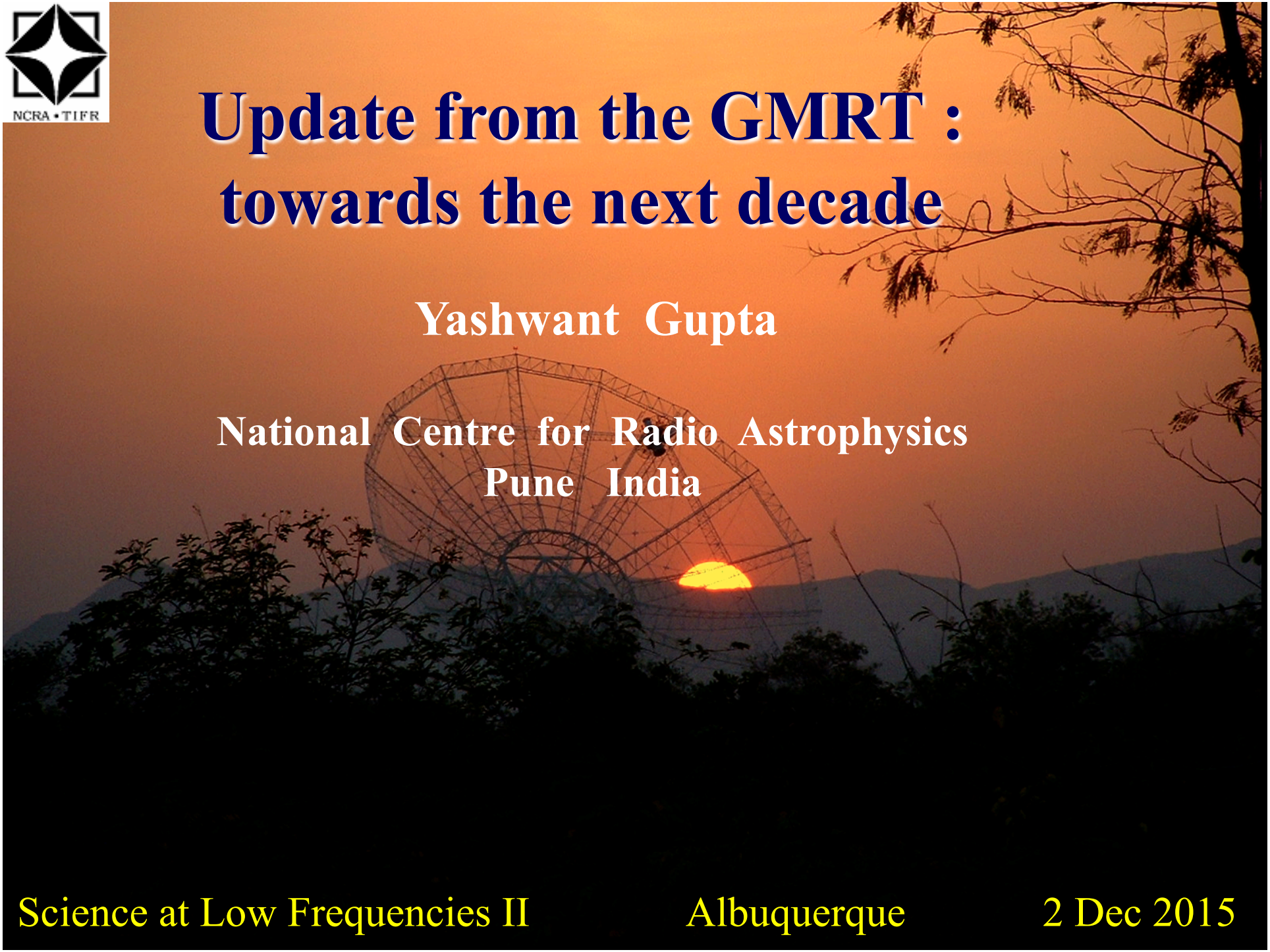


Update from the GMRT : towards the next decade

Yashwant Gupta

National Centre for Radio Astrophysics
Pune India

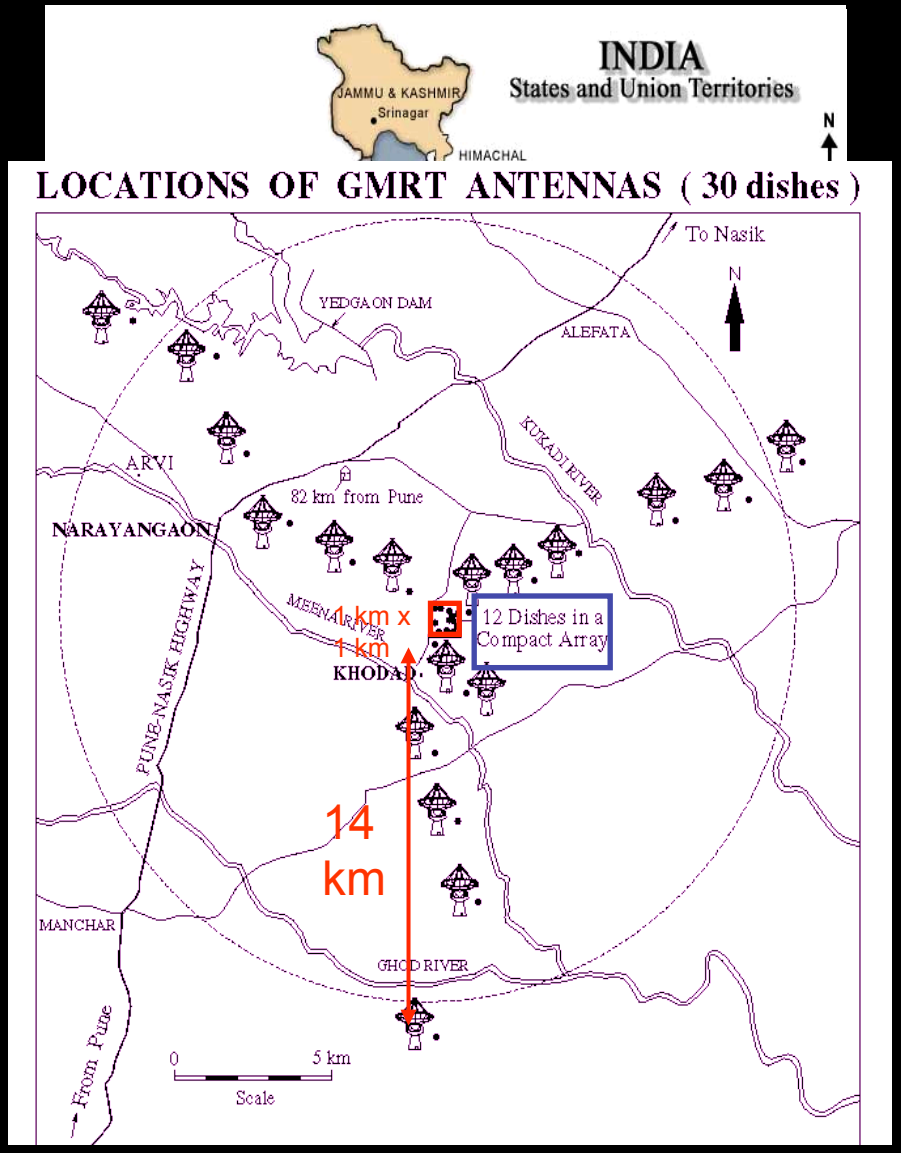
Science at Low Frequencies II Albuquerque 2 Dec 2015

Plan of today's presentation

- The GMRT : the first decade
- Upgrade plans for the GMRT : main features
- Developments & current status of different aspects of uGMRT
- Plans for the future

The GMRT : An Overview

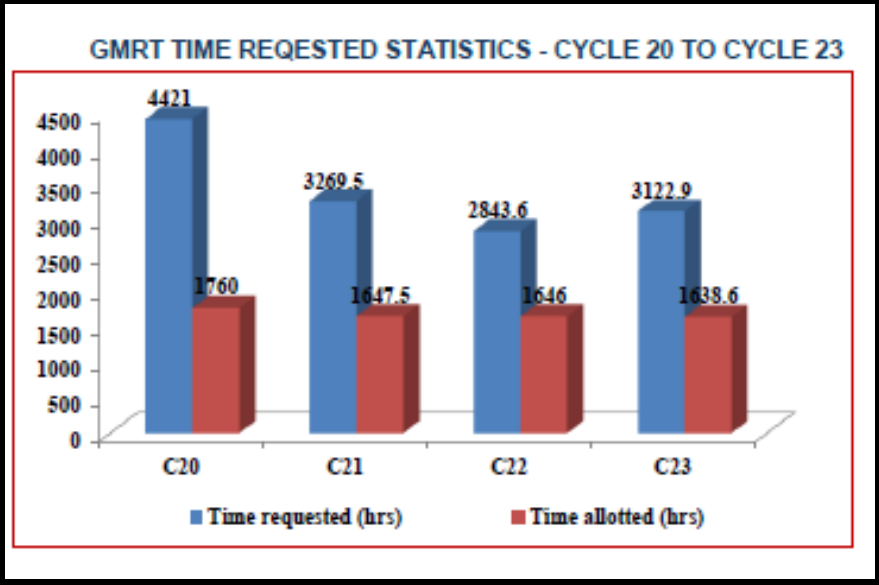
- 30 dishes, 45 m diameter each
  - 12 dishes in a central 1 km x 1 km region (central square)
  - remaining along 3 arms of Y-shaped array
  - baselines : ~ 200 m (shortest);
    ~ 30 km (longest)
- Frequency range :
  - 130-170 MHz
  - 225-245 MHz
  - 300-360 MHz
  - 580-660 MHz
  - 1000-1450 MHz
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

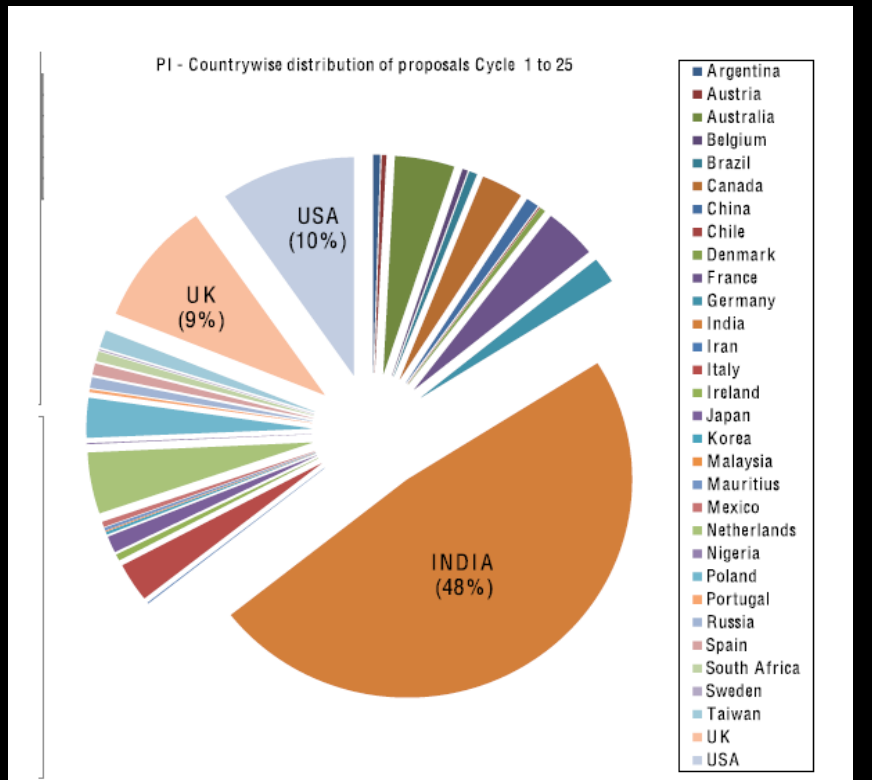


GMRT : Usage Statistics

- 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

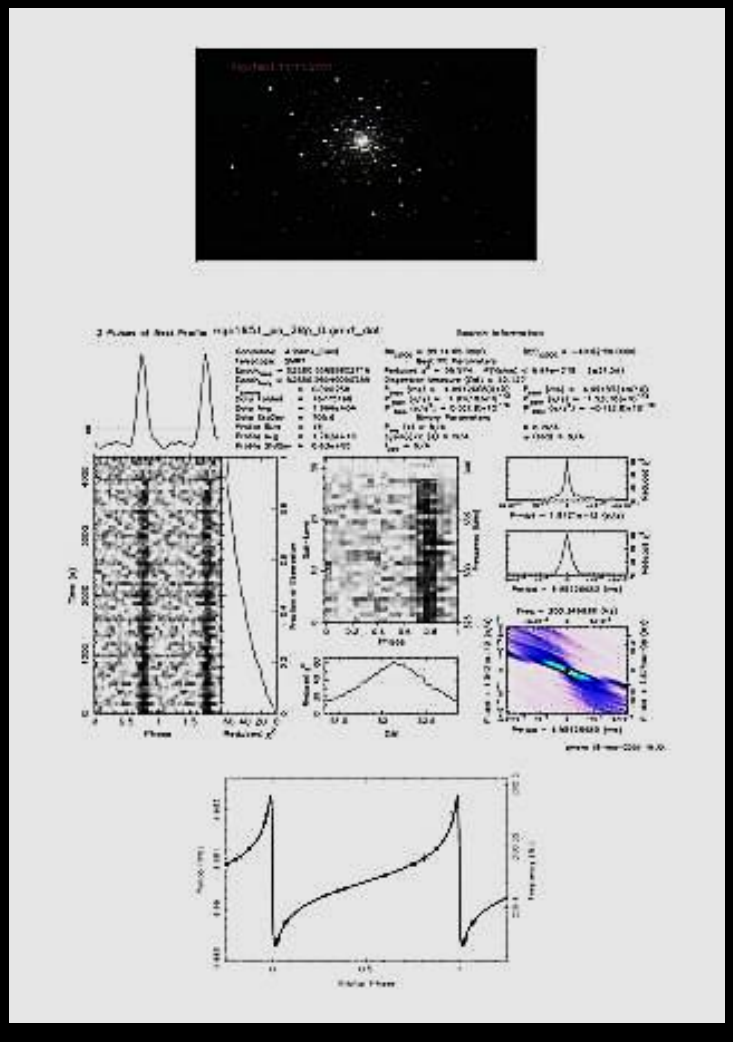
- The GMRT has been used for a wide range of studies (some of these you may hear about this week) :
  - Sun, extrasolar planets, YSOs -- some tantalising detections.
  - Pulsars : rapidly rotating neutron stars – many new results.
  - Other Galactice objects like supernova remnants, microquasars etc
  - 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

One sample of science with the GMRT :

"Pulsars with an interferometer"

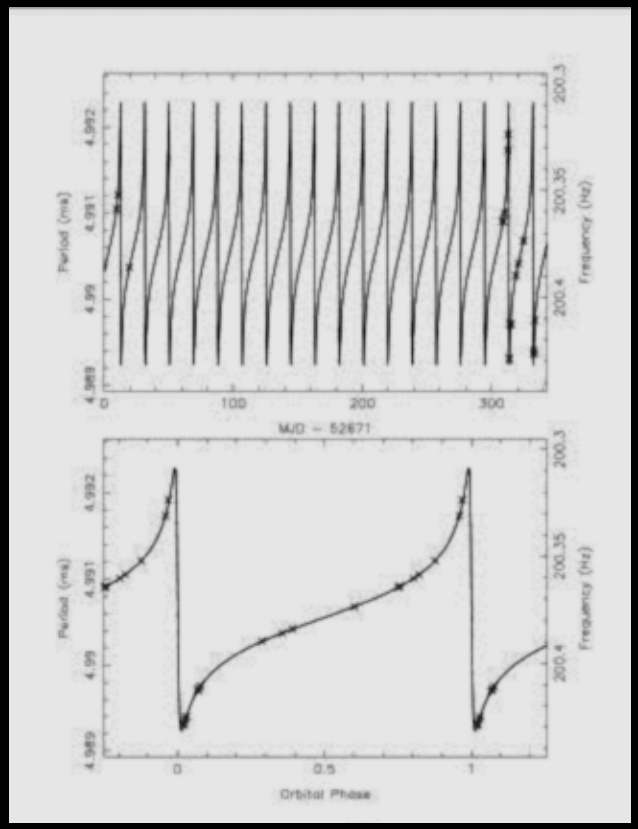
Targeted searches using phased array mode of the GMRT : globular clusters

- Central core of the GMRT used in phased array mode to cover the target
- Binary millisecond pulsar in the Globular Cluster NGC 1851



Very interesting variation of period with epoch !

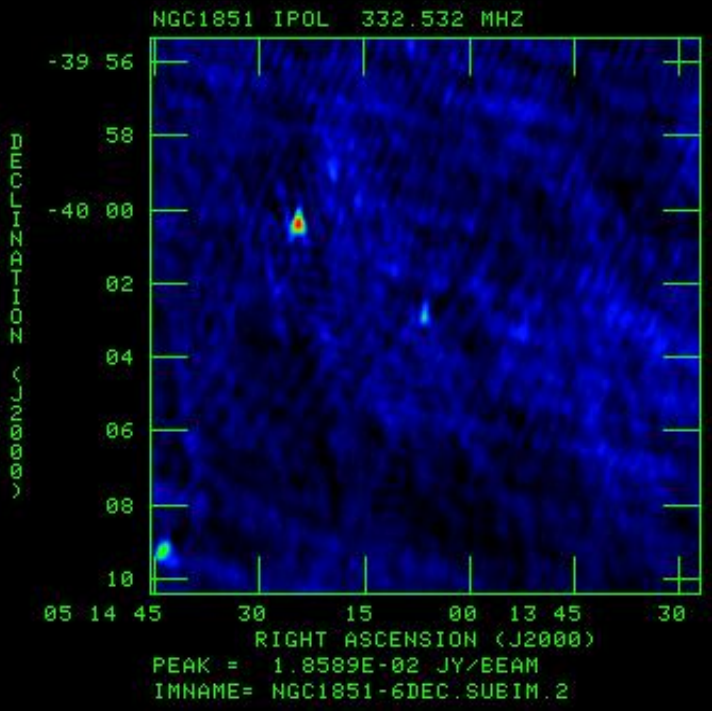
Binary pulsar with *very eccentric orbit (e = 0.89) !*



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

Localising the pulsar using imaging

MAPPING CONCURRENTLY WITH PHASED ARRAY OBSERVATIONS ! (c. 2004)



GMRT radio map of NGC1851 made from data simultaneous with phased array acquisition

NGC1851 : A relatively bright GC (M_v = -8.3) with a very condensed core & high central luminosity density

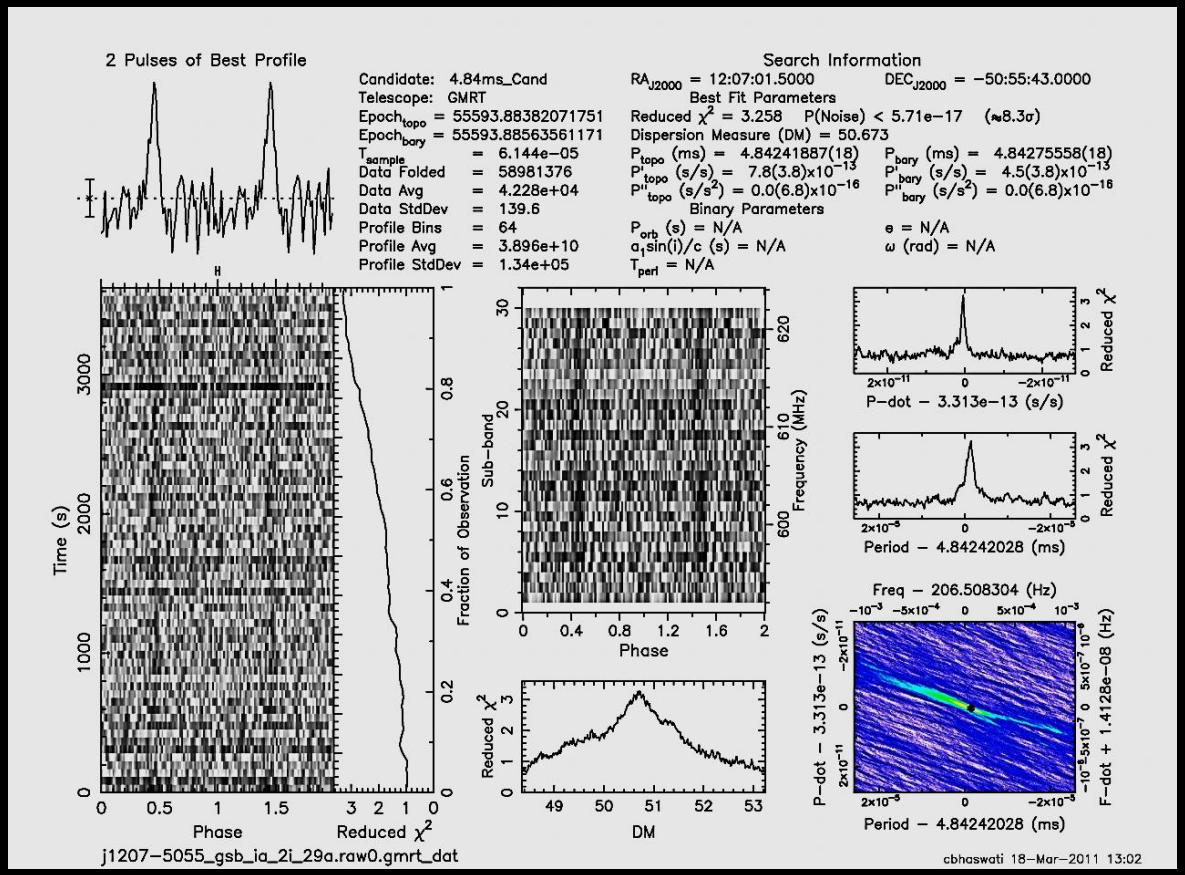
Freire, Gupta, Ransom & Ishwar-Chandra (2004)

Fermi LAT Pulsar Discoveries

Total of 6 new MSPs discovered in follow-up radio searches of Fermi LAT sources, using the GMRT, in the last 2 years

First Fermi LAT discovery with the GMRT

Bhattacharyya et al 2013



GMRT Fermi Search Team : Bhaswati Bhattacharyya, Jayanta Roy, Yashwant Gupta & Dipankar Bhatacharya

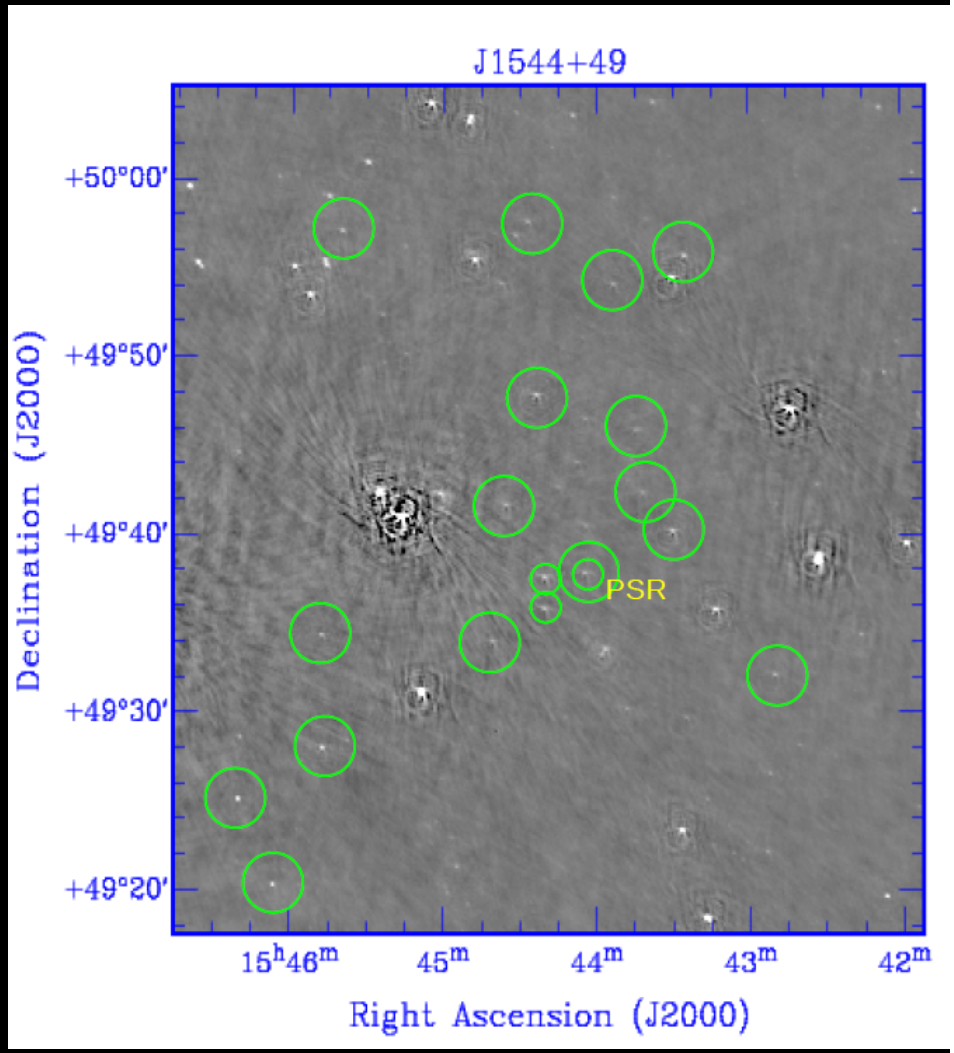
Localising the Fermi LAT Pulsars with the GMRT

GMRT as an interferometer offers unique opportunity to quickly localise the position of the detected pulsar with good accuracy :

First, make a quick map of the FoV

➔ however, many point-like sources !

Record raw voltages for the source and making multiple phased array beams at different possible point source locations, and check for the pulsar !



Roy, Bhattacharyya & Gupta 2013

Localising the Fermi LAT Pulsars with the GMRT

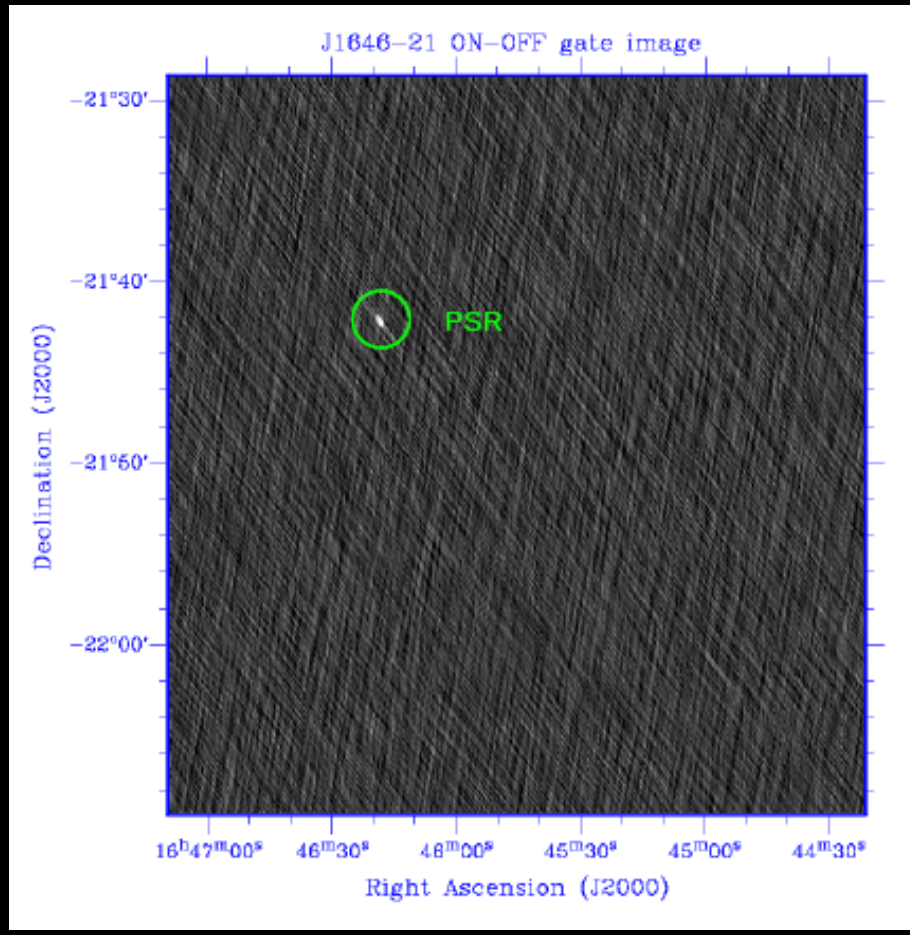
GMRT as an interferometer offers unique opportunity to quickly localise the position of the detected pulsar with good accuracy :

First, make a quick map of the FoV

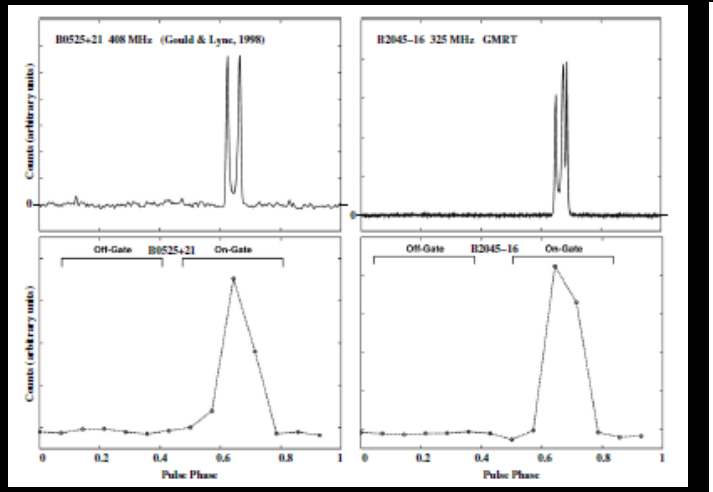
Record raw voltages for the source and making multiple phased array beams at different possible point source locations, and check for the pulsar

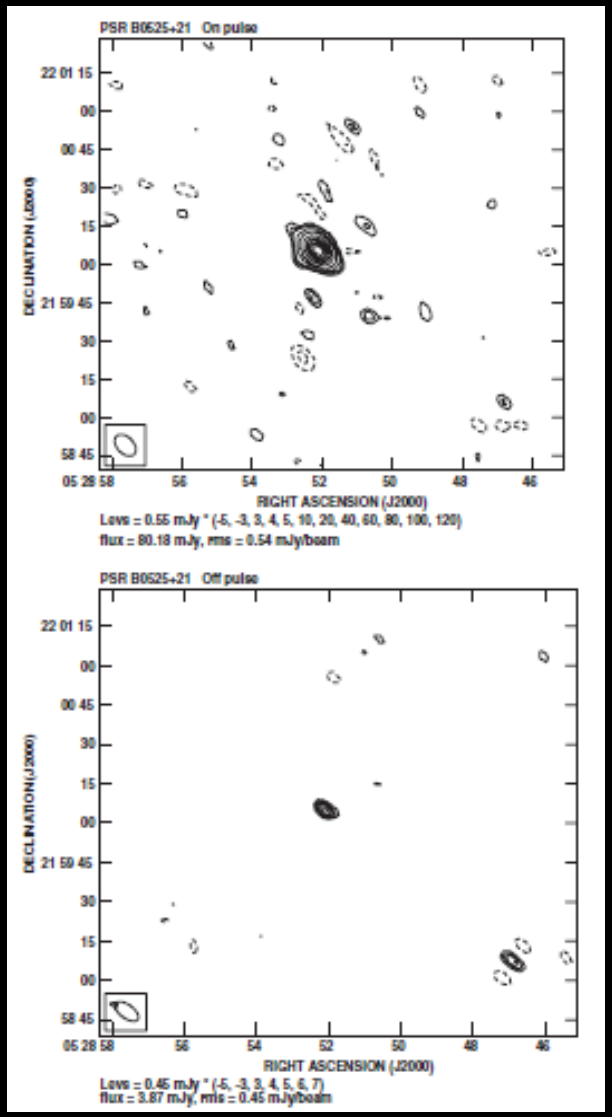
Even better : Gated Correlator : Make On-pulse & Off-pulse maps and subtract !!

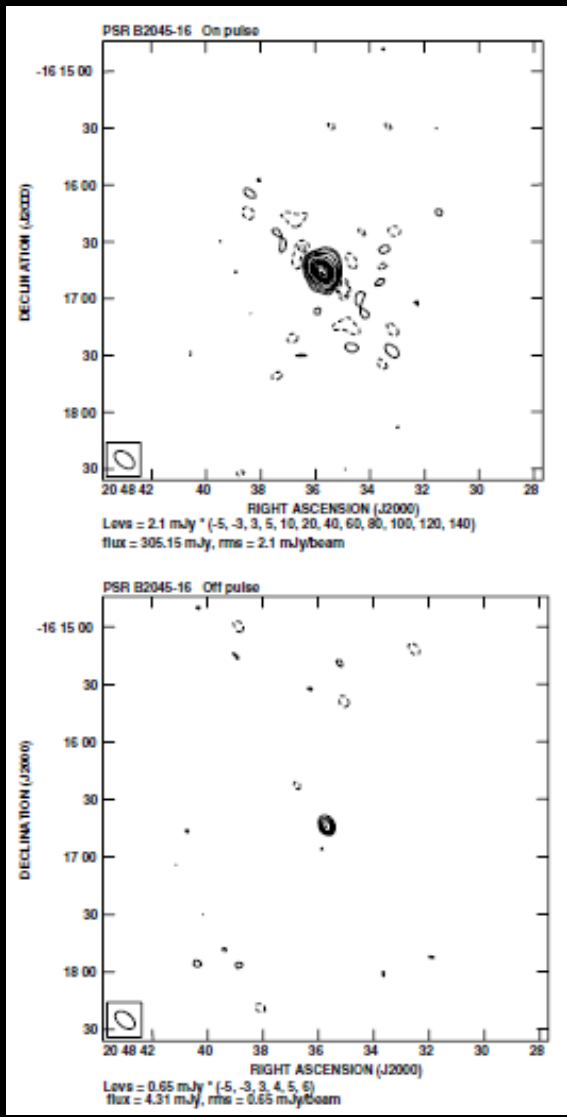
Roy & Bhattacharyya , 2013



New Results : Off-pulse emission from pulsars





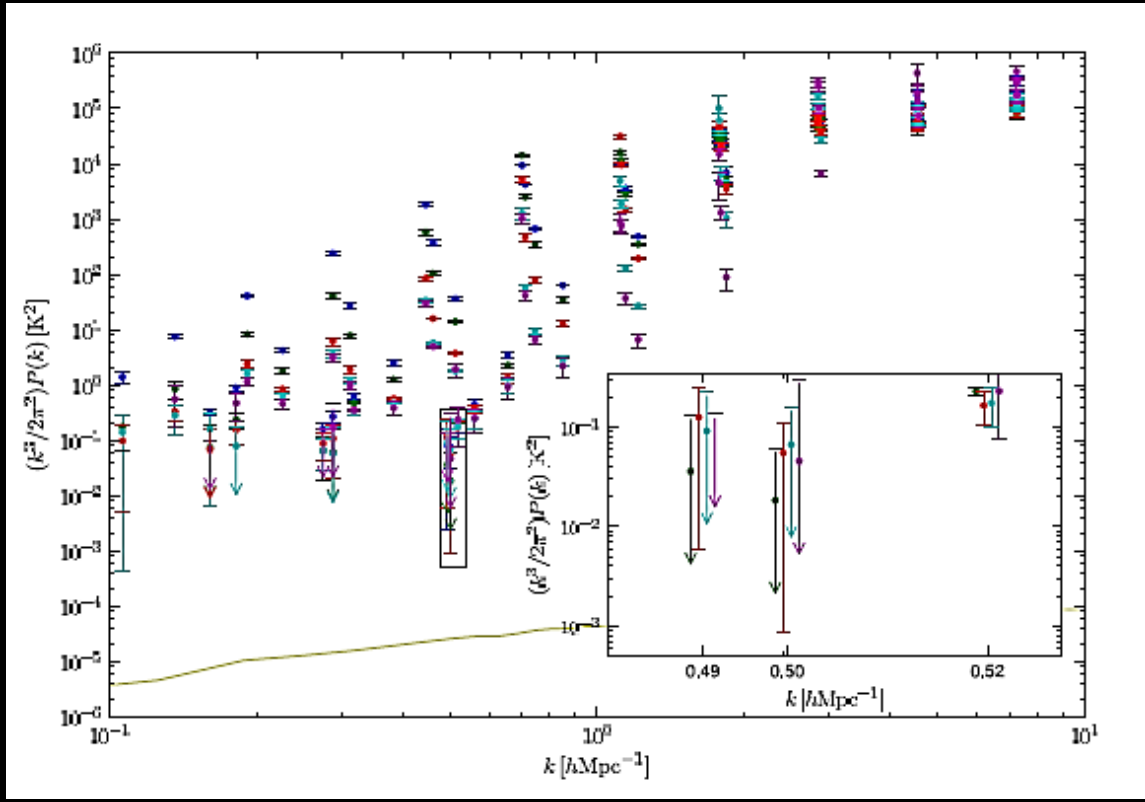


Using gated interferometer to make images for on-pulse and off-pulse regions for some well known pulsars

Basu, Athreya & Mitra (2011 & 2012)

EoR Experiment at the GMRT

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



Paciga et al, 2011 & 2013

NCRA • TIFR

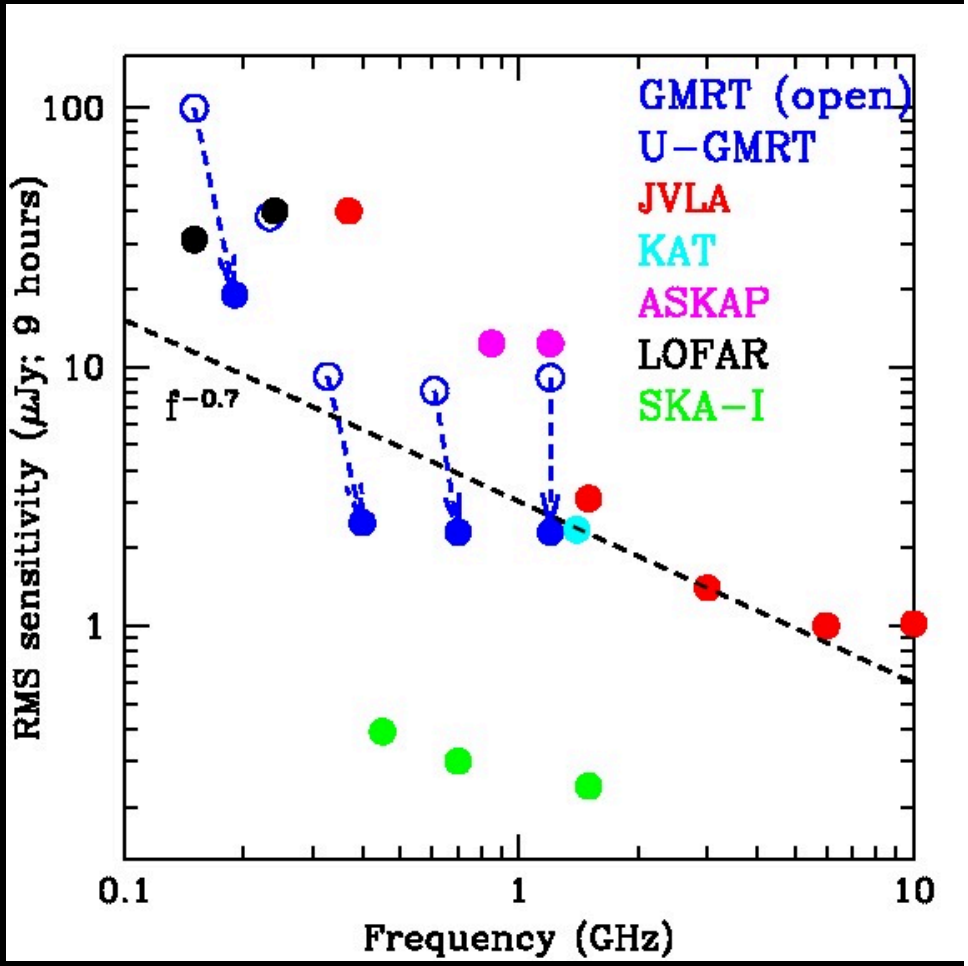
Looking to the future…

Looking ahead : the upgraded GMRT

- 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 developments and other upcoming facilities.
- 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

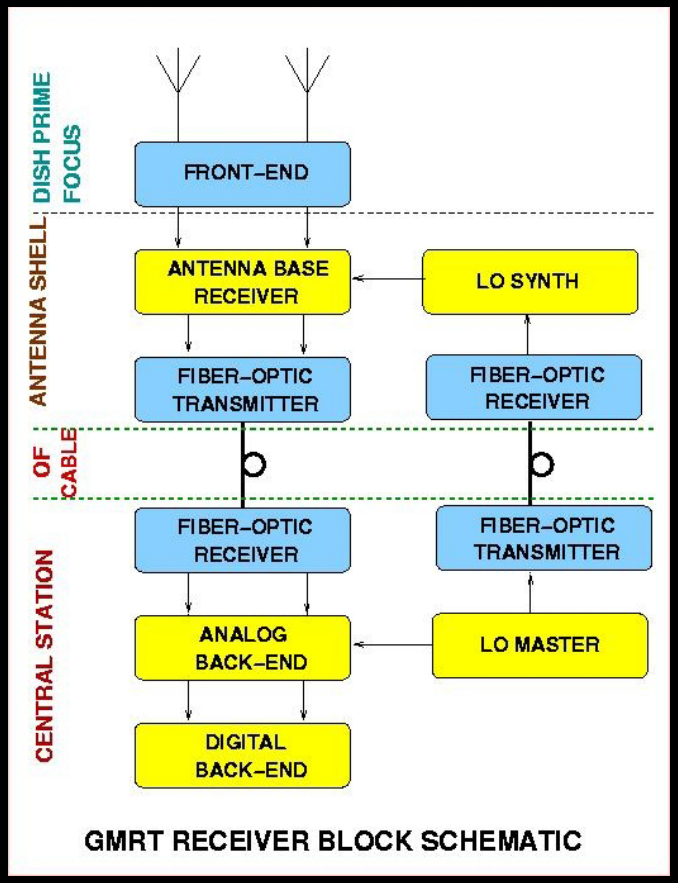
- Spectral lines : broadband coverage will give significant increase in the redshift space for HI lines + access to other lines
- Continuum imaging sensitivity will improve by factor of 3 or so.
- Sensitivity for pulsar observations will also improve by factor of 3.
- Only SKA-I will do better than uGMRT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



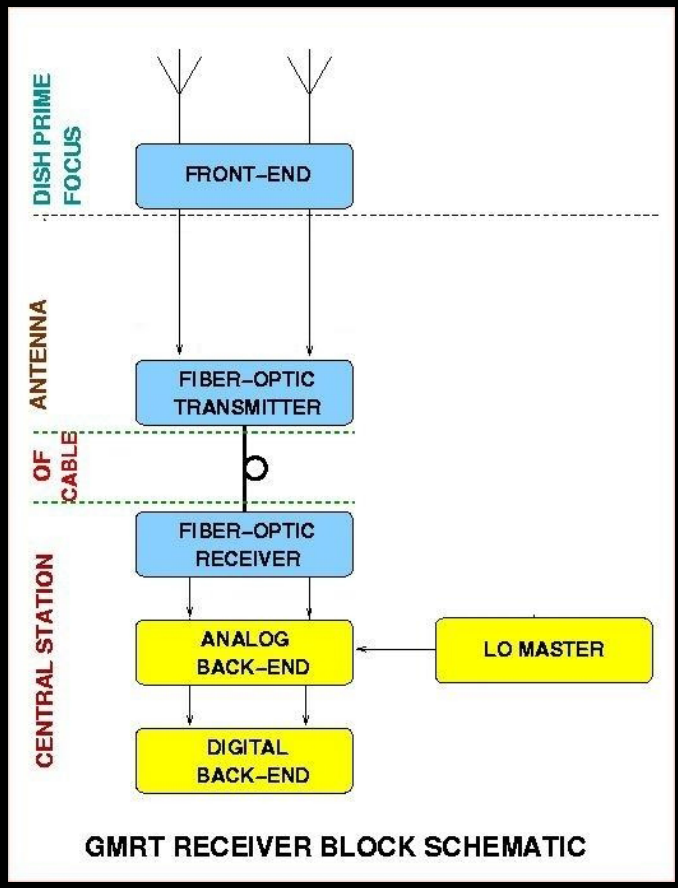
Expected sensitivity performance of the upgraded GMRT compared to other major facilities in the world, present and projected (courtesy : Nissim Kanekar, NCRA)

Overview of uGMRT Receiver System

- Relatively simplified electronics at antenna base
- Many improvements at the dish focus, optical fibre system & backends



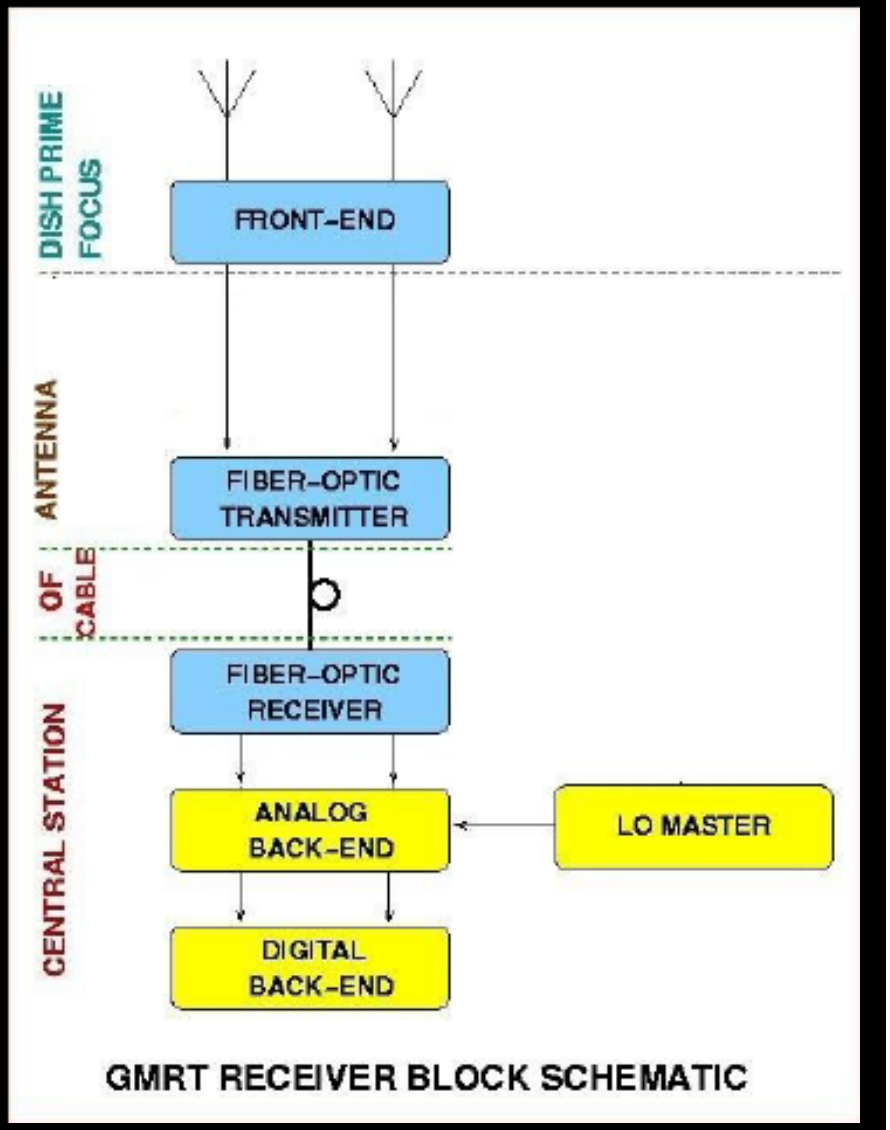
Existing GMRT system



Upgraded GMRT system

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 RECEIVER BLOCK SCHEMATIC

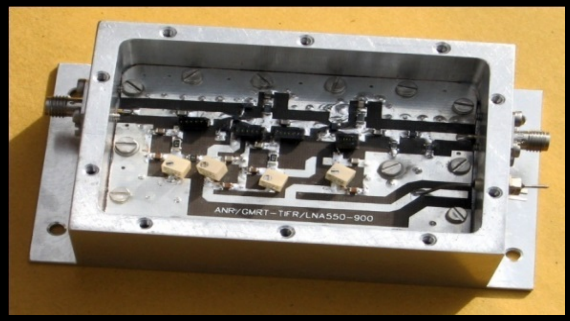
Wideband feeds + FE for uGMRT : L-band system

- For this band, we are going with the existing broadband L-band feed : ~ 900 to 1450 MHz (usable from ~ 1000 MHz upwards due to mobile phone RFI)
- Improved LNA (higher dynamic range) + better filters for rejecting RFI
- 30 antenna system completed more than one year ago; some refinements of filters planned in 2nd phase of improvement
- Sufficient sets of spares in hand now.

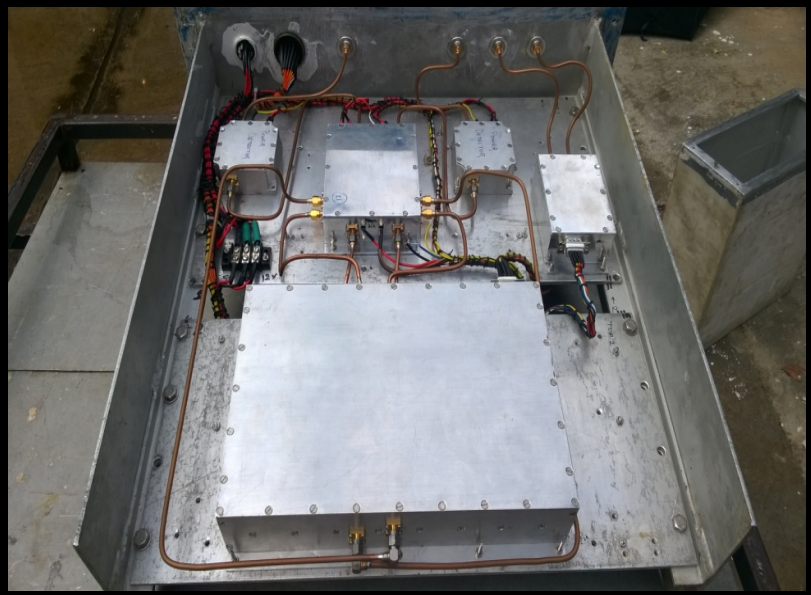
- This system is FULLY READY !

Wideband feeds + FE for uGMRT : 550-900 MHz system

- Broad-band cone dipole feed for 550-900 MHz now finalized, after lot of trials and fine tuning
- Matching wide-band LNA is also finalized, tested and ready
- Main FE box that will contain the rest of the (post LNA) electronics is also finalized.

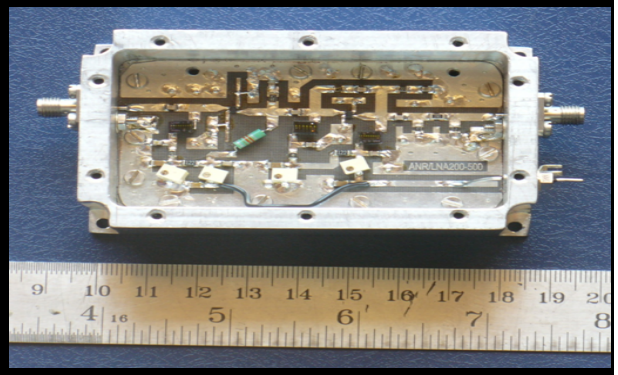


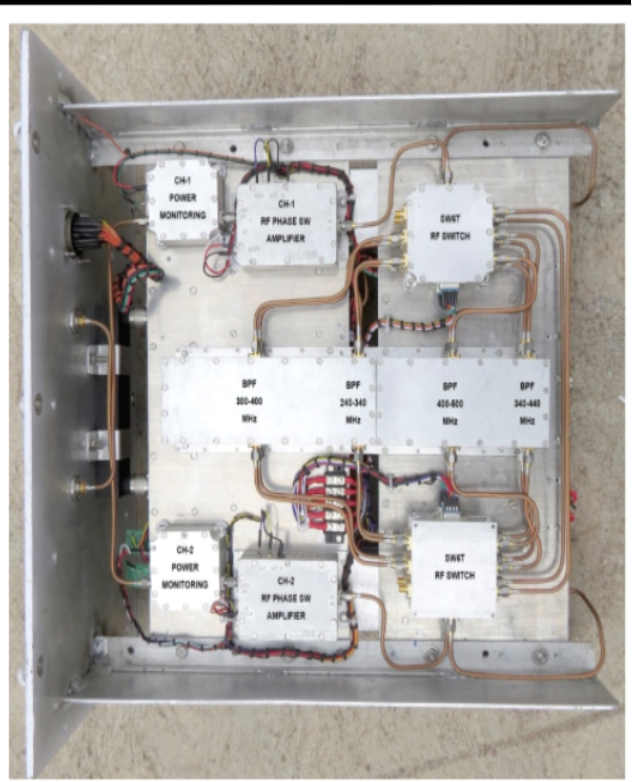
Cone Dipole design (for 550-900)



Wideband feeds + FE for uGMRT : 250-500 MHz system

- Broad-band (250-500 MHz) feed with good E-H pattern match
- Upgraded wideband FE system with new LNA : improved T_lna (22 vs 36 K) & dynamic range
- In mass production, up on 21 antennas with prototype FE box (replaces existing 325 system)



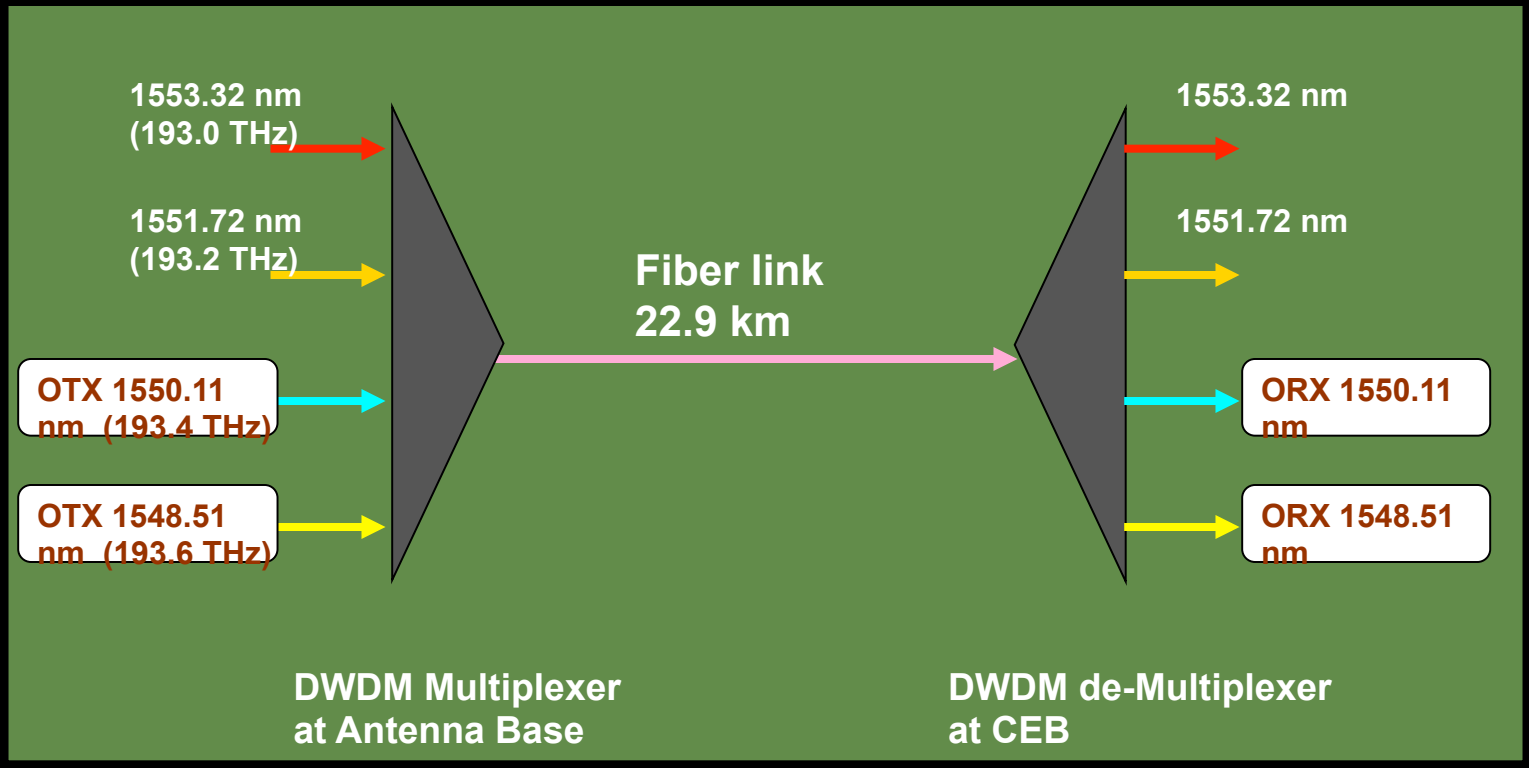


uGMRT : New Wideband Systems
Summary of Current Status

- Proposed configuration of feeds and receivers and their current status :
  - 1000 – 1450 MHz : existing wideband feed + improved dynamic range receiver with appropriate RFI filters : completed on all 30 antennas.
  - 550 – 900 MHz : cone-dipole feed with matching receiver system finalized and now in mas production phase : 3 antennas completed.
  - 250 – 500 MHz : cone-dipole feed + receiver is in mass production & installation : 21 antennas completed.
  - 125 – 250 MHz : modified Kildal ring feed + modified electronics in last stages of testing and validation.
  - 50 – 80 MHz : on hold at present.

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
- Will bring back 2 broad-band RF channels + existing IF channels ; will also support new and existing control and monitoring schemes

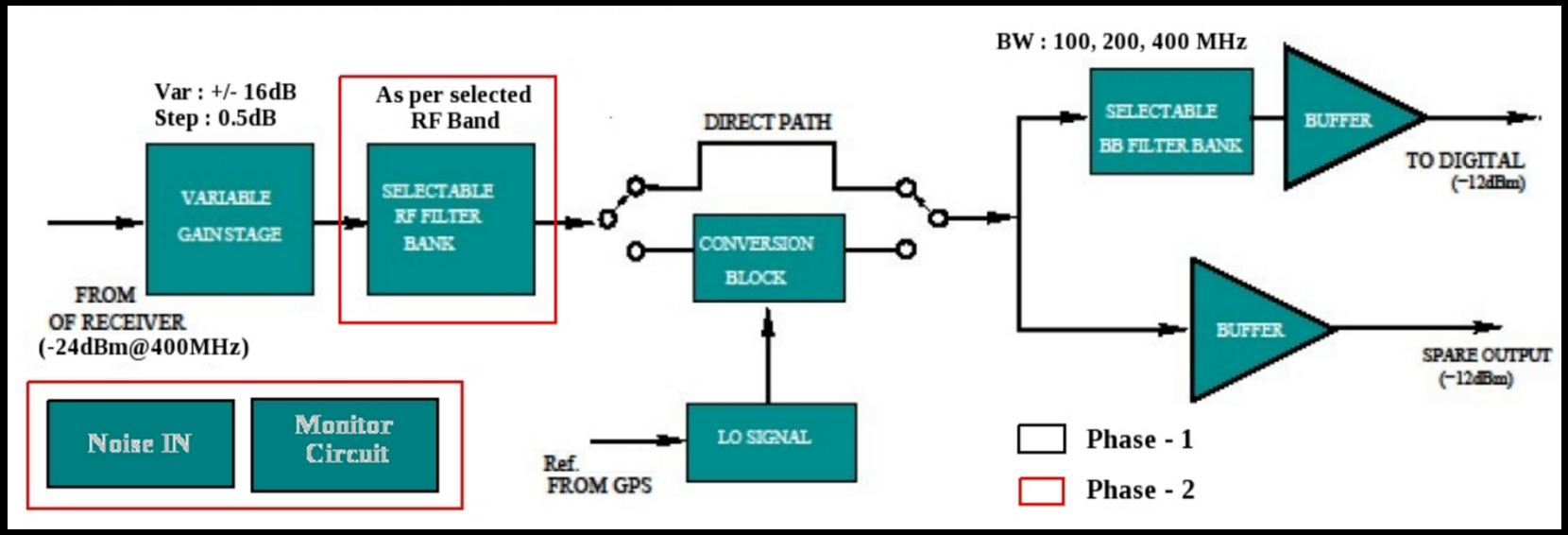


GMRT Upgrade : Optical Fibre Systems

- Completed installation for all 30 antennas in Sept 2015

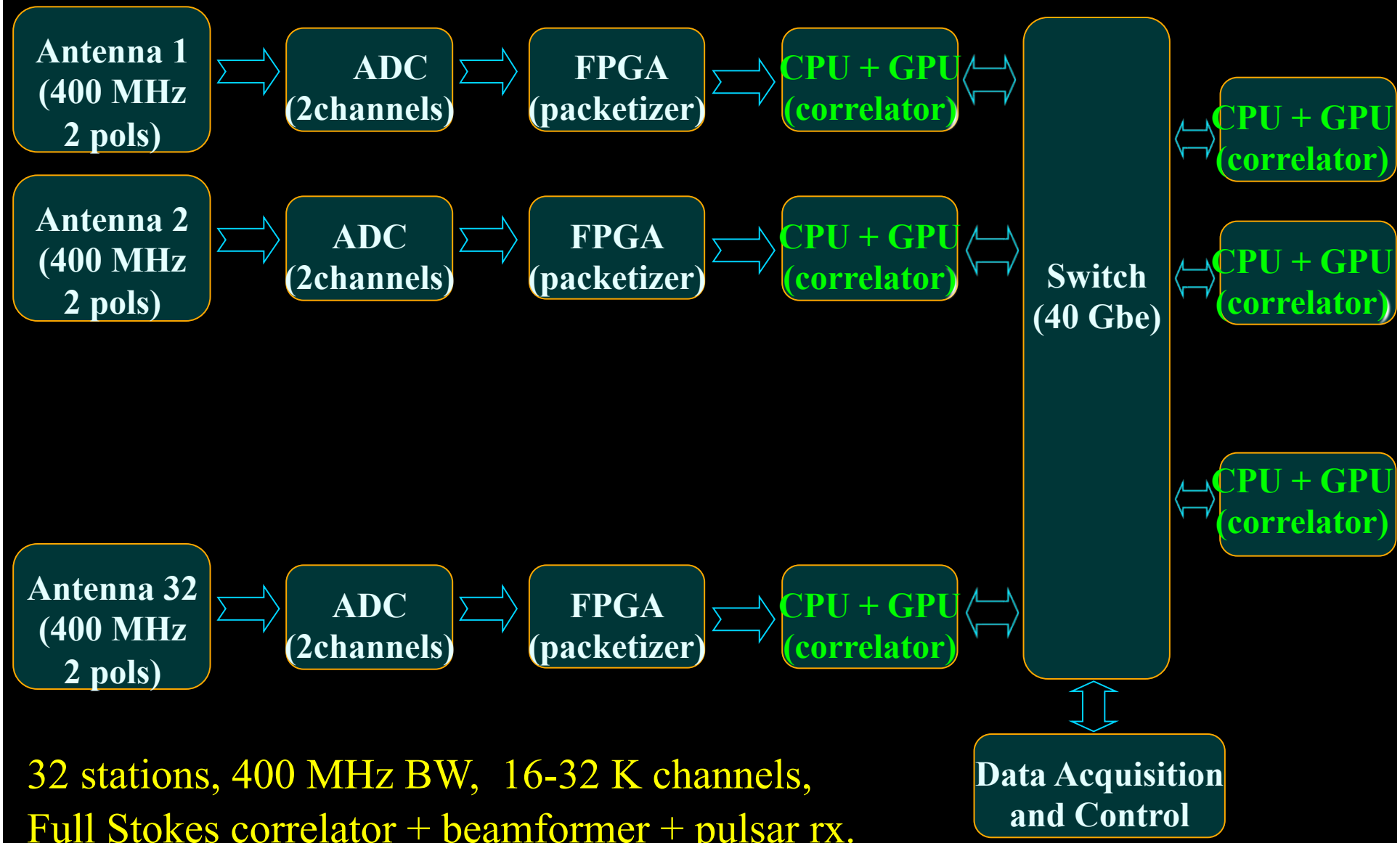
New Optical Fibre System installed in the receiver room

Analog back-end system for uGMRT



- Processes RF signals from output of OF system
- Down converts to final baseband signals of 100, 200, 400 MHz BW
- **Basic system for processing signals from all 30 antennas completed.**

uGMRT Digital Backend : Hybrid Correlator Design



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

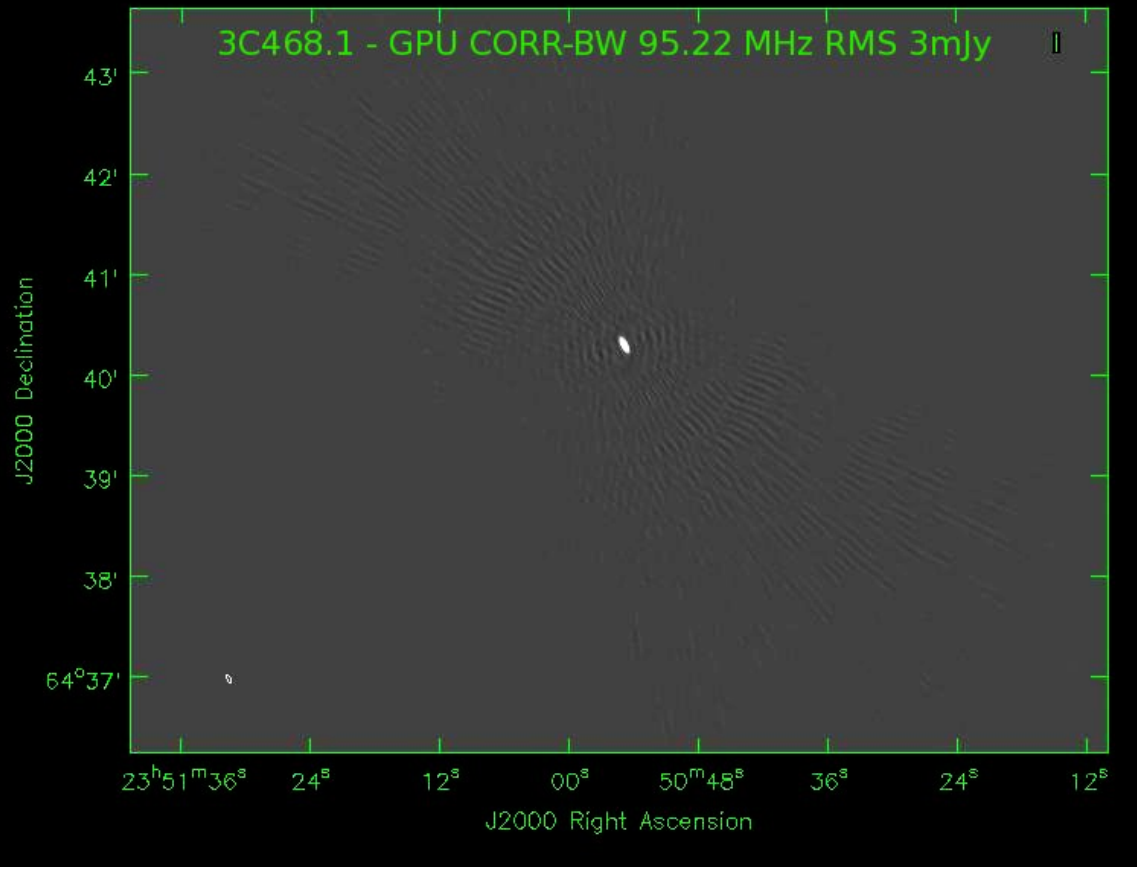
GWB-III : 16 antenna (dual poln) 400 MHz software backend for uGMRT

- 8-node GPU system
- 16 ADC cards + 8 FPGA boards
- Dual K20 GPUs on each T620 node
- Recently installed and released
- BW : 400 MHz, upto 16K channels
- Int Time : 0.67 sec
- IA/PA Beamformer
- Upgrade to 32 stations by mid-2017

Towards a working uGMRT…

First result from new wideband signal path

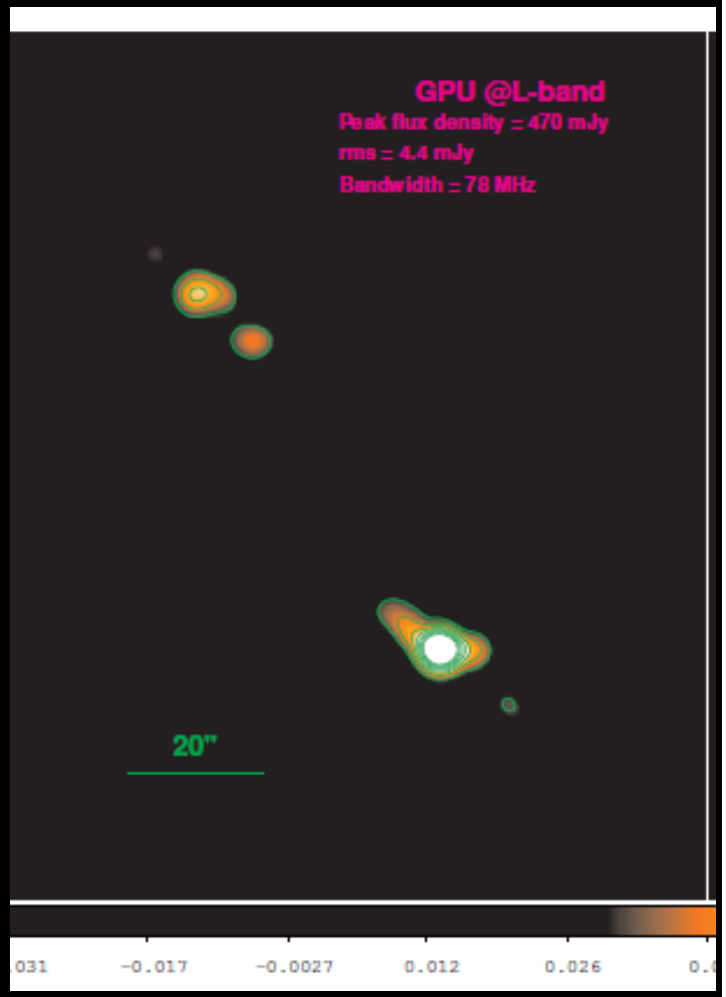
- First GMRT image using 100 MHz RF BW at L-band
- RMS noise : 3 mJy
- August 2012



First light results courtesy :
Dharam Vir Lal

More Recent Results with the Wideband Path of the uGMRT

- First GMRT image of extended source using ~ 100 MHz RF BW
- 3C47 at 1390 MHz
- September 2013



First light results courtesy : Dharam Vir Lal and Poonam Chandra

More Recent Results with the Wideband Path of the uGMRT

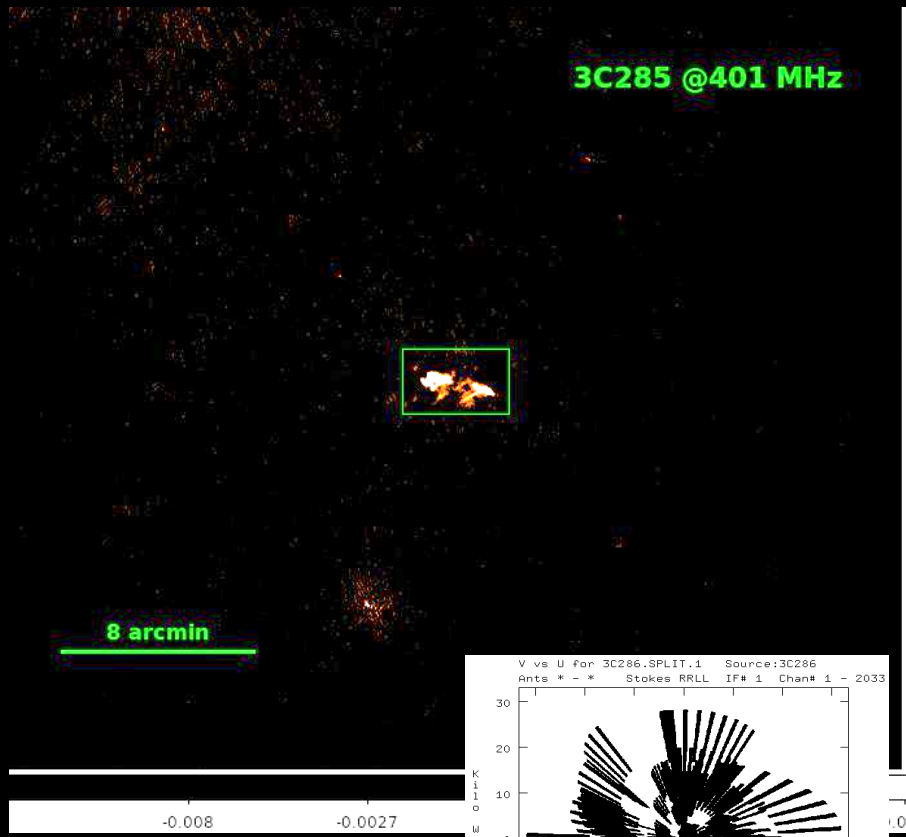
Source : 3C285

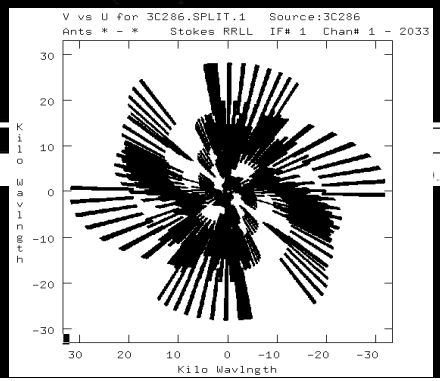
No. of Ant : 11

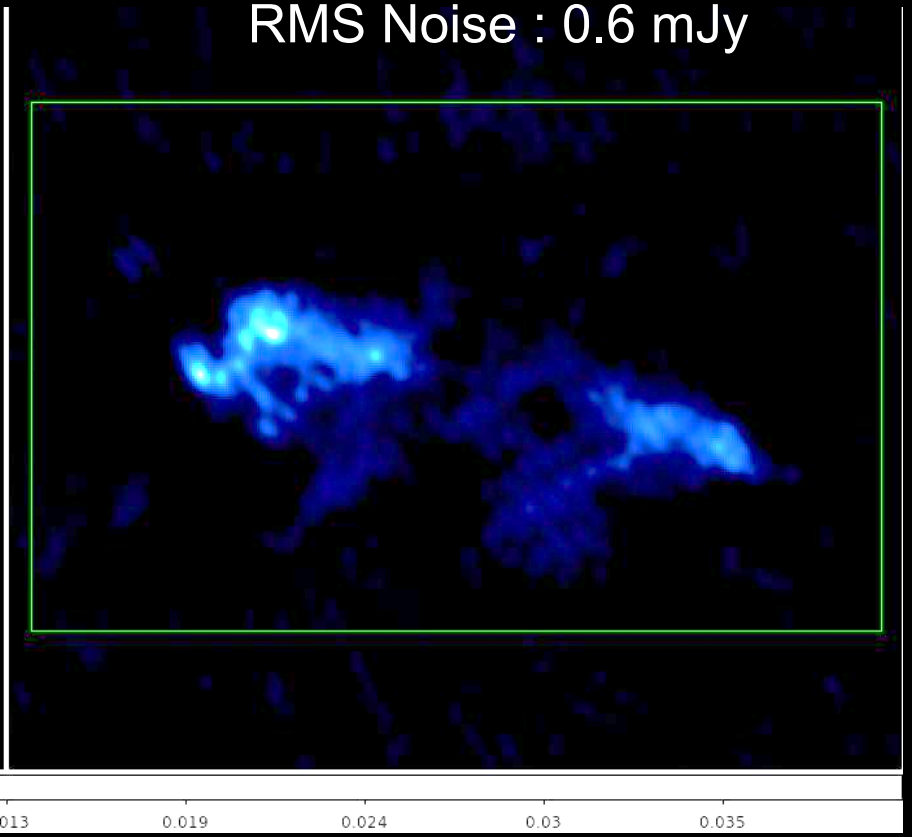
RF Band : 250-500 MHz

BW : 198.5 MHz

RMS Noise : 0.6 mJy



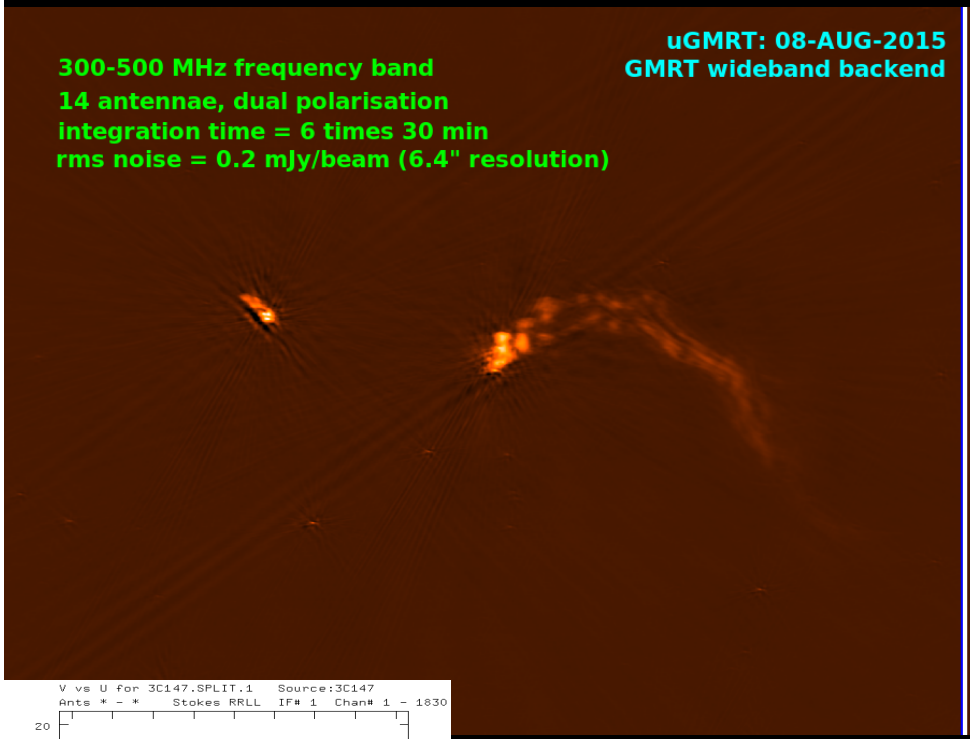


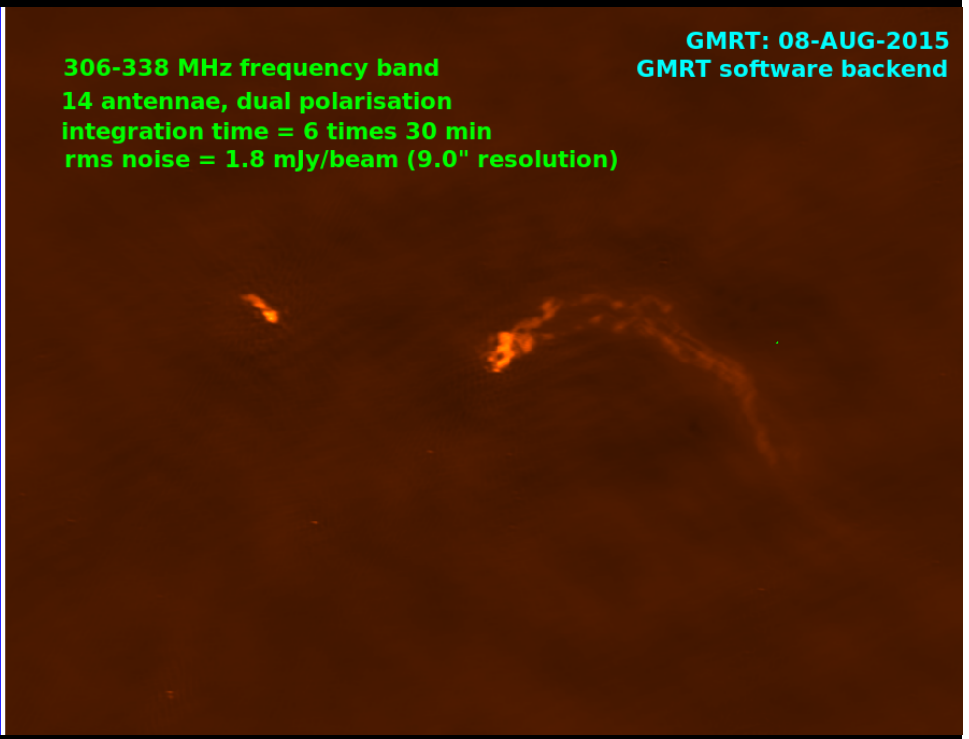


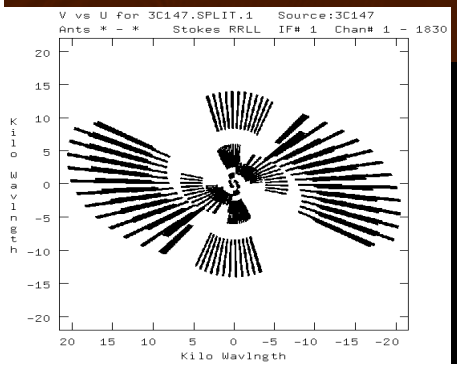
courtesy : Dharam Vir Lal

Even More Recent Results with the Wideband uGMRT

3C129 imaged with the uGMRT system using 14 antennas, 200 MHz BW







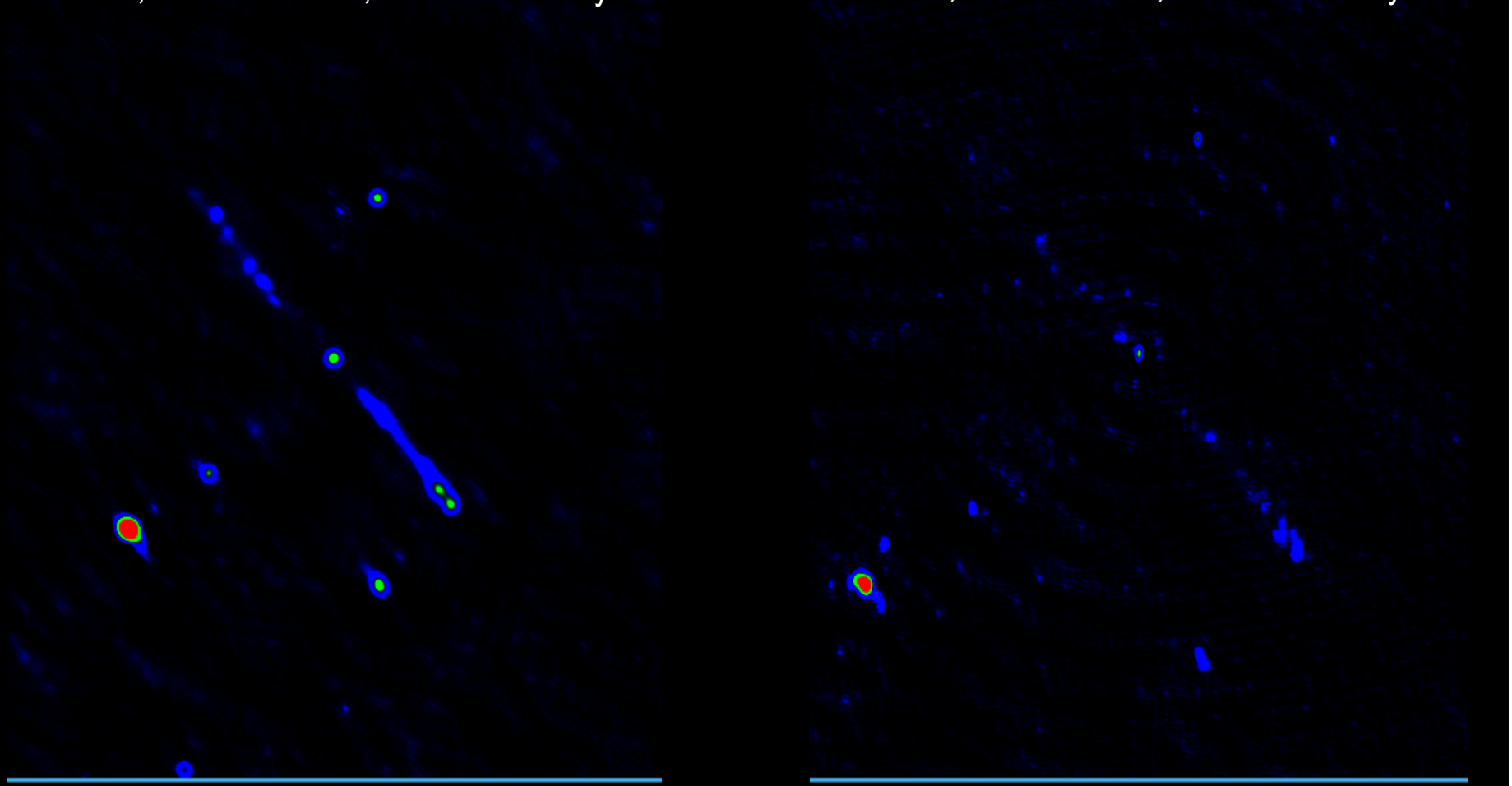
courtesy : Dharam Vir Lal + Binny Sebastian

Even More Recent 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

Wideband pulsar observations

PSR B1508+55

300-500 MHz band

(200 MHz BW)

Using 8 antennas

Phased Array mode.

courtesy : Y. Gupta

Wideband pulsar observations : improved sensitivity

PSR B1508+55

120 MHz at Lband (1330-1450)

vs

33 MHz at Lband (1390 sub-band)

Simultaneous observations using same # of antennas in phased array mode.

courtesy : Y. Gupta

Wideband pulsar observations : Improved sensitivity

Millisecond PSR J1713+0747

120 MHz at Lband (1330-1450)

vs

33 MHz at Lband (1390)

Simultaneous observations using same # of antennas in phased array mode.

courtesy : Y. Gupta

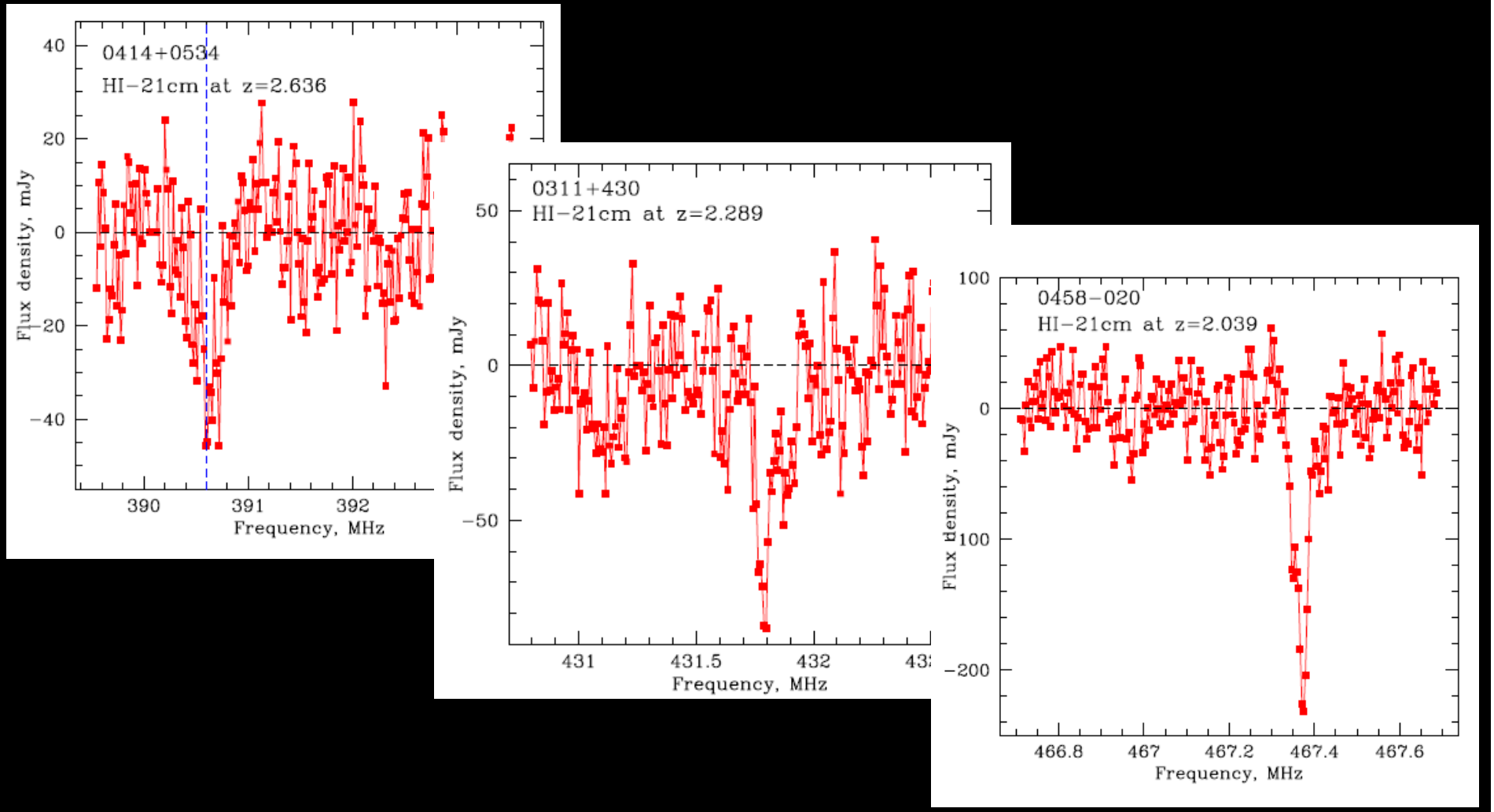
Pulsar timing with the uGMRT

Regular timing observations for a few well known pulsars
Simultaneous observations using GSB and GWB
Residuals align well for GSB & GWB, but have an offset between the two

GSB (red) & GWB (purple) residuals for B1508+55, with & without offset

courtesy : Nikhil Naik & Y. Gupta

Upgraded GMRT : opening new windows



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

Future Plans

- A 16 antenna uGMRT with Lband (1000-1450 MHz) and Pband (250- 500 MHz) with 200/400 MHz final processing BW has been released for internal testing in September 2015.

- Plan to release this on a shared risk basis to outside users from around April 2017, with TAC evaluating the uGMRT proposals.

- Hope to have next level of release by around October 2017.

- So, stay tuned !

That's all !

Thank You

Challenges on the Road to uGMRT

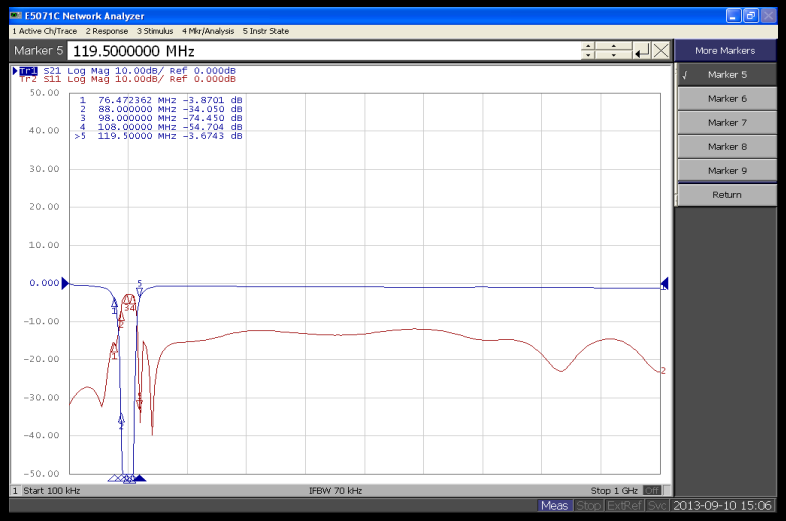
The main challenges that we have encountered have been :

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

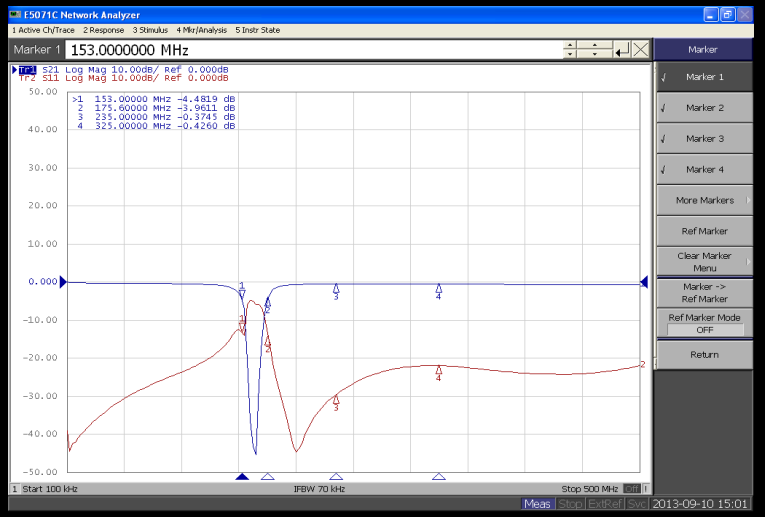
- Operational : keeping the existing GMRT working for our regular users while upgrading simultaneously took some effort

- Taking care of man made Radio Frequency Interference (RFI) is and remains our biggest challenge !

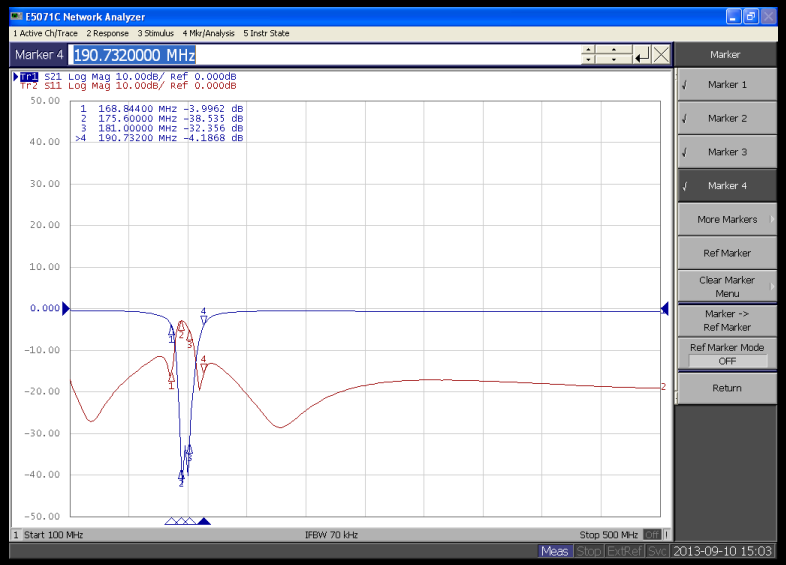
RFI mitigation : filters in analog chain



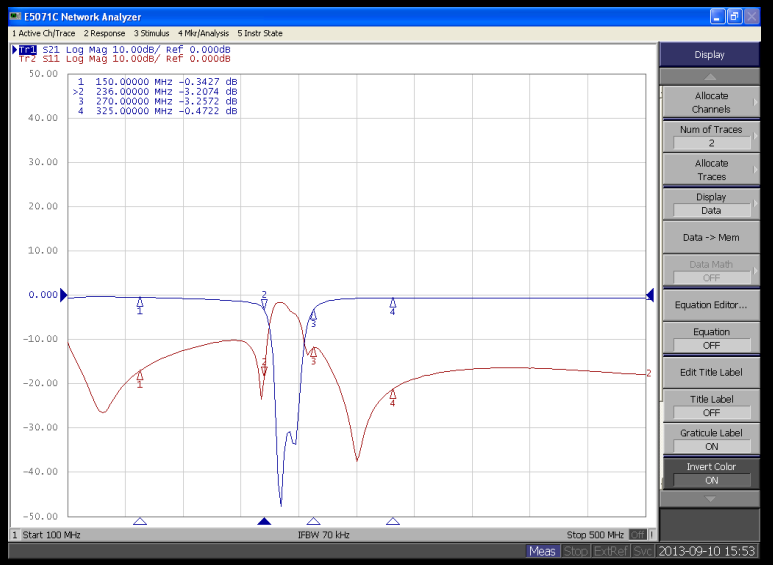
FM (88 – 108MHz) Notch Filter



Police Wireless Notch Filter (159 - 166MHz)



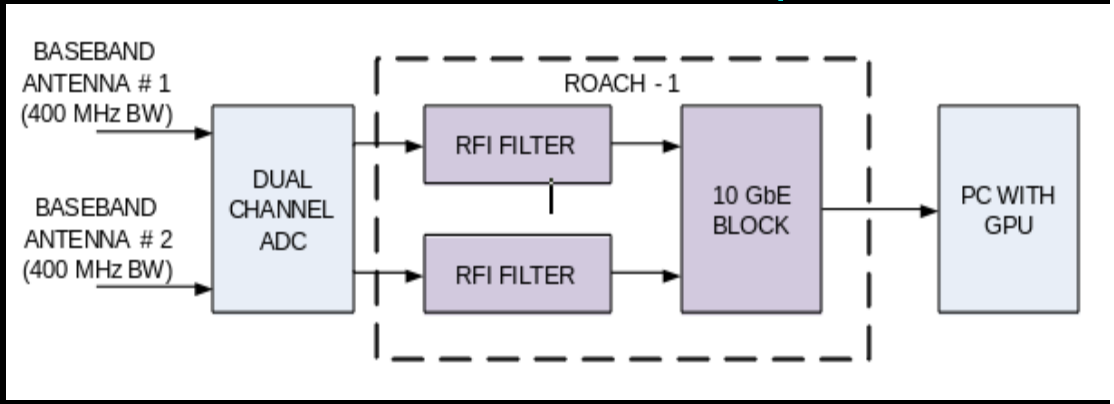
TV Notch Filter (175 -181MHz)



Satellite Notch Filter Filter (236-270MHz)

RFI Detection & Filtering in digital domain

FPGA Implementation



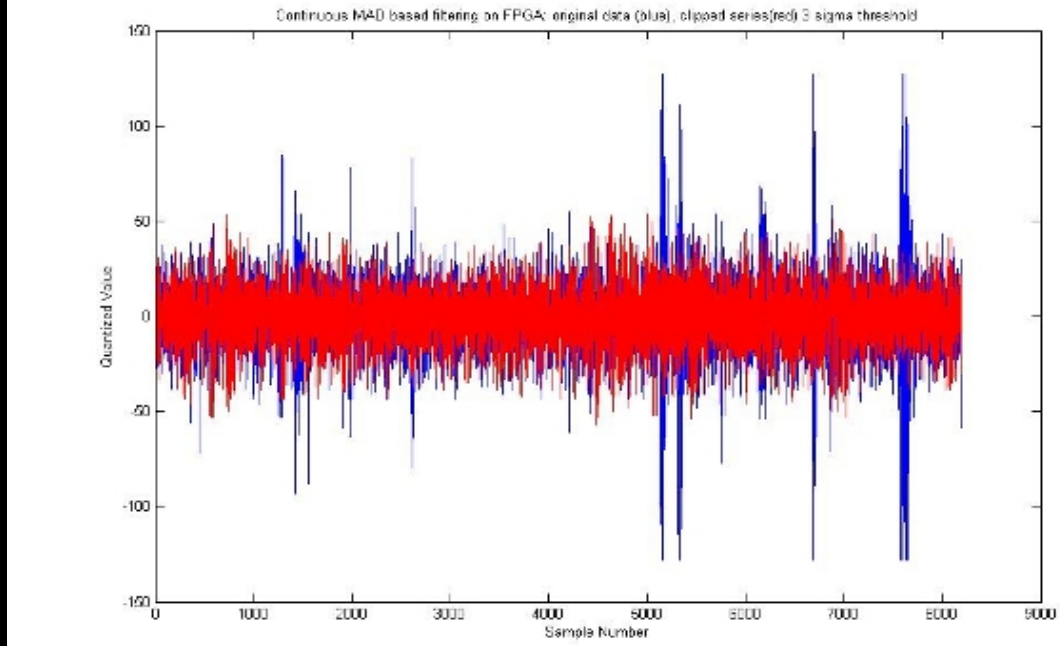
Median Absolute Deviation (MAD) based flagging of RFI

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

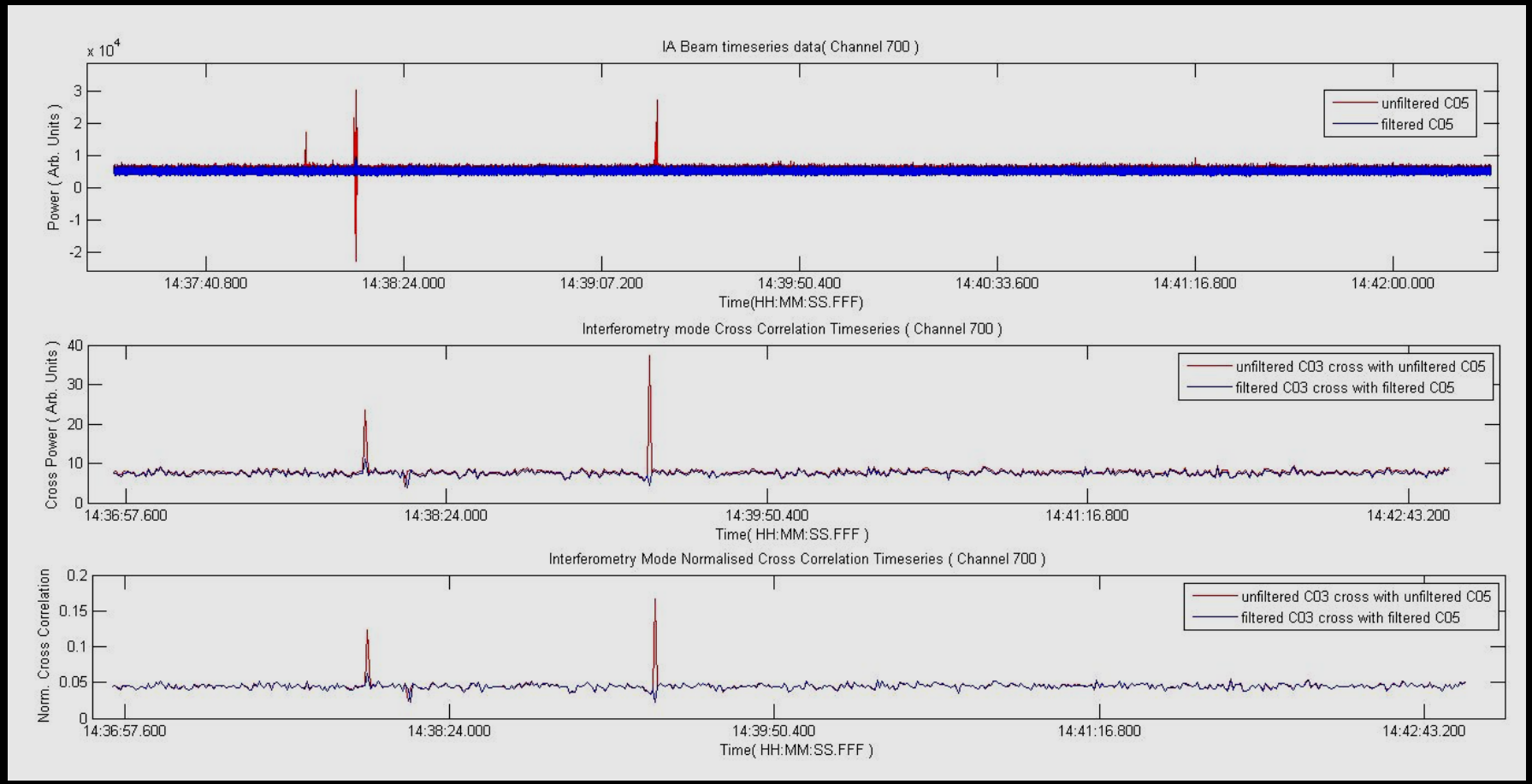
Will soon be integrated into the main correlator design, after some more testing

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



Real-time RFI Detection & Filtering

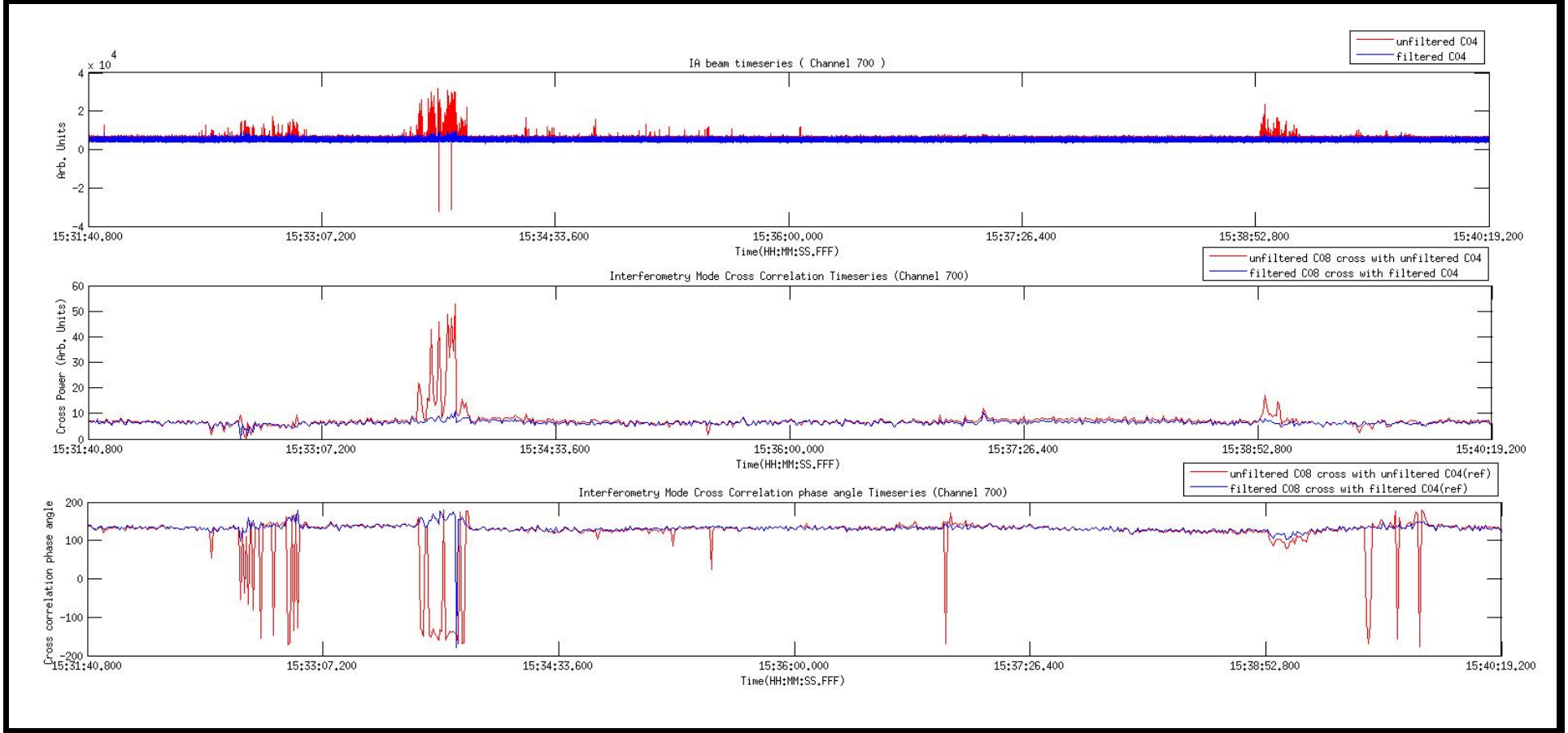
Real-time filter running on broadband voltage data of each antenna
Top panel shows effect of this filtering, in beamformer time series
Bottom panels show effect of this filtering, in visibility domain data



courtesy : K.D. Buch & Y. Gupta

Real-time RFI Detection & Filtering

Real-time filter running on broadband voltage data of each antenna
Top panel shows filtering in high time resln beamformer time series
Bottom panels show filtering in visibility amplitude & phase on 1 baseline



courtesy : K.D. Buch & Y. Gupta

RFI filtering for pulsar observations

Filtering directly on the beamformer data in time and frequency domains

B1642-03 (top)

and

B1508+55 (bottom)

200 MHz BW mode of uGMRT at Lband

➔ Significant improvements in sensitivity for uGMRT observations with RFI filtering !

courtesy : Y. Gupta

Future Plans

- A 16 antenna uGMRT with Lband (1000-1450 MHz) and Pband (250- 500 MHz) with 200/400 MHz final processing BW has been released for internal testing in September 2015.

- Plan to release this on a shared risk basis to outside users from around April 2017, with TAC evaluating the uGMRT proposals.

- Hope to have next level of release by around October 2017.

- So, stay tuned !

That's all !

Thank You