The upgraded GMRT: current status and ongoing plan

Latest status and future developments on continuum surveys with uGMRT

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(Tata Institute of Fundamental Research)
With due thanks to
Ishwara-Chandra CH
colleagues at NCRA,
Scientists, engineers, and
support personnel at
NCRA-TIFR and GMRT.

SPARCS VII (ICRAR, Perth), 18 July 2017

uGMRT

Plan

⊕ The GMRT upgrade or the uGMRT -
  (complement several other observatories
   a testbed to demonstrate wide band,
    wide field-of-view imaging);
  ⊕ current status of uGMRT;
⊕ towards a working uGMRT;
  ⊕ test studies using uGMRT -
    ⊕ understanding data quality,
    ⊕ fidelity of new wide-band backend, and
    ⊕ challenges in data reduction and analysis;
  ⊕ (imaging) results for several targets
    ⊕ (commissioning data)
  ⊕ continuum surveys

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The existing GMRT: An overview

- 30 dishes, 45 m diameter each
  - 12 dishes in a inner 1 km^2 region (central square) and
    - remaining along 3 arms of Y-shaped array
  - baselines : ~100 m ~30 km
- Frequency range:
  - 130-170 MHz
  - 225-245 MHz
  - 300-360 MHz
  - 580-660 MHz
  - 1000-1450 MHz
  - (max instantaneous BW = 32 MHz)
- A_{eff} (2-3% of SKA):
  - 30,000 m^2 at lower frequencies
  - 20,000 m^2 at highest frequencies
- Supports 2 modes of operation:
  - Interferometry, aperture synthesis
  - Array mode (incoherent & coherent)

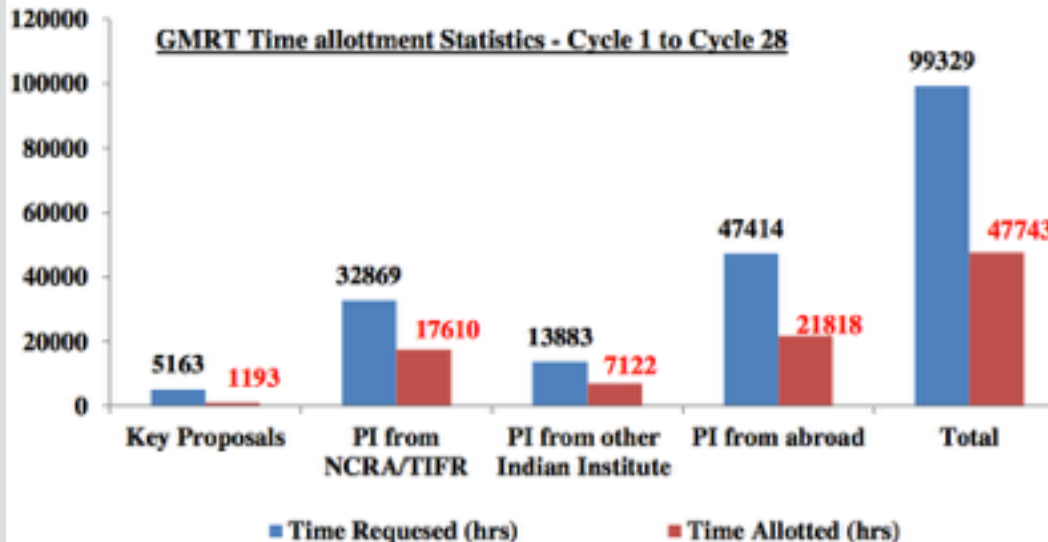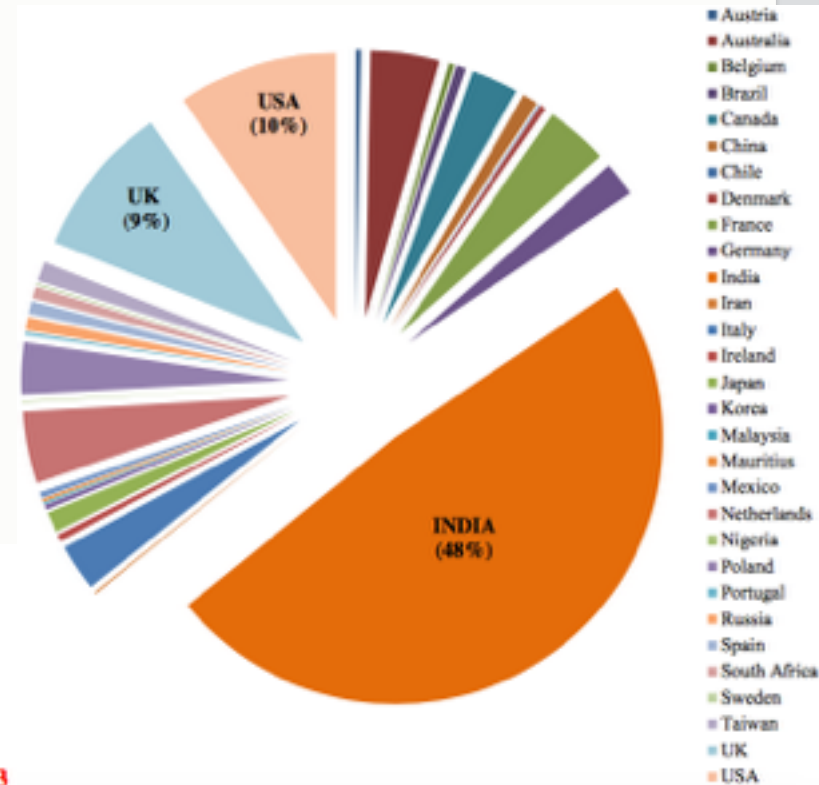LOCATIONS OF GMRT ANTENNAS (30 dishes)
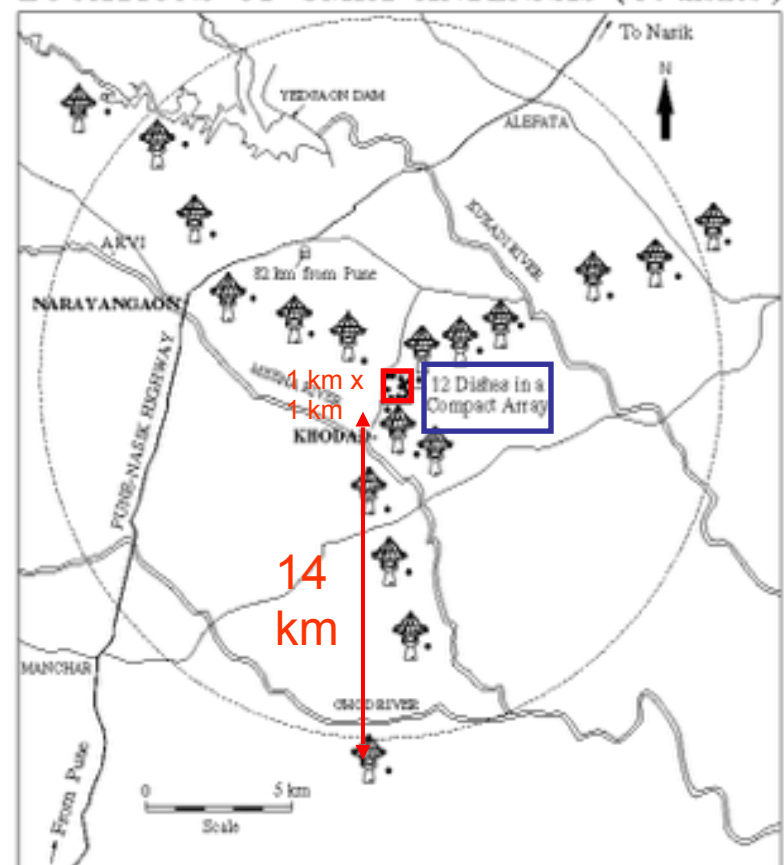
GMRT: usage statistics

- Users/Community, since Oct 4, 2001
- GMRT sees users from all over the world
  - (users) Indian:Foreign = 45:55
- The GMRT has been typically oversubscribed by a factor of 2 or more

Pie chart legend: Austria, Australia, Belgium, Brazil, Canada, China, Chile, Denmark, France, Germany, India, Iran, Italy, Ireland, Japan, Korea, Malaysia, Mauritius, Mexico, Netherlands, Nigeria, Poland, Portugal, Russia, Spain, South Africa, Sweden, Taiwan, UK, USA

USA (10%) · UK (9%) · INDIA (48%)

GMRT Time allottment Statistics - Cycle 1 to Cycle 28

	Key Proposals	PI from NCRA/TIFR	PI from other Indian Institute	PI from abroad	Total
Time Requested (hrs)	5163	32869	13883	47414	99329
Time Allotted (hrs)	1193	17610	7122	21818	47743

Country	Nos	Country	Nos	Country	Nos	Country	Nos	Country	Nos
Argentina	13	China	19	Iran	2	Mauritius	3	Russia	13
Austria	5	Chile	1	Italy	49	Mexico	7	Spain	14
Australia	75	Denmark	6	Ireland	7	Netherlands	75	South Africa	16
Belgium	7	France	66	Japan	21	Nigeria	1	Sweden	2
Brazil	11	Germany	40	Korea	6	Poland	55	Taiwan	20
Canada	50	India	847	Malaysia	3	Portugal	3	UK	163
								USA	169

Total Proposals Received 1769

GMRT: Scientific objectives

- Solar system objects
- Pulsars: rapidly rotating NSs
- Transients
    - Ex. SNRs, GRBs, etc.
- centre of the Galaxy
- Molecular gas, and HI
- Galaxies
    - normal / active galaxies
- Clusters / Groups of galaxies
- Deep-fields / EoR
- All-sky survey

AND many more interesting new results

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The upgraded GMRT: ongoing upgrade and status

uGMRT is a major upgrade of the GMRT

The fundamental goal is to improve

major observational capabilities of the original GMRT (bandwidth, sensitivity).

This is a leveraged project - built upon existing infrastructure of the GMRT.

The project is scheduled to be completed by the end of 2017.

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Generation-Next: The upgraded GMRT

- A **major upgrade** is underway at the **GMRT**,
  - with focus on (nearly) seamless frequency coverage
    - from ~30 MHz to 1500 MHz,
  - design of completely new 'feeds' and 'receiver' system with octave bandwidths
- Improved G/T_{sys},
  - i.e., use of better tech. receivers and reduced T_{sys}
- Increased instantaneous bandwidth to 400 MHz
  - from present 32 MHz using new digital 'backend' receiver
- Revamp Servo-system (brushless drives, new servo computer)
- Modern and more versatile 'control and monitor' system
- Matching improvements in off-line computing facilities and other infrastructure
- Improvements in mechanical, electrical, …

Without compromising availability of "existing GMRT" to users!

uGMRT: the receiver system

⊞ Old vs. upgrade
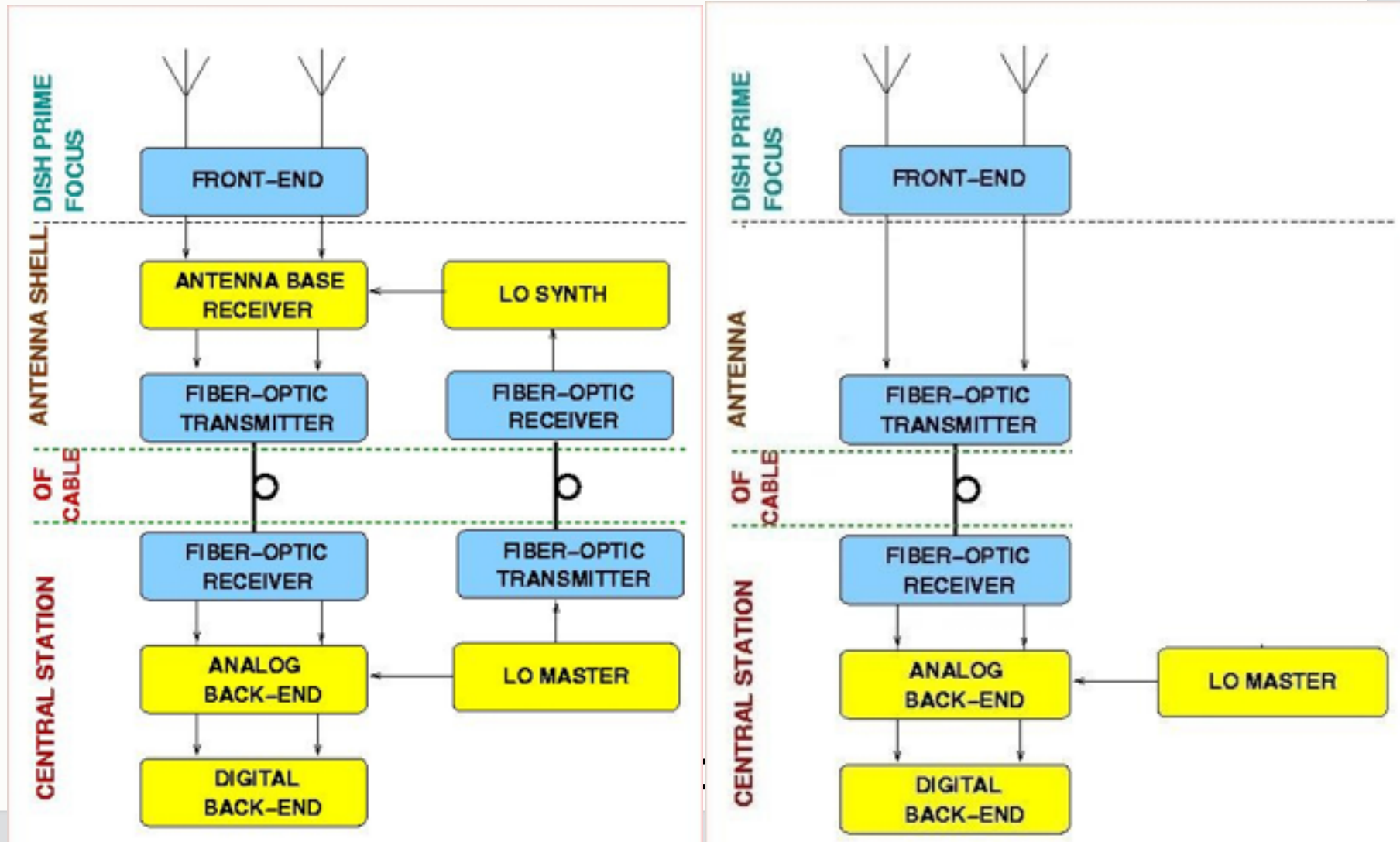
uGMRT: the receiver system

- 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 translates RF signals to 0-400 MHz baseband
- Digital back-end system process 400 MHz BW for
  - interferometric and
  - beam modes

SPARCS VI:

DISH PRIME FOCUS

FRONT-END

ANTENNA

FIBER-OPTIC TRANSMITTER

OF CABLE

CENTRAL STATION

FIBER-OPTIC RECEIVER

ANALOG BACK-END

LO MASTER

DIGITAL BACK-END
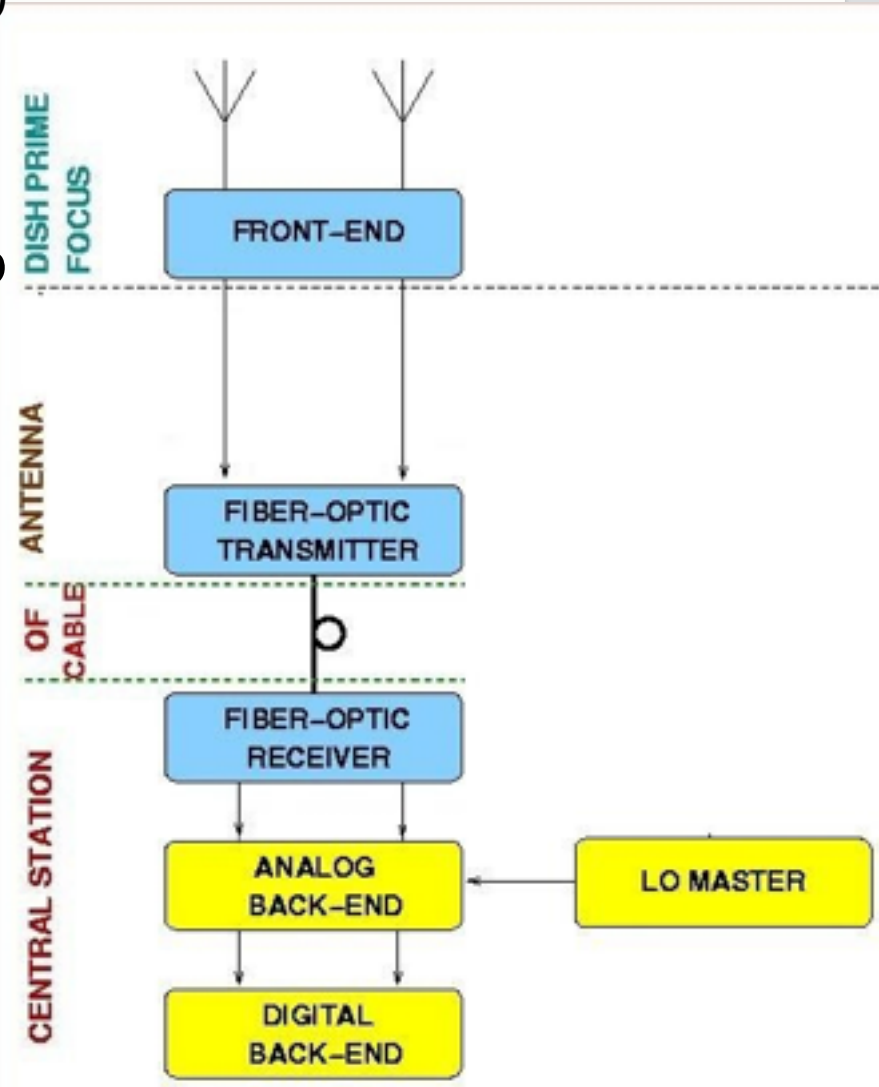
uGMRT: (wideband) feeds

- Cone-dipole design
  - 250-500 MHz
  - 550-900 MHz
- Dual-ring feed
  - 120-250 MHz

Credits: frontend team (H. Rao)

uGMRT: L-band (Band 5)

- Here, we have gone 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 1 yr ago; refinements of filters are planned in 2nd phase
- Sufficient sets of spares

This system is FULLY READY!

Performance of L-band system is monitored regularly by the FE team to keep the system in good health
 – we need to watch out for growing RFI!   SPA

E04CH1-(1420MHz)-(ON source-Off source)
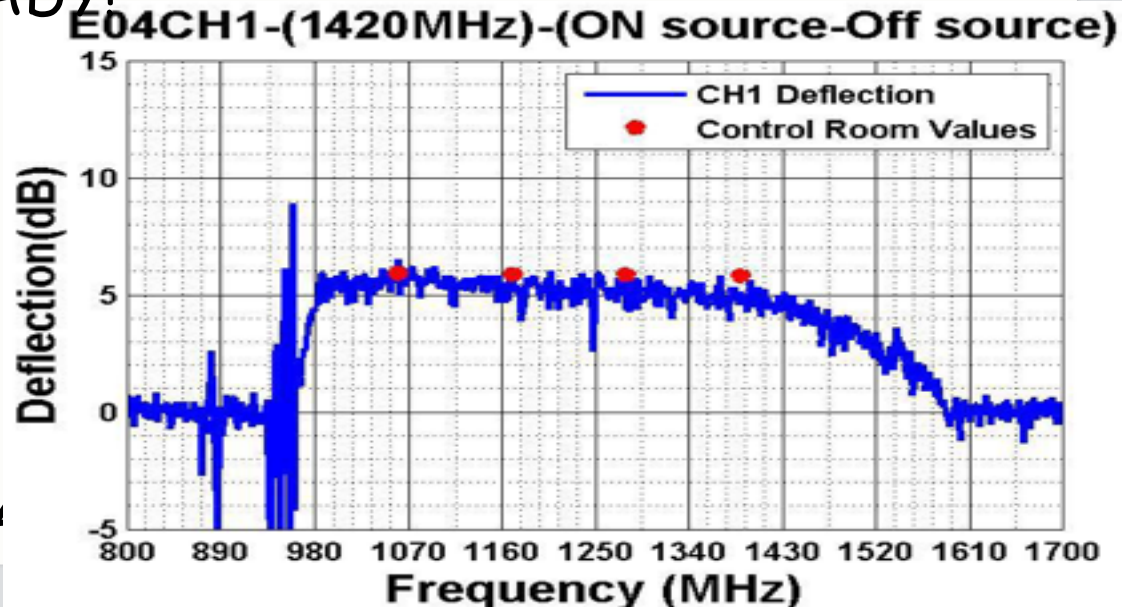
uGMRT: 250-500 MHz band (Band 3)

- Replaces existing 325 MHz system
- Broad-band (250-500 MHz) feed with good E-H pattern match
- Upgraded wideband FE system with new LNA: improved T_{sys} (22 K vs 36 K) & improved dynamic range
- Completed on all 30 antennas!
- Sufficient sets of spares

This system is also FULLY READY!

Credits: frontend team
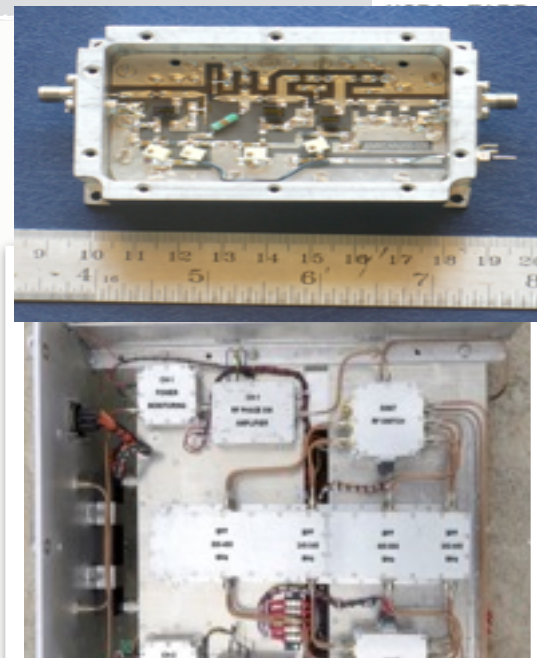
CDF250-500MHz: Deflection Test antenna via broadband optical link; RF Channel-I;

Legend:
— Deflection
— Expected Deflection

(Deflection (dB) vs frequency(MHz))
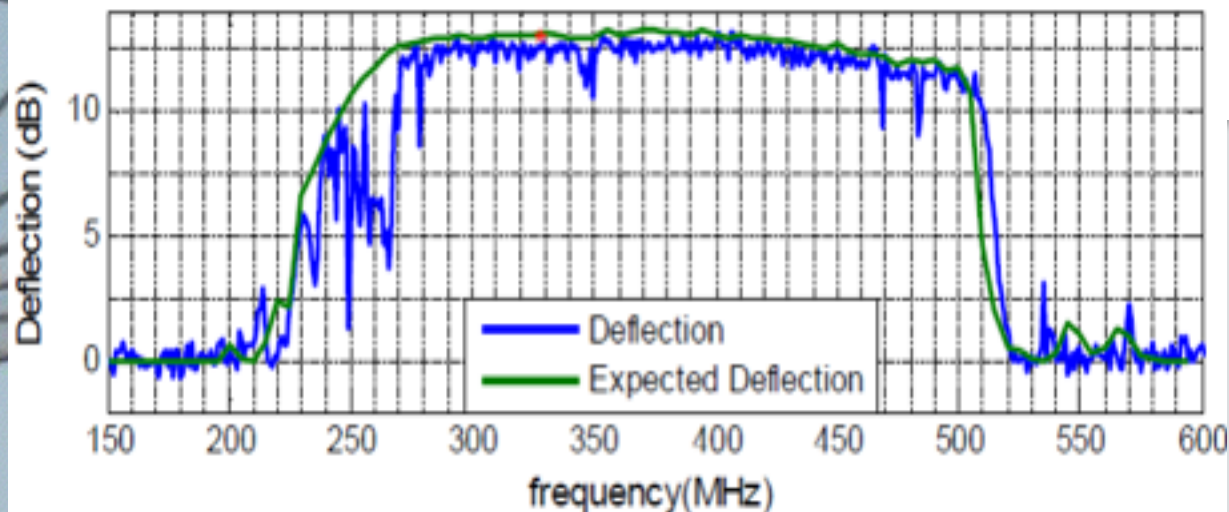
uGMRT: 550-900 MHz band (Band 4)

- Replaces existing 235/610 system
- Front-End system split into two parts :
  - Polariser + LNA is right next to feed (to minimise the loss)
  - Rest of the FE electronics is in the regular box
- Now installed on 19 antennas and growing…

CDF 550-900 MHz vs co-axial feed 610 MHz: Deflection test on CAS-A @ W01 antenna base; HRB; 14/06/2016

Existing co-axial feed @ 610 MHz
Upgrade feed @ 550-900 MHz
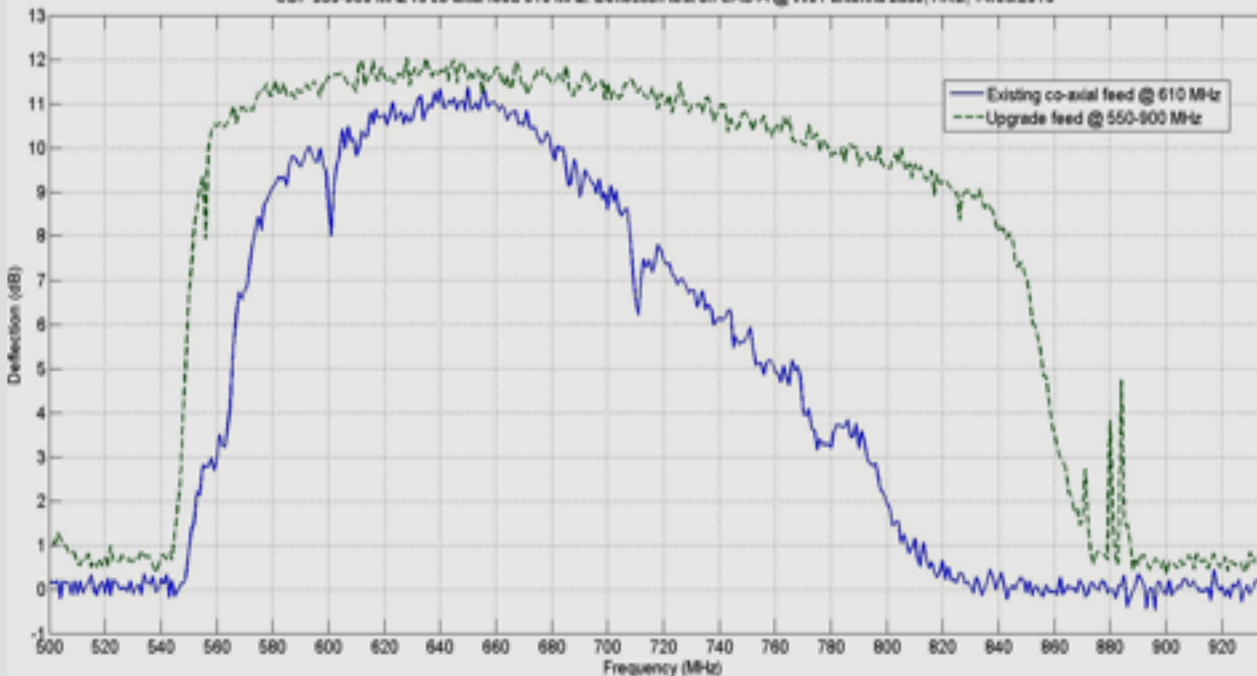
uGMRT: 120-250 MHz band (Band 2)

- Replaces existing 150 MHz system
- Broad-band feed for 120-250 MHz in final acceptance phase, installed on 9 antennas
- Sensitivity:
    - at 150 MHz, better than existing;
    - at 235 MHz comparable!

Credits: frontend team
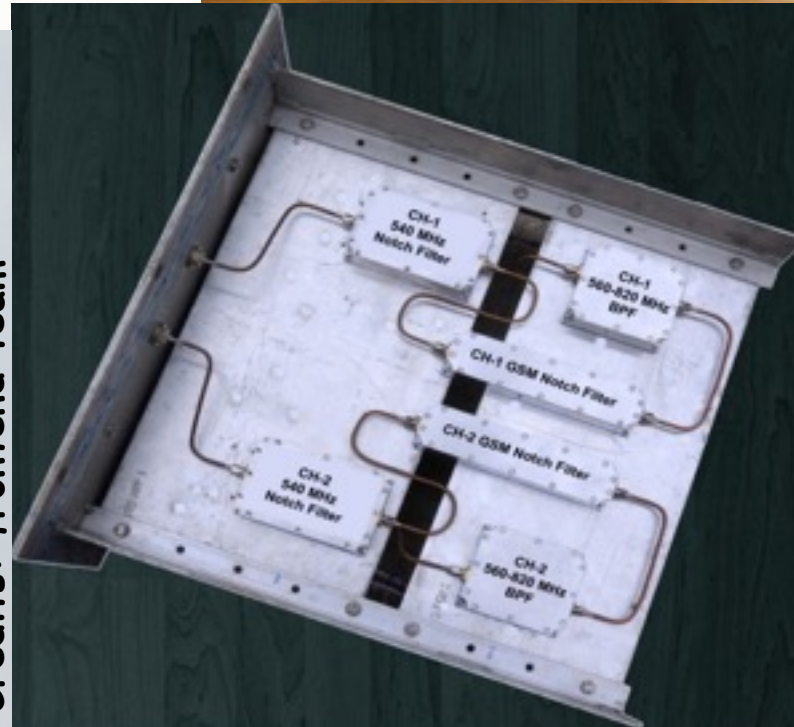
Summary (uGMRT): (wideband) systems

- Configuration of feeds, receivers and their current status:
  - Band 5 (1000 – 1450 MHz): existing wideband feed + improved dynamic range Rx with appropriate RFI filters - completed on 30 antennas!
  - Band 3 (250 – 500 MHz): cone-dipole feed + receiver is well into mass production & installation - completed on 30 antennas!
  - Band 4 (550 – 900 MHz): cone-dipole feed with matching receiver system finalized and now in mass production phase - 19 antennas completed.
  - Band 2 (120 – 250 MHz): modified Kildal (dual) ring feed + modified electronics in last stages of validation – populated on 9 antennas.
  - Band 1 (50 – 80 MHz): on hold at present.

Performance of several systems are monitored on a regular basis by respective teams - to keep the system in good health – next, we need to watch out for the growing RFI!

uGMRT: optical fibre systems

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

Credits: OF team

uGMRT: analog backend

⊞ Phase-I 30-antenna system installation completed.
⊞ Peripheral units under installation as part of phase-II.

Credits: backend team

uGMRT: digital backend

Antenna 1 (400 MHz 2 pols)	⇒	**ADC (2channels)**	⇒	**FPGA (packetizer)**	⇒	**CPU + GPU (correlator)**

Antenna 1 (400 MHz 2 pols) ⇒ **ADC (2channels)** ⇒ **FPGA (packetizer)** ⇒ **CPU + GPU (correlator)** ⇕

Antenna 2 (400 MHz 2 pols) ⇒ **ADC (2channels)** ⇒ **FPGA (packetizer)** ⇒ **CPU + GPU (correlator)** ⇕

Antenna 32 (400 MHz 2 pols) ⇒ **ADC (2channels)** ⇒ **FPGA (packetizer)** ⇒ **CPU + GPU (correlator)** ⇕

Switch (40 Gbe)

CPU + GPU (correlator)

CPU + GPU (correlator)

CPU + GPU (correlator)

⇕ **Data Acquisition and Control**

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

uGMRT: (now GWB IV)

- BW: 400 MHz, upto 16K channels
- t_{int}: 0.67 sec
- IA/PA Beamformer
- Upgrade to 32 stations (January 2017)

uGMRT: Mechanical improveme

- A <u>major upgrade</u>
- Antenna surface
- BLDC
- Mechanical
  - HLP, gearbox, etc.
- M-&-C system
- Servo control computer
- Electrical system
  - (RFI friendly) UPS
- Workshop machinery
- ...

Credits: mechanical team
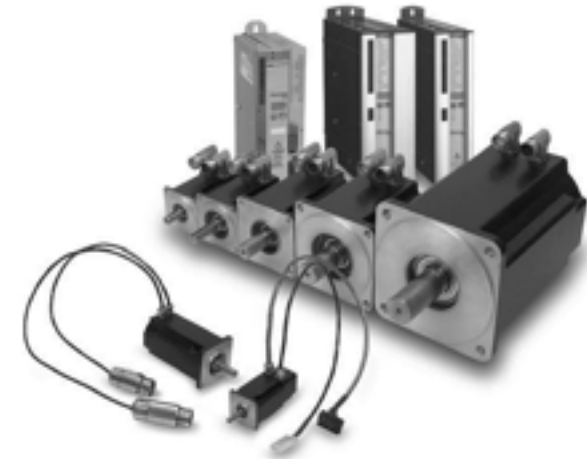
), 18 July 2017

uGMRT

The upgraded GMRT: expected amount of improvement

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uGMRT *vs.* GMRT: frequency coverage

NCRA • TIFR

- Fractional bandwidth
  - old and new

Credits: Ruta Kale

Δv/v

0.7 — 120 – 250 Band-2
0.21, 0.14 — 120 – 250 Band-2

0.67 — 250 – 500 Band-3
0.1 — 250 – 500 Band-3

0.43 — 550 – 850 Band-4
0.05 — 550 – 850 Band-4

0.32 — 1050 – 1450 Band-5
0.02 — 1050 – 1450 Band-5

Frequency (**V**) MHz
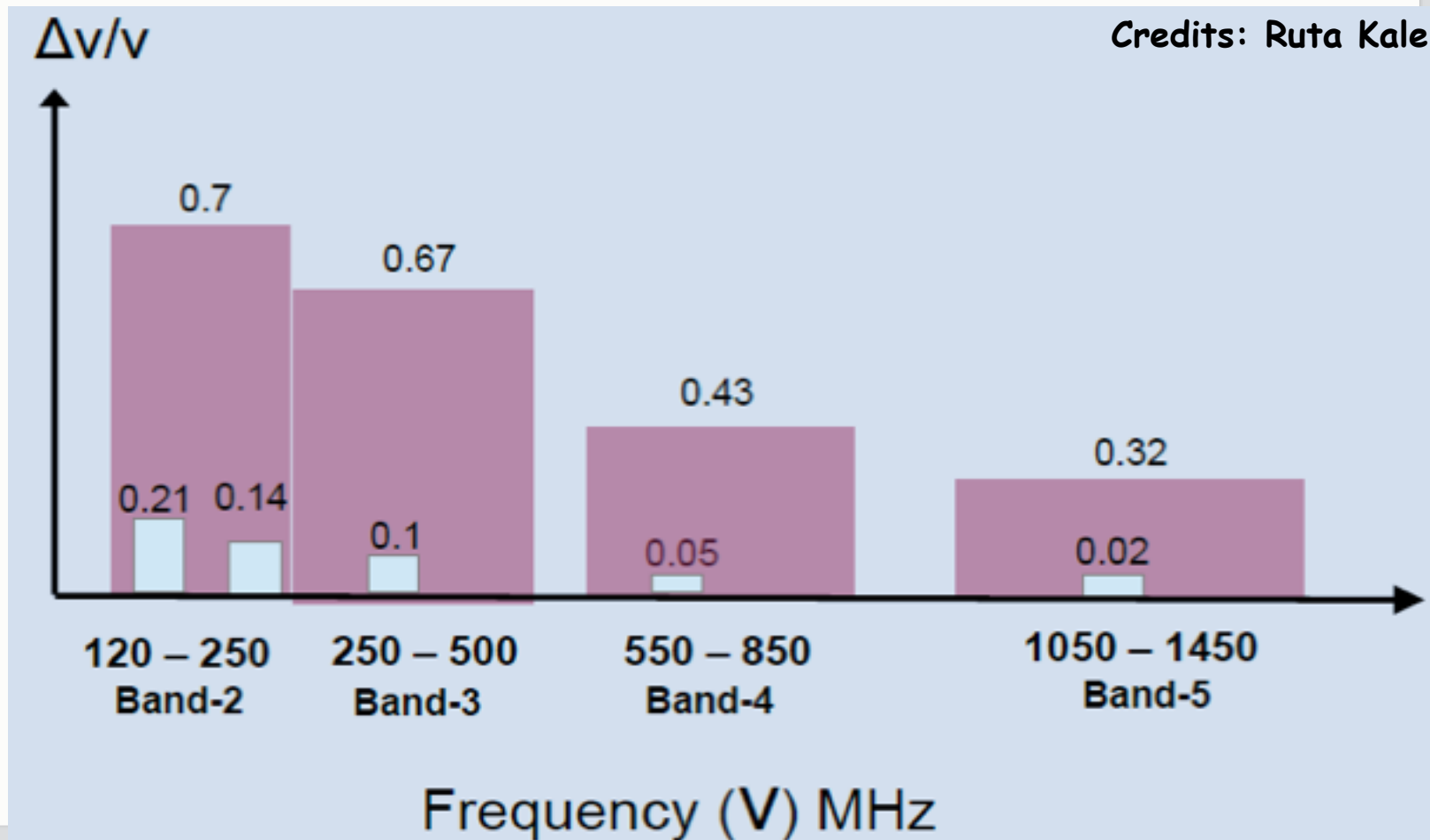
uGMRT: Expected performance

- 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 10s of cm-wavelengths

**Credits: N. Kanekar**
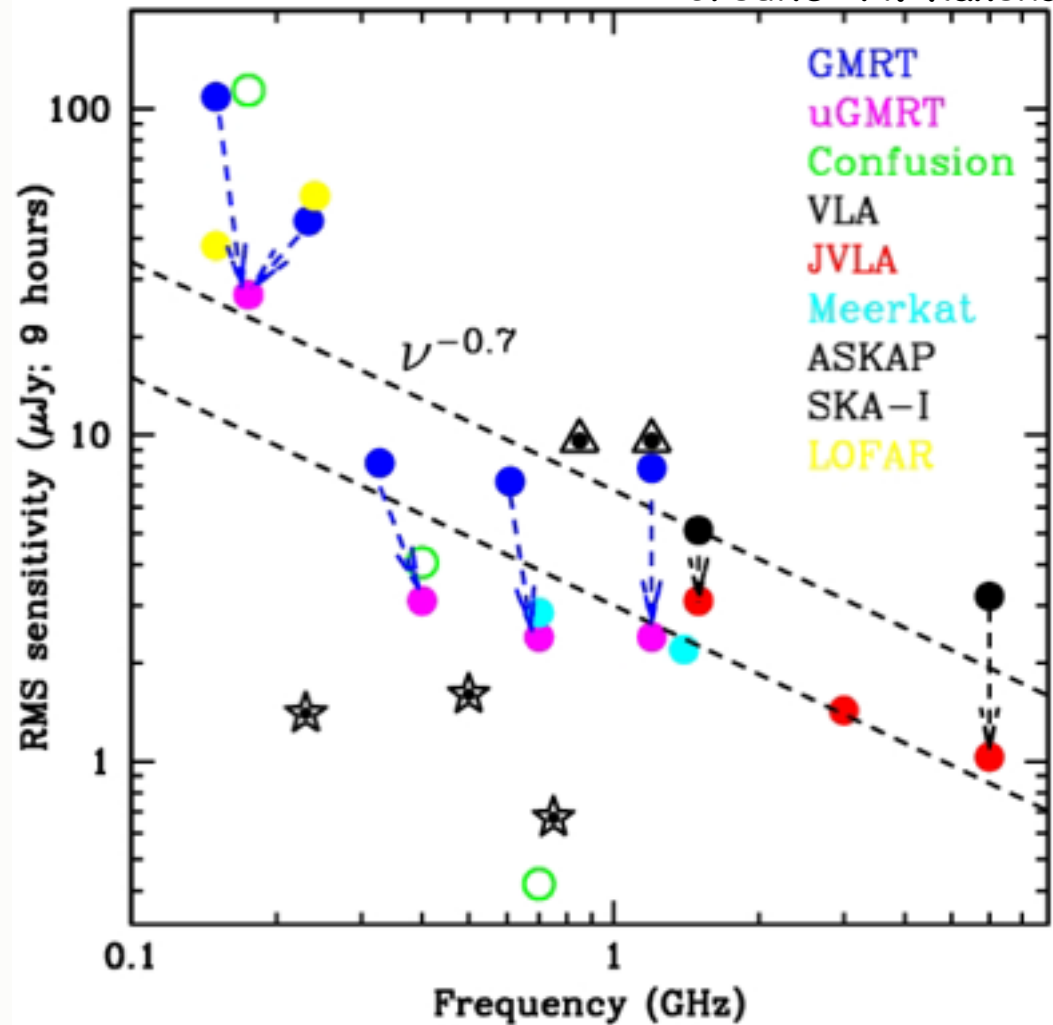
Expected sensitivity performance of the uGMRT and ...

uGMRT: Expected performance
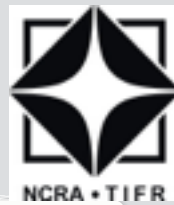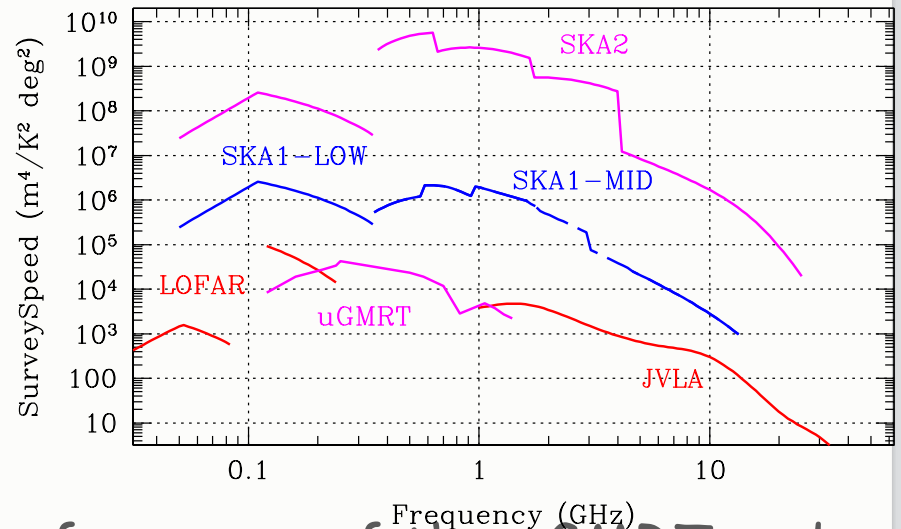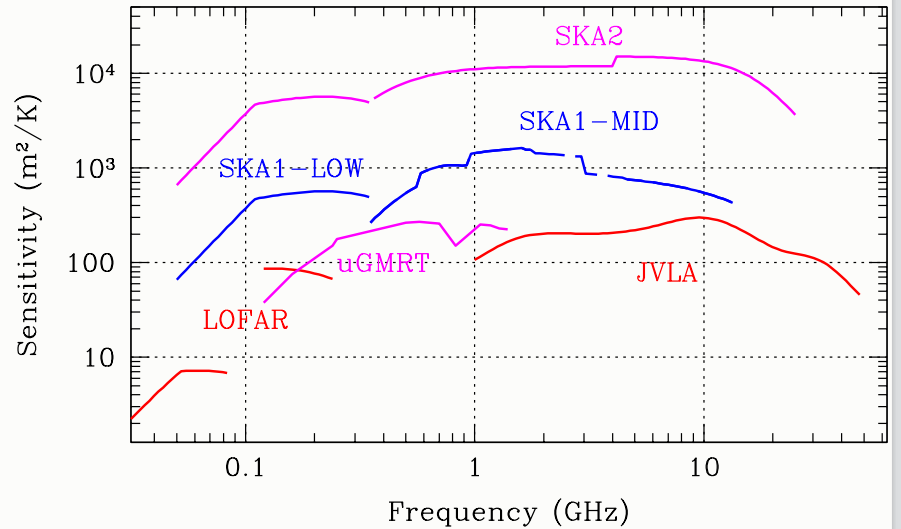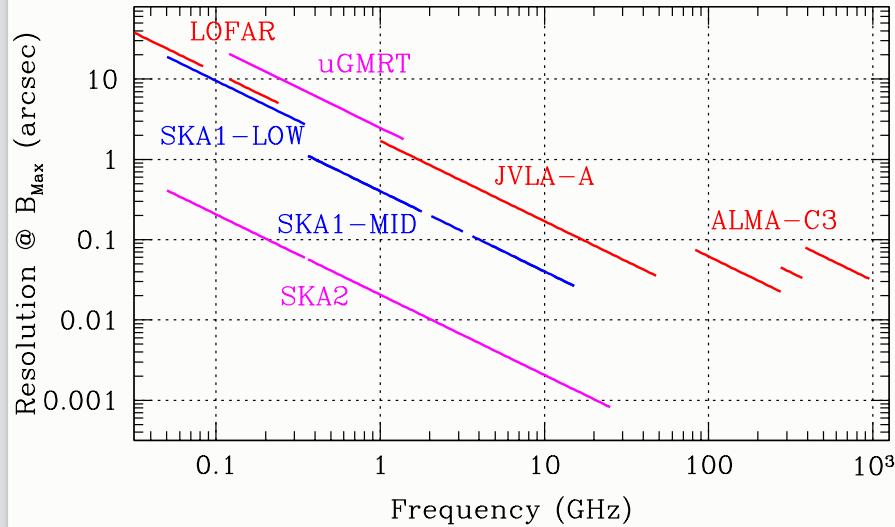
Expected sensitivity performance of the uGMRT and ...

The upgraded GMRT:
# a working instrument!

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uGMRT: Wideband

- Larger bandwidth
  - better sensitivity
  - 32 MHz -> 200 MHz => 2.5 times increase in sensitivity
- Increased (u,v) coverage
  - lower side-lobe levels of psf => better dynamic range
- Information of spectral structure of the source.

uGMRT: (u,v) coverage
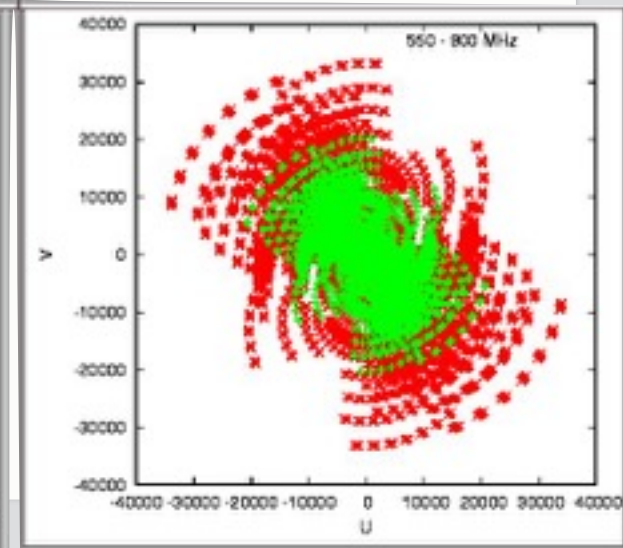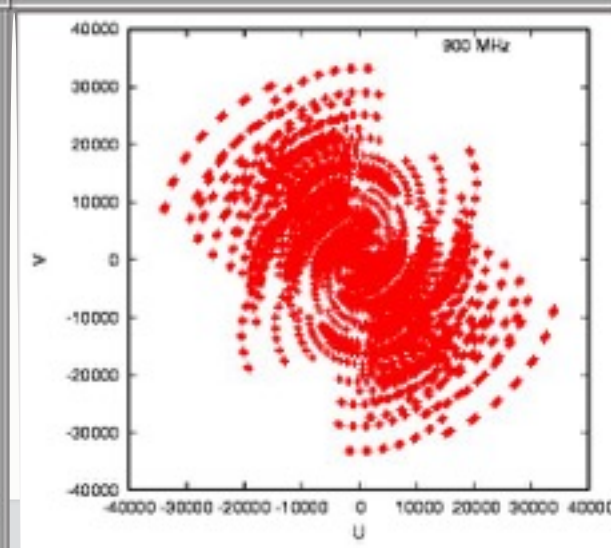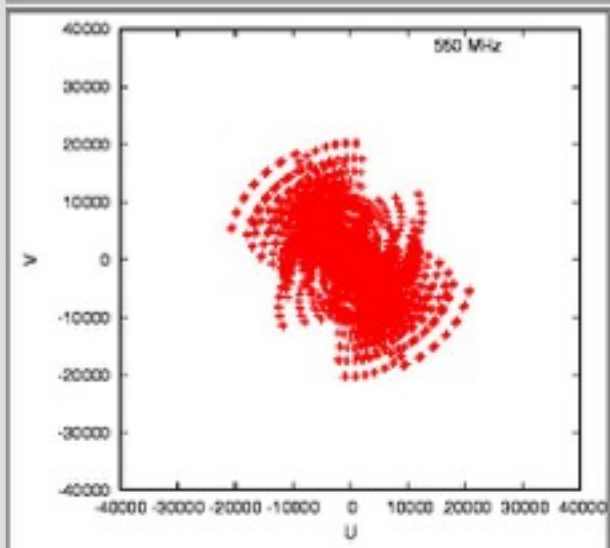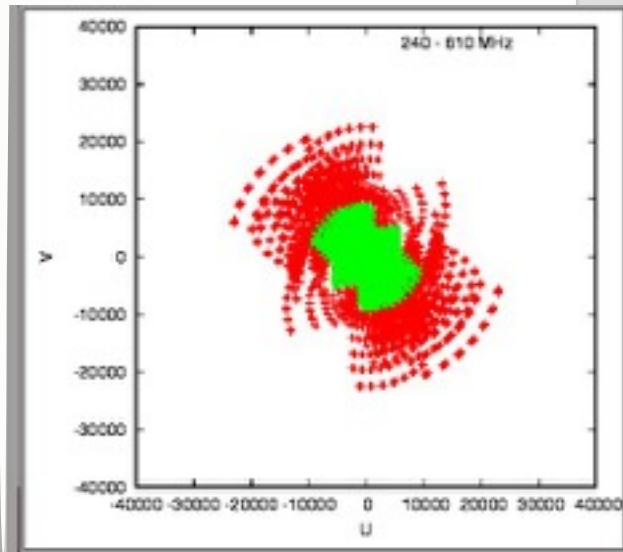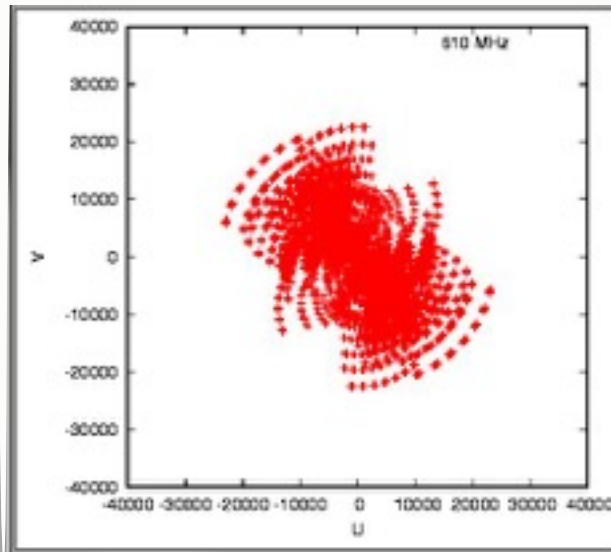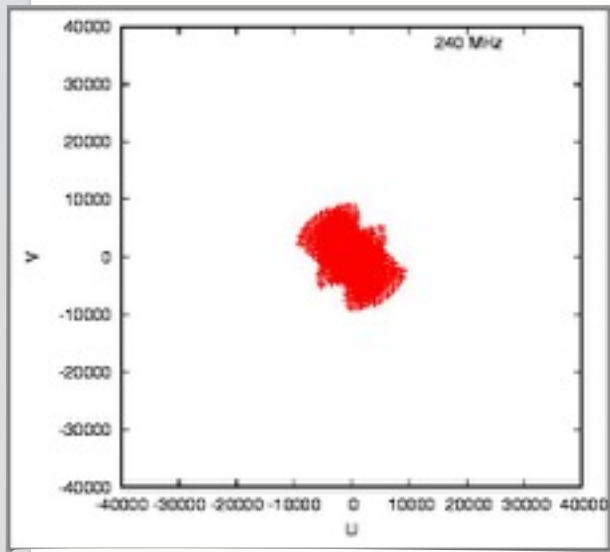
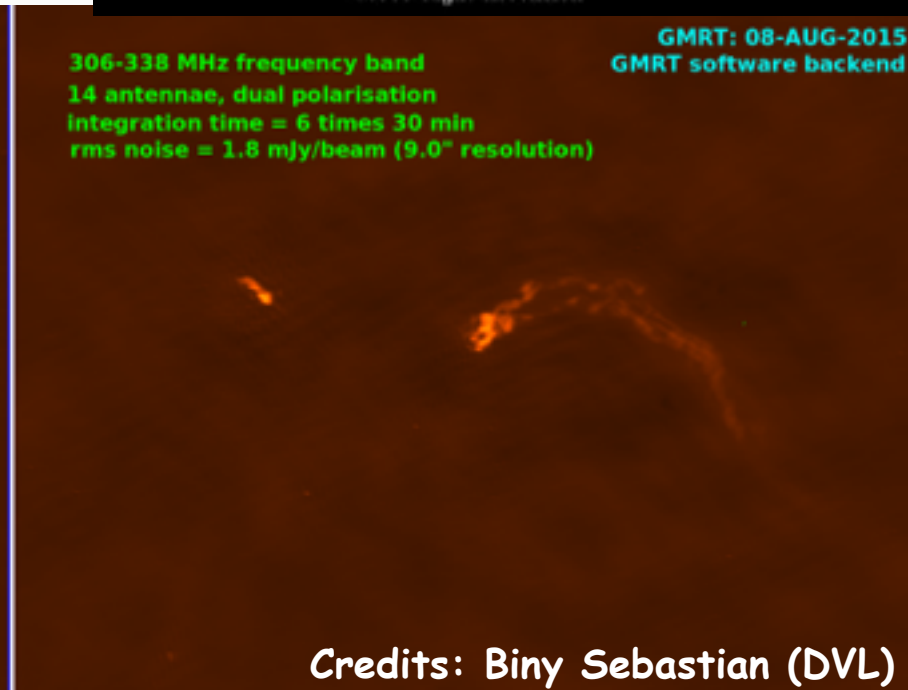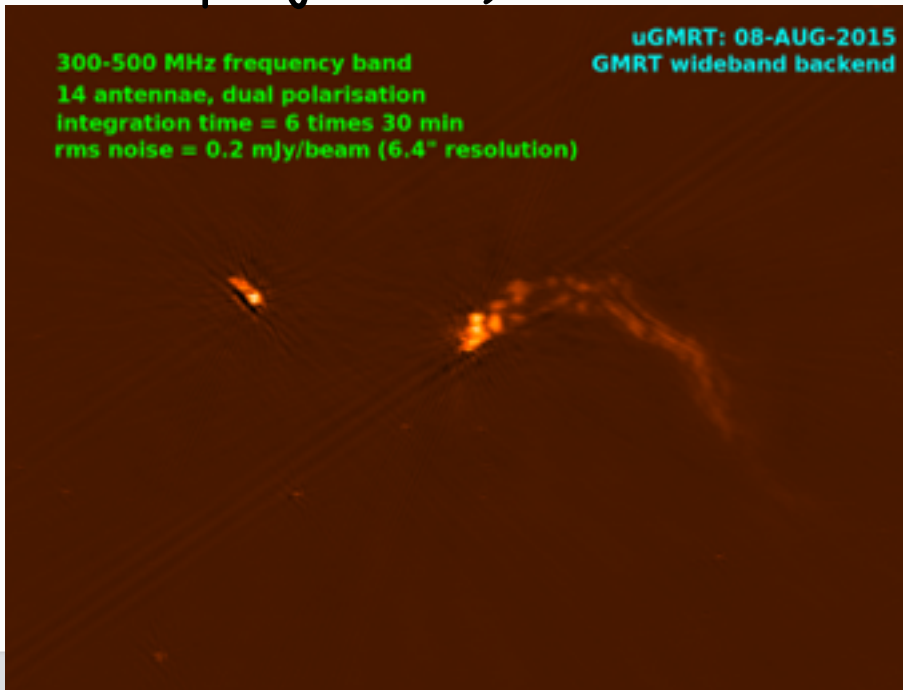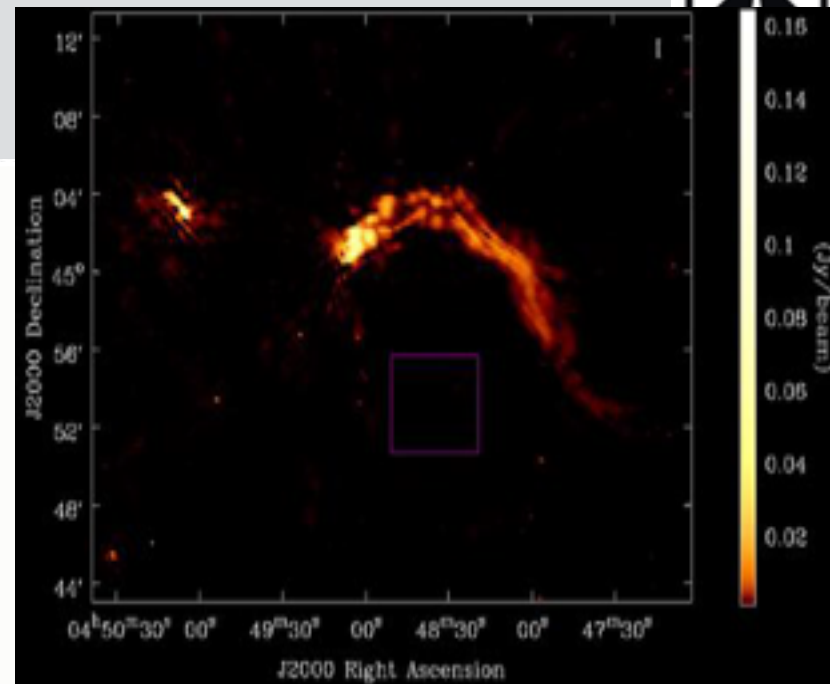# uGMRT: Challenges

Wide field imaging, DD-calibration, A-projection Primary beam and MS-MFS,and several of these can only be done in CASA.

Credits: B. Sebastian
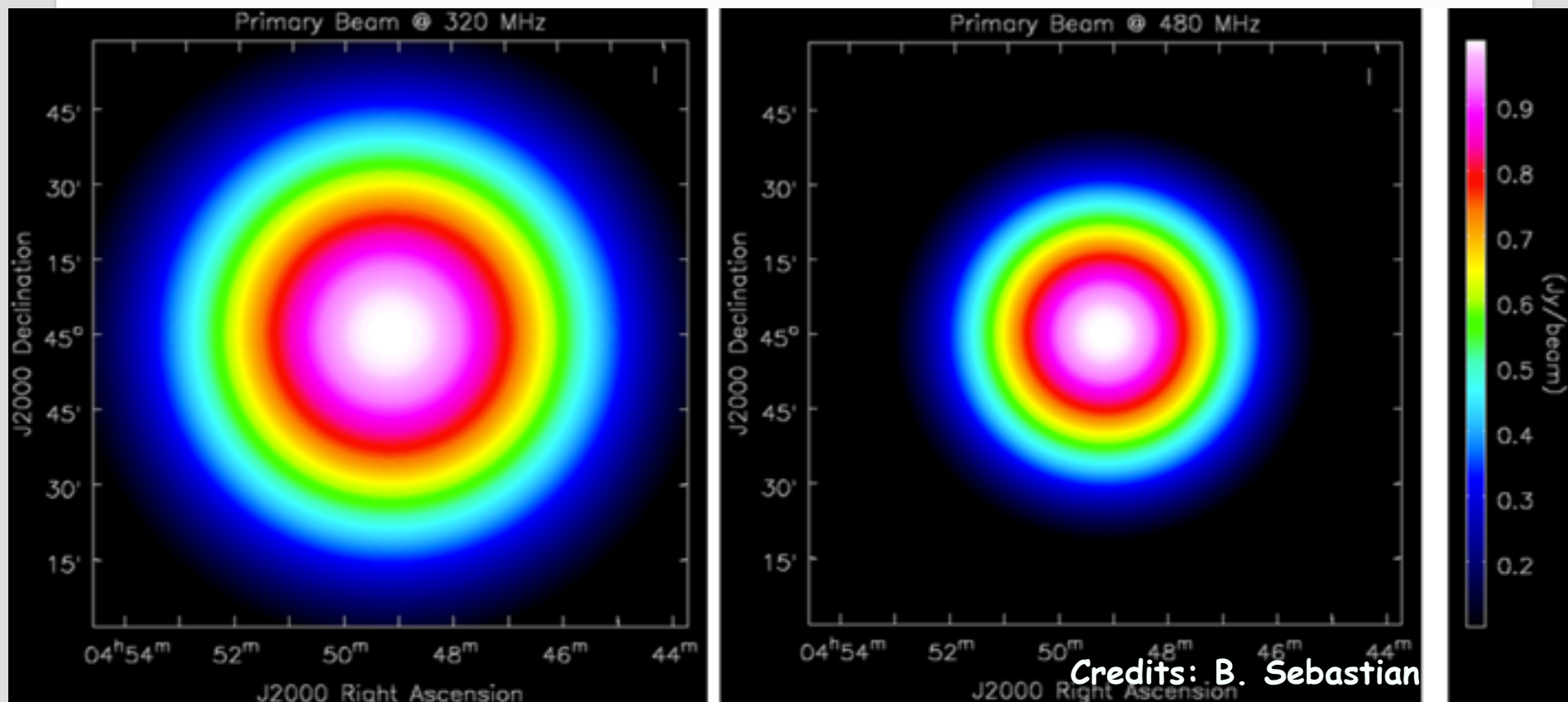
uGMRT: 3C129

- 200 MHz bandwidth
- 80 microJy rms
- ~3 hr on-source t_{int}
- 14 antennas
  - calibration in AIPS
  - imaging in CASA (ms-mfs, w-projection)

uGMRT: 08-AUG-2015
GMRT wideband backend

300-500 MHz frequency band
14 antennae, dual polarisation
integration time = 6 times 30 min
rms noise = 0.2 mJy/beam (6.4" resolution)

GMRT: 08-AUG-2015
GMRT software backend

306-338 MHz frequency band
14 antennae, dual polarisation
integration time = 6 times 30 min
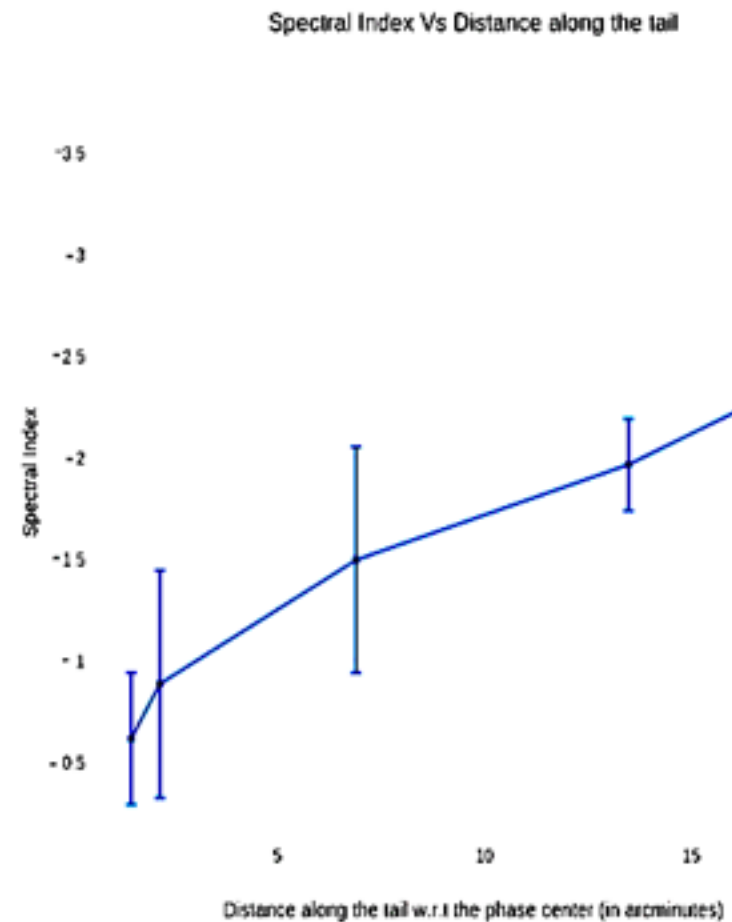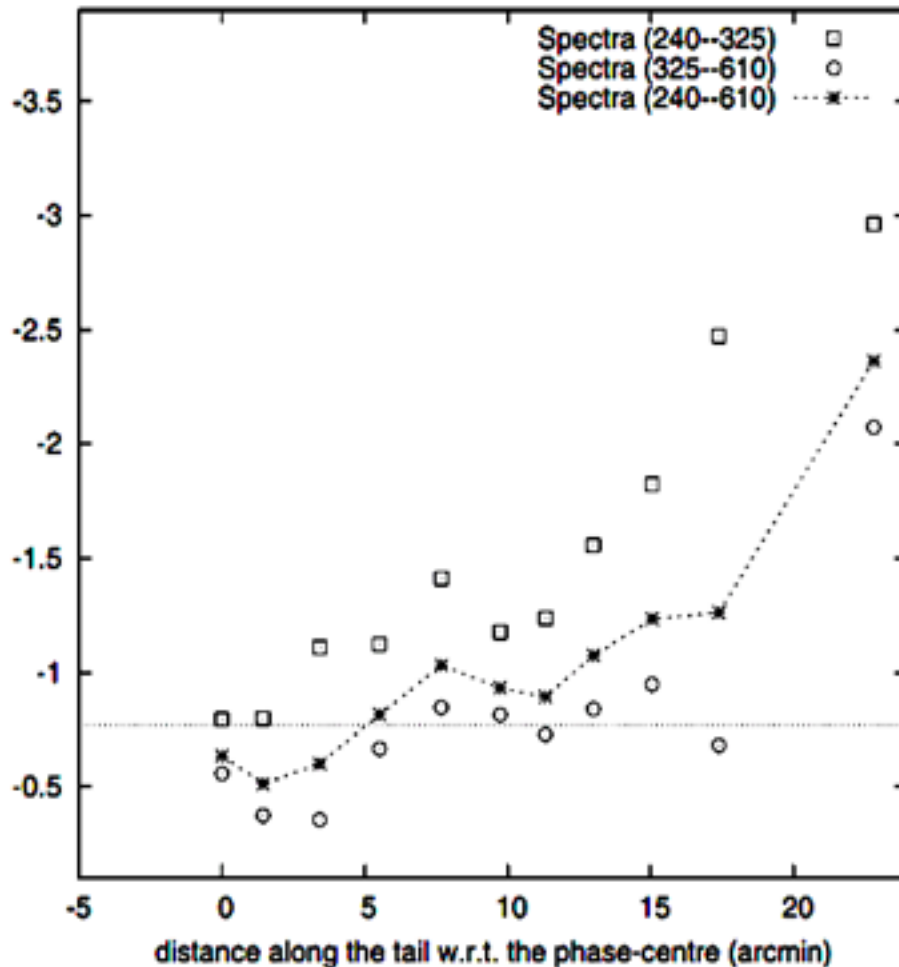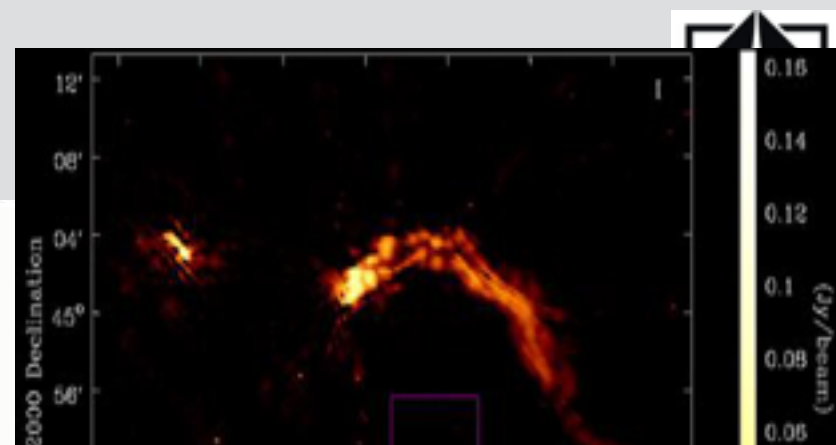rms noise = 1.8 mJy/beam (9.0" resolution)

Credits: Biny Sebastian (DVL)

uGMRT: 3C129

- z = 0.021
- uGMRT verification science
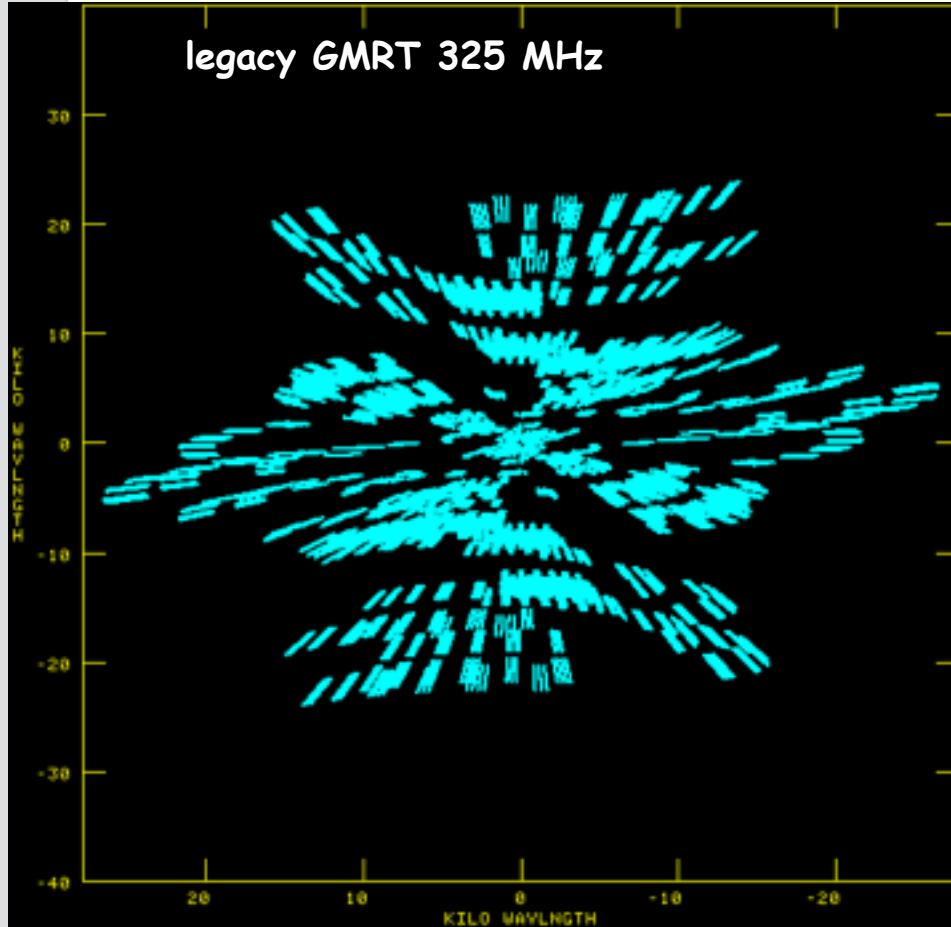
uGMRT

A85 (Relics / … / dead radio plasma)

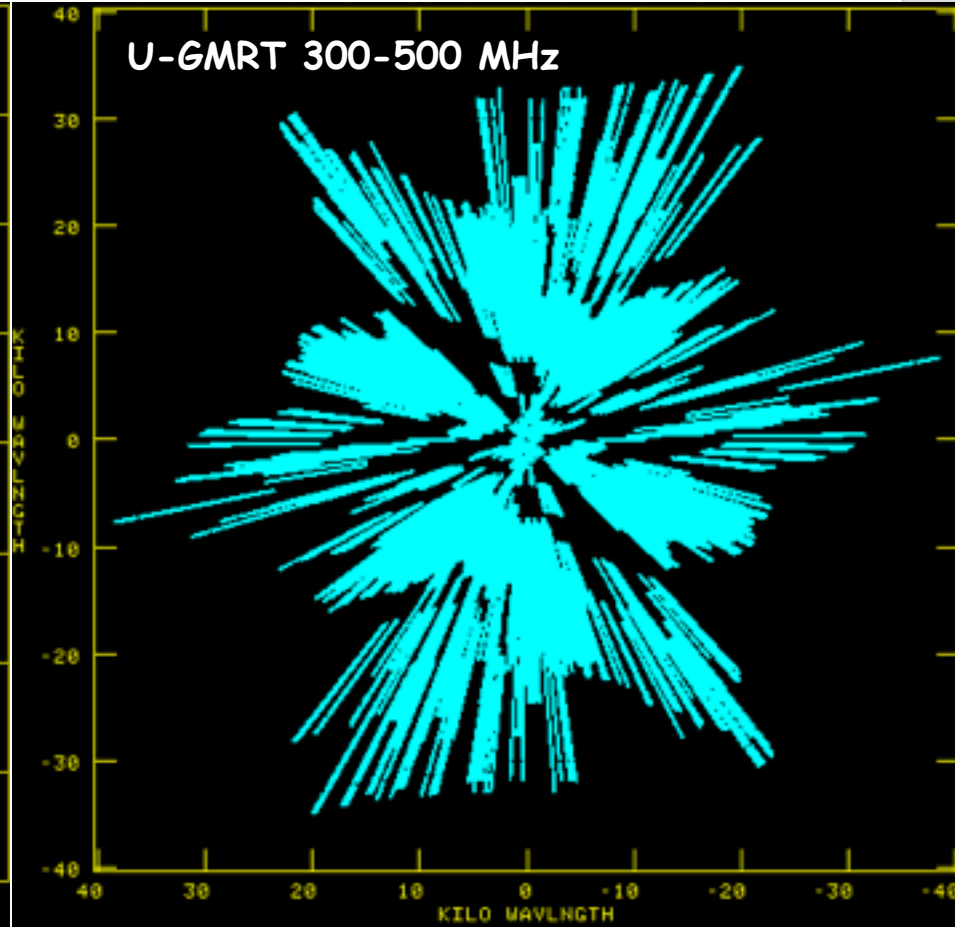(demo science: Ishwara-Chandra C.H. and D.V. Lal)

- z = 0.055

legacy GMRT 325 MHz

U-GMRT 300-500 MHz

uGMRT: Image fidelity

- Abell 85 (relic / ... / dead radio plasma)
- z = 0.055

Ishwara-Chandra + DVL
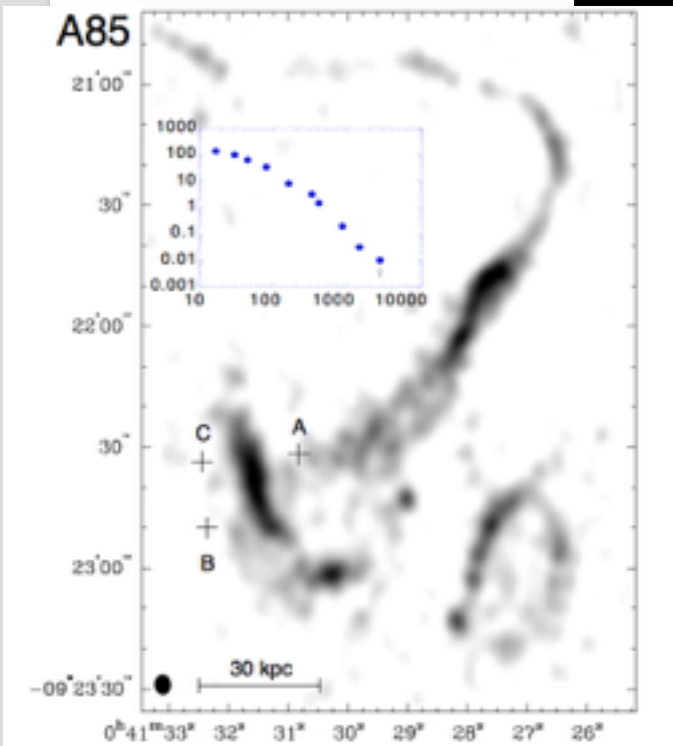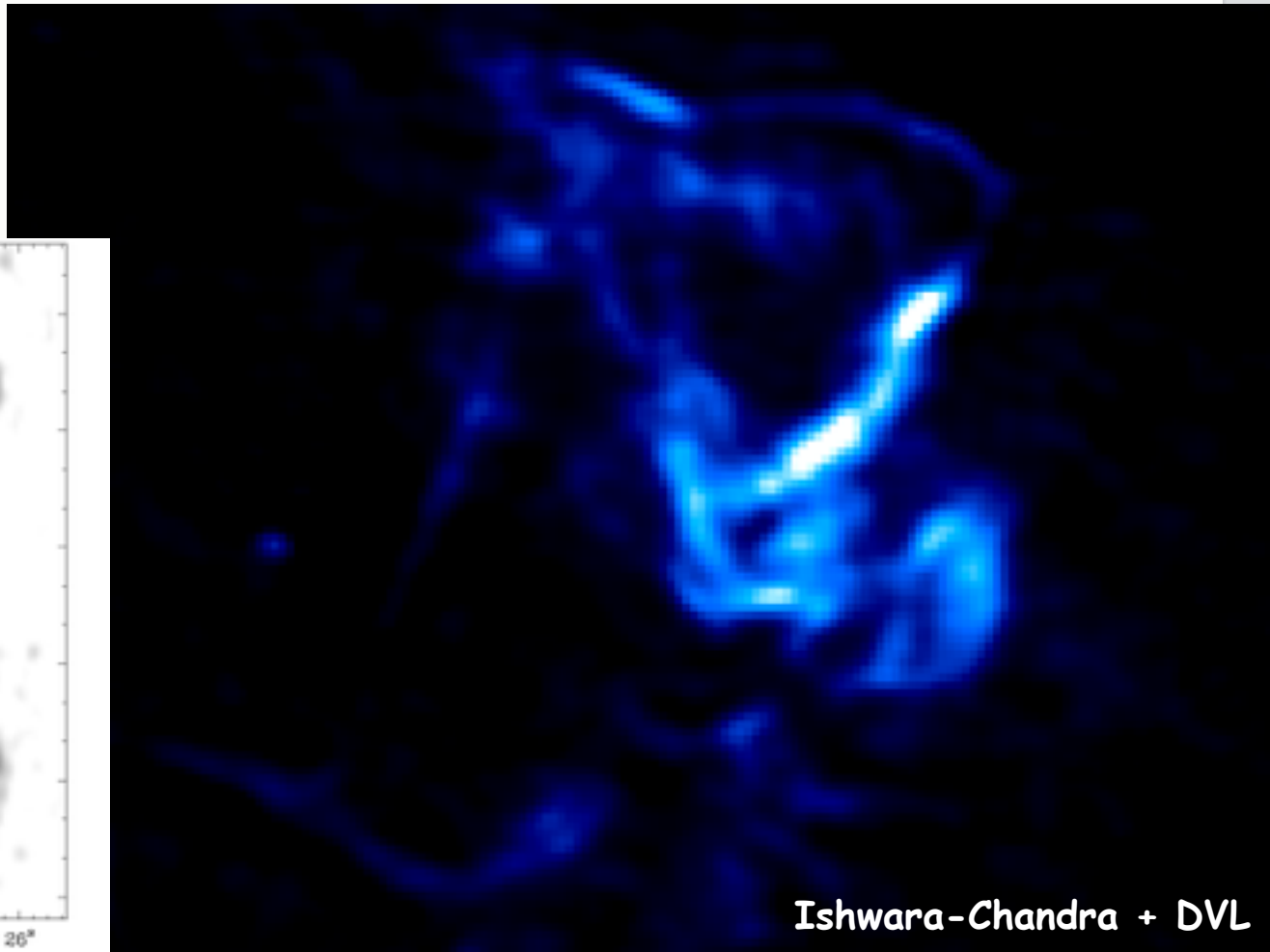
uGMRT

The upgraded GMRT:
a working instrument!
spectral-line
pulsars

…

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External sources of RFI

Broadband RFI

Sparking

Narrowband RFI

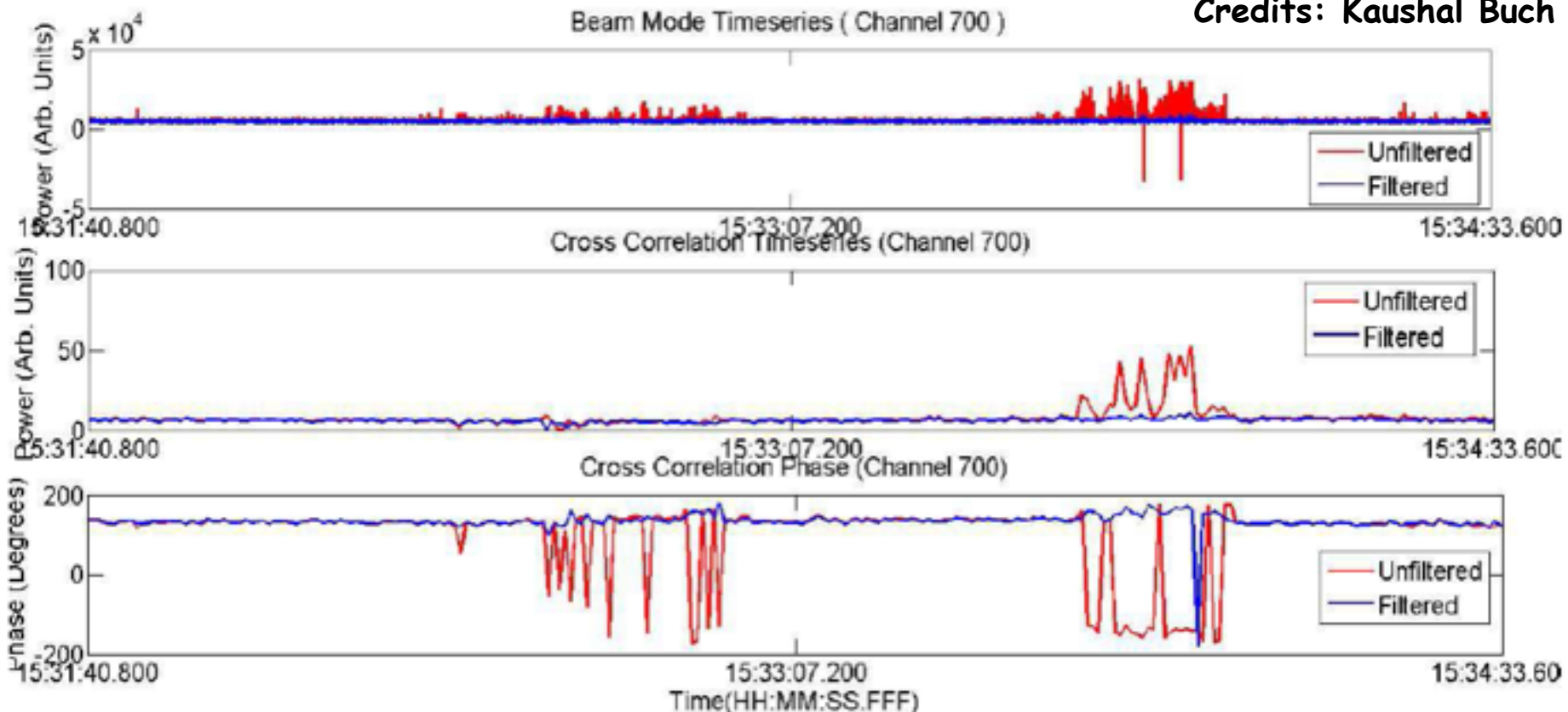Image Courtesy: Wikipedia

uGMRT: radio frequency interference

⊕ Real-time filter running on BB voltage data of each antenna
⊕ panels show effect of this filtering,
- ⊕ in beamformer time series (top) and
- ⊕ in visibility domain data (bottom-two!)

Credits: Kaushal Buch

uGMRT: Avoiding RFI from satellites

✤Real-time prediction of positions of known satellites
  ✤both stationary and moving…
✤Real-time warning when observing antenna beam comes within zone of avoidance (decided by beam-width and strength of signal from satellite)
✤Predictive warning: can work on your submitted observing file
✤Post-facto warning: can work on your recorded data file
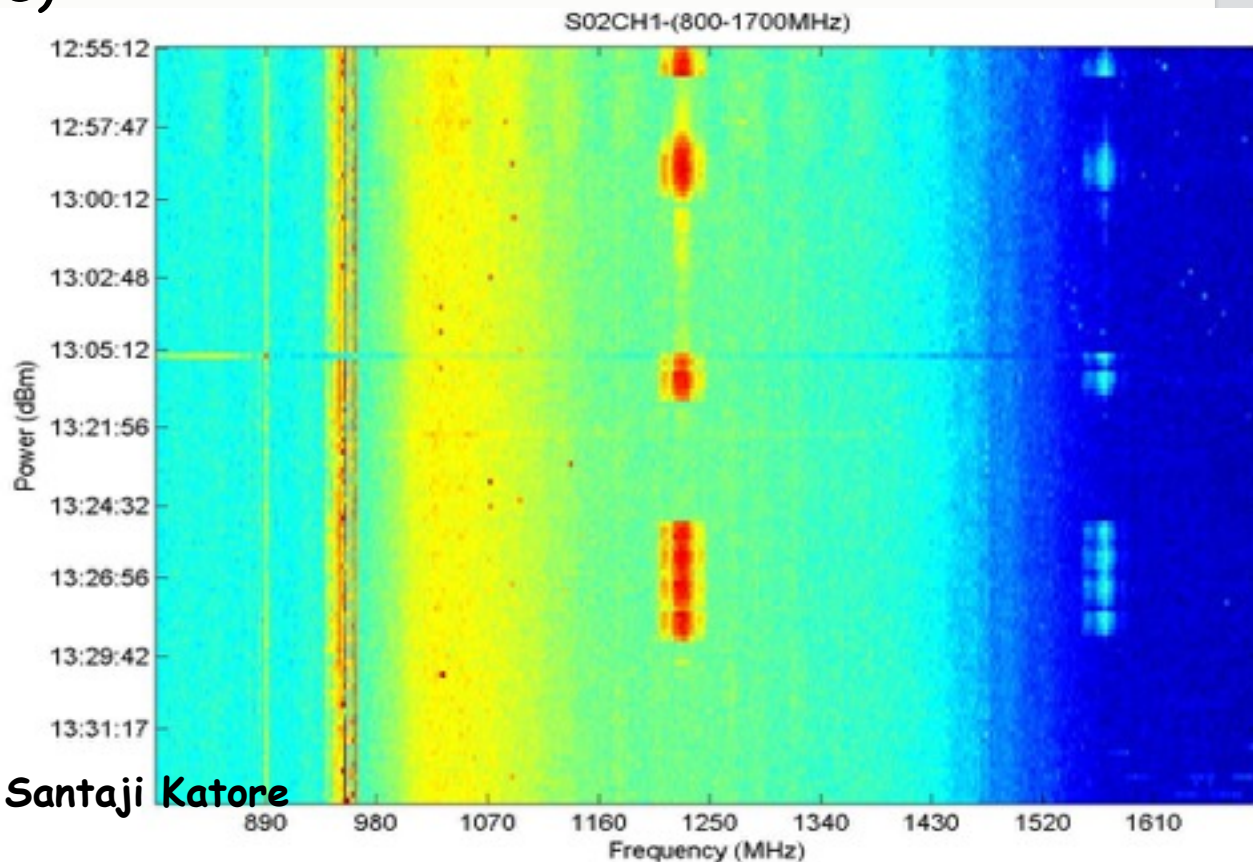
Credits: K. Buch / Santaji Katore

S02CH1-(800-1700MHz)

uGMRT

The upgraded GMRT: Continuum surveys

…

legacy GMRT: continuum surveys (TGSS)

⊞ TGSS
   (talks by Jess / Natasha)

The GMRT 150 MHz All-sky Radio Survey: First Alternative Data Release TGSS ADR1

H.T. Intema, P. Jagannathan, K.P. Mooley, D.A. Frail

(Submitted on 14 Mar 2016 (v1), last revised 13 Oct 2016 (this version, v2))

We present the first full release of a survey of the 150 MHz radio sky, observed with the Giant Metrewave Radio Telescope between April 2010 and March 2012 as part of the TGSS project. Aimed at producing a reliable compact source survey, our automated data reduction pipeline efficiently processed more than 2000 hours of observations with minimal human interaction. Through application of innovative techniques such as image-based flagging, direction-dependent calibration of ionospheric phase errors, correcting for systematic offsets in antenna pointing, and improving the primary beam model, we created good quality images for over 95 percent of the 5336 pointings. Our data release covers 36,900 square degrees (or 3.6 pi steradians) of the sky between −53 deg and +90 deg DEC, which is 90 percent of the total sky. The majority of pointing images have a background RMS noise below 5 mJy/beam with an approximate resolution of 25" x 25" (or 25" x 25" / cos (DEC − 19 deg) for pointings south of 19 deg DEC). We have produced a catalog of 0.62 Million radio sources derived from an initial, high reliability source extraction at the 7 sigma level. For the bulk of the survey, the measured overall astrometric accuracy is better than 2" in RA and DEC, while the flux density accuracy is estimated at ~10 percent. Within the scope of the TGSS ADR project, the source catalog as well as 5336 mosaic images (5 deg x 5 deg) and an image cutout service, are made publicly available online as a service to the astronomical community. Next to enabling a wide range of different scientific investigations, we anticipate that these

legacy GMRT: continuum surveys (TGSS)

⊞ TGSS
   (talks by Jess / Natasha)

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Astrophysics > Cosmology and Nongalactic Astrophysics

The GMRT 150 MHz All-sky Radio Survey: First Alternative Data Release TGSS ADR1

H.T. Intema, P. Jagannathan, K.P. Mooley, D.A. Frail

We present the first full release of a survey of the 150 MHz radio sky, observed with the Giant Metrewave ... Aimed at producing a ... processed more than ... of innovative ... spheric phase errors, ... eam model, we created ... overs 36,900 square ... is 90 percent of the ... nJy/beam with an ... gs south of 19 deg ... itial, high reliability ... erall astrometric ... ed at ~10 percent. ... aic images (5 deg x 5 ... the astronomical ... anticipate that these
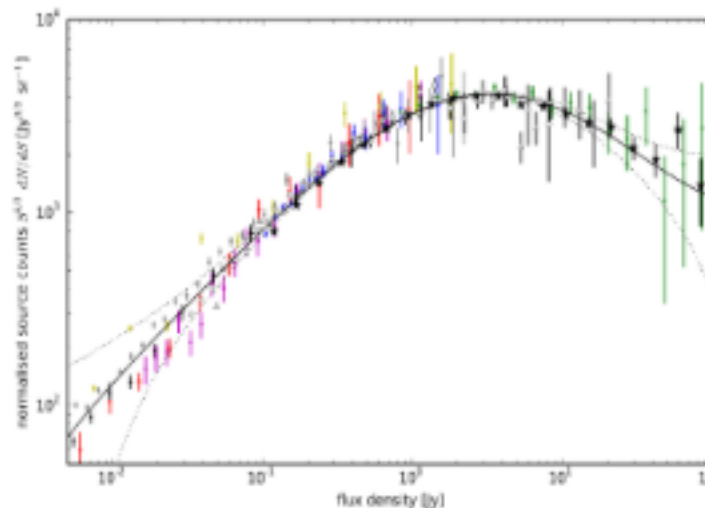
sky coverage

source counts at 150 MHz
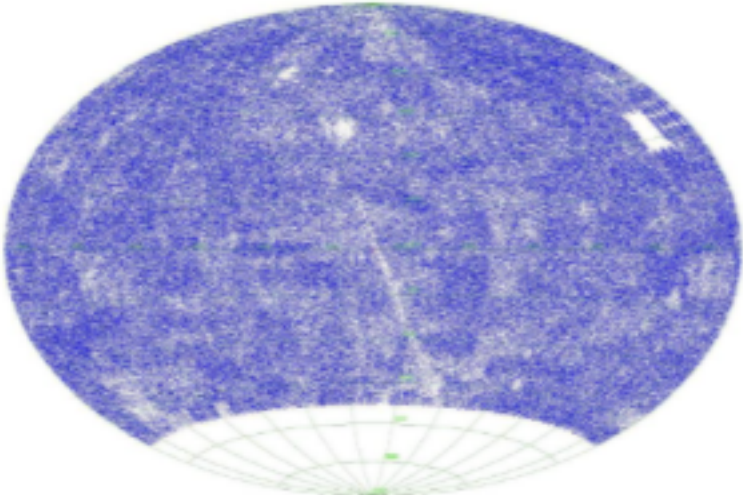
legacy GMRT: continuum (archive project)

⊕ TGSS and

⊕ GMRT archival survey project

   (reaching out to larger user base)

   (H. Intema, Ishwara-Chandra CH & Y. Wadadekar)

⊕ New SPAM pipeline to process all legacy continuum obs.

⊕ AIM: to deliver (near-) science-ready data products to the astronomical community

⊕ data products will be linked to observations regular GMRT archive interface

GMRT Online Archive

Logout   Profile   Help

This interface allows one to view the data. In order to download the data you have to log in.
The login and password are same as that for the NAPS system. There is no need to re-register if you have NAPS account.
To provide feedback, report system related issues or problems, please emails us at goa@ncra.tifr.res.in

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Title : Filling the gaps in the 150 MHz GMRT sky survey

Observation	Add to cart	Source	RA 2000	DEC 2000	Time on src(Mins)	Frequency 1(MHz)	Frequency 2(MHz)	Channel Width(KHz)
9026	Add to cart	0116-208	1h16m51s	-20d52m7s	20	156.0	156.0	65.1
		3C48	1h37m41s	33d9m35s	22	156.0	156.0	65.1
		R05D07	1h20m0s	-40d50m6s	14	156.0	156.0	65.1
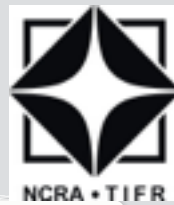
400MUGS:
400 MHz uGMRT survey
(PI: Francesco de Gasperin)

...

uGMRT: continuum surveys (400MUGS)

- Observing strategy:
  - 5 min per pointing
    - in 3 epochs, each of 100 sec
  - 40k pointings (in phase I & II)
  - 300-500 MHz (band-3)
  - 7" angular resolution
  - 0.3 mJy/beam
  - sky coverage - 40% (phase I) and 90% (phase I & II)
  - wrt WENSS
    - 10 x better rms noise
    - 10 x better angular resolution!
  - Complementary data:
    - Lofar LBA sky survey (LoL-SS) 42-66 MHz

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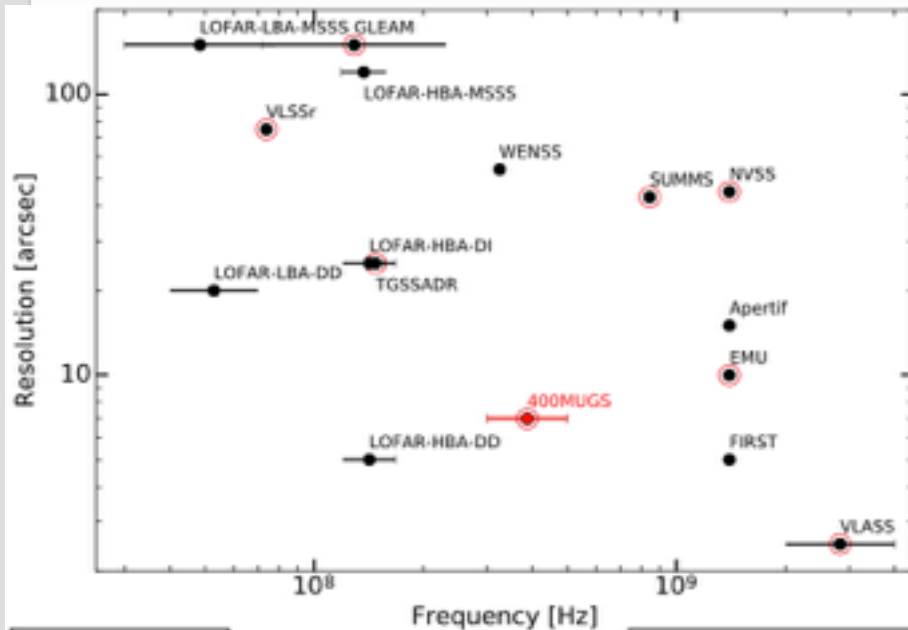
uGMRT: continuum surveys (400MUGS)

- Science cases:
  - AGN accretion modes => galaxy evolution
  - unbiased selection of 10s of 1000s of LLAGN
  - morphological studies
    (including X-shaped, DD, HYMORs, …)
  - AGN (radio-band SEDs)
  - radio-FIR relation
  - fast transients (n*, brown dwarfs,…)
  - high-z radio galaxies
  - cosmology:
    - clustering, …

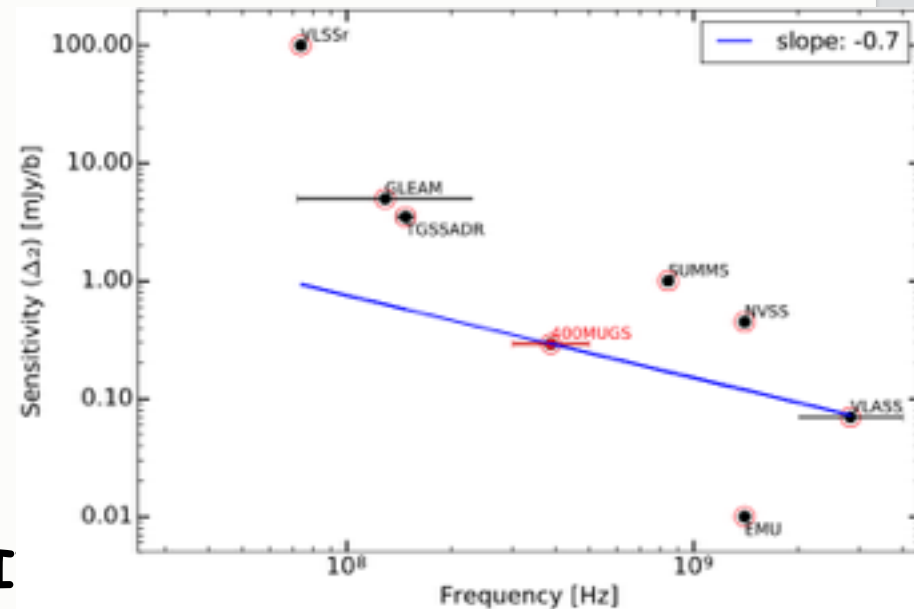**SPARCS VII (ICRAR, Perth), 18 July 2017**

uGMRT: continuum surveys (400MUGS)

- 400MUGS vs. ...:

Resolution: 7"   Freq: 300-500 MHz

Sensitivity: <300 uJy/b   Freq: 300-500 MHz

uGMRT: continuum su

- 400MUGS vs. …:

uGMRT: continuum surveys (400MUGS)

- Status:
  - GAMA12
  - COSMOS
  - Galactic plane
  - Hydra A
- 5 hr DDT time (end of Nov 2017)
- 52 hrs (Feb 2017)

Sky region	Dec range	Coverage	Total hours	Number of sources
Phase 1 - Southern sky	$-40° < \delta < 10°$	40%	2271	2.0 millions
Phase 2 - Full sky	$\delta > -53°$	90%	5110	4.4 millions

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uGMRT: continuum surveys (400MUGS)

- Status:
  - GAMA12
  - COSMOS
  - Galactic plane
  - Hydra A
- 5 hr DDT time (end of Nov 2017)
- 52 hrs (Feb 2017)

- An ex. -
  - 60 pointings
  - 3 x 100 s per pointing!
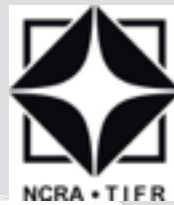 - some data has been processed

uGMRT 31_008 GAMA 9 Feb 27 pointings selected from the 400MUGS 45,000 all-sky pointings scheme
FWHM = 1.13° | $N_{selected}$ = 60 | $\langle \theta_{slew} \rangle$ = 0.973° | RA_{center} = 129.5° | δ_{center} = 3°

- - - slewing path
  ● 400MUGS pointings
  ● field center
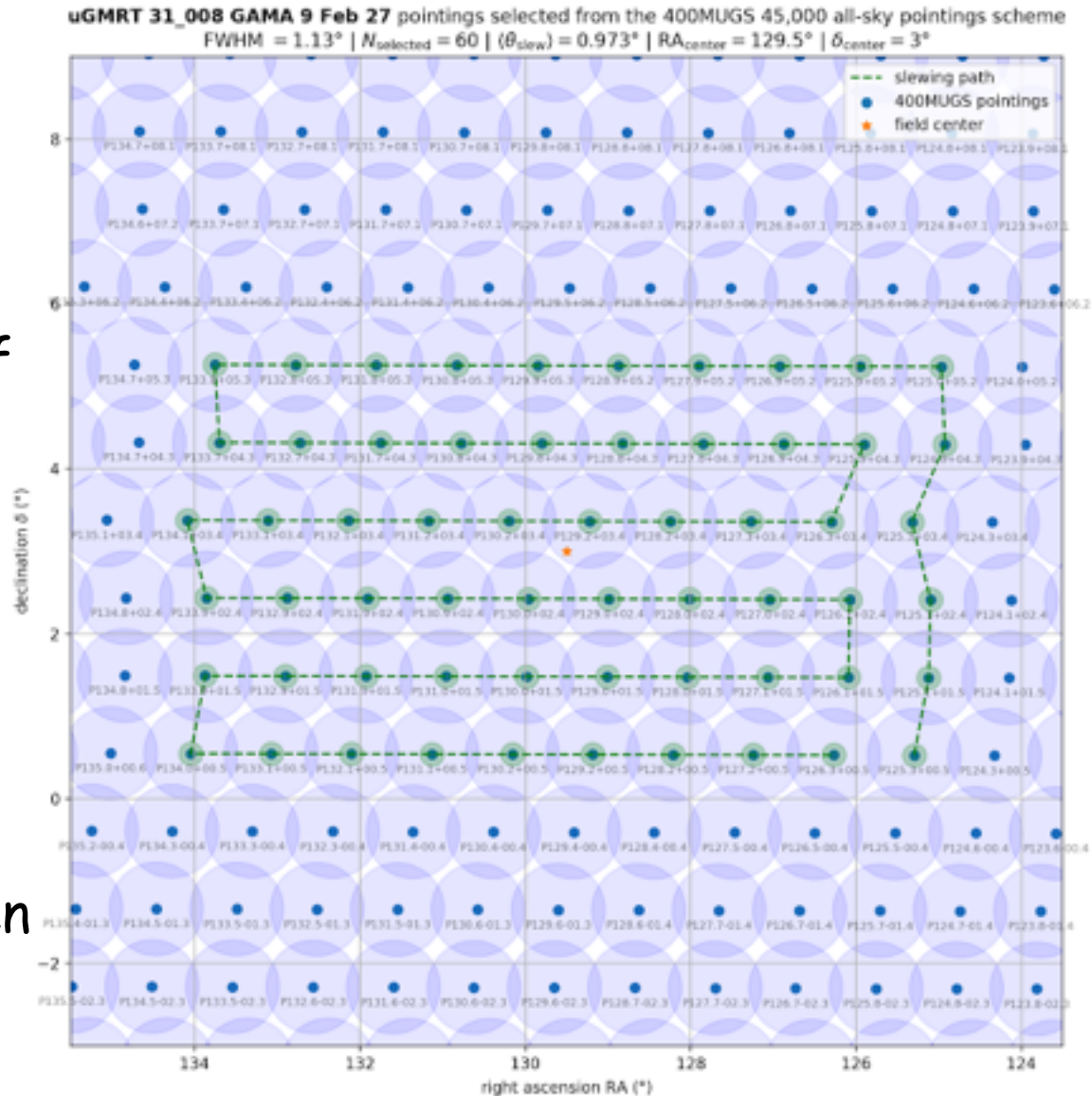
uGMRT-GLASS:
(GAMA legacy ATCA southern survey)
(PI: Minh Huynh - ATCA-GAMA)
- band-3 (250-500 MHz)
- 0.015 mJy/beam (thermal)
- ~50 sq. deg. (observations during next month)
- Science goals
  - life cycle of RL AGN
  - CSS/GPS/GRGs
  - AGN galaxy environment
  - RQ AGN
  - Faint radio source population
  - thermal/non-thermal fraction in SF gal.

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E-CDFS:
uGMRT-MIGHTEE survey
(PI: Russ Taylor)

... (talk by Bradley Frank)

uGMRT: continuum surveys (E-CDFS)

- Observing strategy:
  - total intensity + full polarisation
  - 30 hr per pointing
    - 3 pointings
  - 550-850 MHz (band-4)
  - 4" angular resolution
  - 0.005 mJy/beam
    - (a factor of 2 off from thermal noise!)
  - Complementary data:
    - 1.75 - 2.75 GHz (~5.5 sq. deg.)
    - 0.6 - 1.6 GHz (all 20 sq. deg.)

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uGMRT: continuum surveys (E-CDFS)

- Science goals:
  - star formation history of the universe
  - faint AGNs
  - nature of steep spectrum objects
  - cosmic magnetic field
  - ...

- Technical challenges:
  - (thermal) noise limited images
  - high dynamic range imaging
  - joint deconvolution of uGMRT and MeerKAT data
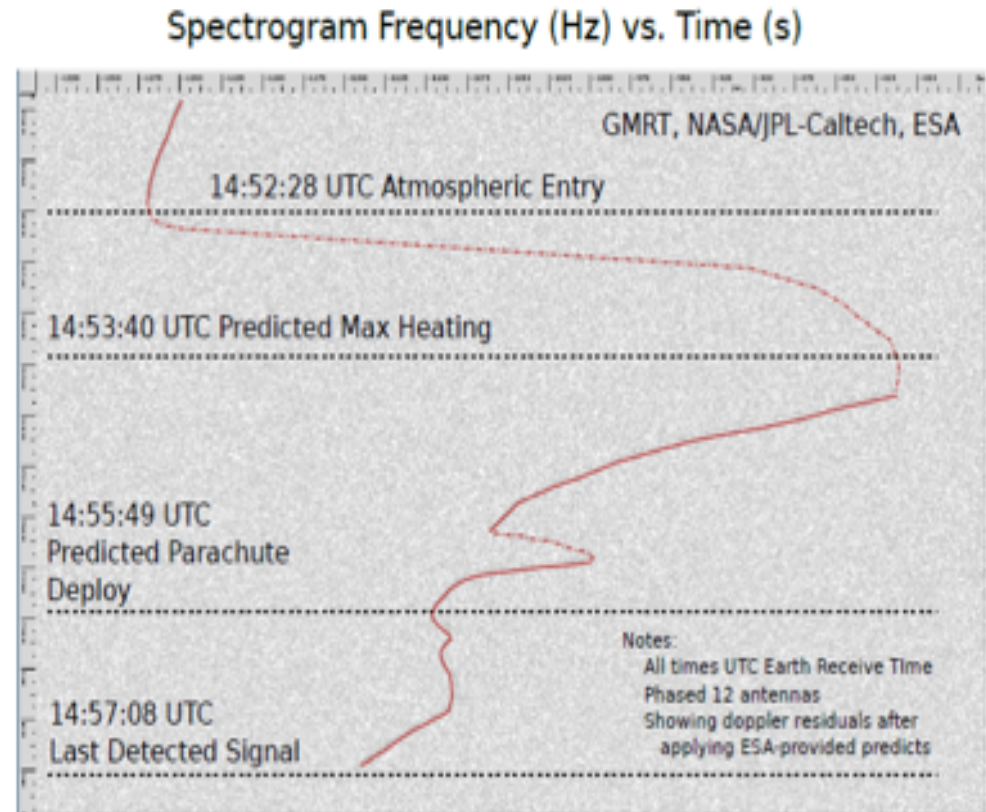 - ionosphere calibration
  - ...

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uGMRT: some fun stuff!

Tracking space probe with the uGMRT

✛ Ground support for ExoMars mission of ESA
✛ GMRT + NASA collaboration
✛ Faithfully tracked ESA's Schiaparelli Lander module: ~ 3 W signal @401 MHz from Mars!
✛ ExoMars / Schiaparelli / EDM
  ✛ Entry, Decent, Landing Detection at GMRT, India (2016/10/19)

SPARCS

Spectrogram Frequency (Hz) vs. Time (s)

GMRT, NASA/JPL-Caltech, ESA

14:52:28 UTC Atmospheric Entry

14:53:40 UTC Predicted Max Heating

14:55:49 UTC
Predicted Parachute
Deploy

14:57:08 UTC
Last Detected Signal

Notes:
All times UTC Earth Receive Time
Phased 12 antennas
Showing doppler residuals after
applying ESA-provided predicts

14:57:50 : Predicted Backshell & Parachute Jetison
(This exposes +6 dBiC antenna), Thrusters On
14:58:20 : Predicted Thursters Off & Touchdown

uGMRT is available for users

- Releases in multiple phases:
  - First release of 8 antenna trial system – way back in September 2013.
  - Release of 16 antenna system for internal users – September 2015.
  - Release of 16 antenna system for all users - April 2016.
- Now available: Release of 30 antenna system with 2 bands fully functional:
  - Band 5 (1000 to 1450 MHz) and Band 3 (250-500 MHz) - October-November 2016 (GTAC cycle 31) onwards.
- Future plans - release of fully upgraded GMRT:
  - 30 antenna configuration with all 4 bands fully functional - targeted for 2017 end
  - And monitor & control system as a SKA prototype

Please stay tuned!   **SPARCS VII (ICRAR, Perth), 18 July 2017**

uGMRT

Summary

- The GMRT upgrade or the uGMRT -
    (complement several other observatories
     a testbed to demonstrate wide band,
      wide field-of-view imaging);
  - current status of uGMRT;
- towards a working uGMRT;
  - test studies using uGMRT -
    - understanding data quality,
    - fidelity of new wide-band backend, and
    - (imaging) results for several targets.

uGMRT is a much improved instrument over the existing GMRT.

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Radio Astronomy School – 2017

28th August – 08th September, 2017