The upgraded GMRT : Opening New Windows to the Low Frequency Radio Universe

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The *existing* 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 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)

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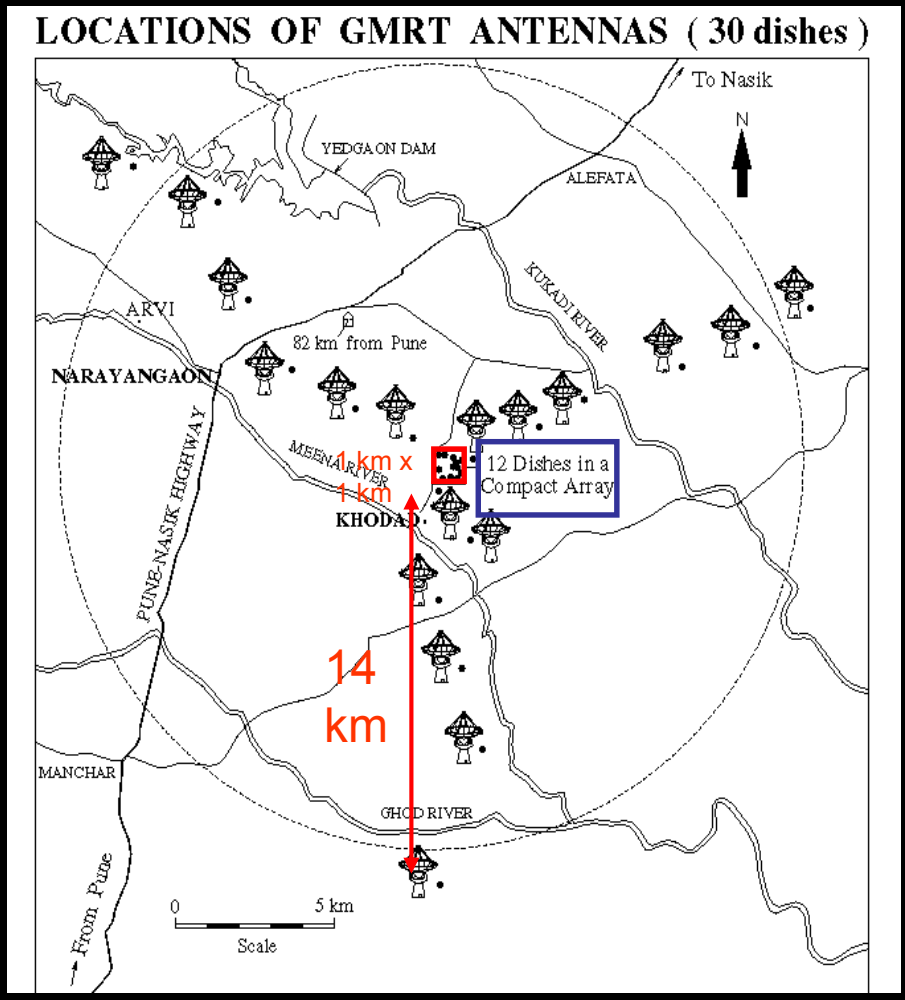


Dedication of the GMRT

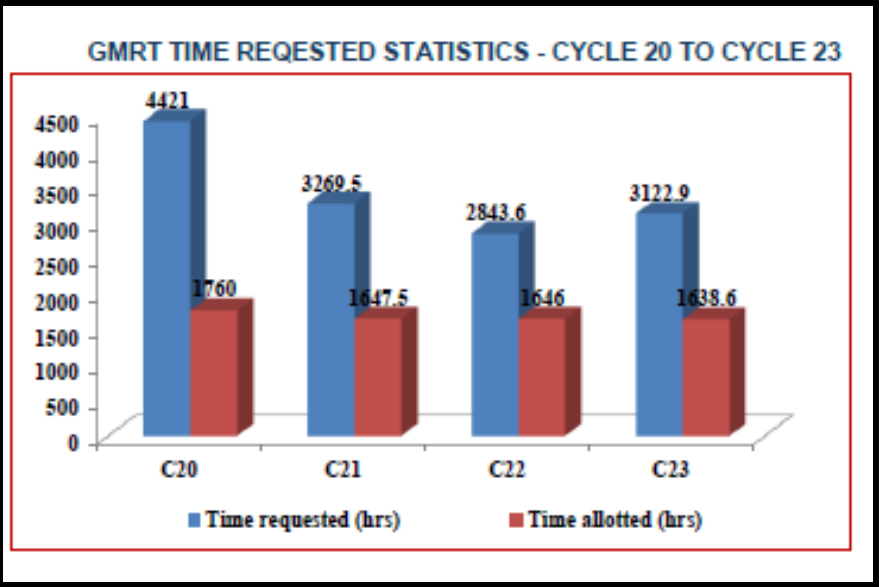
The Giant Metrewave Radio Telescope was dedicated to the World Scientific Community by the Chairman of TIFR Council, Shri Ratan Tata.

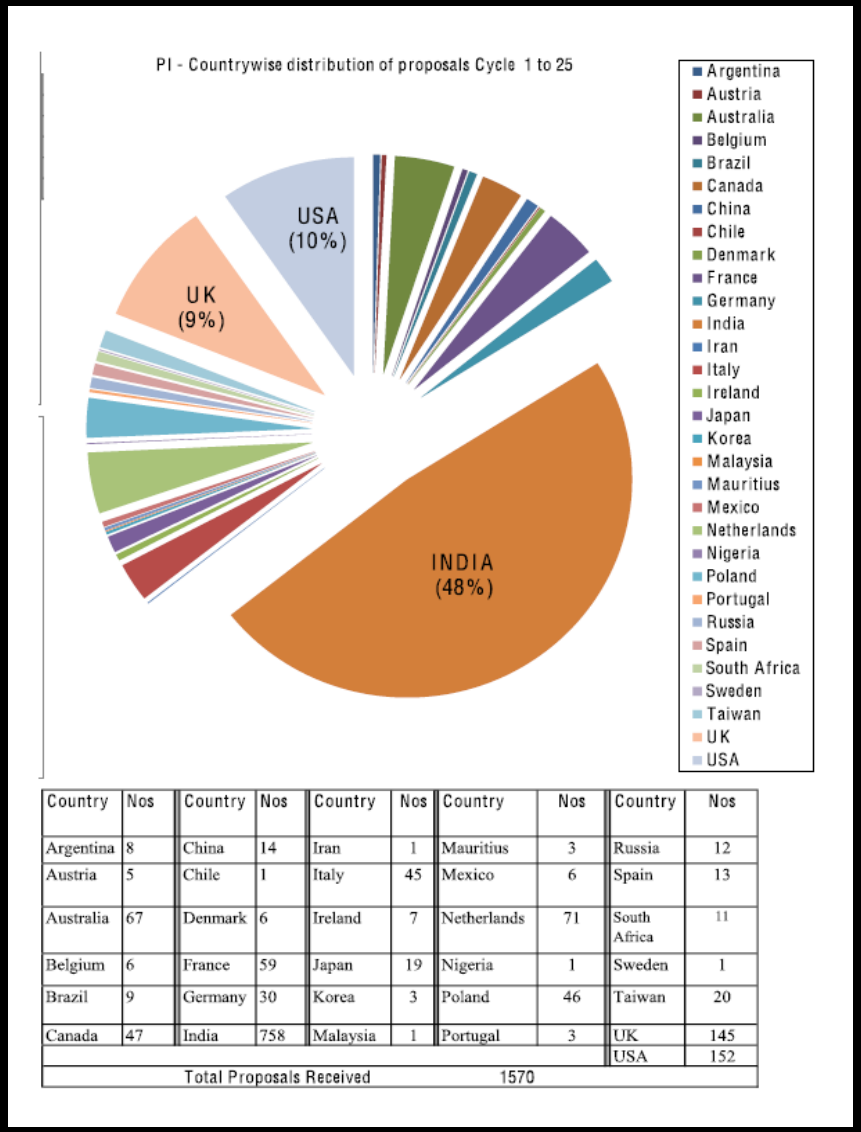
October 4, 2001

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 is a powerful instrument to probe several astrophysical objects and phenomena :

- The Sun, extrasolar planets
- Pulsars : rapidly rotating neutron stars
- 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)
- 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

Looking ahead : the upgraded GMRT

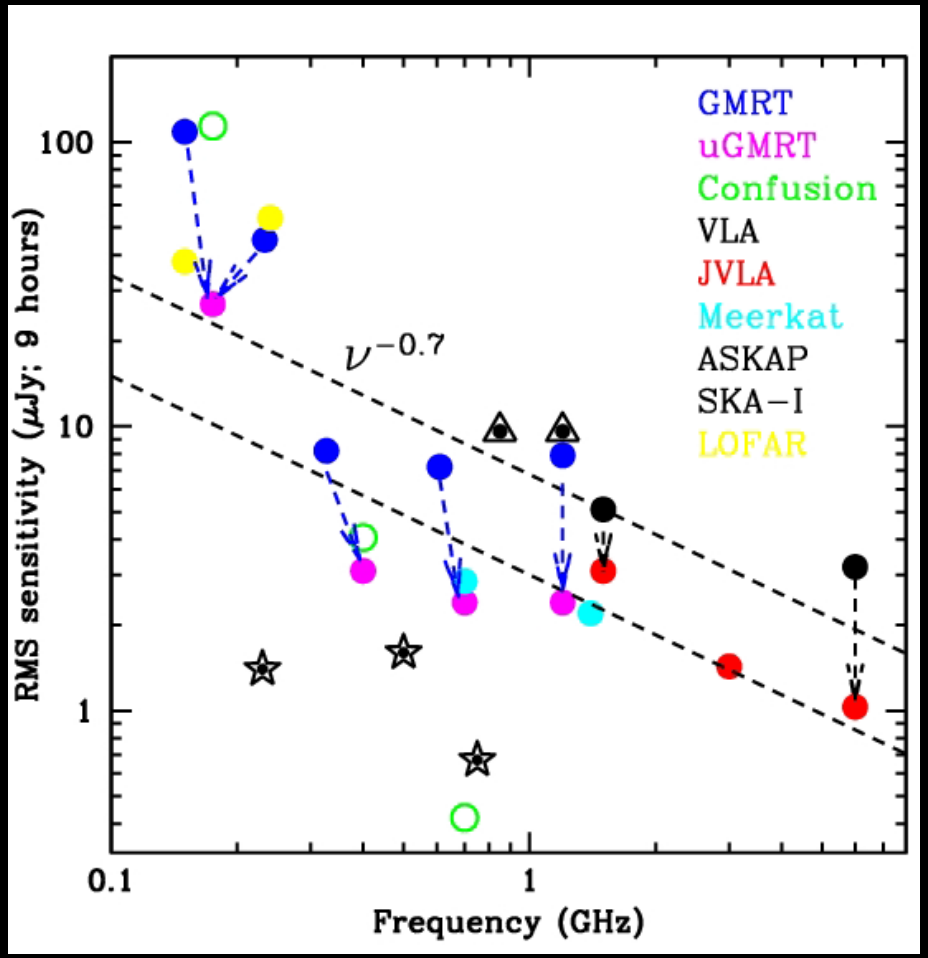
First concepts mooted : 2007-2008
Detailed work started : 2012
Now nearing completion

Next Generation : The uGMRT

- For last several years the GMRT has been working well on the global stage; however, it was time to think of the future & upgrade the facility, keeping in mind technology development for global efforts such as the SKA.
- 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

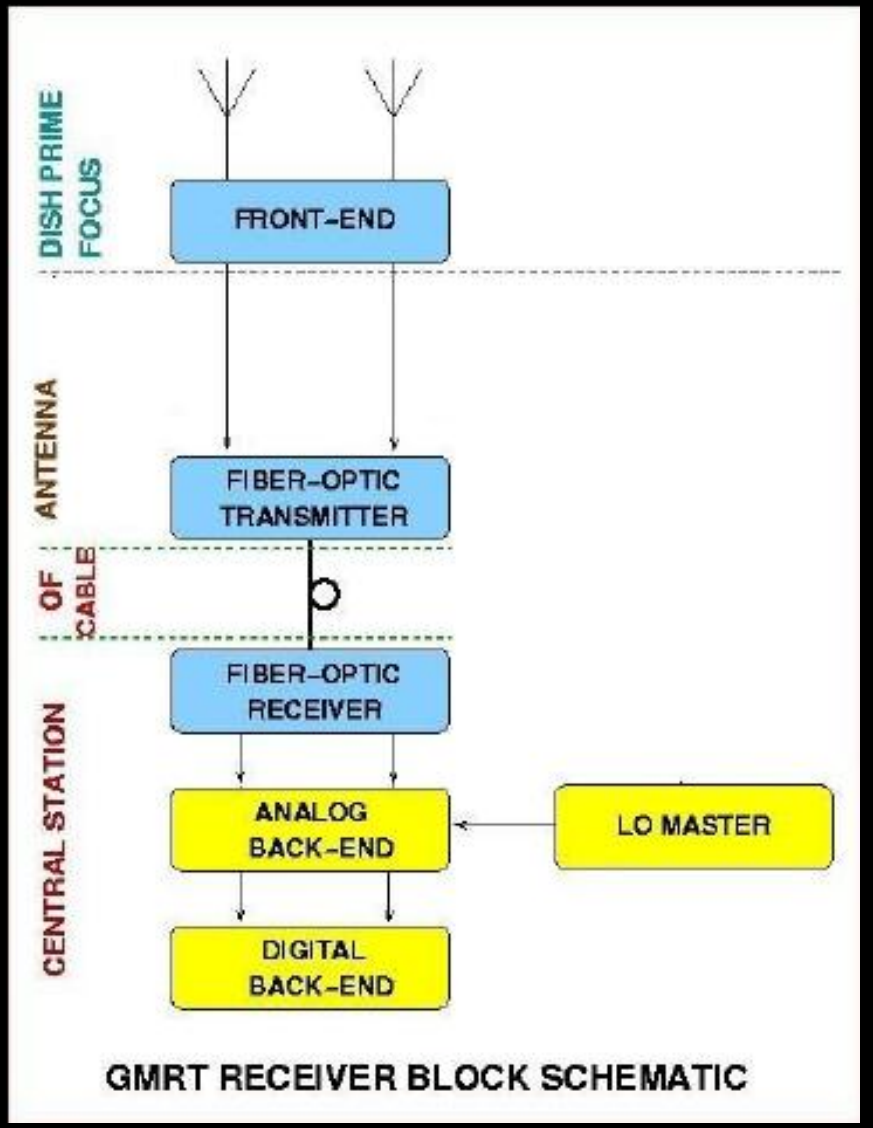
- Spectral lines : broadband coverage will give significant increase in the redshift space for HI lines + access to other lines
- Continuum imaging sensitivity will improve by factor of 3 or so.
- Sensitivity for pulsar observations will also improve by factor of 3.
- Only SKA-I will do better then uGMRT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

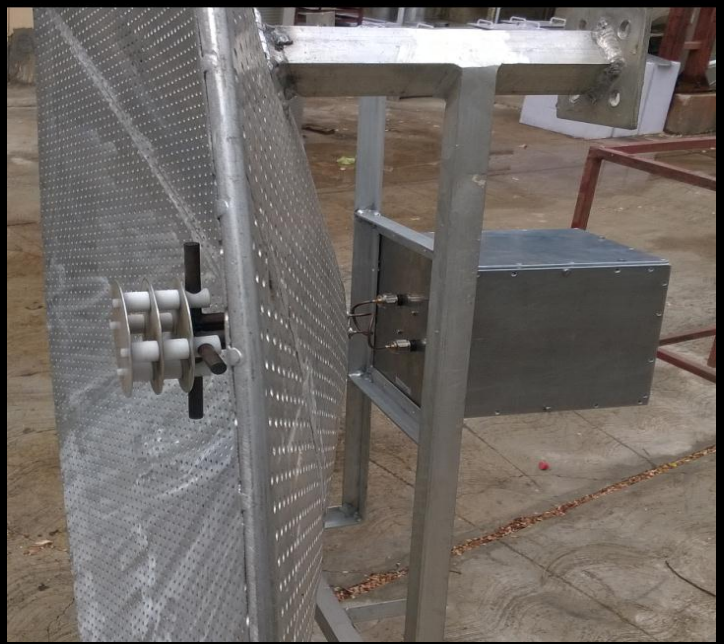
- Broad-band feeds + FE (in octaves) :
  - 1000 – 1450 MHz (updating L-band)
  - 550 – 900 MHz (replacing 610)
  - 250 – 500 MHz (replacing 325)
  - 120 – 250 MHz (replacing 150)
- Modified optical fibre system to cater to wideband (50 to 2000 MHz) dual pol RF signals (while allowing existing IF signals)
- Analog back-end system to translate RF signals to 0 - 400 MHz baseband
- Digital back-end system process 400 MHz BW for interferometric and beam modes



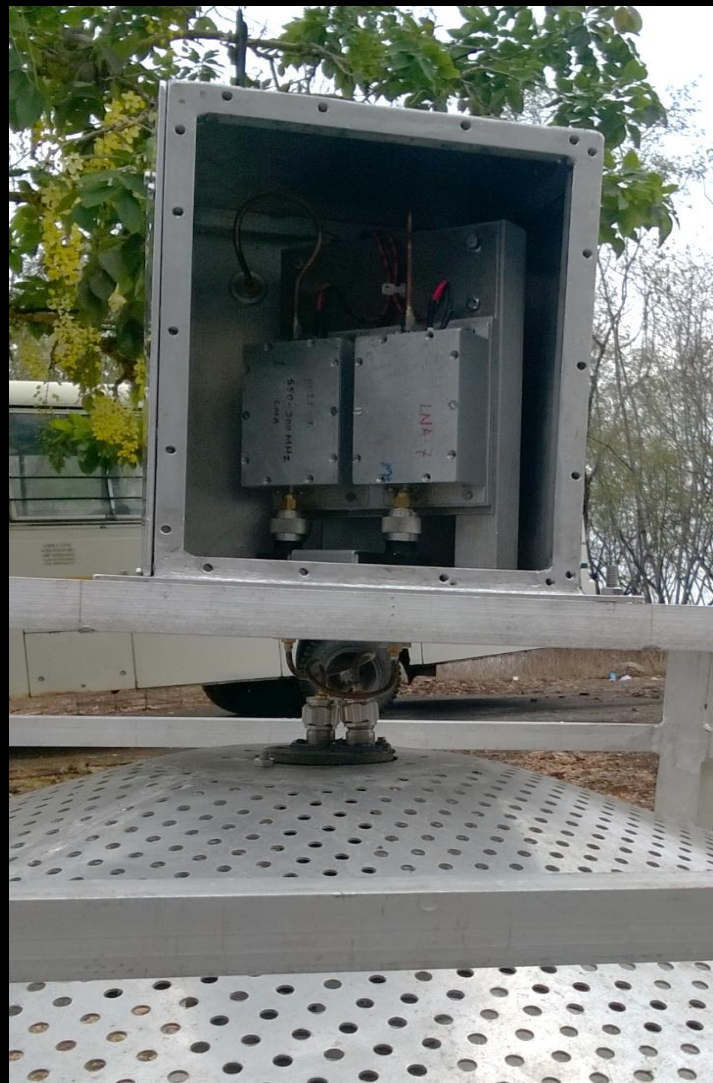
GMRT RECEIVER BLOCK SCHEMATIC

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

- Replaces existing 235/610 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

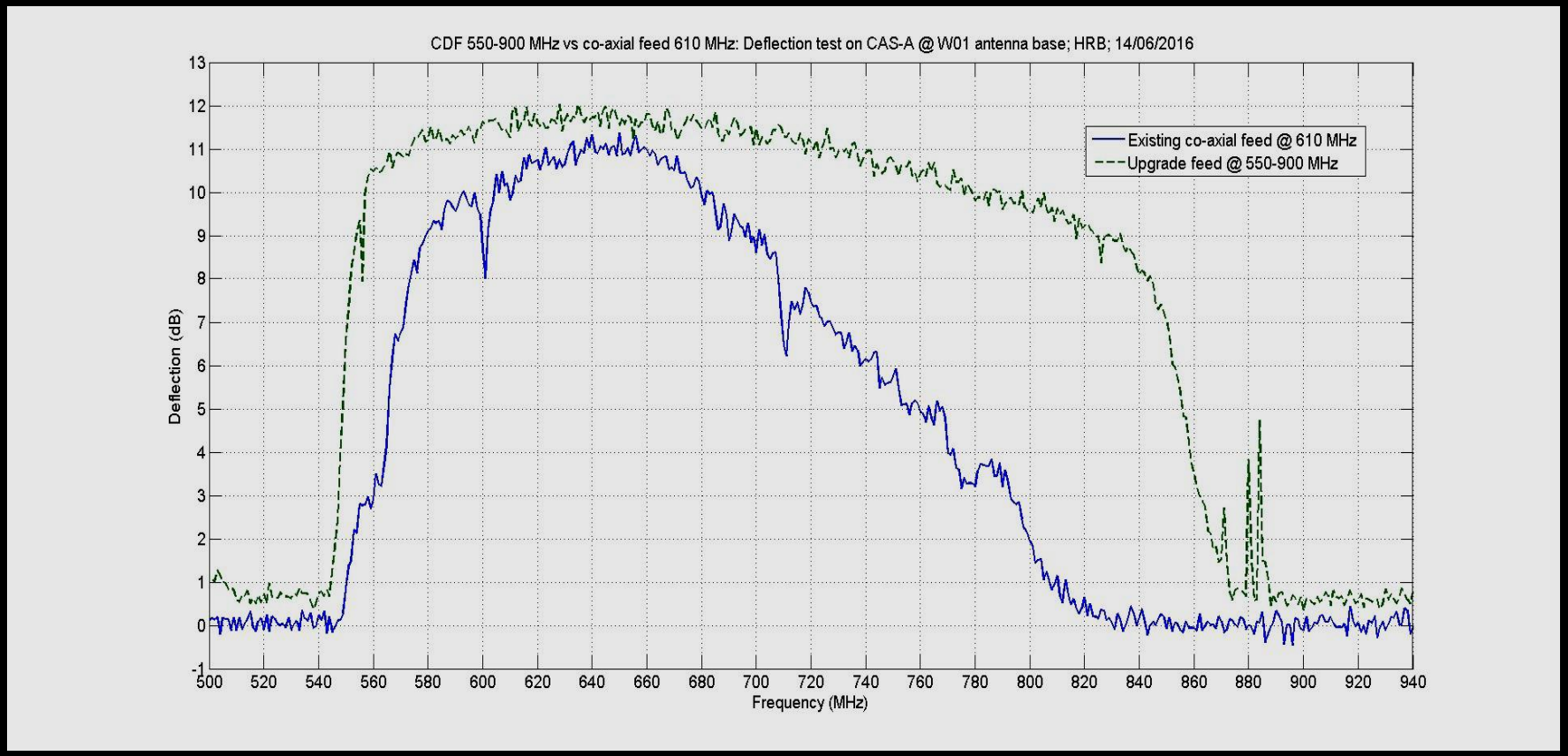


Cone Dipole feed (for 550-900) alongwith polarizer and LNA



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

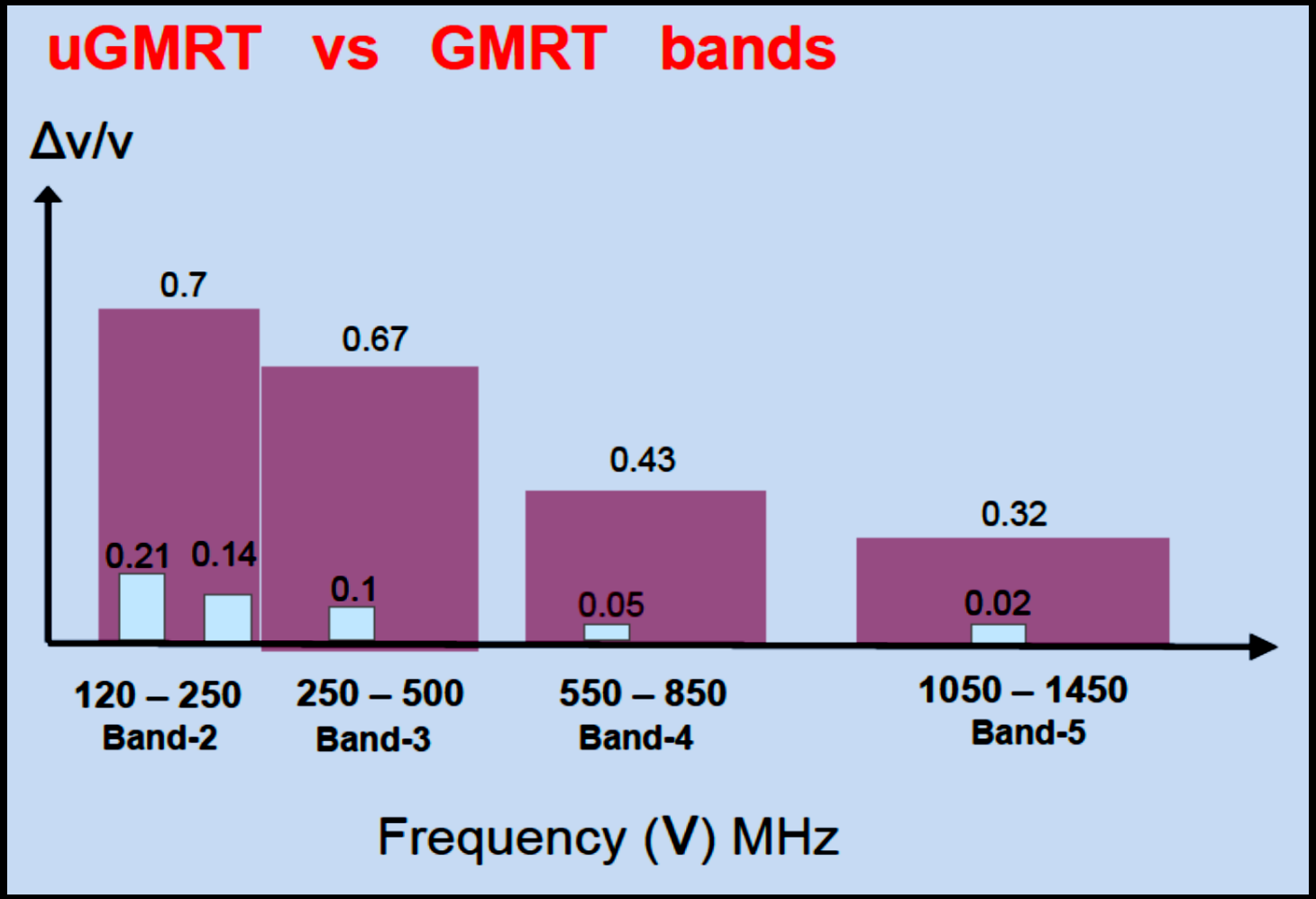
- Performs better than existing feed at 610 MHz
- Nice, clean band with negligible RFI



uGMRT : New Wideband Systems Summary

- Proposed configuration of feeds and receivers and their current status :
  - Band 5 (1000 – 1450 MHz) : existing wideband feed + improved dynamic range rx with appropriate RFI filters -- all 30 antennas completed !
  - Band 4 (550 – 900 MHz) : cone-dipole feed with matching receiver system finalized and now in mas production phase -- 28 antennas completed.
  - Band 3 (250 – 500 MHz) : cone-dipole feed + receiver is well into mass production & installation -- 30 antennas completed !
  - Band 2 (120 – 250 MHz) : modified Kildal ring feed + modified electronics in last stages of validation – populated on 24 antennas.
  - Band 1 (50 – 80 MHz) : on hold at present.

GMRT vs uGMRT : Frequency Coverage



courtesy : Ruta Kale

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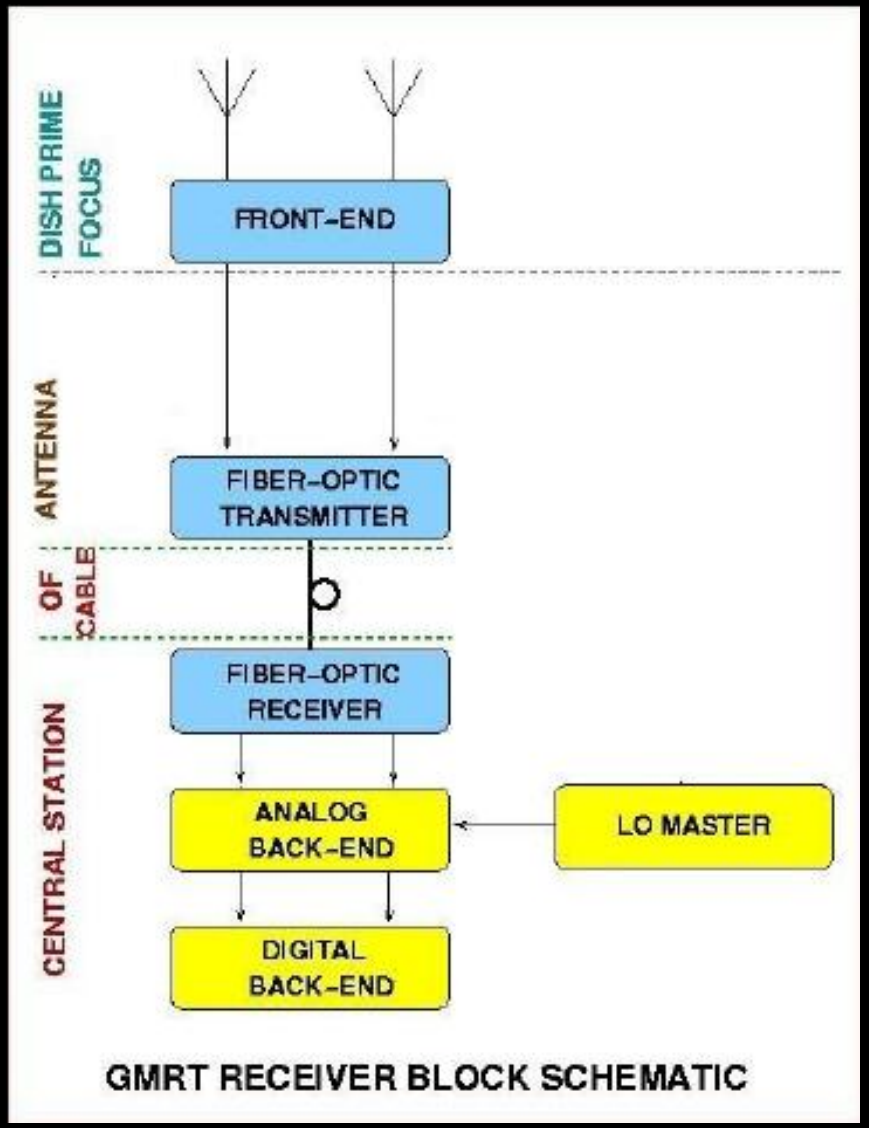
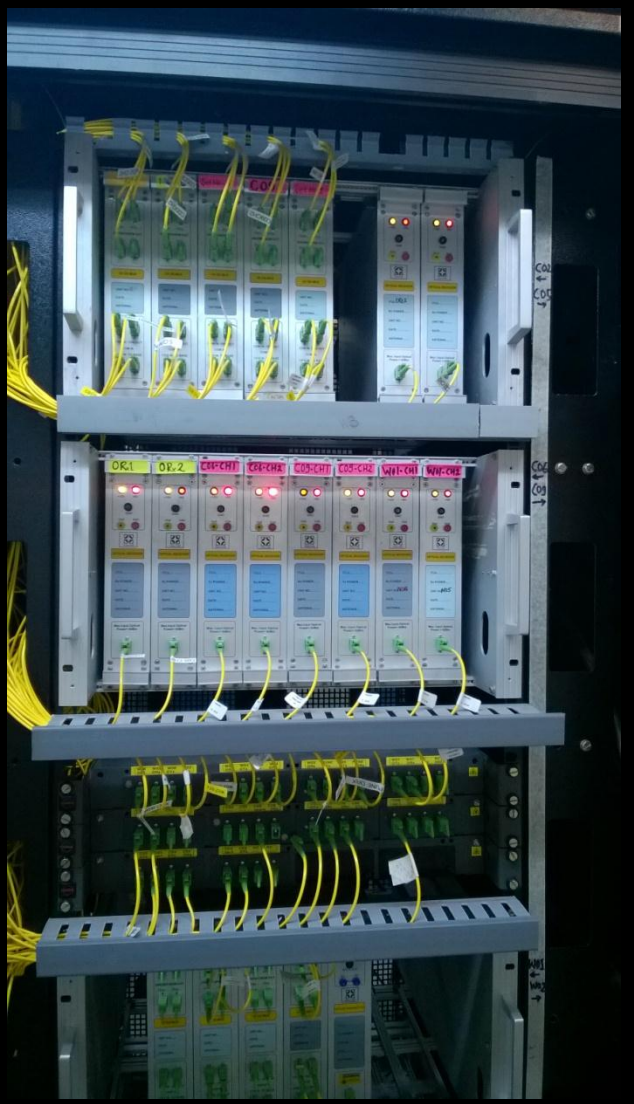


GMRT RECEIVER BLOCK SCHEMATIC

GMRT Upgrade : Optical Fibre Systems

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



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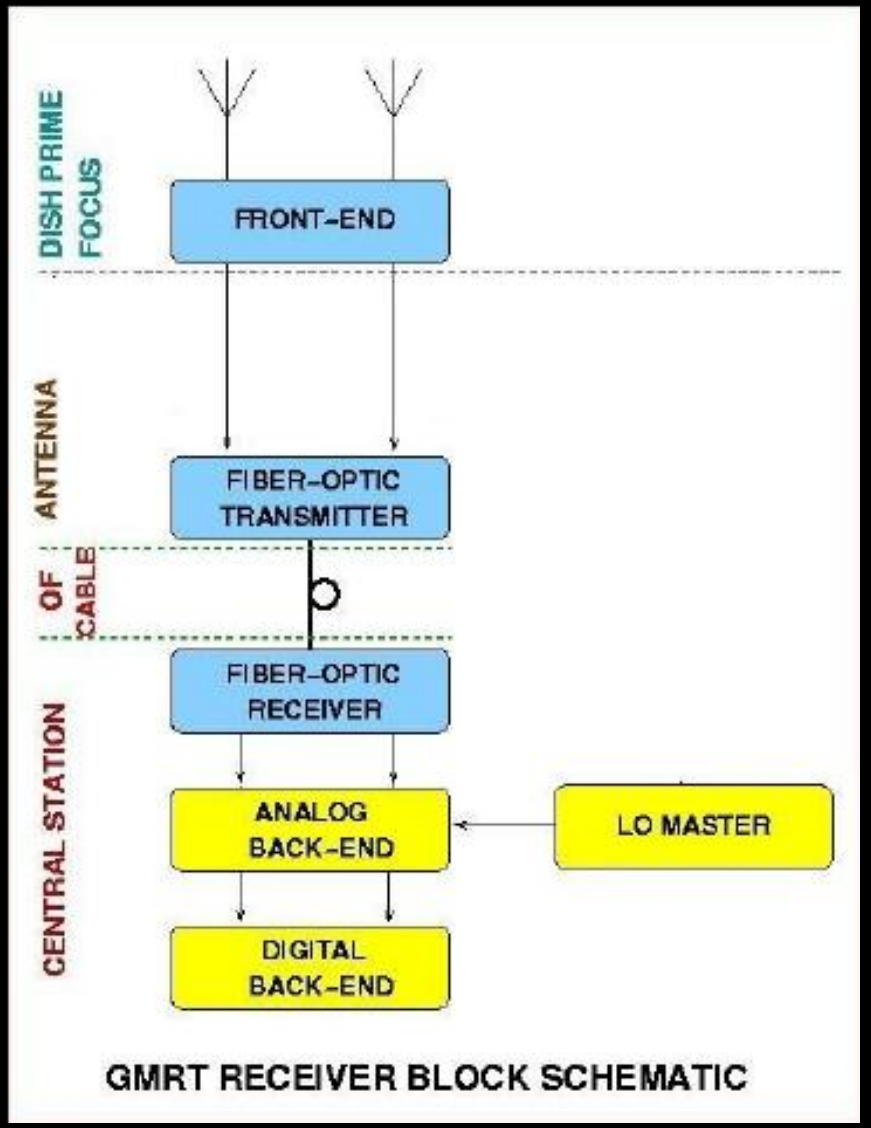
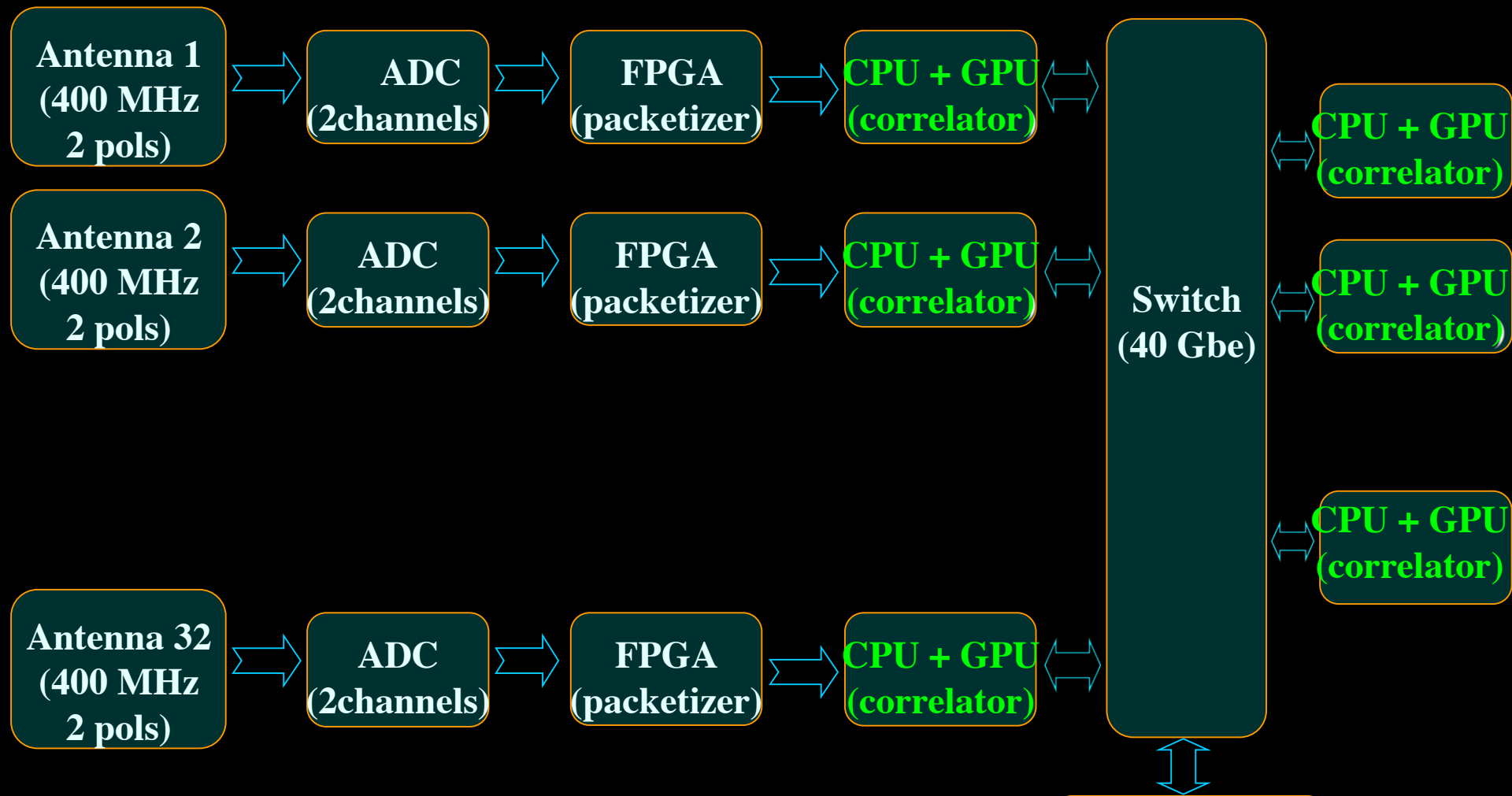


GMRT RECEIVER BLOCK SCHEMATIC

uGMRT Digital Backend : Hybrid Correlator Design



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

Full Stokes correlator + beamformer + pulsar rx.

GWB-III : 16 antenna (dual poln) 400 MHz software backend for the uGMRT

- 8-node GPU system
- 16 ADC cards + 8 FPGA boards
- Dual K20 GPUs on each T620 node
- Released in September 2015

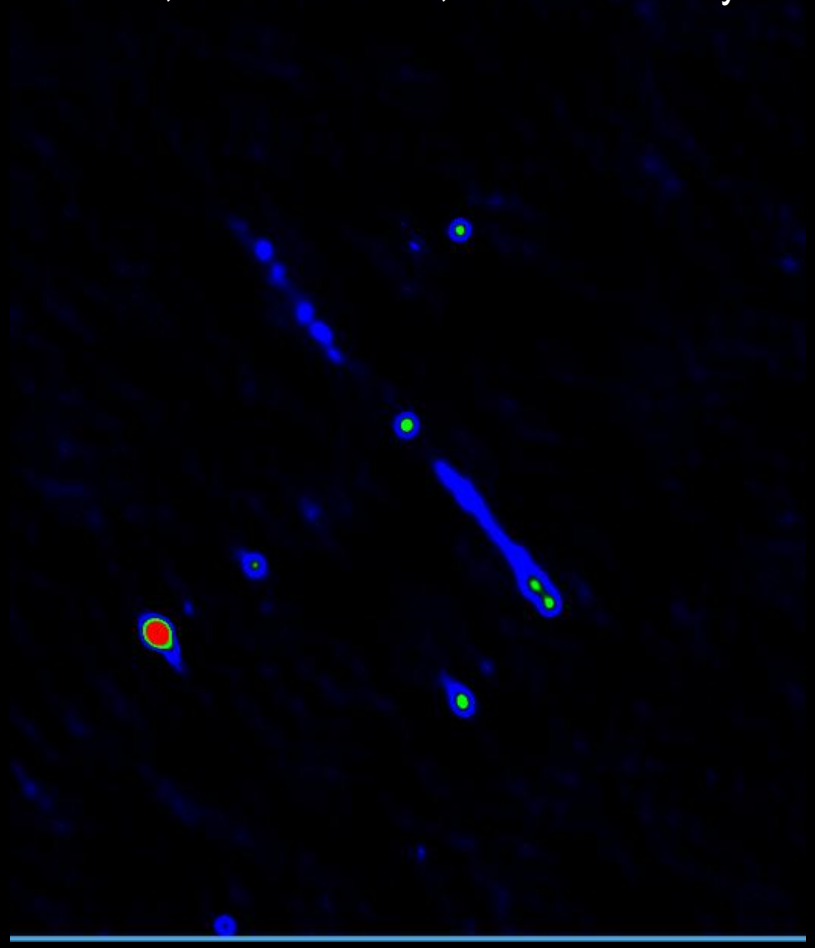
- BW : 400 MHz, upto 16K channels
- Int Time : 0.67 sec
- IA/PA Beamformer
- **Upgraded to 32 stations : Dec 2016**

Towards a working uGMRT…

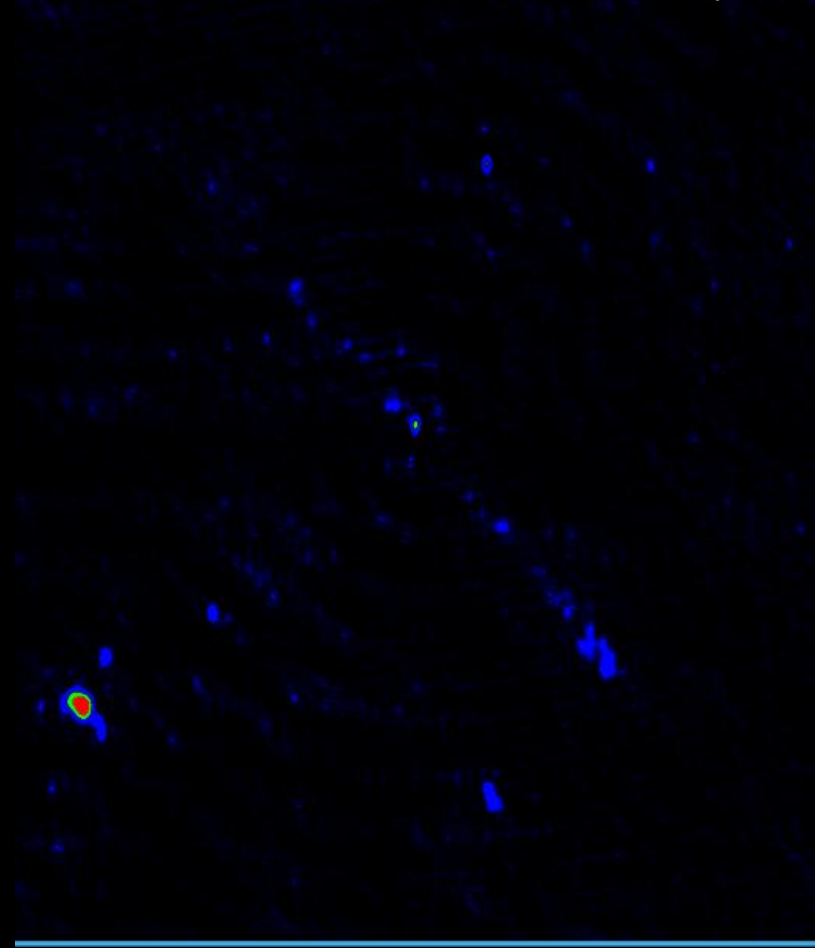
uGMRT : Early Sample Results

Imaging with the 400 MHz bandwidth mode at Lband

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



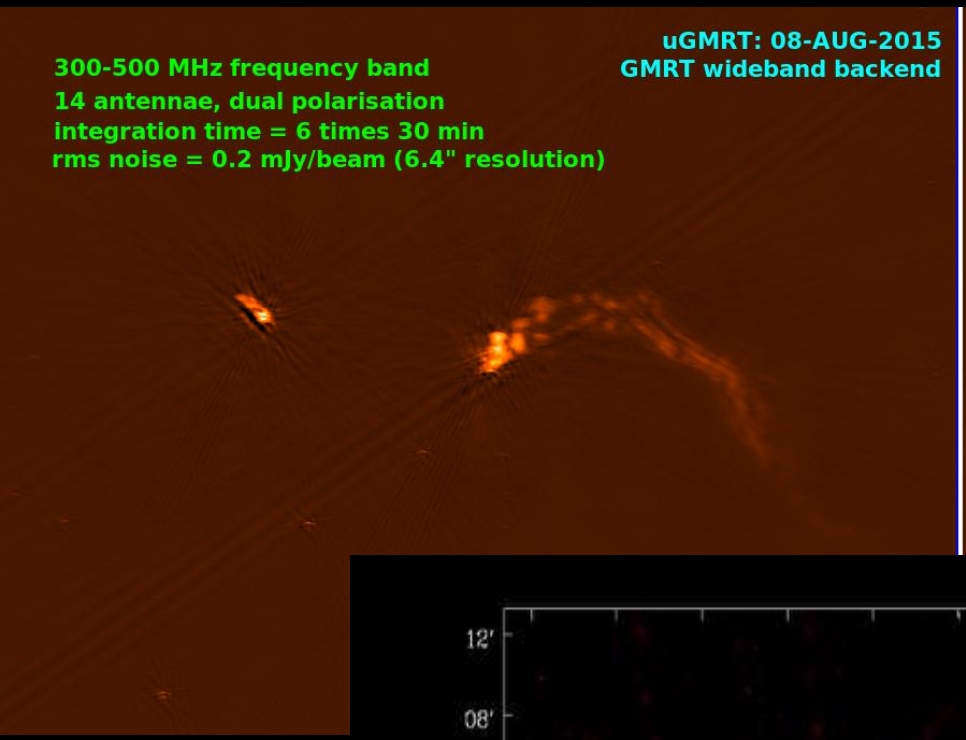
GHB: 4 hrs, BW: 14 MHz, rms=55 microJy/beam

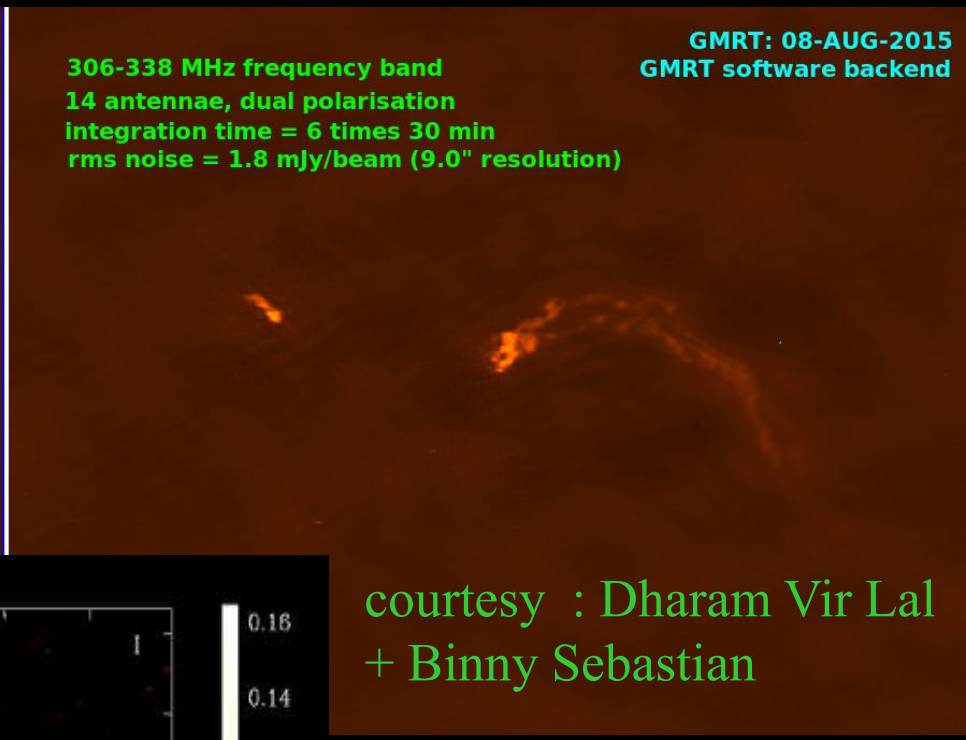


courtesy : C.H. Ishwara-Chandra + Binny Sebastian

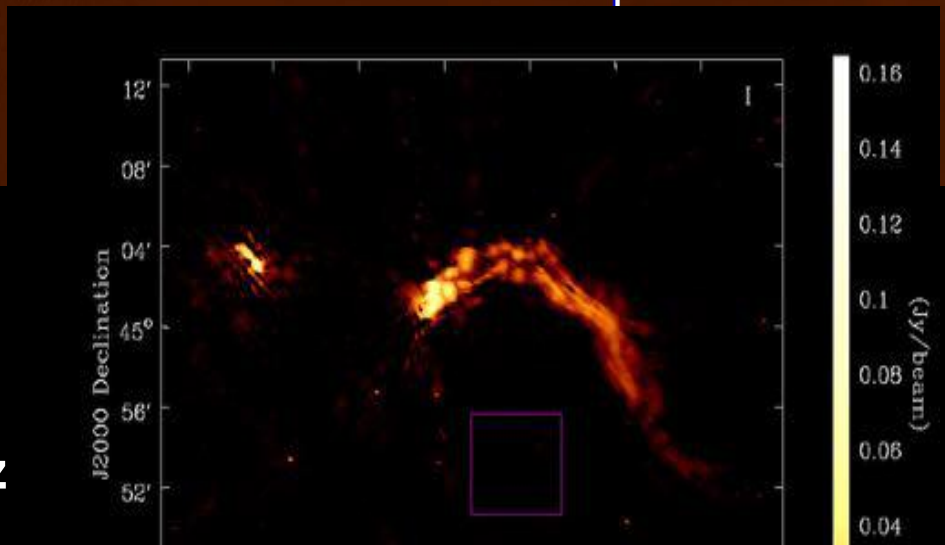
uGMRT : Early Sample Results

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





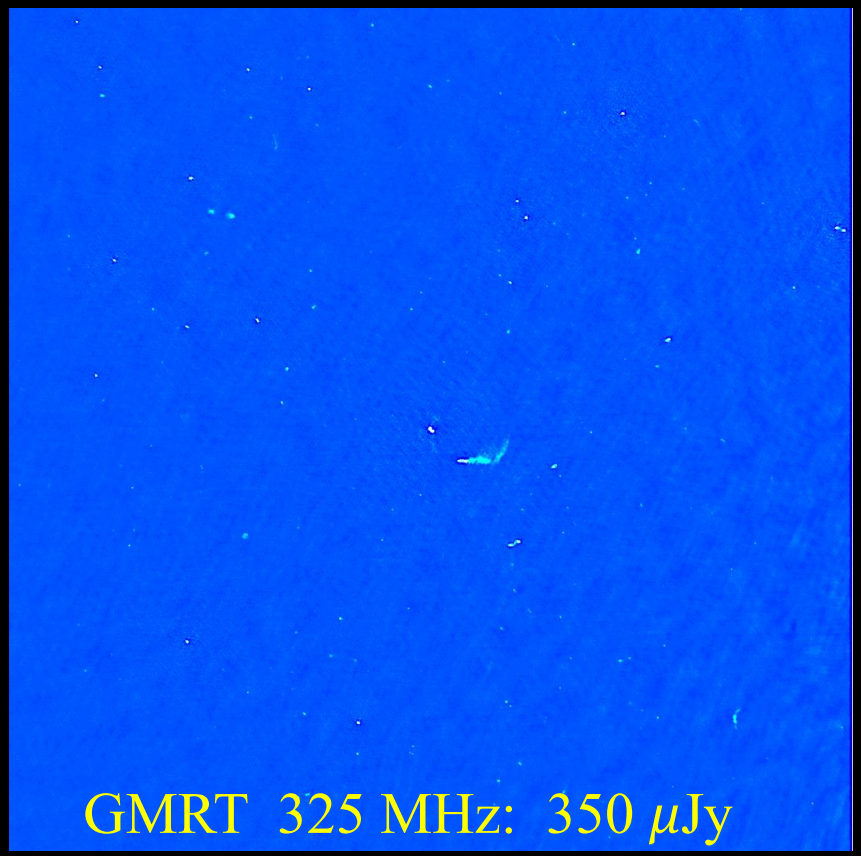
courtesy : Dharam Vir Lal
+ Binny Sebastian



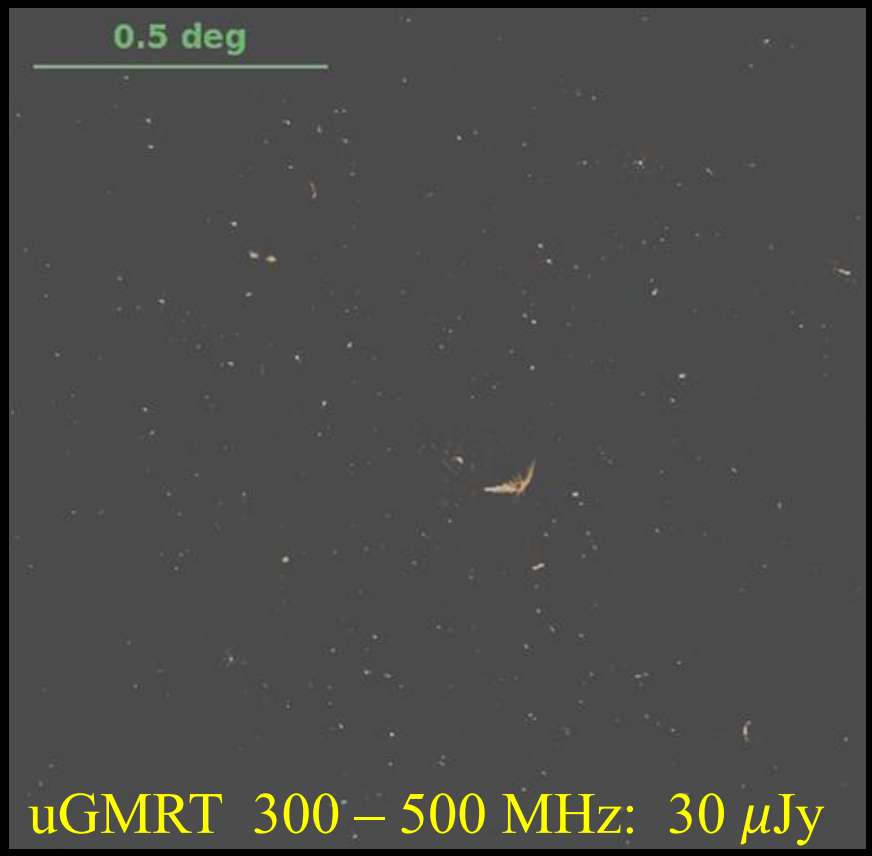
- 80 microJy
- 3 hours
- 14 antennas
- 300-500 MHz

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

Improved imaging with uGMRT

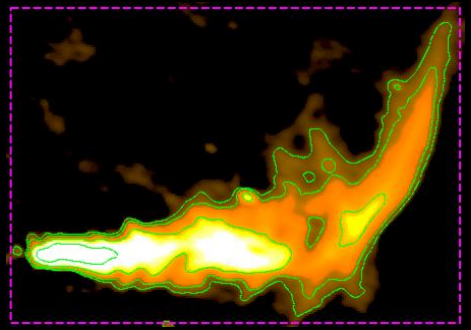


GMRT 325 MHz: 350 μJy



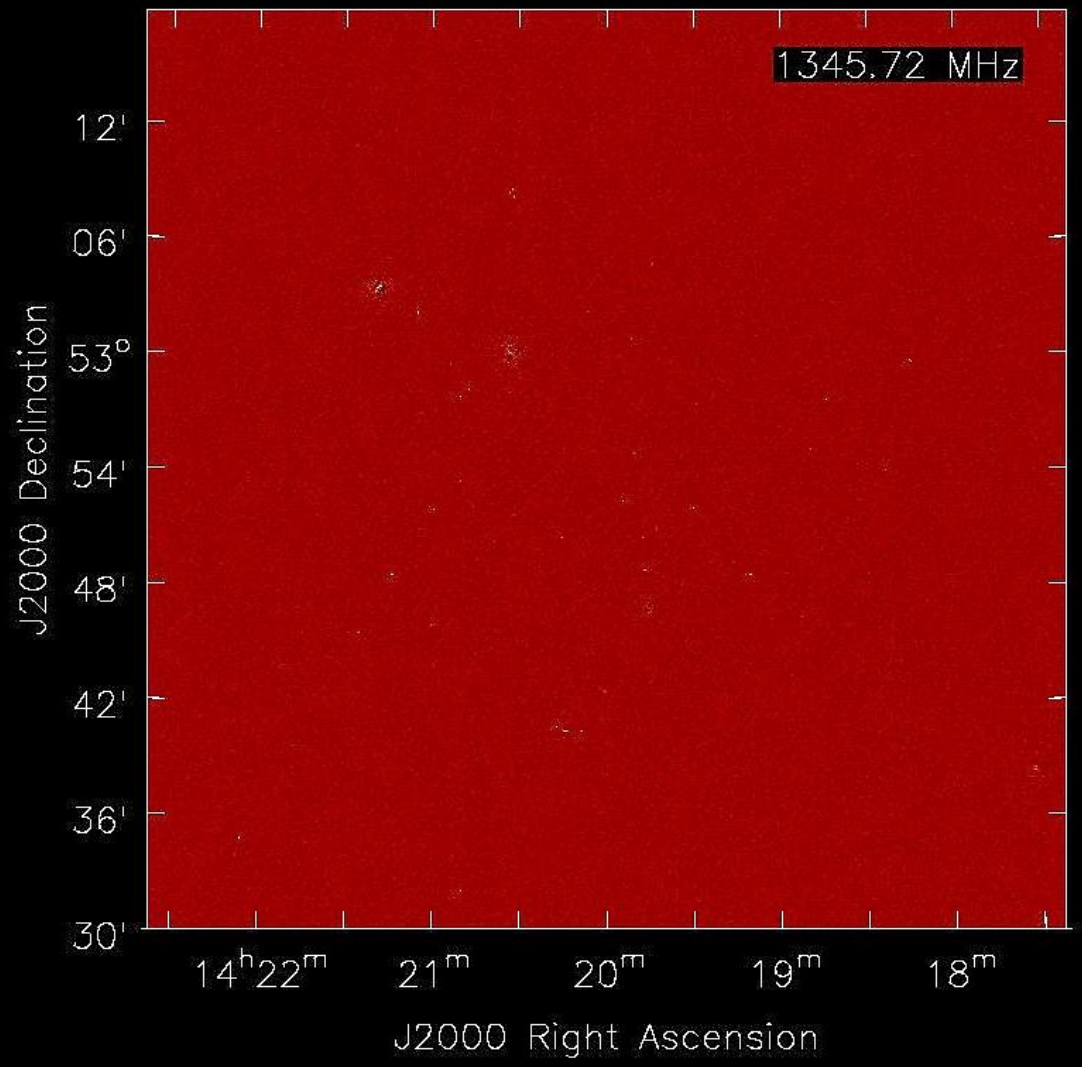
uGMRT 300 – 500 MHz: 30 μJy

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



Improved imaging with uGMRT

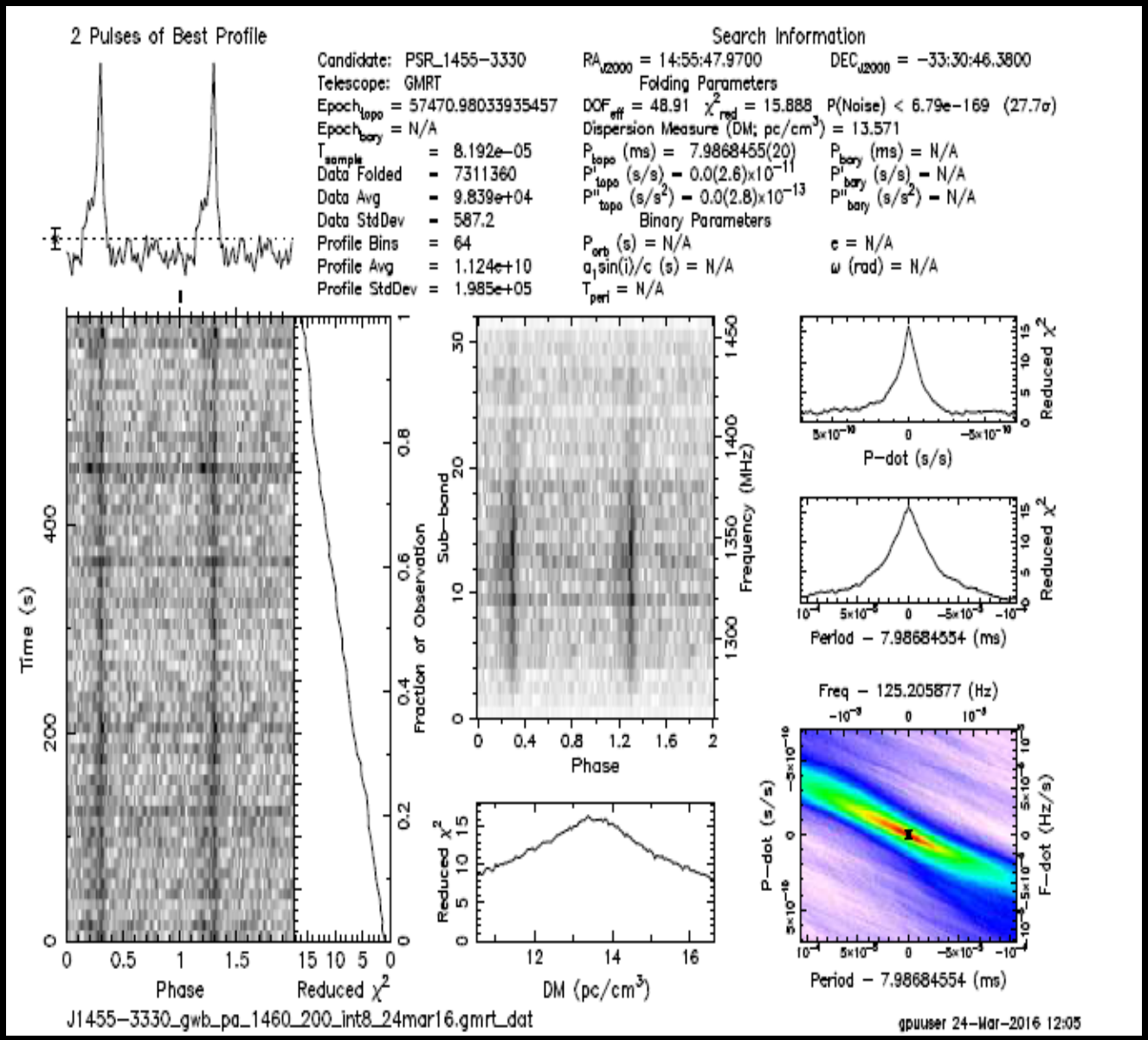
- Search for redshifted HI 21cm & radio continuum emission from star-forming galaxies in the Extended Groth Strip
- Deepest image with uGMRT to date : ~ 6 microJy RMS (can do better)
- Will allow direct detection of rado emission from star formation
- Similar deep images now being made with the uGMRT, at different bands



Bera, Kanekar & Chengalur

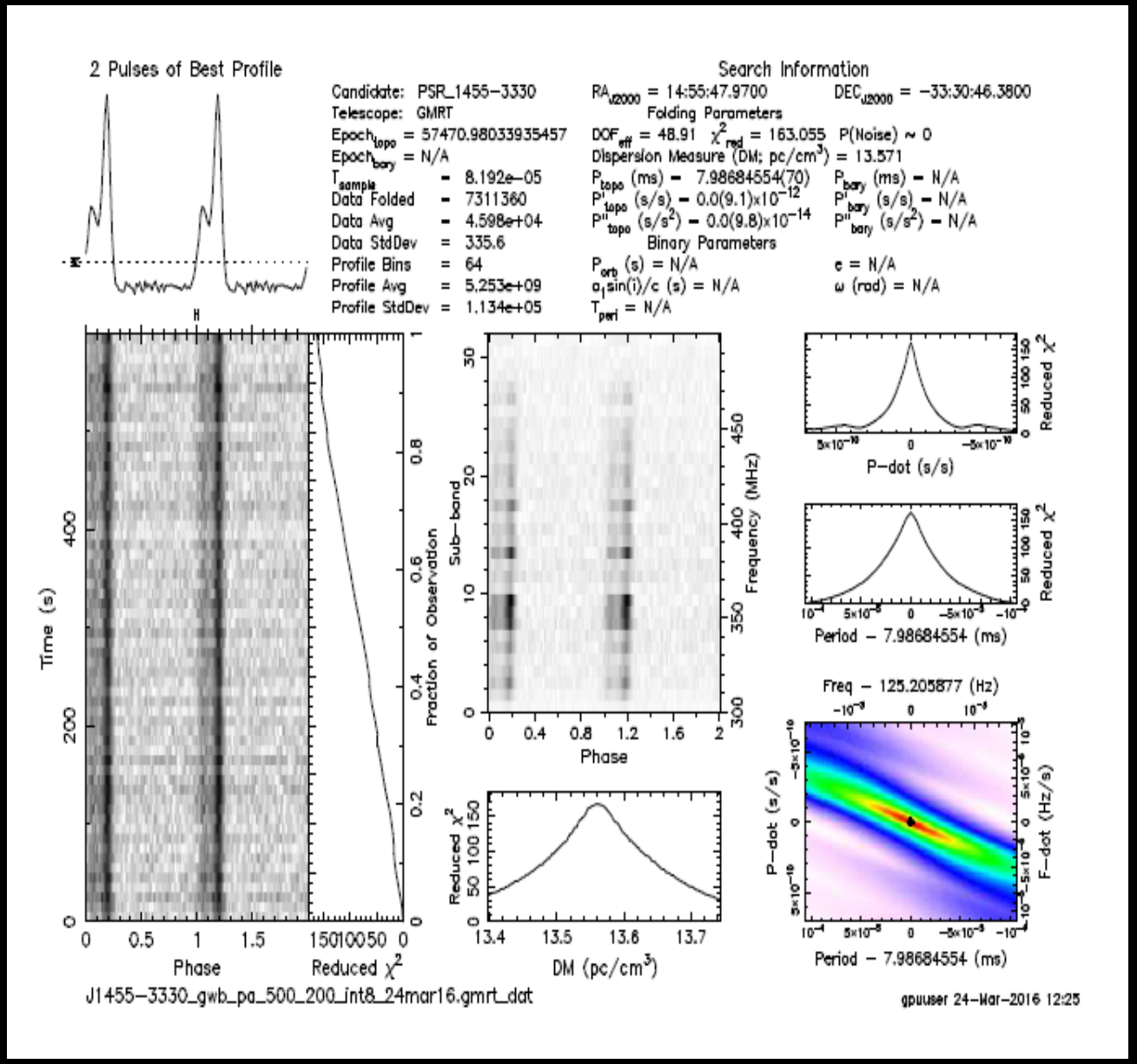
Pulsars with uGMRT : sample profiles

- J1455-3330
- S_1400 = 1.2 mJy
- Band-5 (1260 to 1460 MHz)
- 10 mins scan
- 12 antennas



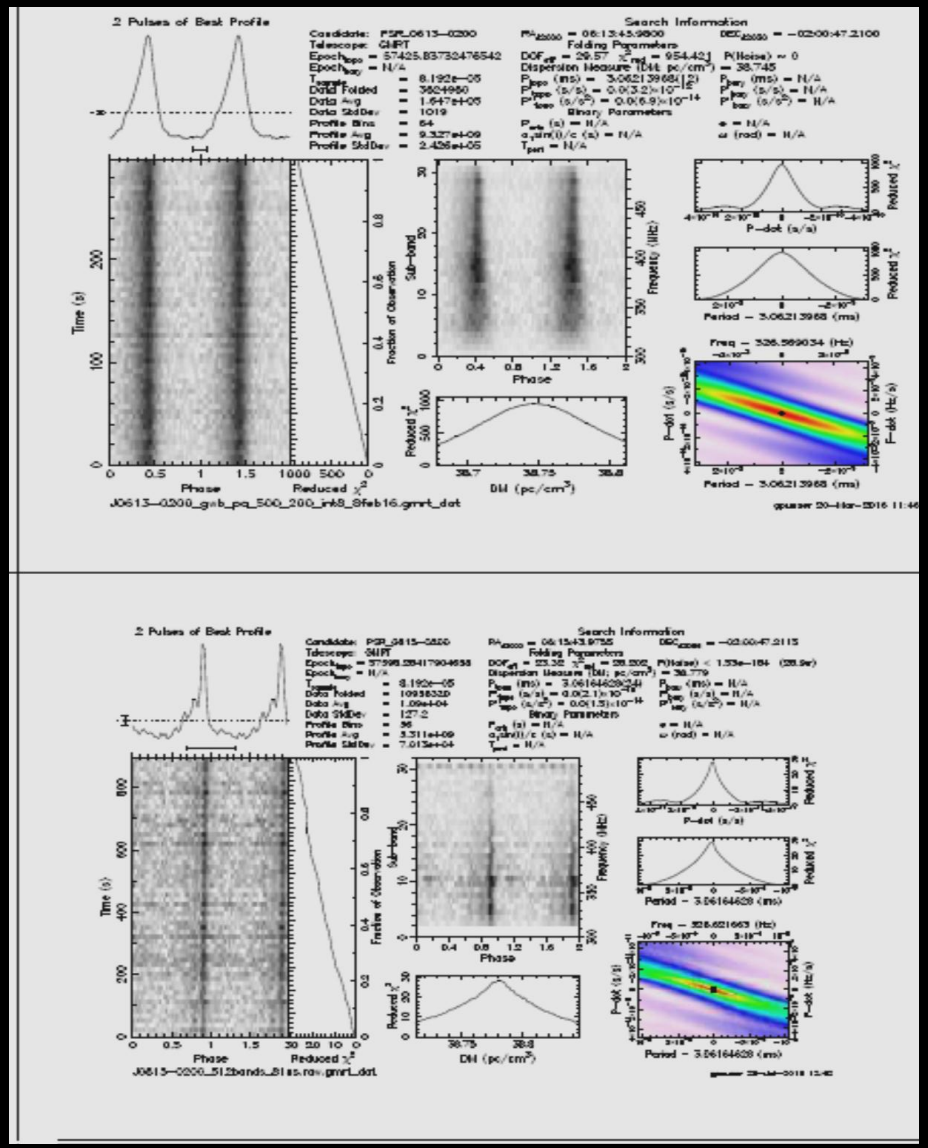
Pulsars with uGMRT : sample profiles

- MSP : J1455-3330
- S_400 = 9 mJy
- Band-3 (300 to 500 MHz)
- 10 mins scan
- 4 antennas (only)



Wideband Coherent Dedispersion for the uGMRT

- Coherent Dedispersion on voltage output of phased array mode of uGMRT
- Working in real-time (GPUs), for 100 to 200 MHz BWs, at low frequencies.
- Will be released soon for the general user community.
- Will increase the quality of pulsar timing with the uGMRT



Comparison of

regular phased array beam output

with

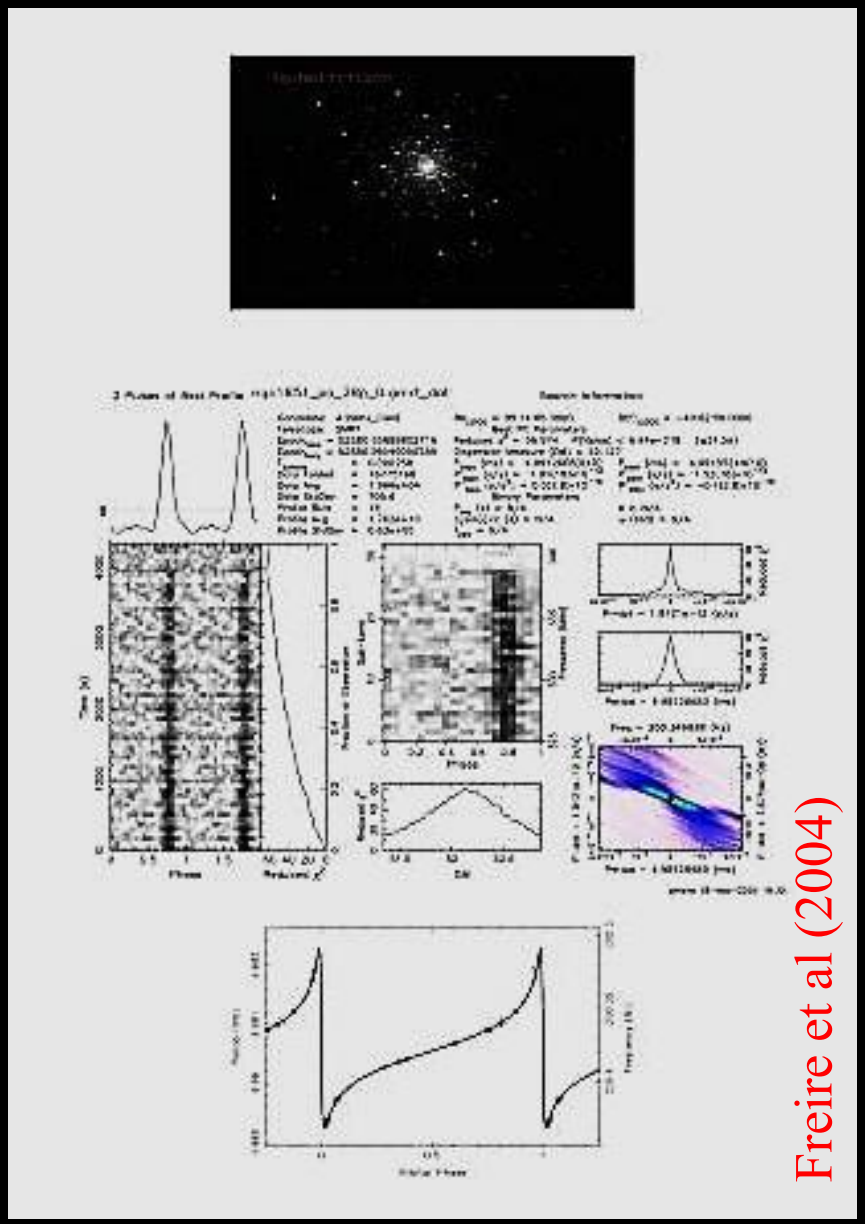
coherent dedispersion output

for 300 to 500 MHz band of the uGMRT, for PSR J0613-0200

courtesy : Kishalay De & Y. Gupta

PSR J0514-4002A : improved timing with uGMRT

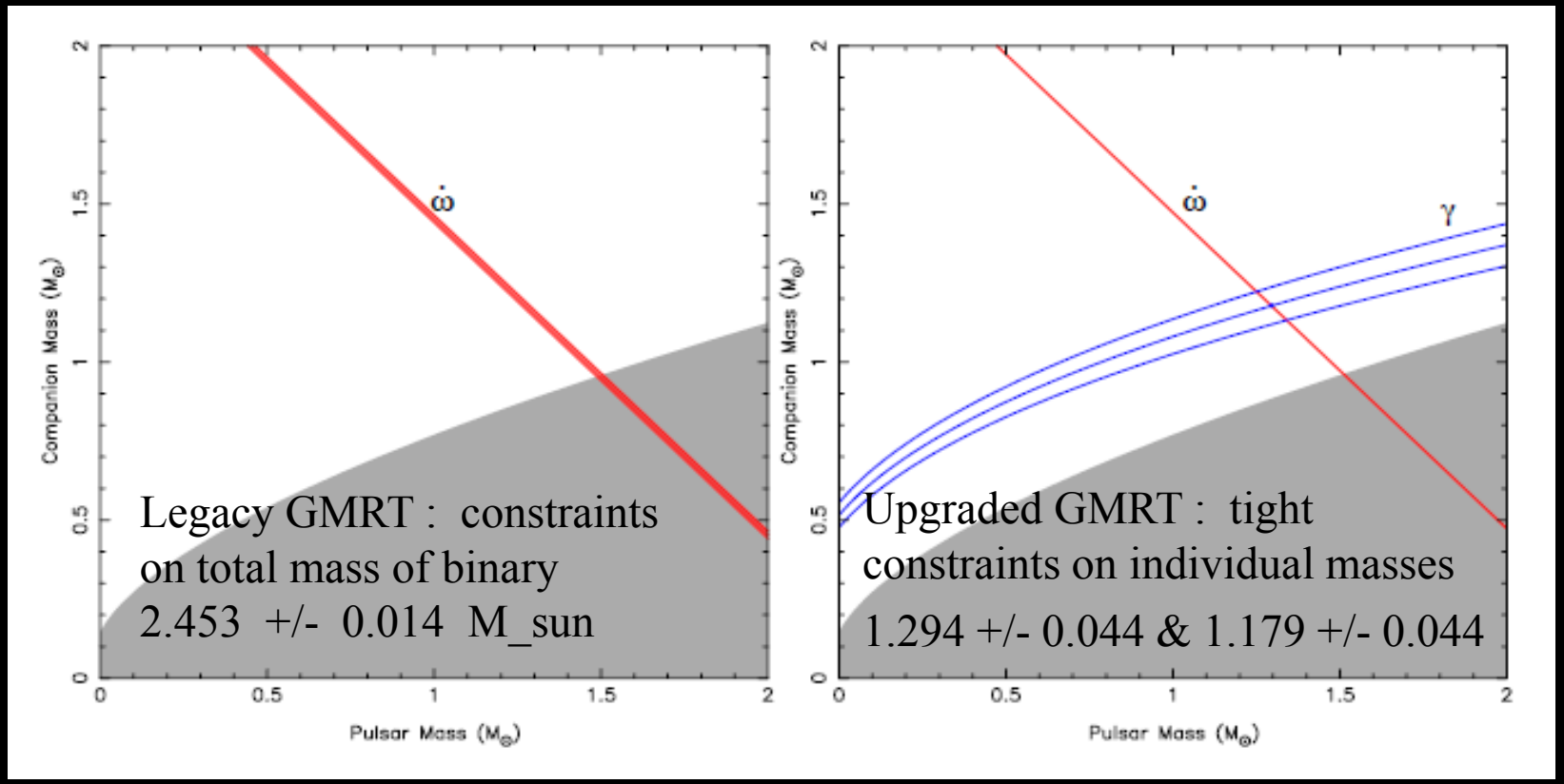
- GMRT discovered the binary millisecond pulsar in the Globular Cluster NGC 1851
- Binary pulsar with *very eccentric orbit (e = 0.89) !* -- was record holder for many years.
- Initial timing observations provided constraints on the total mass of the system, from measurements of the advance of periastron : 2.453 +/- 0.014 M_sun
- More accurate & sensitive observations with uGMRT allow timing baseline to be extended over the 13 years interval !
- Could measure a 2nd post-Keplerian parameter – the Einstein delay – with a 20-sigma significance
- Independent estimates of masses of neutron star and companion : 1.294 +/- 0.044 & 1.179 +/- 0.044 M_sun



Freire et al (2004)

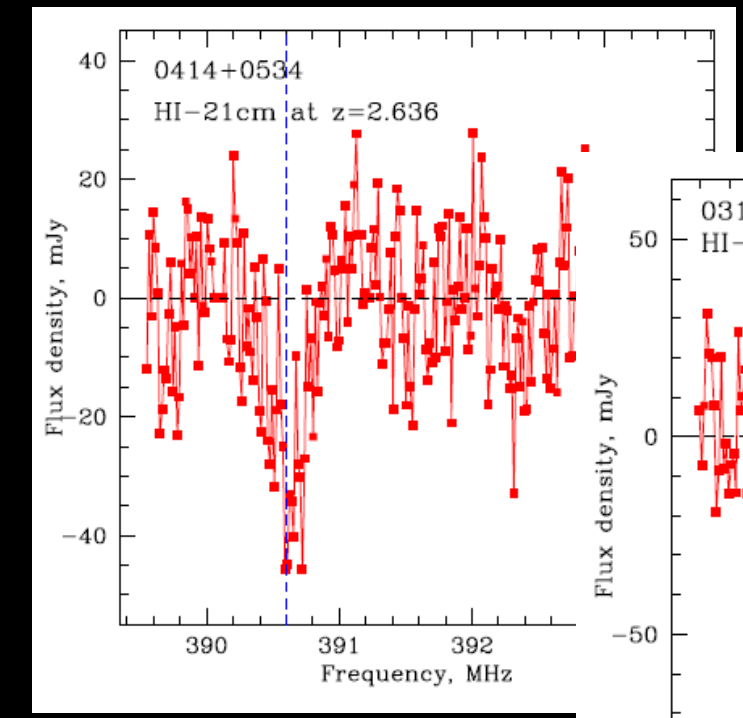
PSR J0514-4002A : timing observations with uGMRT reveal lightest MSP yet ?

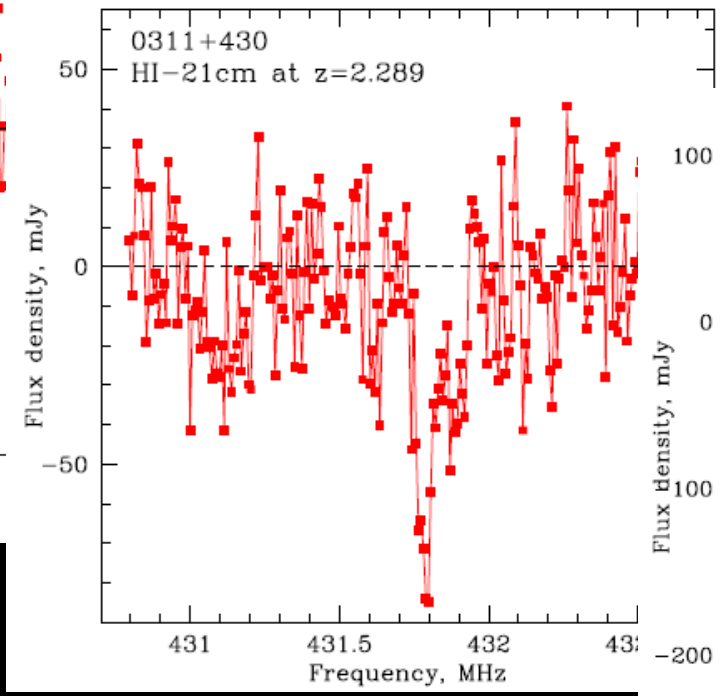
- Improved results from accurate timing measurements with the uGMRT
- New constraints on mass of pulsar and companion for binary J0514-4002A with the uGMRT (right panel) : 1.294 +/- 0.044 M_sun & 1.179 +/- 0.044 M_sun
- This may be the lightest millisecond pulsar with precisely measured mass !

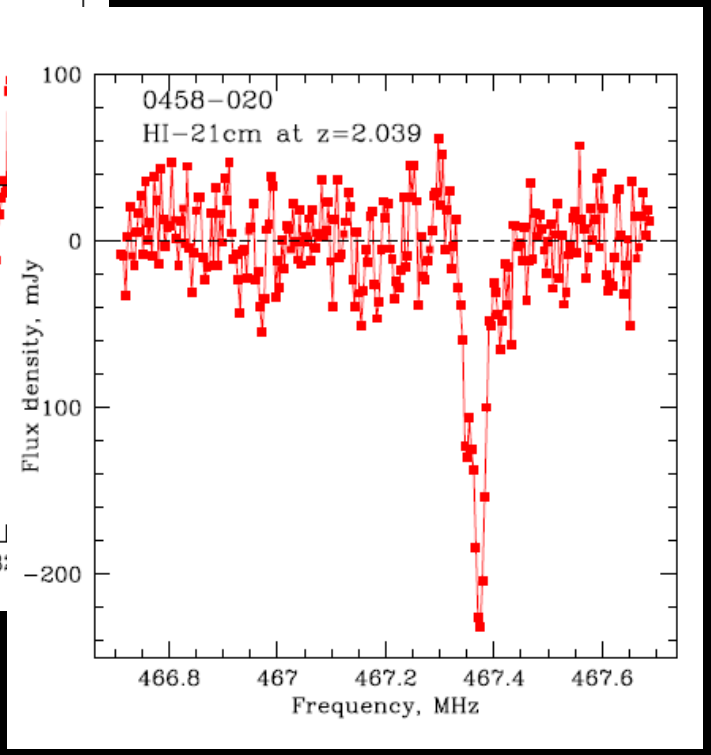


Freire, Gupta & Ridolfi

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

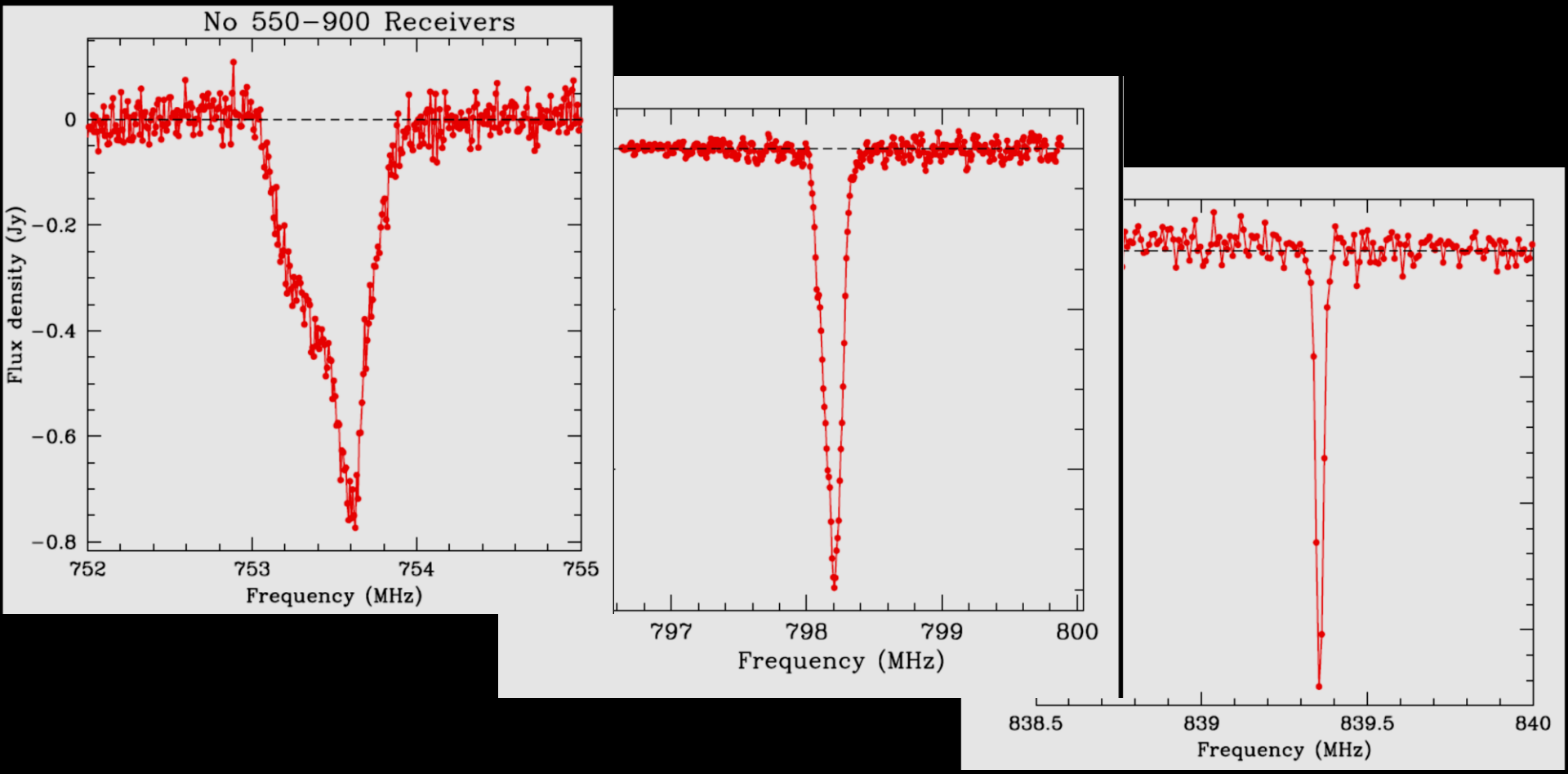






First light results : spectral lines from different sources, at different parts of the 250-500 MHz band (Nissim Kanekar)

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)

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

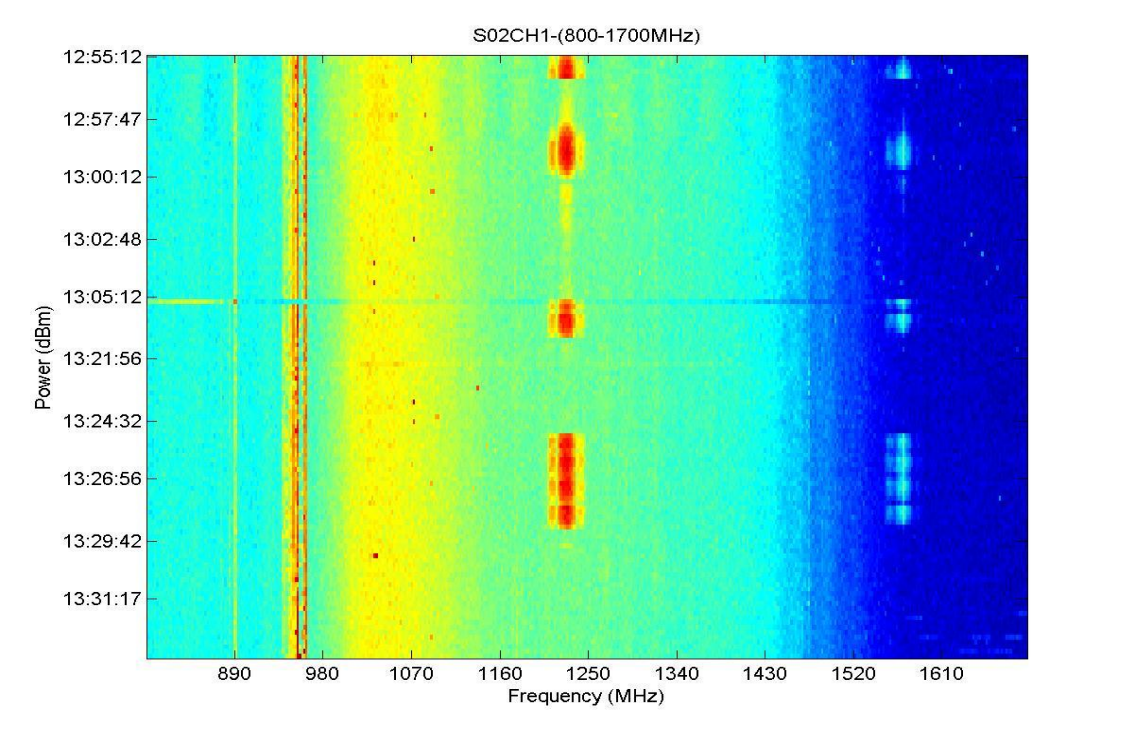
- Operational : keeping the existing GMRT working for our regular users while upgrading simultaneously took some effort

- 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

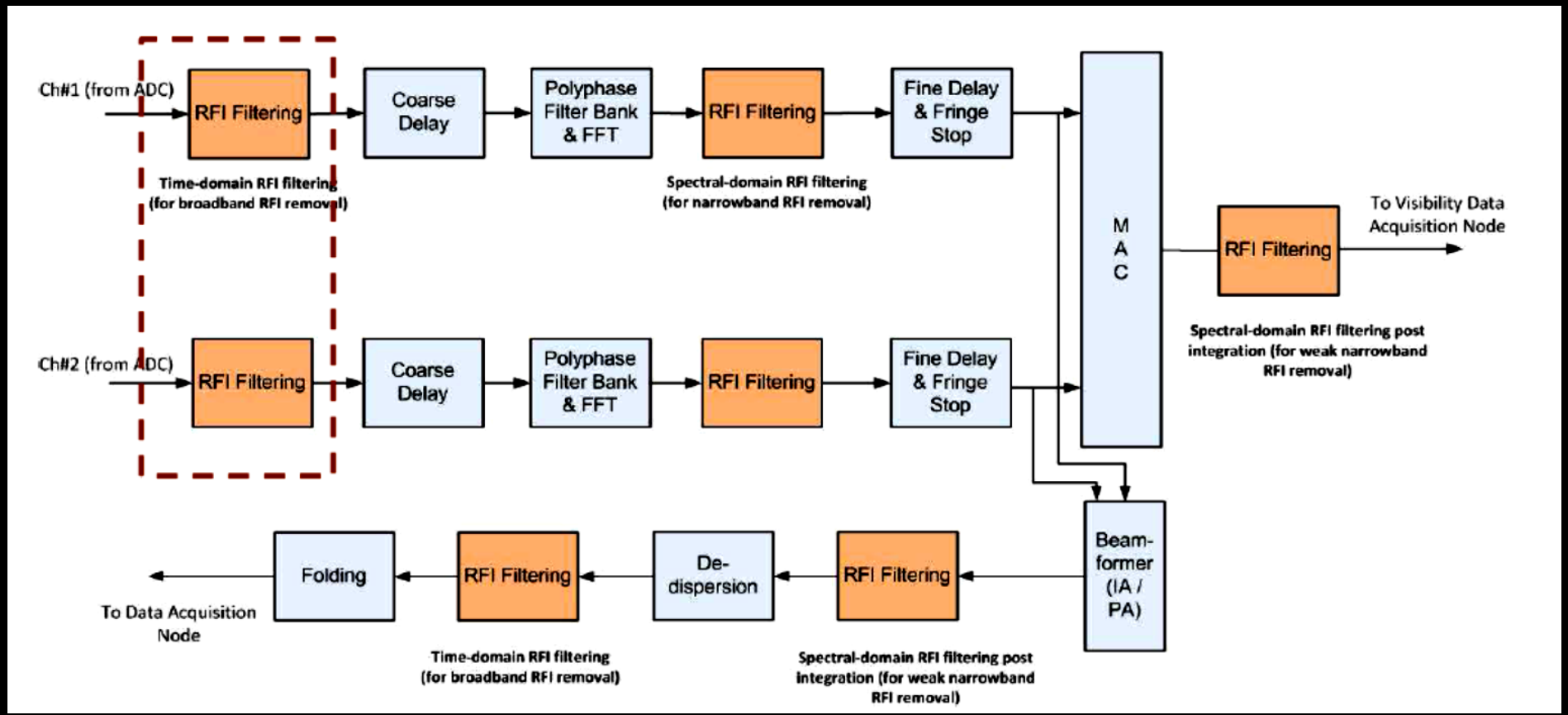
Avoiding RFI from satellites

- Real-time prediction of positions of known satellites (stationary and moving)
- Real-time warning when observing antenna beam comes within zone of avoidance (decided by beamwidth and strength of satellite)
- Predictive warning : can work on your submitted observing file
- Post-facto warning : can work on your recorded data file



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.



RFI mitigation in digital domain

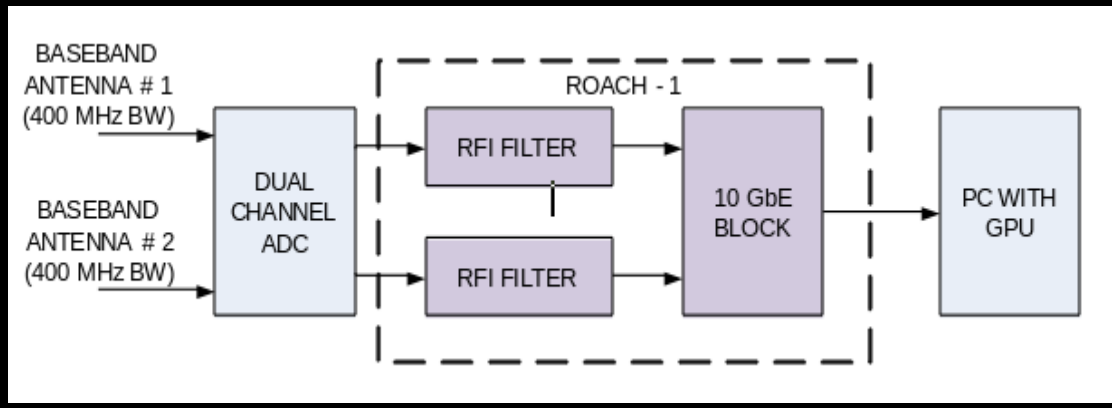
Median Absolute Deviation (MAD) based flagging of RFI

Detection followed by filtering and clipping the value at the threshold or replacement with random noise or median value

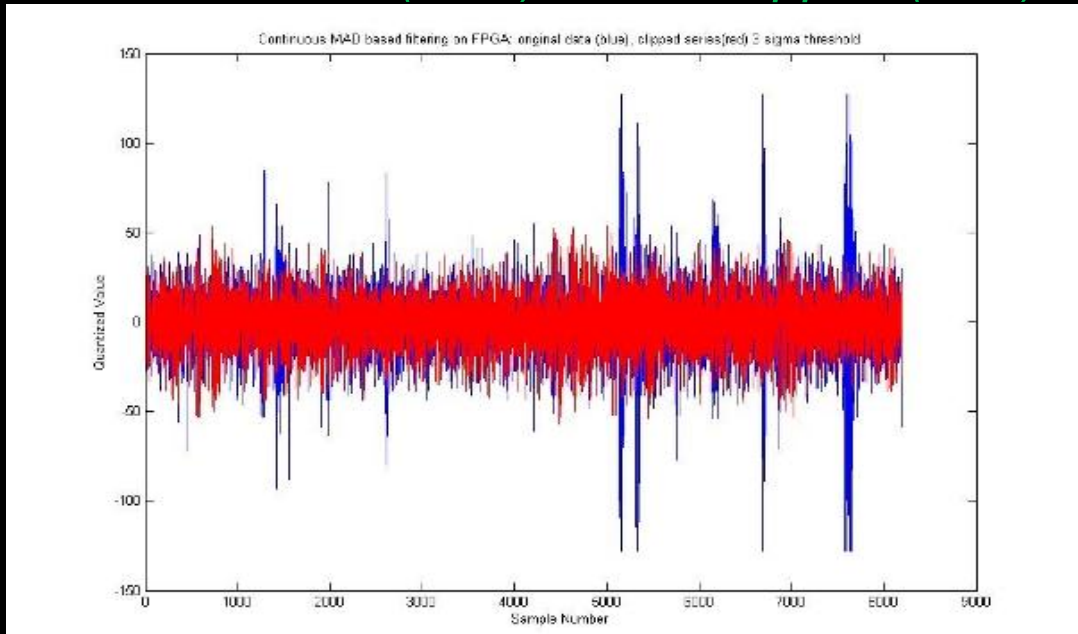
Can detect broadband random noise spikes (e.g. powerline RFI) in real-time on dedicated FPGA hardware

Is being integrated into the main correlator design; trial version will be released soon.

FPGA Implementation

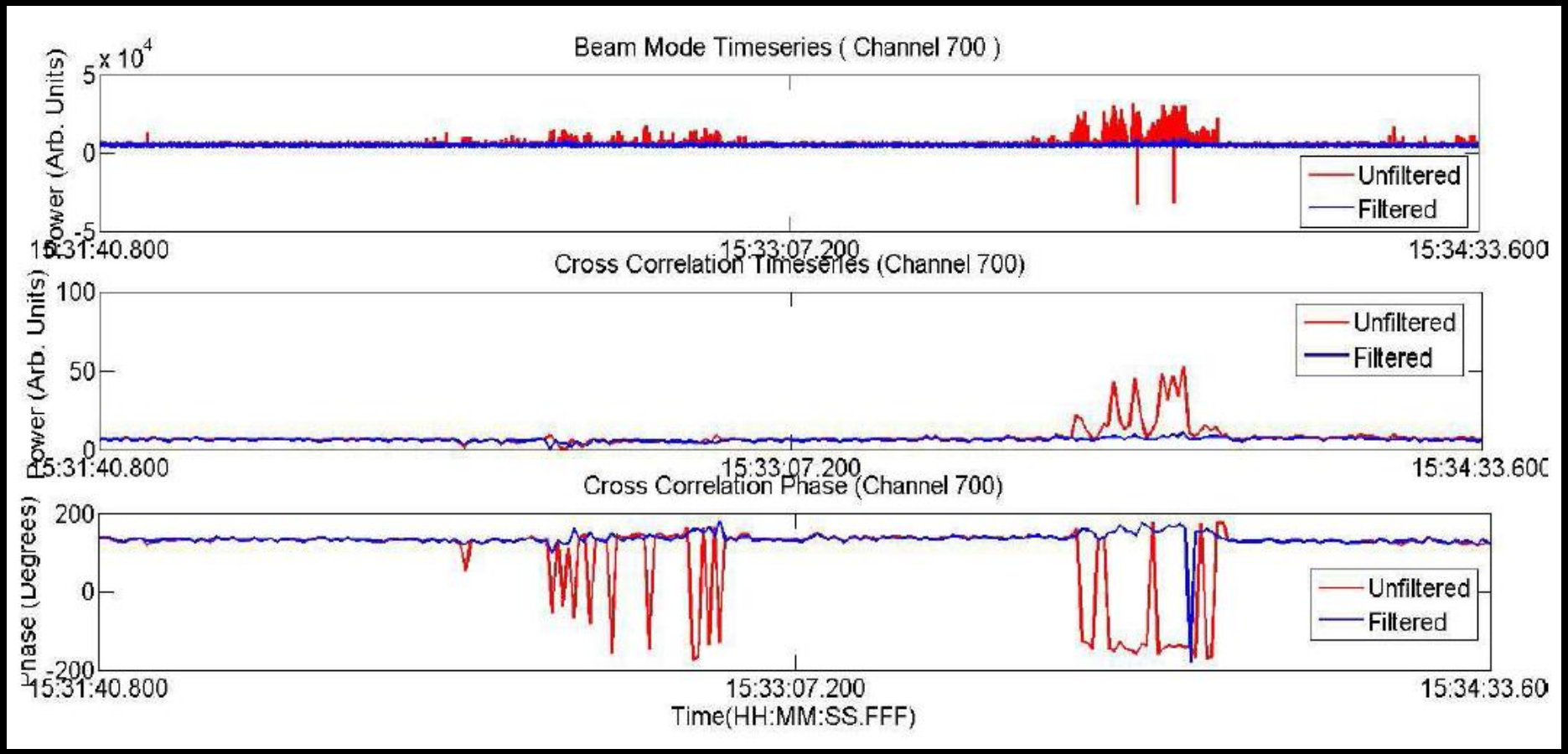


RF @ 150MHz (Blue) and 3σ clipped (Red)

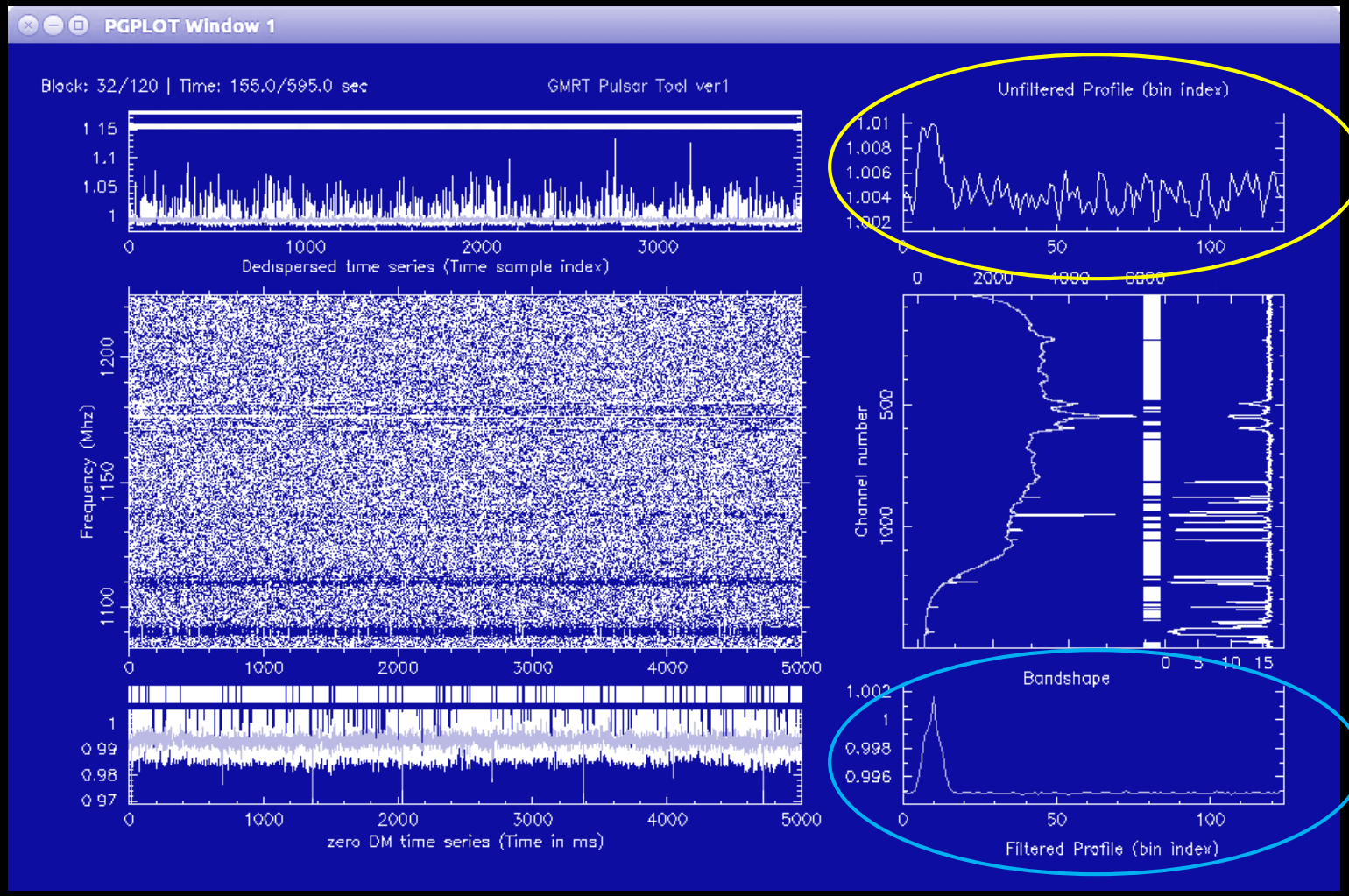


Real-time RFI Detection & Filtering

- Real-time filter running on broadband voltage data of each antenna
- Top panel shows effect of this filtering, in beamformer time series
- Bottom panels show effect of this filtering, in visibility domain data



Real-time RFI Detection & Filtering

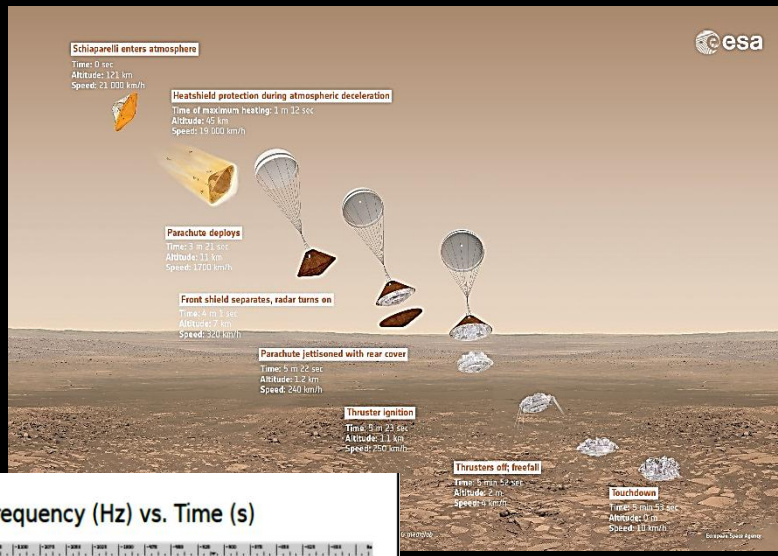


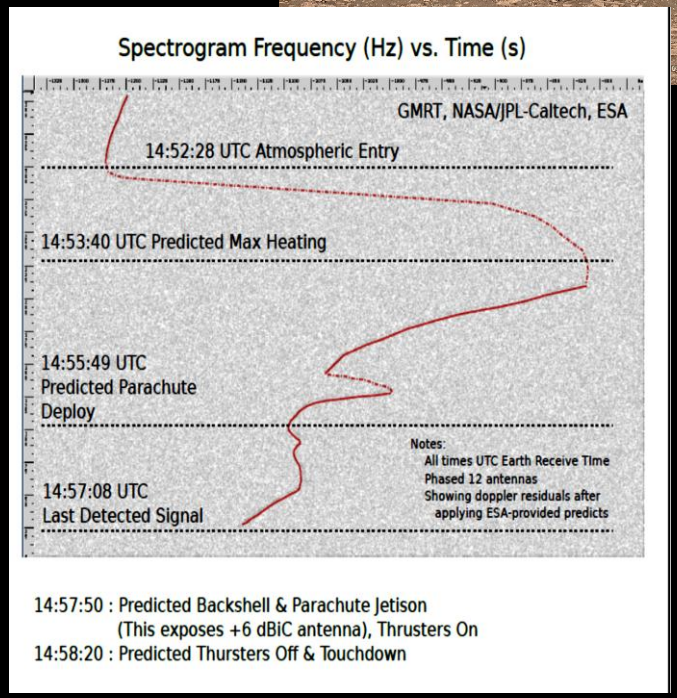
Real-time filtering of time-frequency of beamformer data – now available

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

Completion of uGMRT

uGMRT completion and release to users has been in phases :

1. April 2016 -- First release : 16 antenna system in shared risk mode

2. October 2016 -- Release of 30 antenna system with 2 bands fully functional : Band-5 (1000-1450 MHz) & Band-3 (250-500 MHz)

3. October 2017 -- Added a 3rd band : Band-4 (550-850 MHz) + more modes in digital back-end

4. April 2018 -- Will add Band-2 (120-250 MHz) and complete all other upgraded activities

5. Formal inauguration of uGMRT planned in 2018.

→ *Stay tuned !*

Thank You

Questions ?