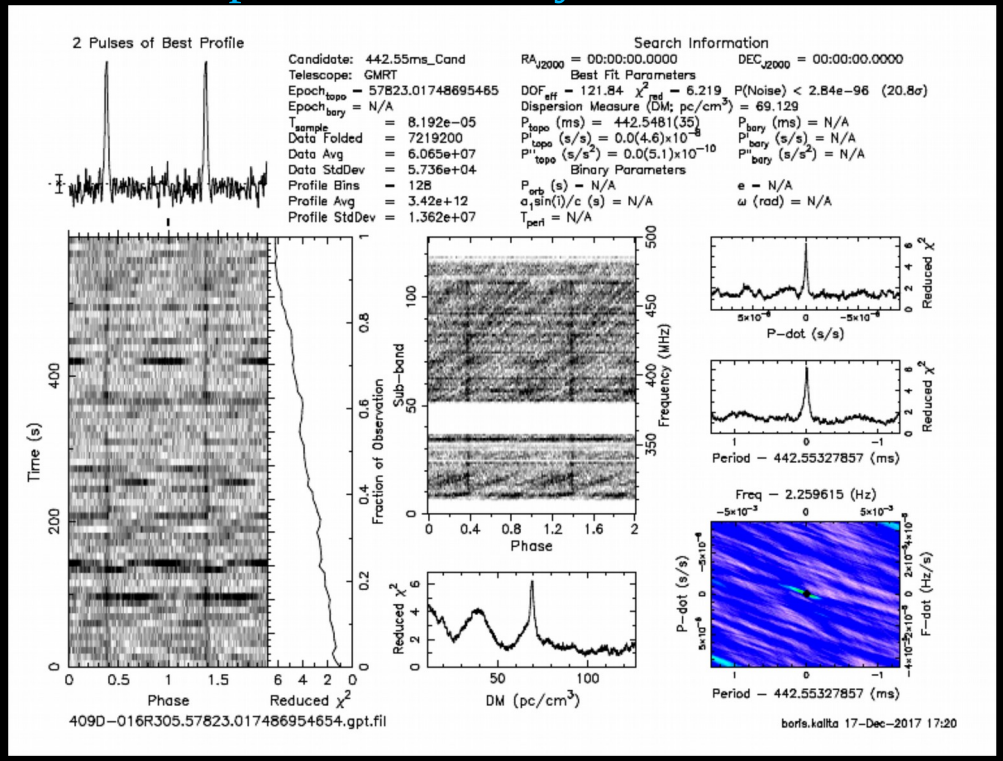


First light results : spectral lines from different sources, at different parts of the 550-900 MHz band (Nissim Kanekar)

Finding new pulsars with the uGMRT

- uGMRT has significant potential for discoveries of new pulsars (0.5 mJy in 10 mins in incoherent array mode) and transients
- Some of the ongoing / planned pulsar searches are :
  - GHRSS : legacy GMRT + upgraded GMRT
  - uGMRT survey for pulsars (Pugmarks)
  - Targeted search in selected globular clusters
  - Targeted search in TGSS steep spectrum sources

First new pulsar discovery with the uGMRT !



Pugmarks survey team, 2017

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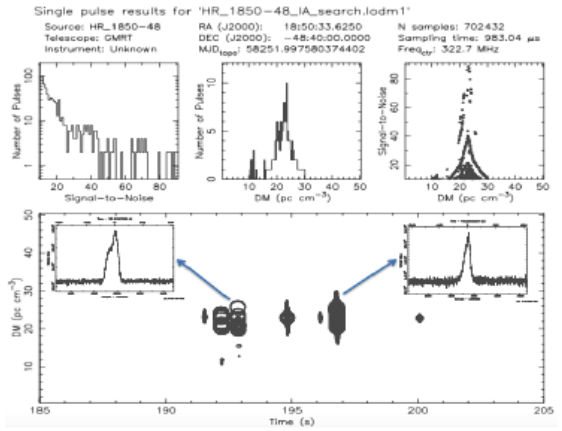
First new RRAT discovery with the uGMRT !

1st RRAT discovered with the GMRT



Credit : GHRSS team

J1850-48 at DM of 23 pc cm^{-3} and period of 327 ms is a RRAT discovered from the GHRSS survey

7 pulses (< 10 ms wide) see over 10-mins. The strongest pulse is at ~ 3 Jy

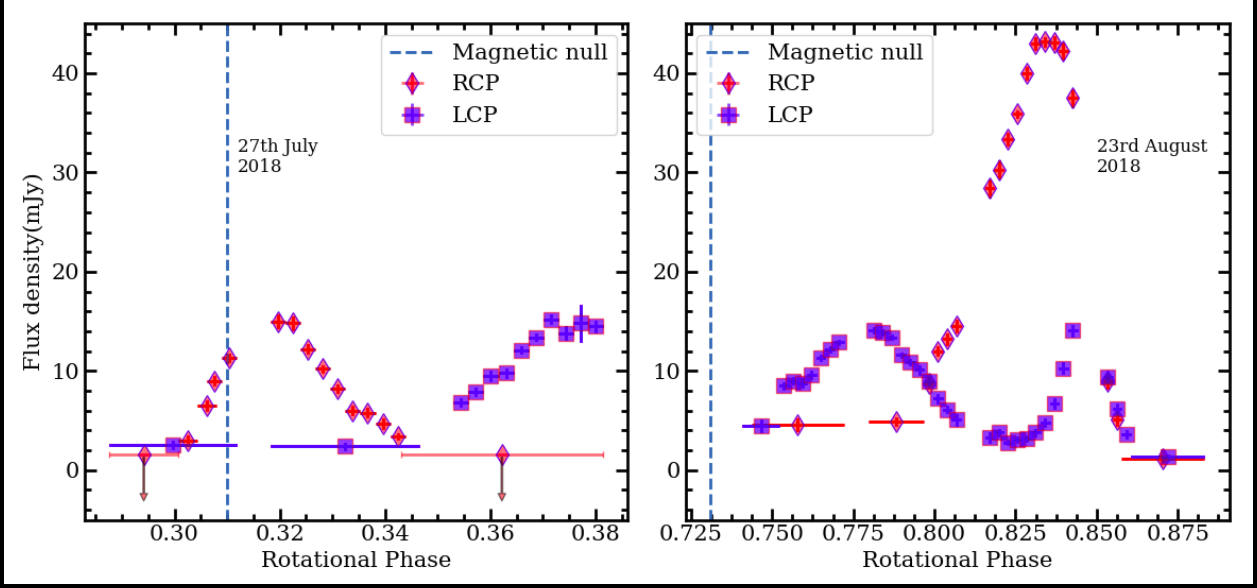
One of the nearby RRAT @ 0.8 kpc

GHRSS team

Jan 2019

Magnetic stars with the uGMRT

- Coherent radio emission from hot stars with ordered magnetic fields
- Electron Cyclotron Maser Emission thought to be the likely candidate
- Only 1 star was known before GMRT jumped into the field
- 3 new discoveries with uGMRT in last couple of years – natural advantages
- Excellent probe of stellar magnetoshpere at different heights
- Now looking at a wider survey to better understand this new field



Das & Chandra 2017 onwards

Challenges on the Road to uGMRT

The main challenges that we have encountered have been :

- Technological : design of the wideband receiver systems was a major challenge

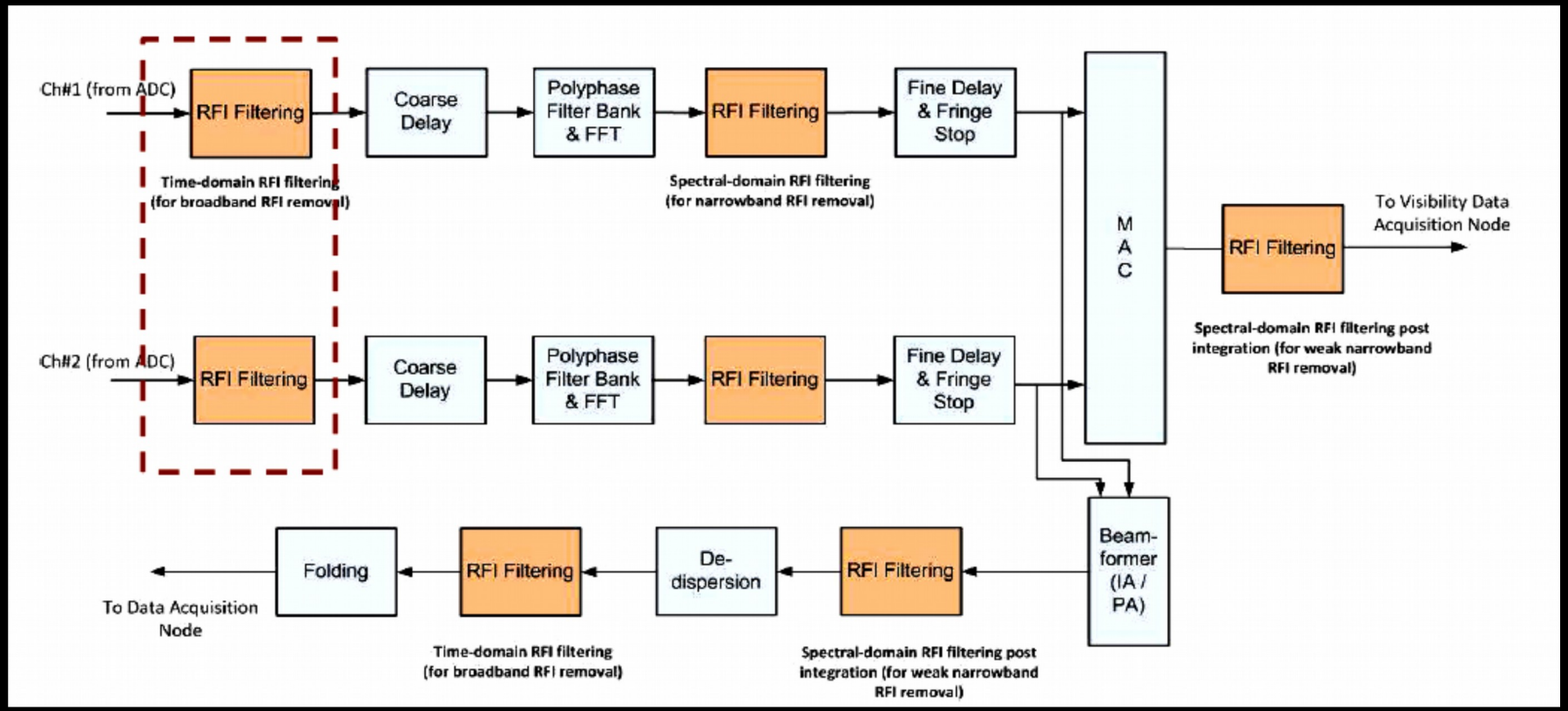
- Operational : keeping the existing GMRT working for our regular users while upgrading simultaneously took some effort

- Taking care of man made Radio Frequency Interference (RFI) is and remains our biggest challenge !
  - Containing self generated RFI
  - Mitigating RFI from external sources :

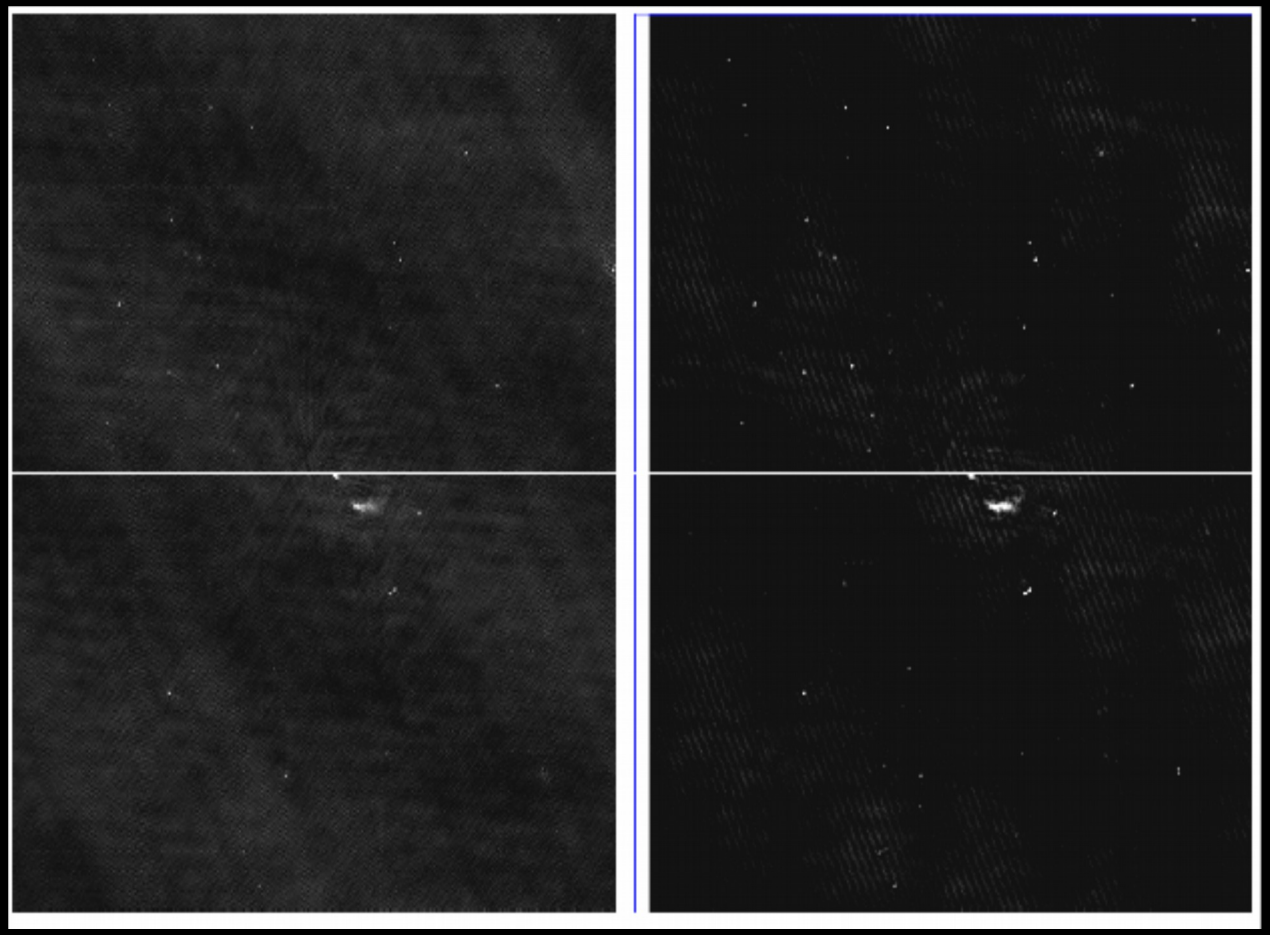
    (i) broadband impulsive (ii) spectral line

uGMRT : RFI Detection & Filtering

- Real-time filter running on broadband voltage data of each antenna
- Real-time spectral line filter running on spectra from each antenna
- Real-time filter running on time-frequency visibility data (planned)
- Real-time filter on time & frequency data of beamformer data stream.



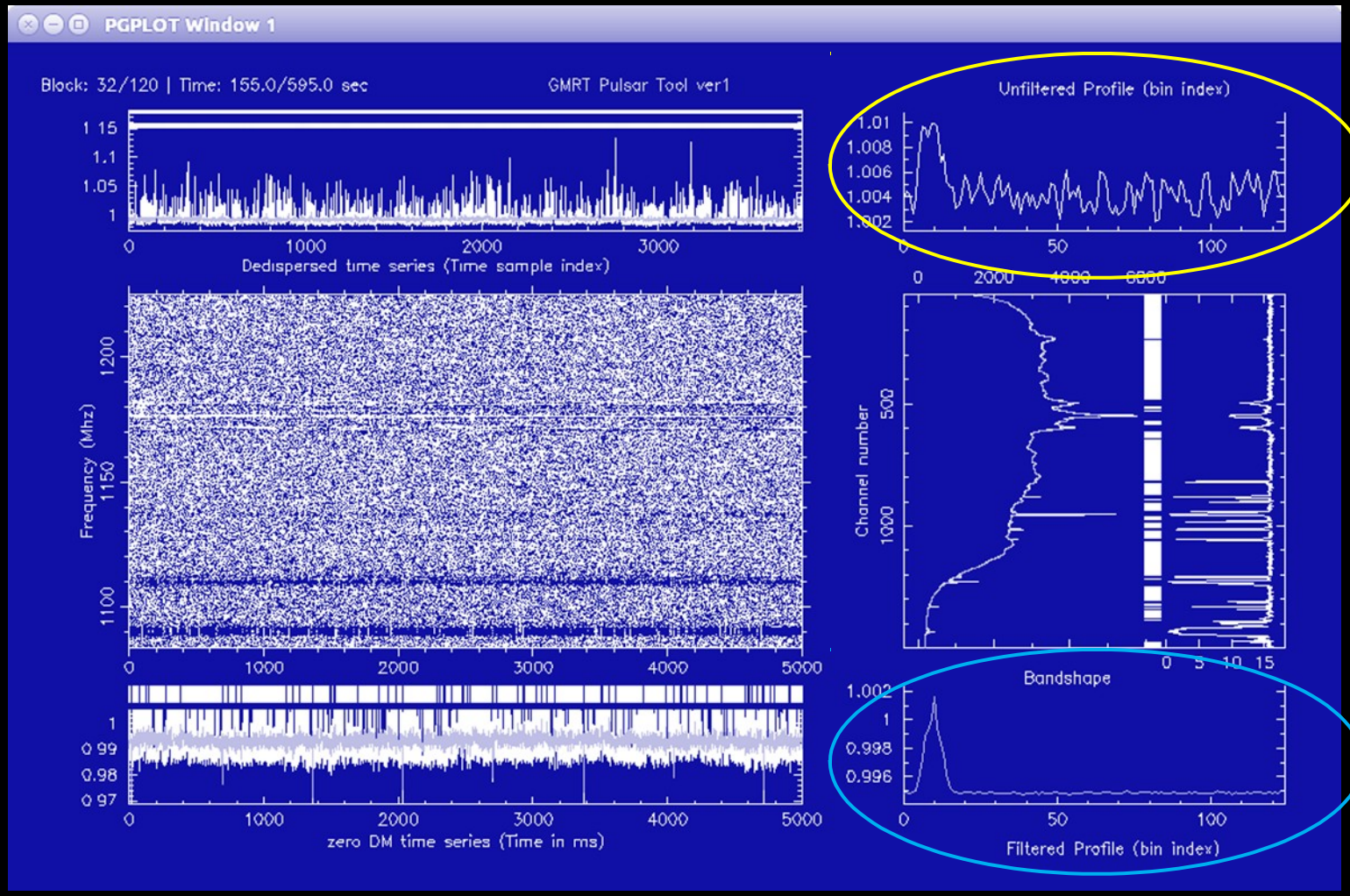
Real-time RFI Detection & Filtering



courtesy :
Kaushal Buch
Ruta Kale
and
D V Lal

- First light sample results from voltage domain filtering
- 16 antennas, 300-500 MHz, without (L poln) & with (R poln) filter
- Factor of ~ 2 improvement in noise !

Real-time RFI Detection & Filtering

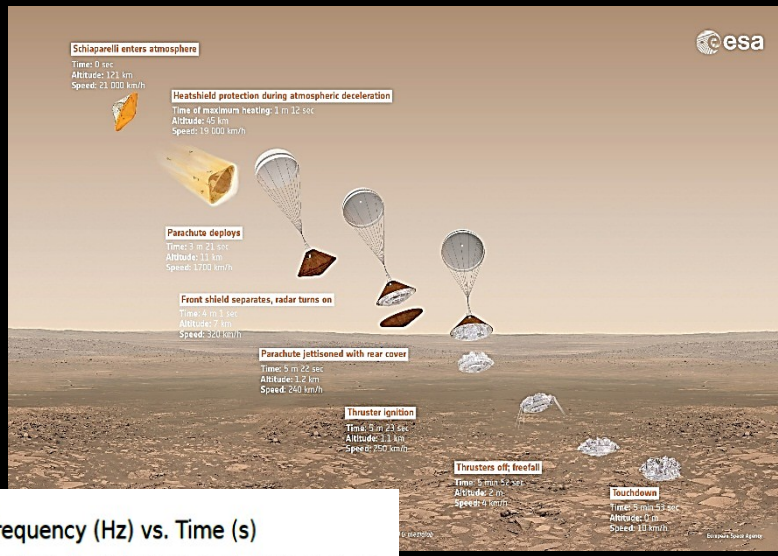


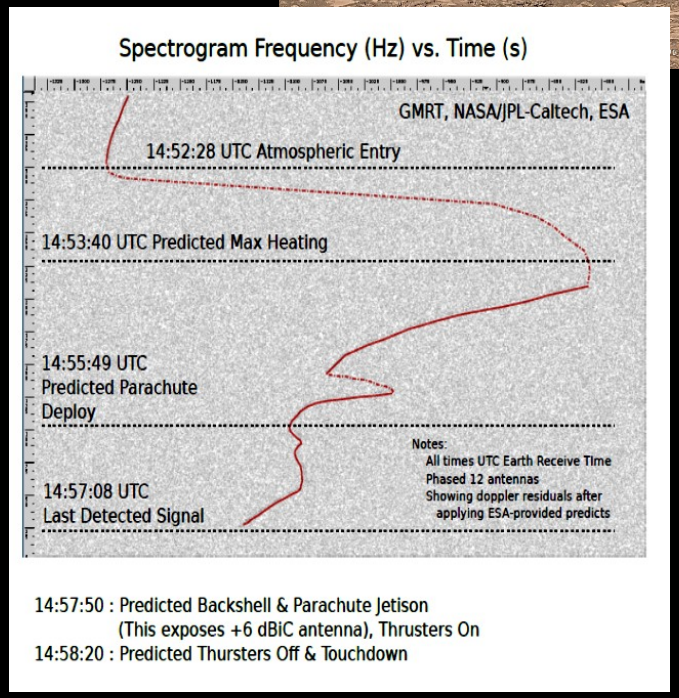
Real-time filtering of time-frequency of beamformer data – now available

courtesy : A. Chowdhury

“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

Release of uGMRT to users

Releases 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 for all users -- April 2016 .
4. Release of 30 antenna system with 2 bands fully functional : Band-5 (1000 to 1460 MHz) and Band-3 (250-500 MHz) -- October 2016
5. Release of 30 antenna system with 3 bands fully functional (completed Band-4 550-850 MHz), with 400 MHz back-end – October 2017
6. Release of 30 antenna system with all 4 bands fully functional (completed Band-2 120-240 MHz), with additional back-end modes – October 2018
7. Full release, including new monitor and control system – March 2019

Formal full release of uGMRT scheduled for LATER TODAY (!), so stay tuned… (for another 3 hrs or so) !!

That’s all !

Thank You