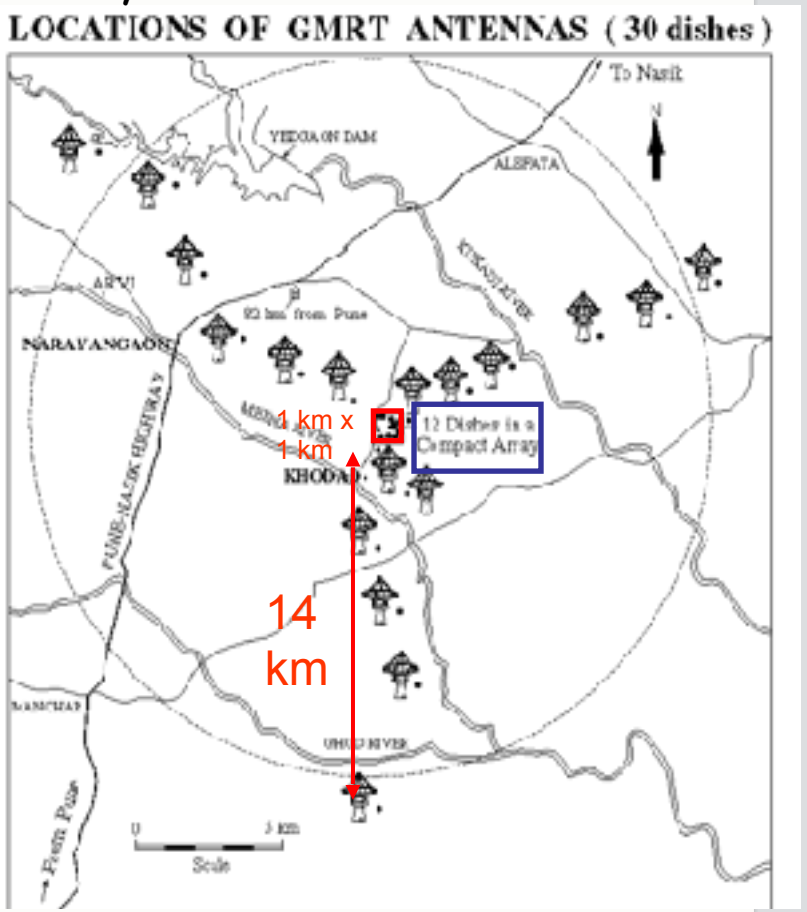
Giant Metrewave Radio Telescope: An introduction and science with GMRT

Dharam Vir Lal, NCRA (TIFR)

IAS, 02 July 2018

The legacy GMRT

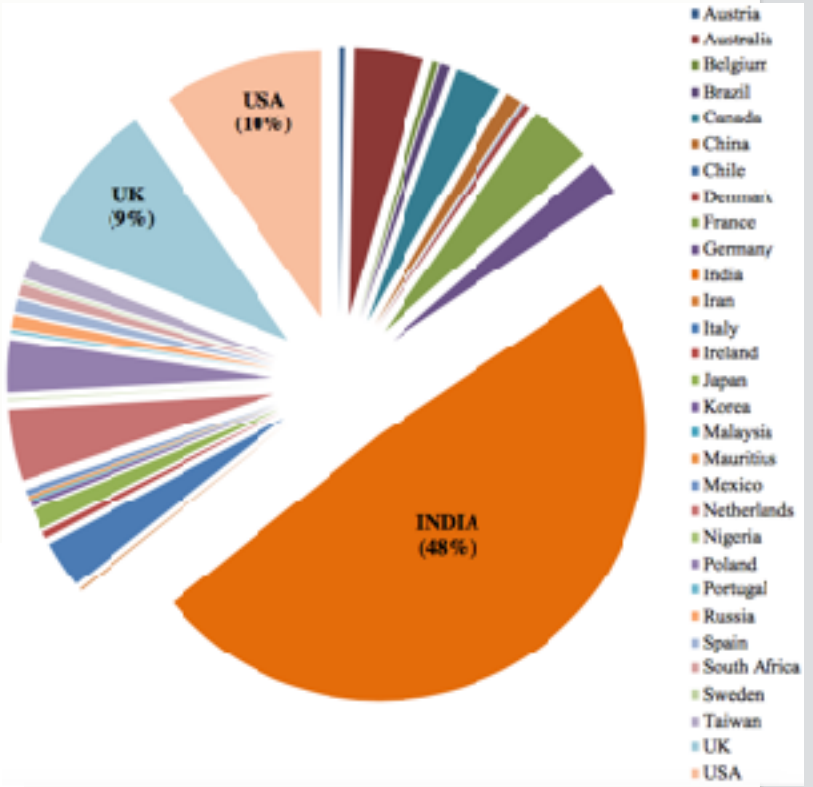
- 30 dishes, 45 m diameter each
  - 12 dishes in a inner 1 km^2 region (central square) and
    - remaining along 3 arms of Y-shaped array
  - baselines : ~200 m ~30 km
- Frequency range:
  - 130-170 MHz
  - 225-245 MHz
  - 300-360 MHz
  - 580-660 MHz
  - 1000-1450 MHz
    - max instantaneous BW = 32 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)

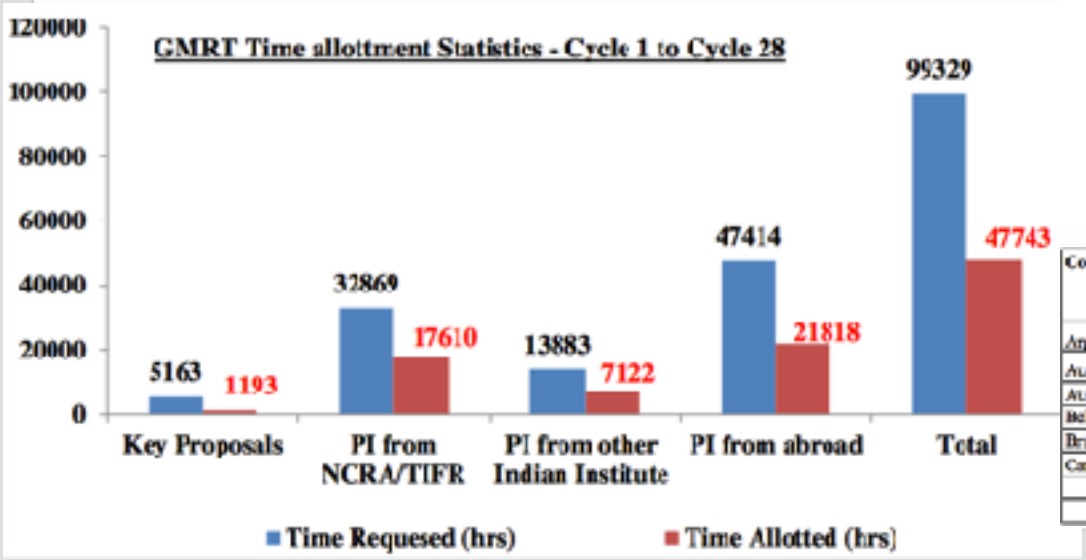


GMRT: usage statistics

- 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

Credits: Reena S. (GTAC)





Country	Nos	Country	Nos	Country	Nos	Country	Nos	Country	Nos
Argentina	13	China	15	Iran	2	Mauritius	3	Russia	13
Austria	5	Chile	1	Italy	49	Mexico	7	Spain	14
Australia	75	Denmark	5	Ireland	3	Netherlands	75	South Africa	16
Belgium	7	France	58	Japan	21	Nigeria	1	Sweden	2
Brazil	11	Germany	40	Korea	5	Poland	55	Taiwan	20
Canada	50	India	847	Malaysia	3	Portugal	5	UK	163
								USA	166
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

Generation-Next: the upgraded GMRT

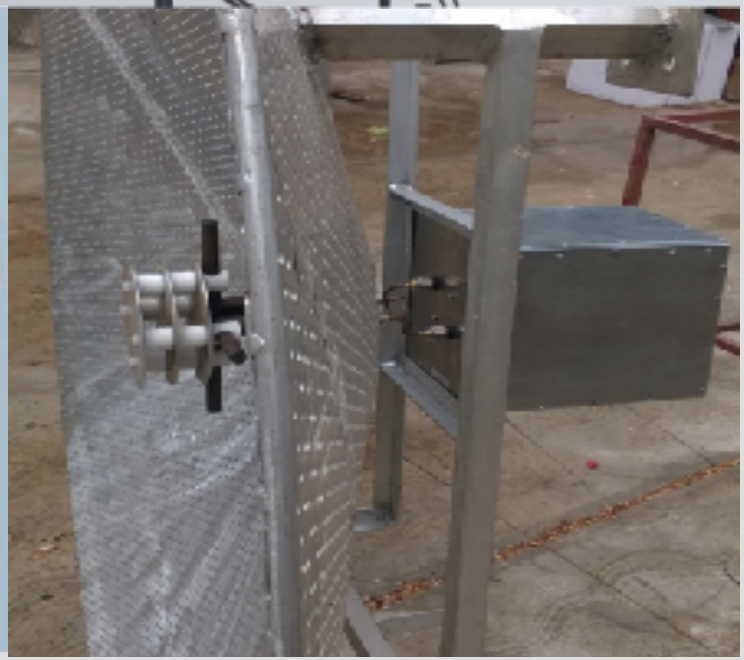
- A **major upgrade** is underway at the **GMRT**,
  - with focus on (nearly) seamless frequency coverage
    - from ~30 MHz to 1500 MHz,
  - design of completely new 'feeds' and 'receiver' system with octave bandwidths
- Improved G/T_{sys},
  - i.e., use of better tech. receivers and reduced T_{sys}
- 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: (wideband) feeds

- Cone-dipole design
  - 250-500 MHz
  - 550-850 MHz
- Dual-ring feed
  - 120-250 MHz

Credits: frontend team (H. Rao)



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
    - completed on 30 antennas!
  - Band 4 (550 – 850 MHz): cone-dipole feed with matching receiver system
    - completed on 30 antennas!
  - Band 2 (120 – 250 MHz): modified Kildal (dual) ring feed + modified electronics in last stages of validation
    - completed on all 30 antennas!
  - Band 1 (50 – 80 MHz): on hold at present.

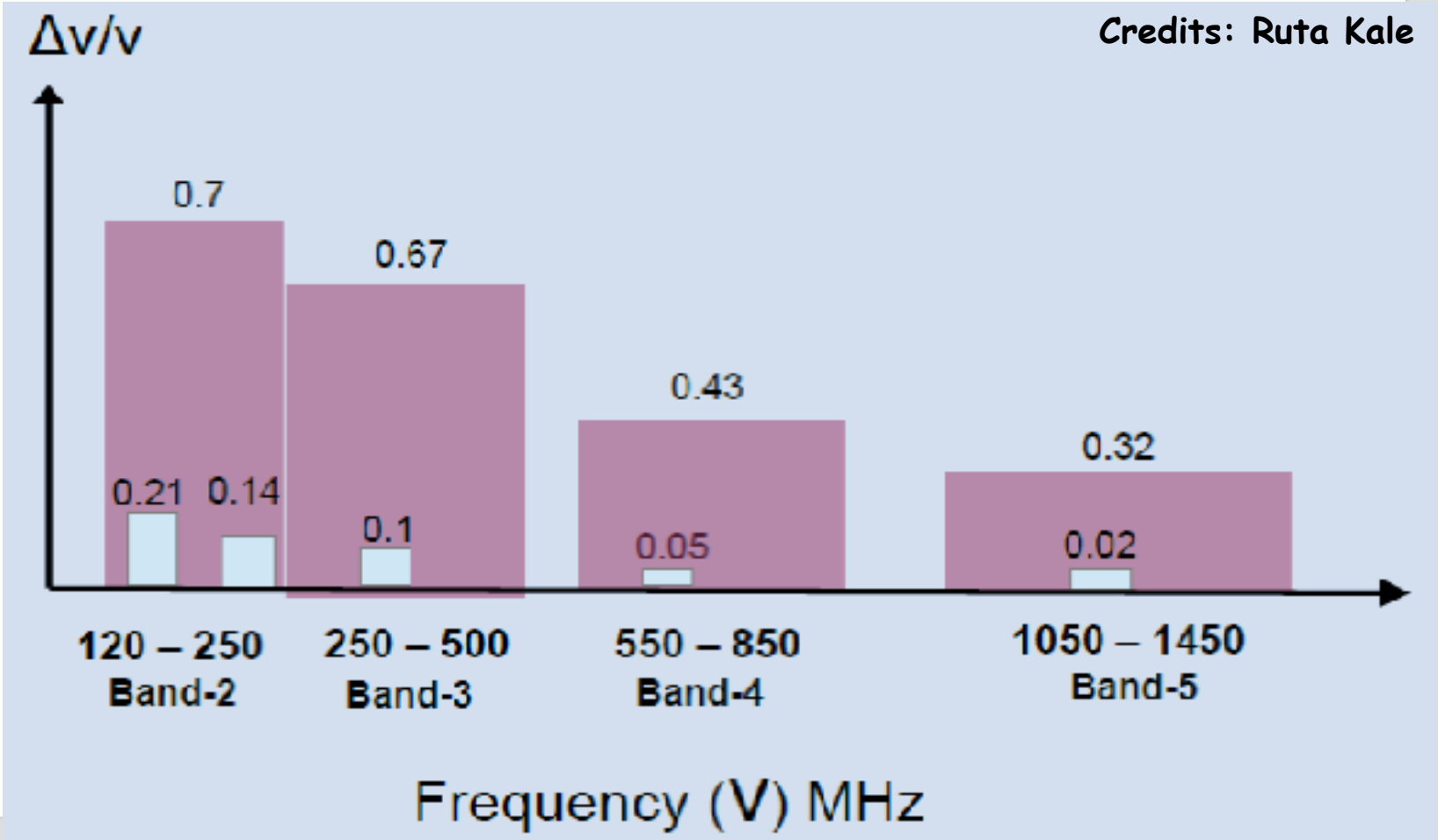
Performance of several systems are monitored on a regular basis by respective teams - to keep the system in good health – next, we need to watch out for the growing RFI!

uGMRT: the receiver system

- Broad-band feeds + FE (in octaves):
  - 1000 – 1450 MHz (updating L-band)
  - 550 – 850 MHz (replacing 235/610)
  - 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

uGMRT *vs.* GMRT: frequency coverage

- Fractional bandwidth
  - old and new

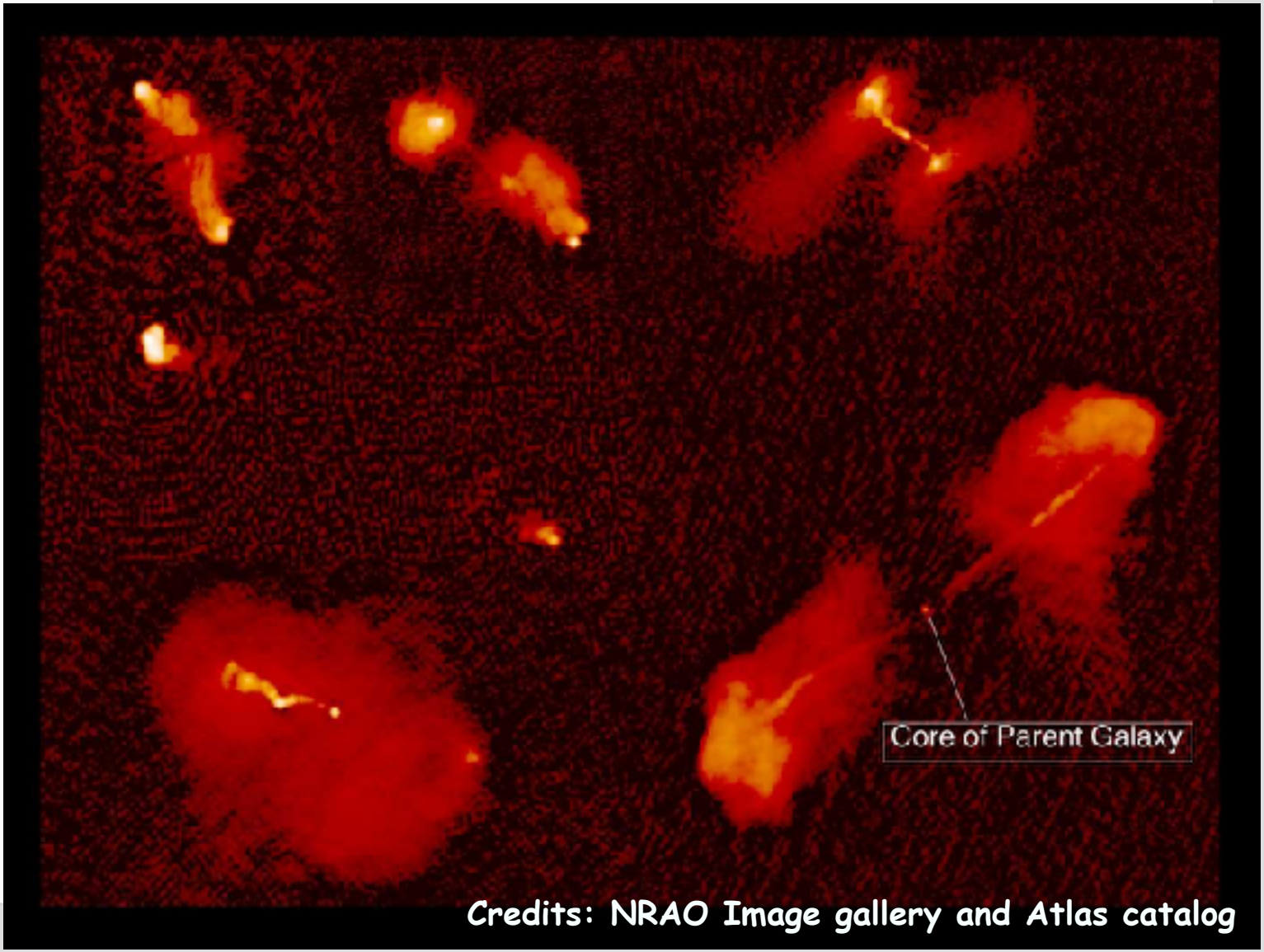


uGMRT *vs.* GMRT: frequency coverage

- Larger bandwidth
  - better sensitivity
  - 32 MHz -> 400 MHz
    this implies 3.5 times increase in sensitivity
- Increased (u,v)-coverage
  - lower side-lobe levels, better pdf
    this implies better dynamic range

uGMRT: radio galaxies

- What kind of sources would benefit from the upgrade of GMRT?



Credits: NRAO Image gallery and Atlas catalog

uGMRT: optical fibre systems

Credits: OF team

uGMRT: analog backend

- Phase-I 30-antenna system installation completed.

Credits: backend team

uGMRT: GWB

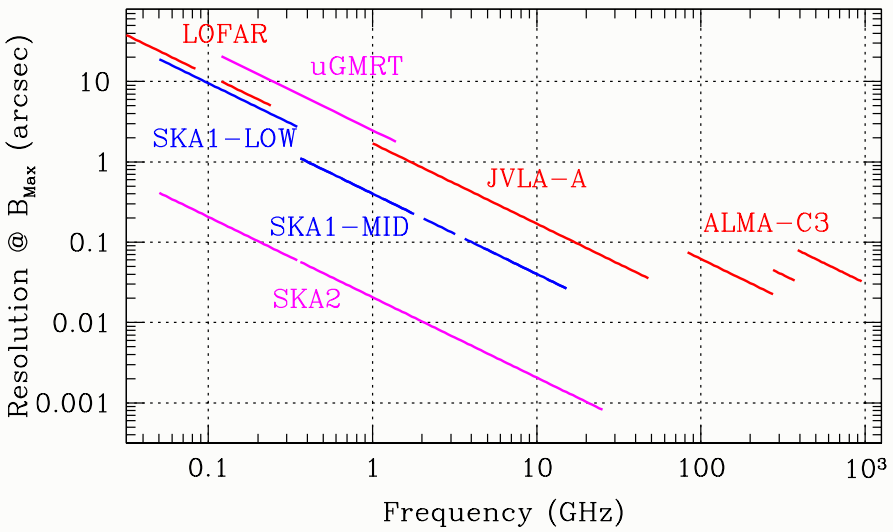
Generation-Next: the upgrade

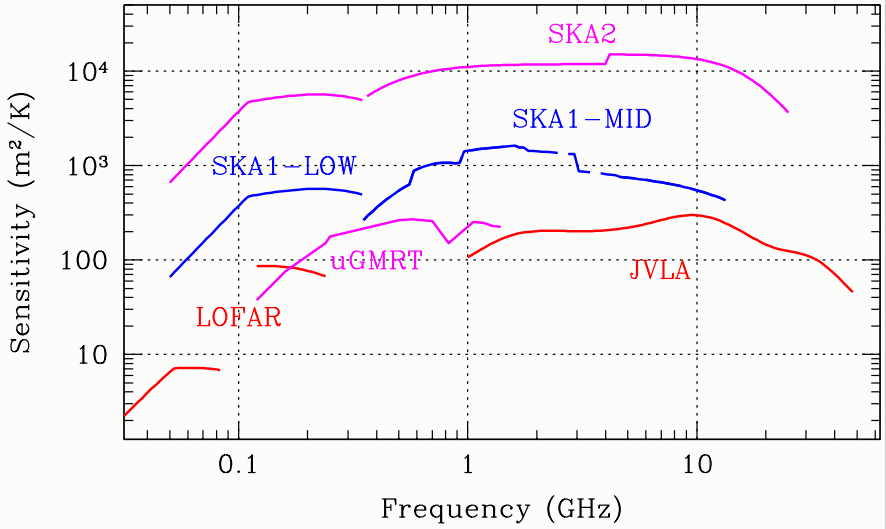
- A major upgrade
- Antenna surface
- BLDC
- Mechanical
  - HLP, gearbox, etc.
- M-&-C system
- Servo control computer
- Electrical system
  - (RFI friendly) UPS
- Workshop machinery
- ...

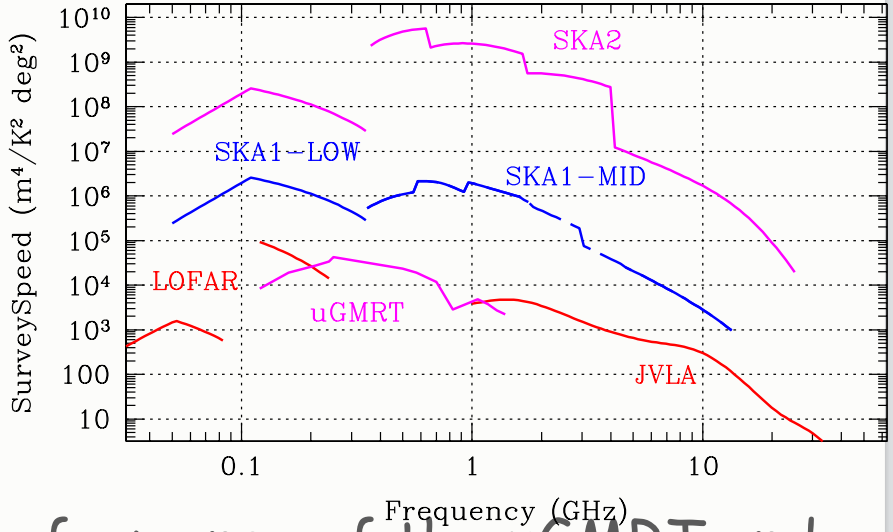
Credits: mechanical team

uGMRT: expected performance

Credits: R. Braun



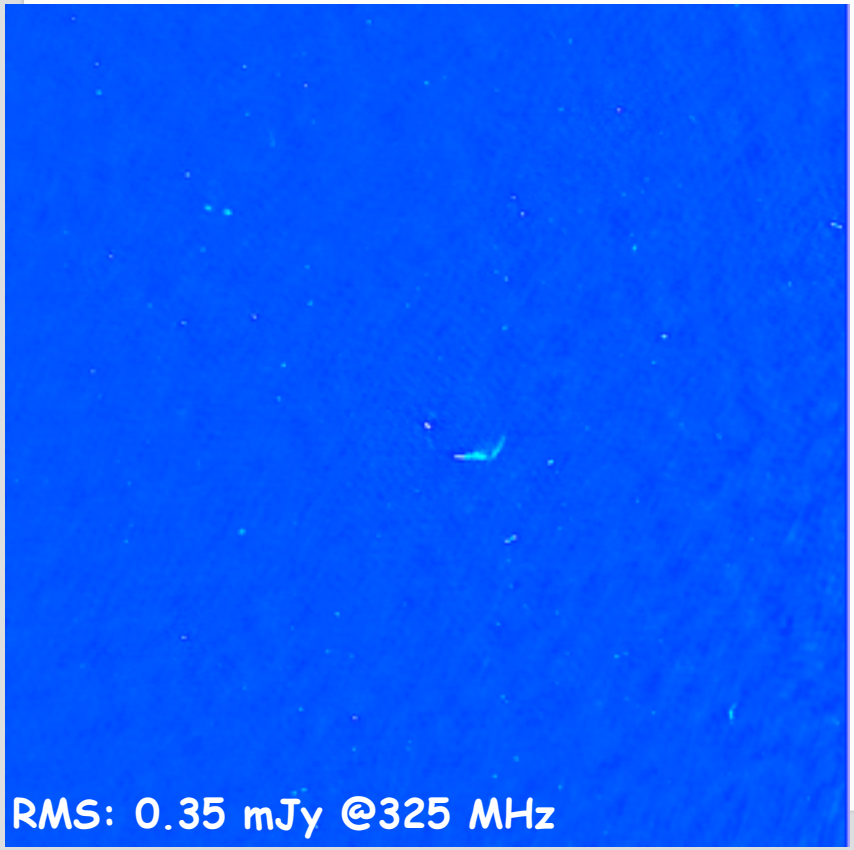


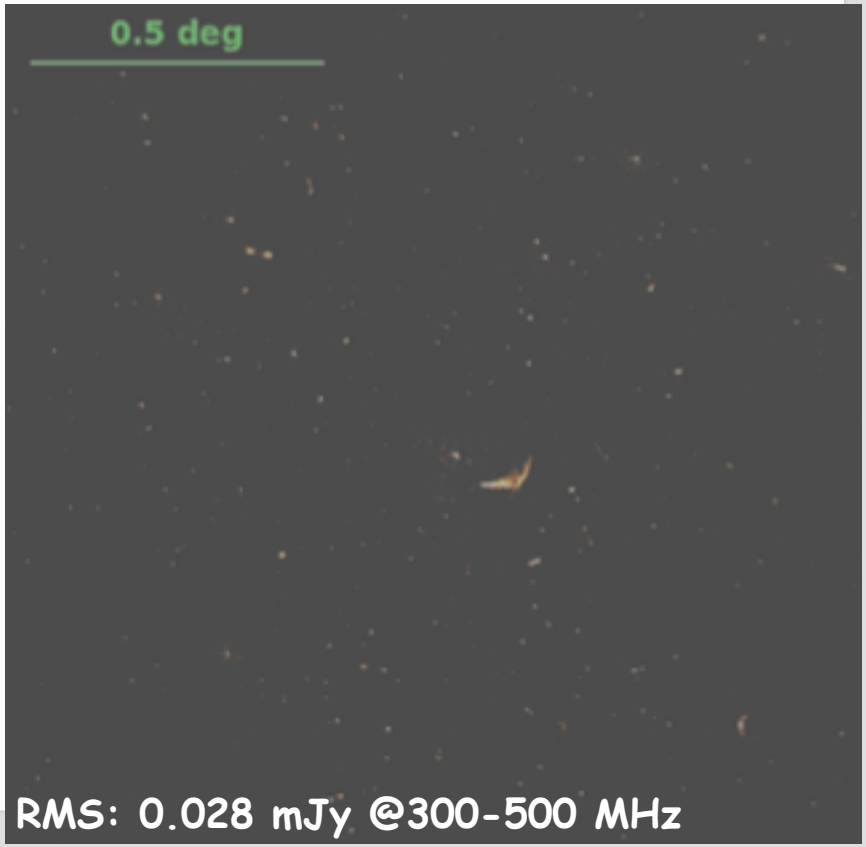


Expected sensitivity performance of the uGMRT and ...

uGMRT: improved imaging

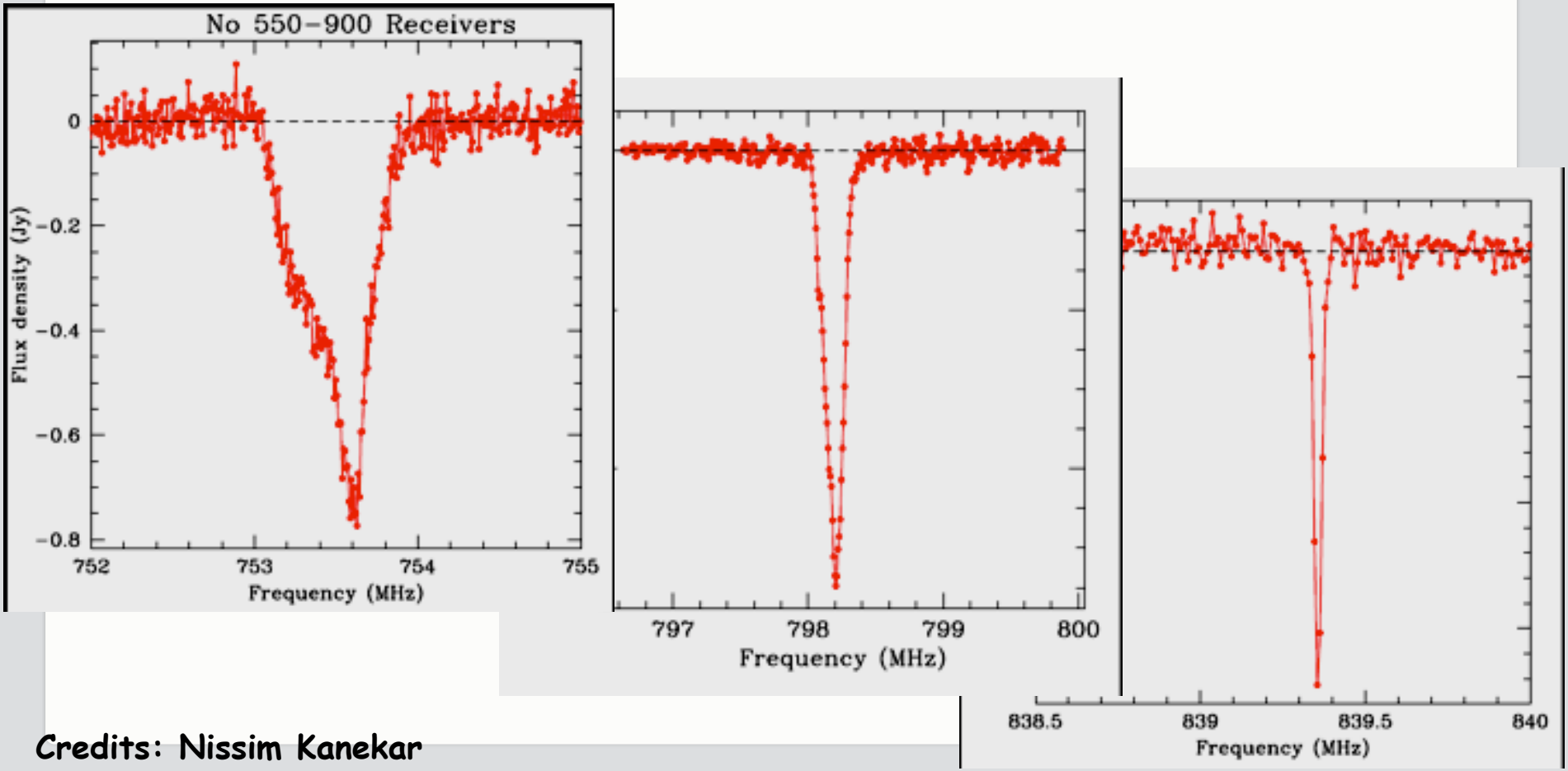
- test observation:
  - 10 times lower RMS in uGMRT image for similar observing times, and
  - could detect 30 radio galaxies in the Coma, some for the first time!





uGMRT: opening new spectral window

- spectral lines from different sources, at different parts of the 550-850 MHz band



Credits: Nissim Kanekar

uGMRT: pulsar observations

- Improved sensitivity

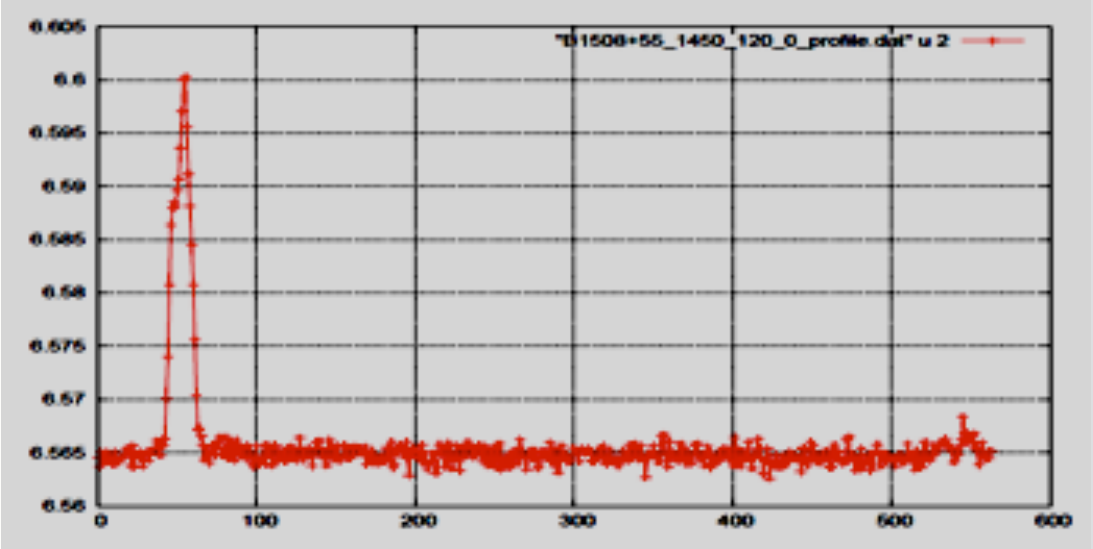
B1508+55

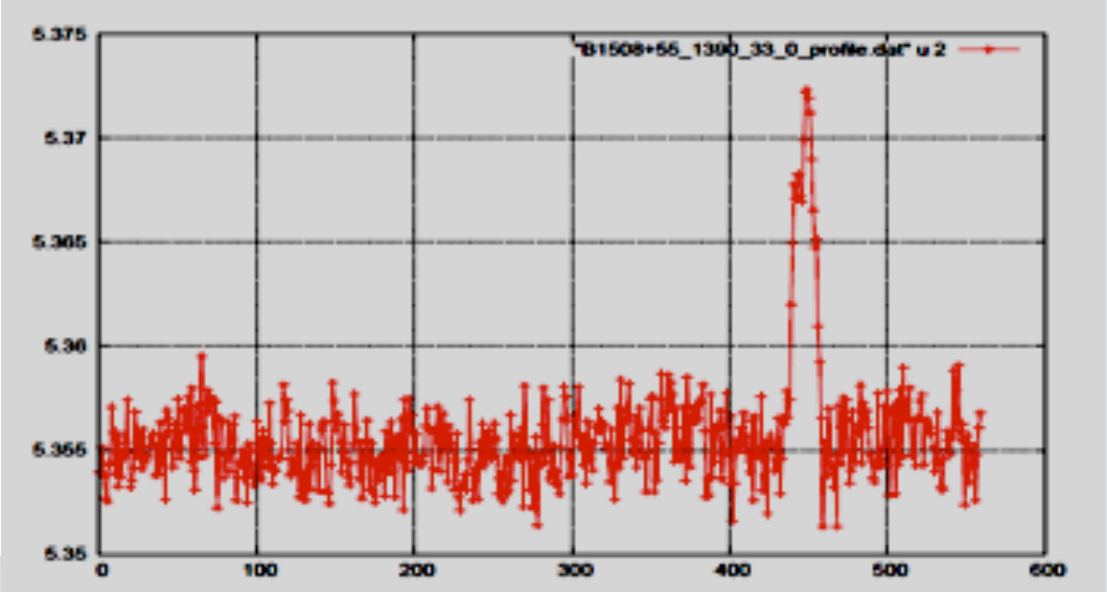
120 MHz bandwidth at L-band (1330-1450)

vs.

33 MHz at L-band (1390 sub-band)

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

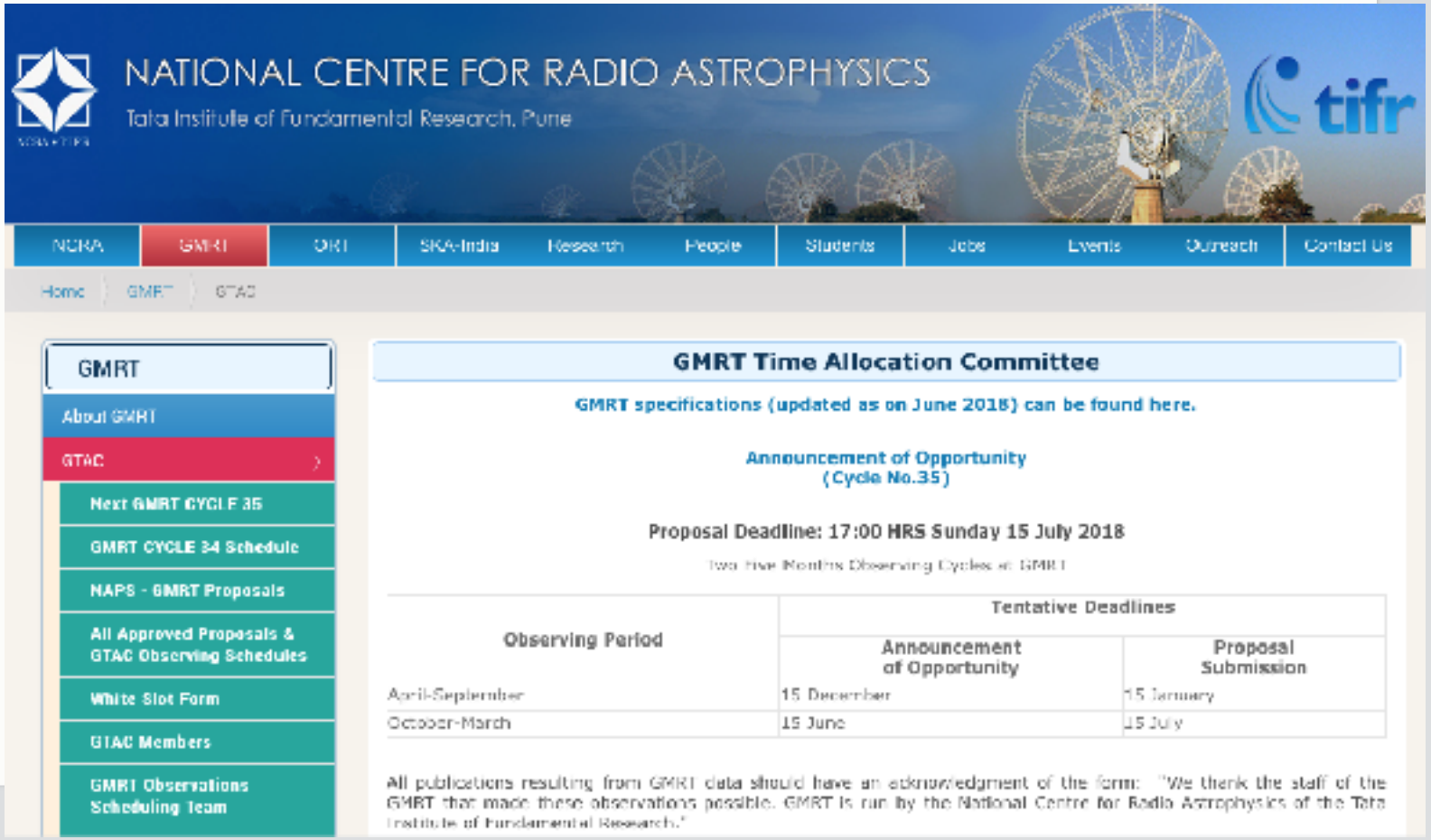




Credits: Yashwant Gupta

uGMRT

The upgraded GMRT:
it is available for users…



uGMRT: challenges to build uGMRT

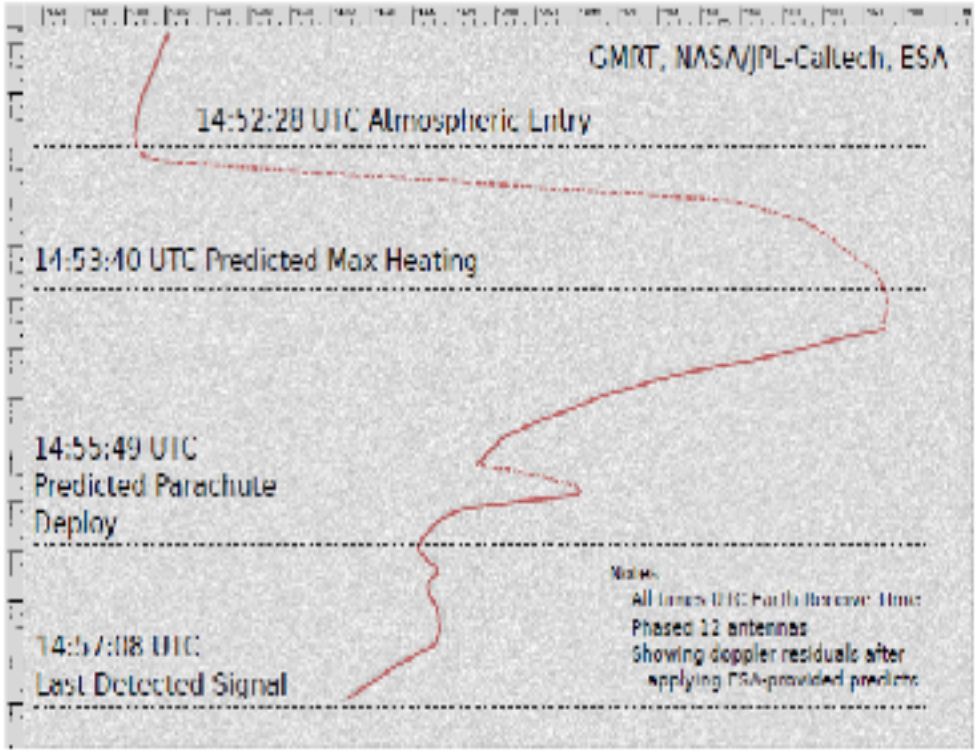
The main challenges that we have encountered have been -

- 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 RFI is and remains our biggest challenge!
- Containing self generated RFI
  - Mitigating RFI from external sources:
    - (i) broadband impulsive
    - (ii) spectral line

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)



uGMRT is available for users

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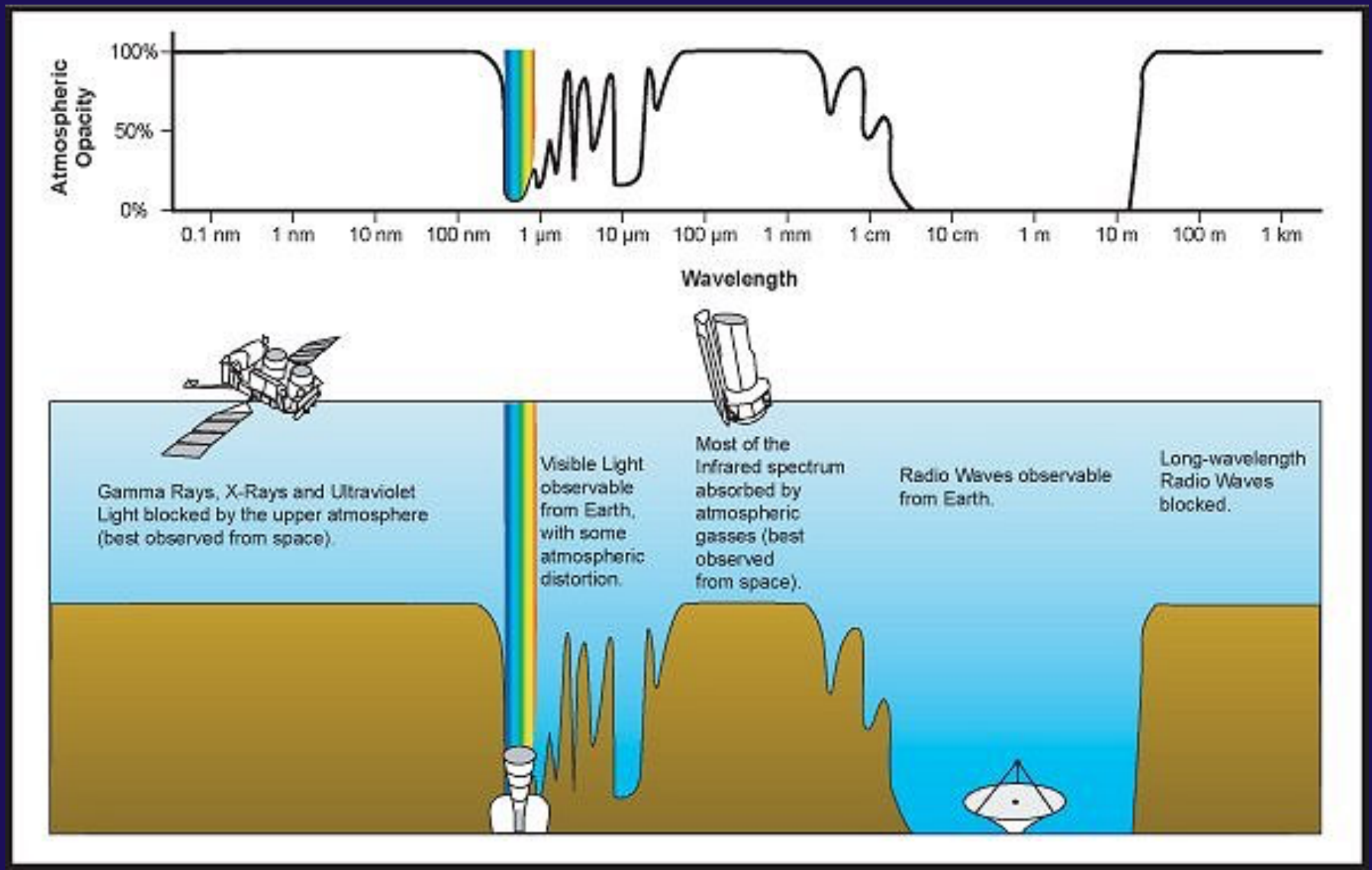

Atmospheric Opacity
100%
50%
0%
0.1 nm
1 nm
10 nm
100 nm
1 μm
10 μm
100 μm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength
Gamma Rays, X-Rays and Ultraviolet Light blocked by the upper atmosphere (best observed from space).
Visible Light observable from Earth, with some atmospheric distortion.
Most of the Infrared spectrum absorbed by atmospheric gasses (best observed from space).
Radio Waves observable from Earth.
Long-wavelength Radio Waves blocked.

GMRT: Science 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 surveys

D. Oberoi

Y. Gupta, B.C. Joshi, D. Mitra, S. Konar, B. Bhattacharyya, J. Roy, J.N. Chengalur

P. Chandra, J. Roy, Ishwara-Chandra, S. Roy, J.N. Chengalur, N. Kanekar, P. Chandra, …

J.N. Chengalur, N. Kanekar, N.G. Kantharia, C.H. Ishwara-Chandra, V.R. Marthi, T.R. Choudhury

N.G. Kantharia, C.H. Ishwara-Chandra, S. Roy, P. Kharb, DVL

R. Kale, Ishwara-Chandra, DVL

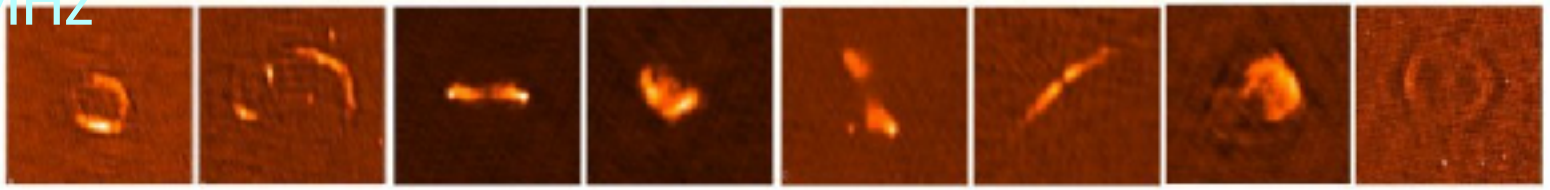
Y. Gupta, T.R. Choudhury, Ishwara-Chandra, Y. Wadadekar, DVL, …

…

TIFR-GMRT Sky Survey

Team: Sirothia, Kantharia, Ishwara-Chandra, Gopal-Krishna

- @150 MHz



TGSS Alternative Data Release

Science team

Huib T. Intema (Leiden/NRAO), Preshanth Jagannathan (NRAO/UCT), Kunal P. Mooley (Oxford/NRAO) & Dale A. Frail (NRAO)

Description

The Giant Metrewave Radio Telescope (GMRT) was used to survey the radio sky at 150 MHz between 2010 and 2012. To date, the data collected by the TIFR GMRT Sky Survey (TGSS) project team remained largely unpublished within the scope of that project. We independently reprocessed the TGSS data using the SPAM pipeline, which includes corrections for direction-dependent ionospheric phase effects. Our first alternative data release (ADR1) includes continuum stokes I images of 99.5 percent of the radio sky north of -53° DEC (3.6π sr, or 90 percent of the full sky) at a resolution of 25" x 25" north of 19° DEC and 25" x 25" / cos(DEC-19°) south of 19°, and a median noise of 3.5 mJy/beam. The extracted radio source catalog contains positions, flux densities, sizes and more for 0.62 Million sources down to a 7-sigma peak-to-noise threshold. The data processing and products are described in detail in Intema et al. (2017).

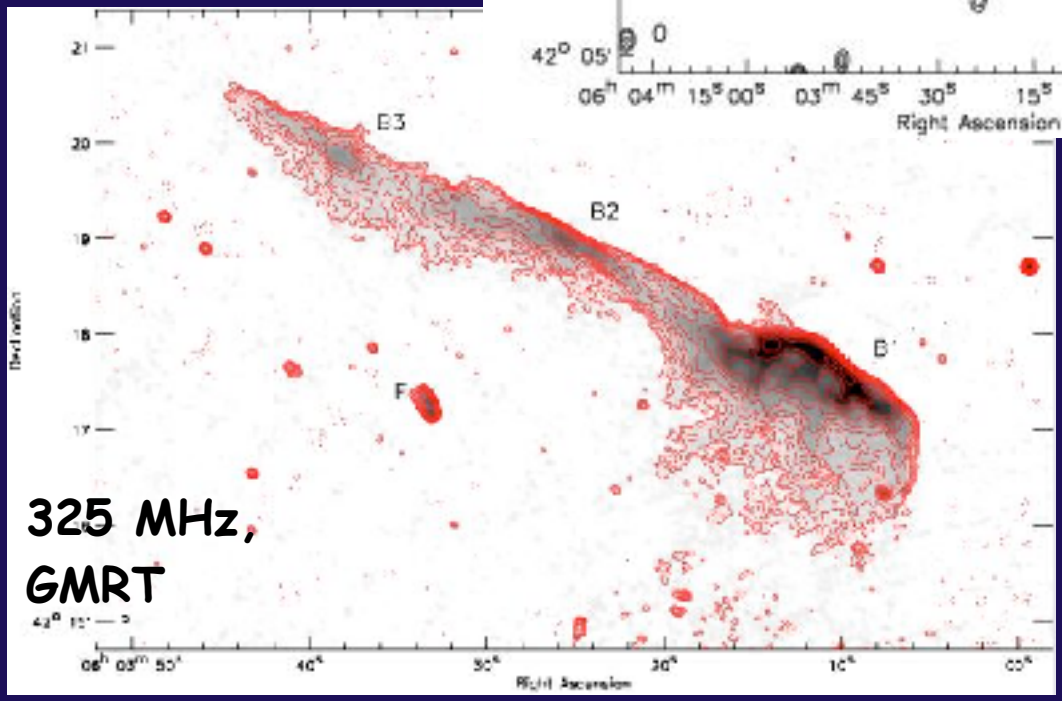
The TGSS-NVSS spectral index data release page is found here.

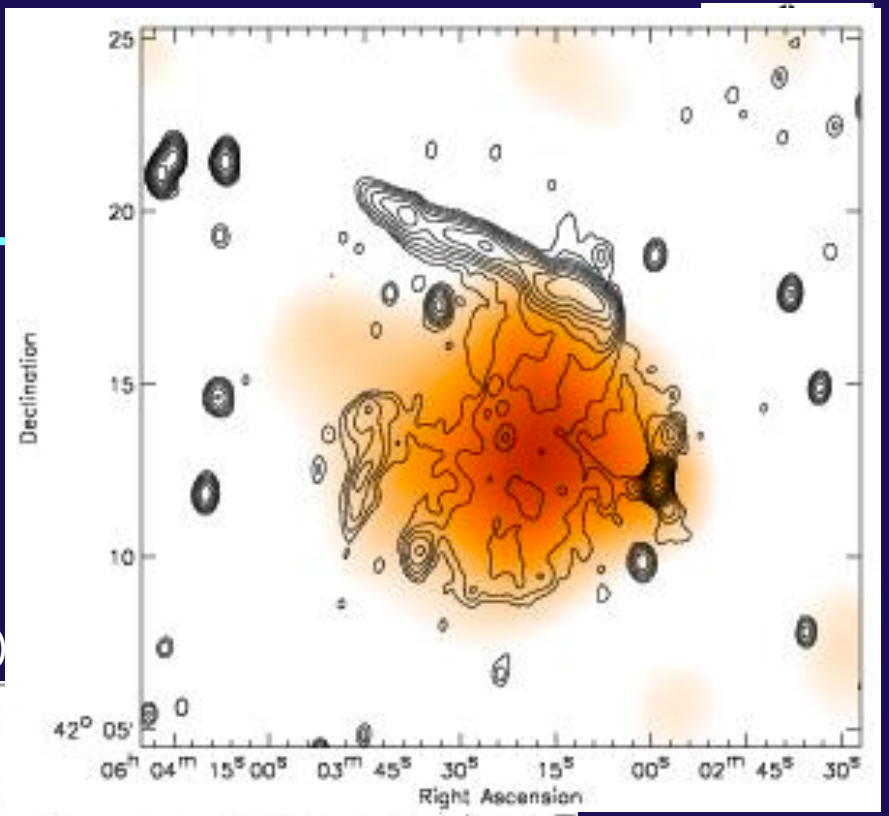
News

Tooth-brush relic

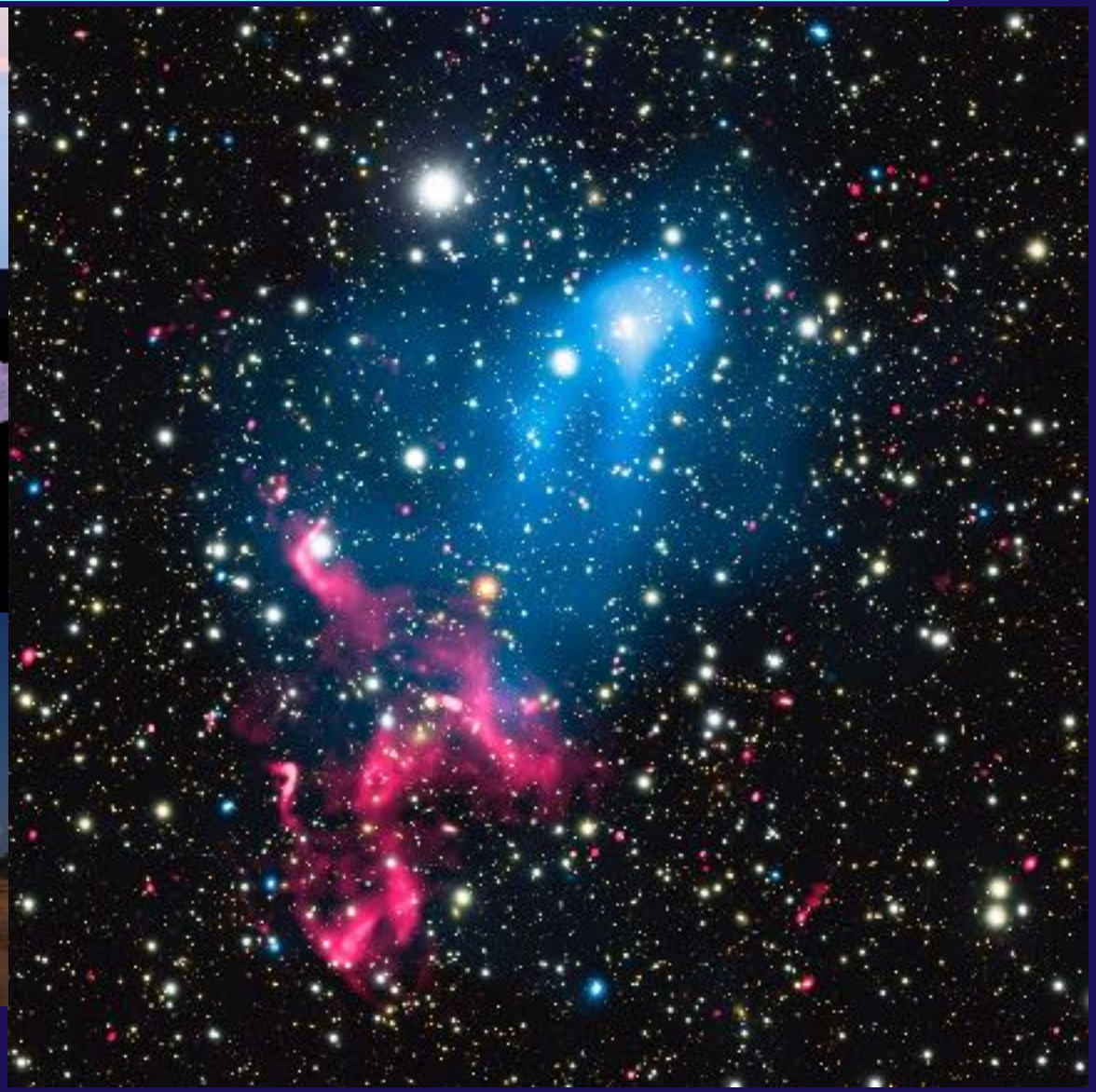
- Evidence for a coherent linear 2 Mpc scale shock wave in massive merging galaxy cluster

van Weeren et al. (2012)

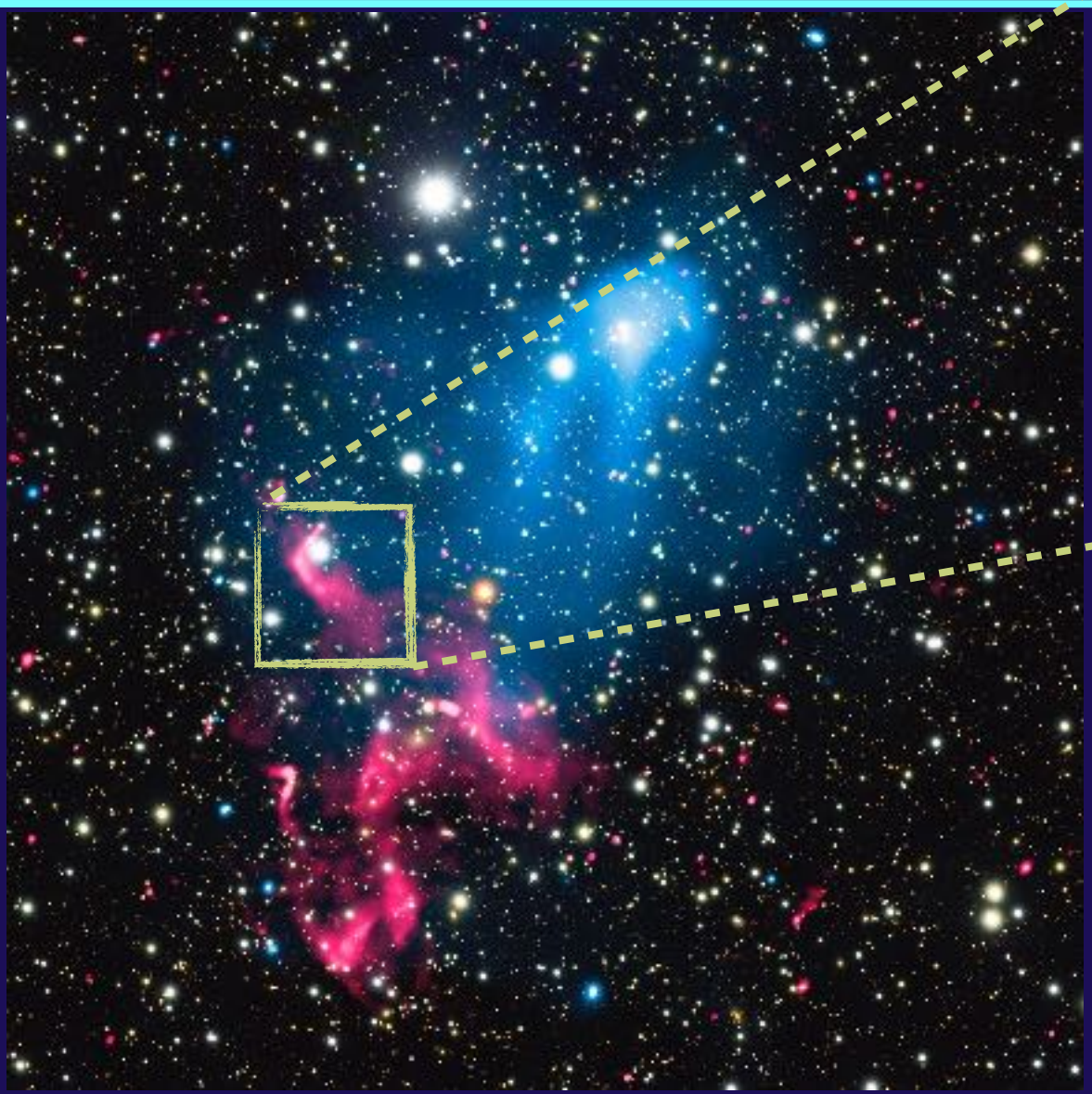


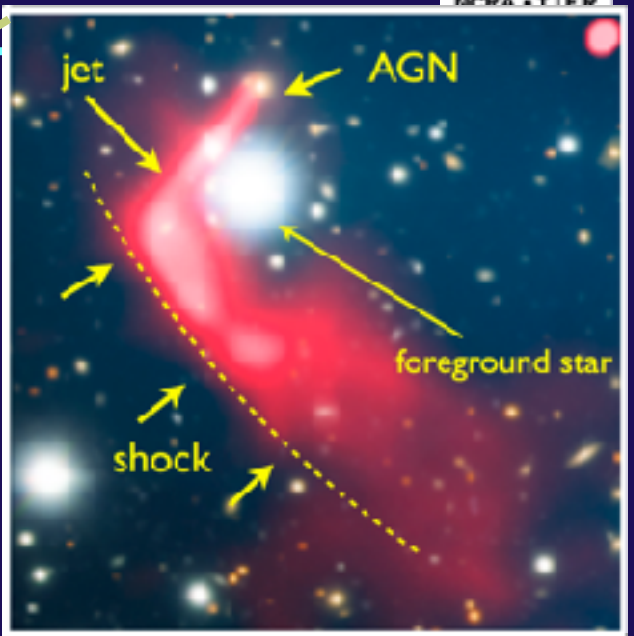


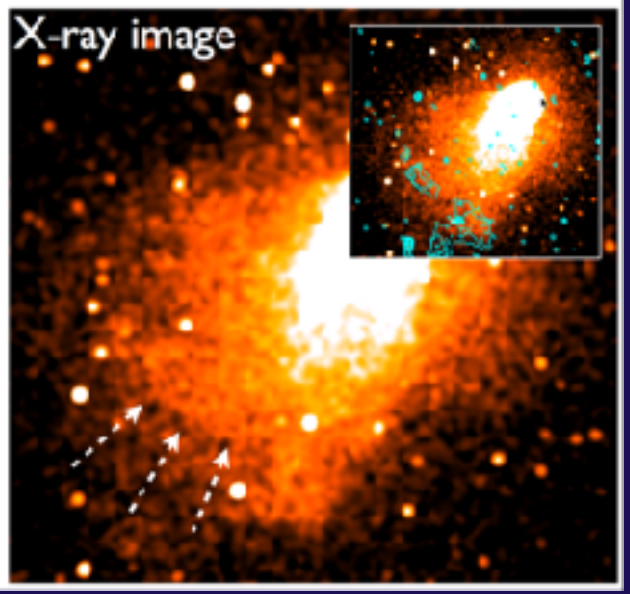
Abell 3411 / 3412



Abell 3411 / 3412

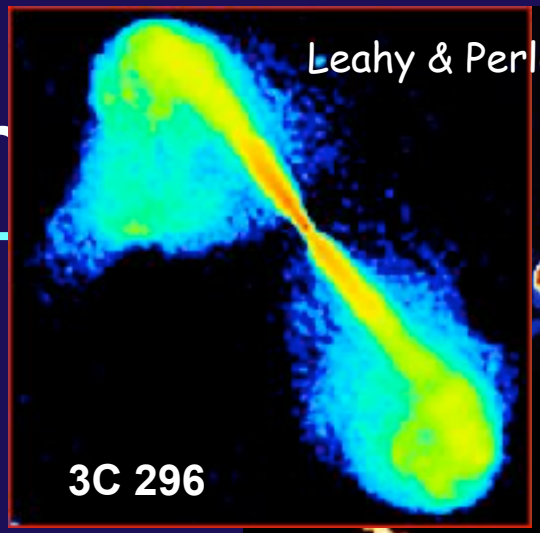






AGN: Taxor

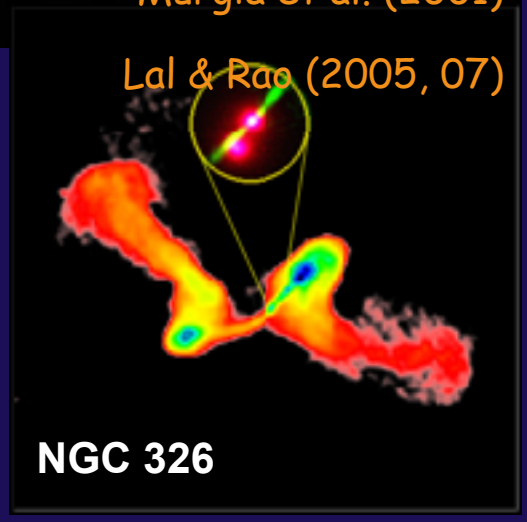
- FR I / FR II (FR 1974)
  - radio luminosity & morphology
  - Physically important distinction is whether the jet terminates at a shock.
- Head-tail radio galaxies
  - NAT / WAT (Jaffe & Perola 1973)
    - cluster potential & environment
- X-shaped / winged
  - merger / re-orientation / ???



Leahy & Perley (1991); Perley et al. (1984)

Murgia et al. (2001)

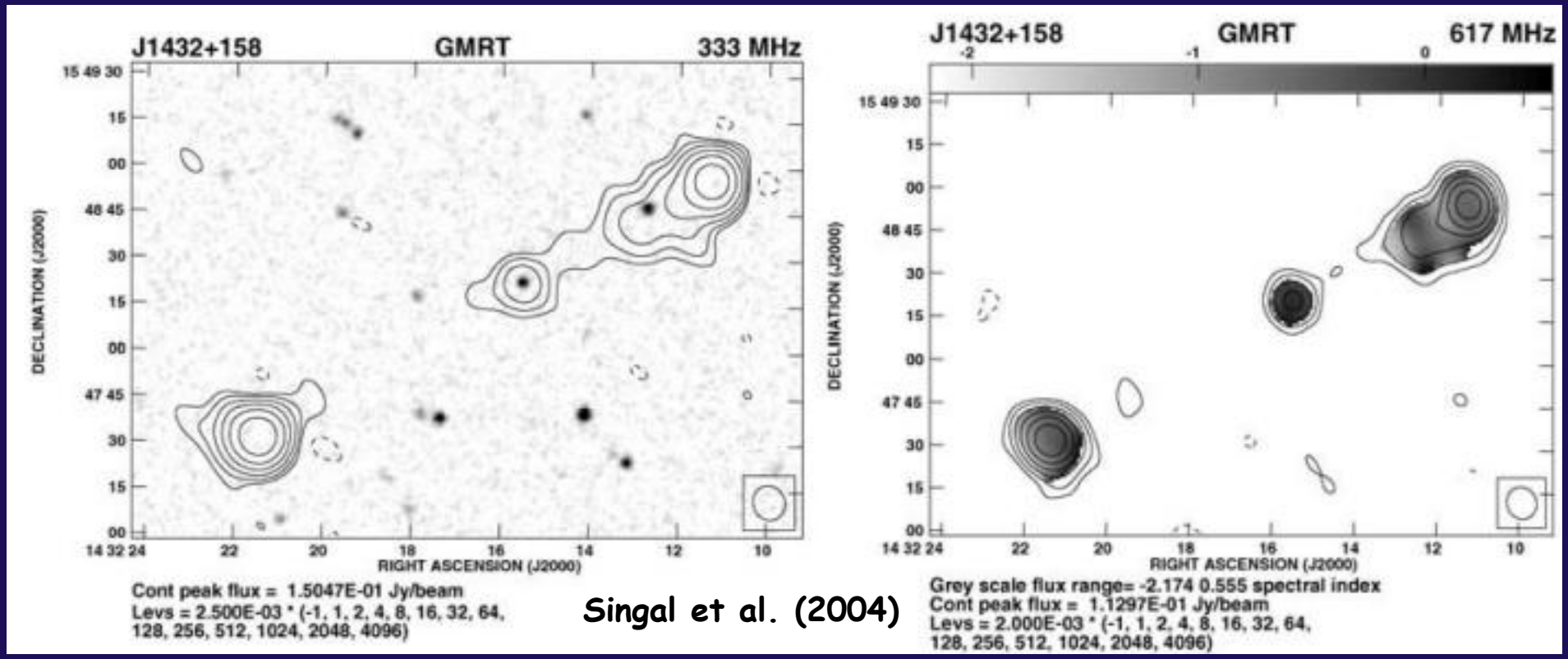
Lal & Rao (2005, 07)



Most distant, giant quasar

J1432+158 (z = 1.005)

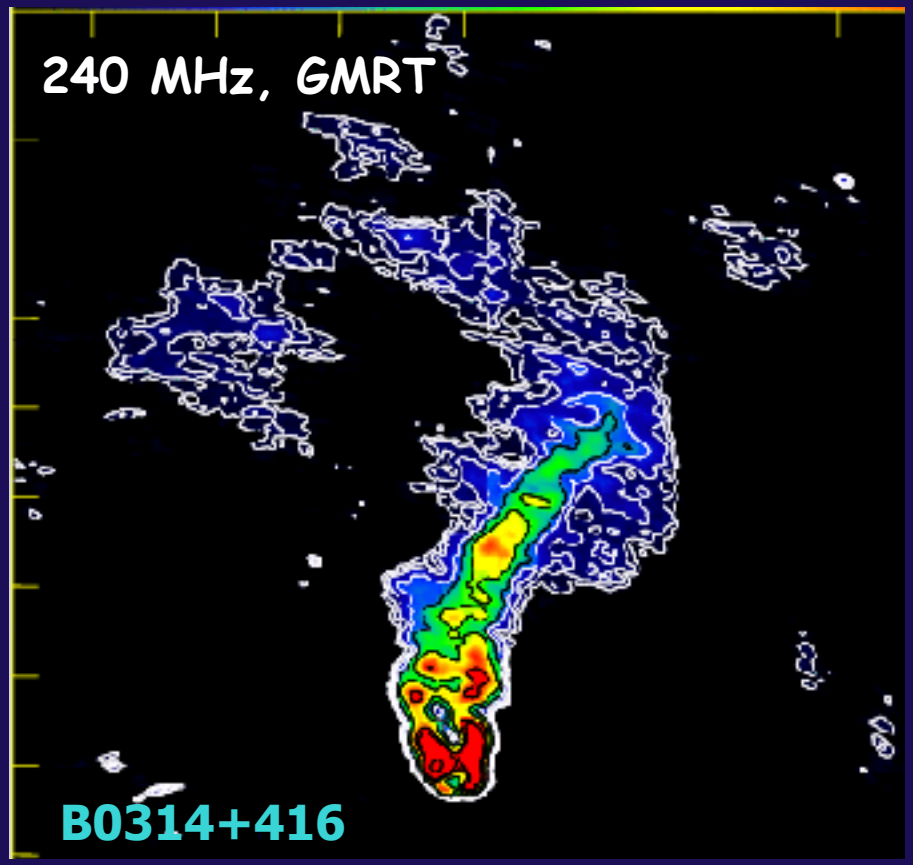
- giant radio quasar
- ~168″ = 1.35 Mpc

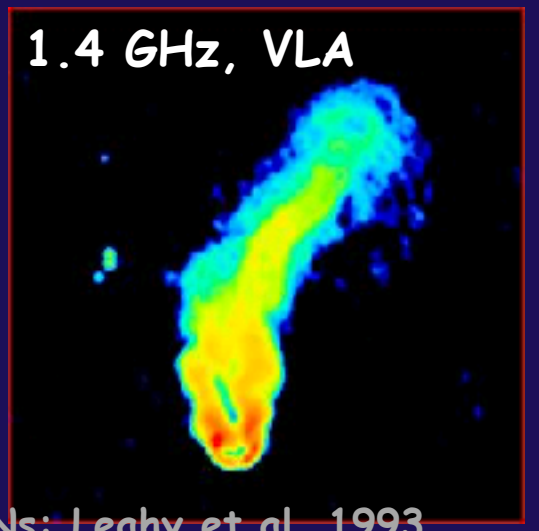


Singal et al. (2004)

Radio sources in clusters

The radio sources in cluster environments show presence of steep spectrum diffuse emission at low radio frequencies as against at high radio frequencies.

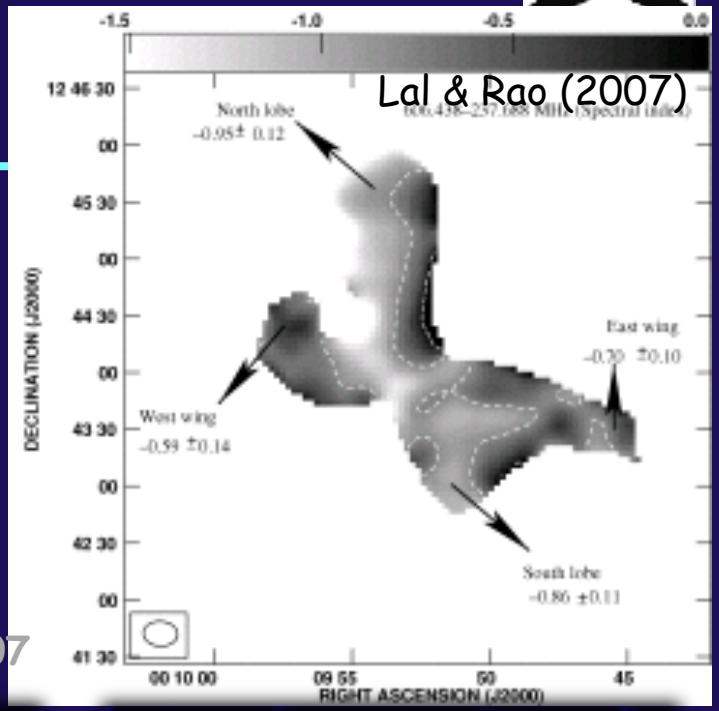




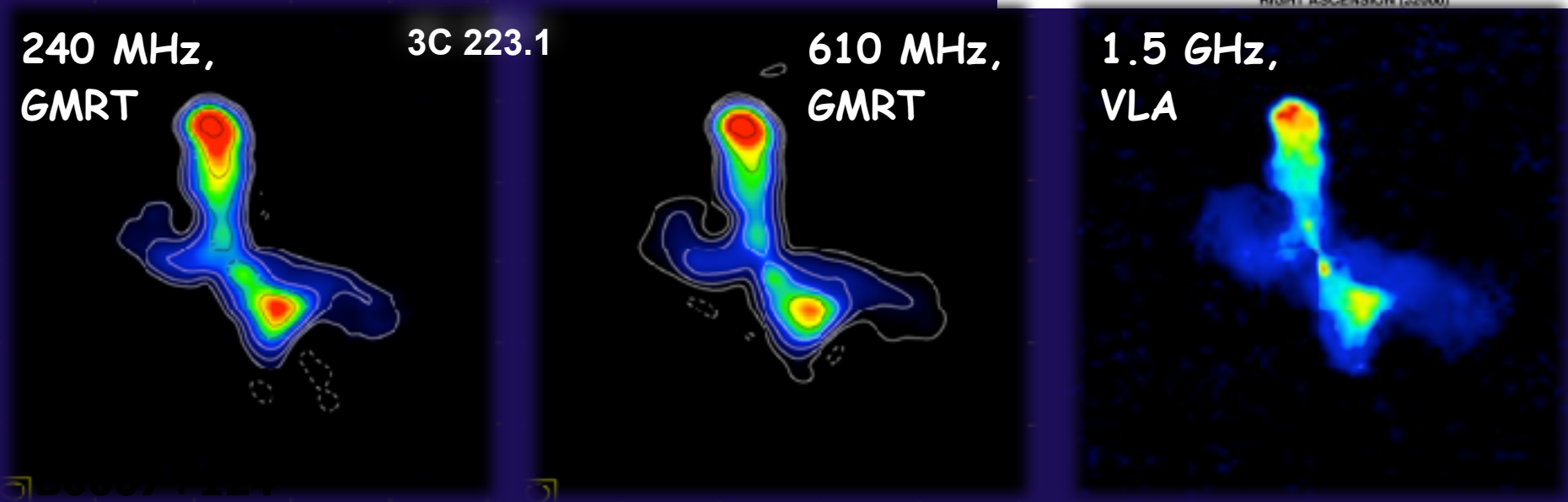
ATLAS of DRAGNs: Leahy et al. 1993

Unusual spectrum?

It is not true that the low surface brightness features always have steeper spectral indices.

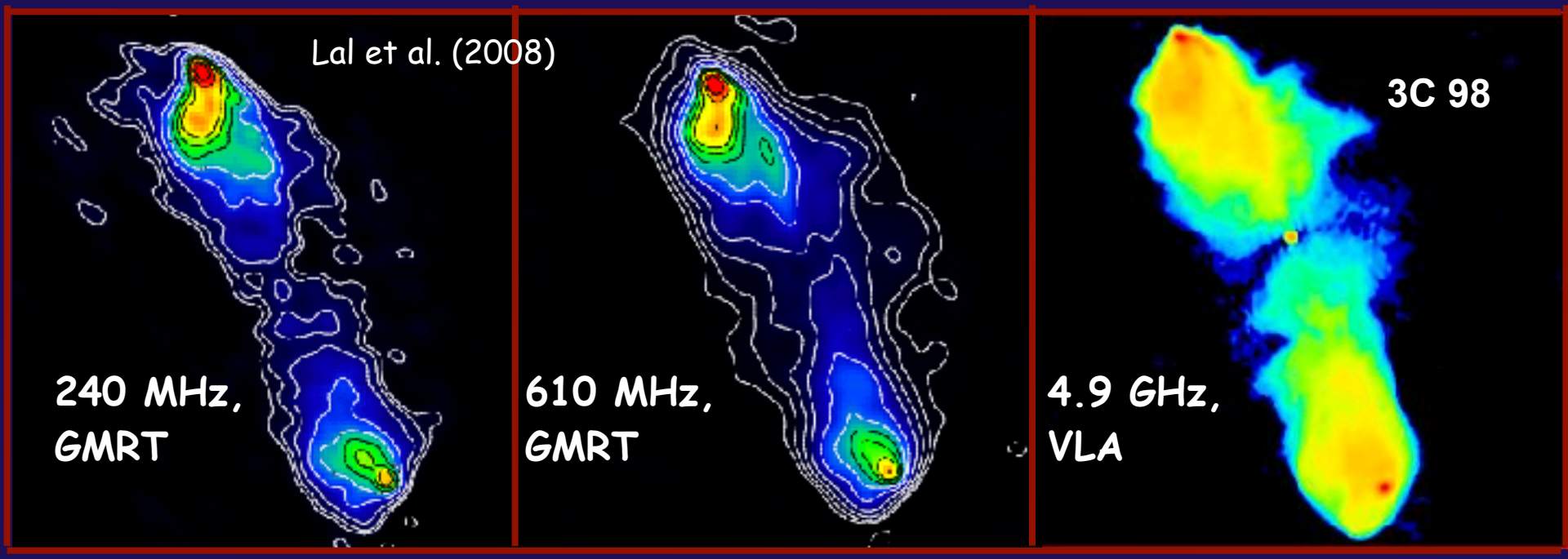


ATLAS of DRAGNs: Leahy et al. 1993 and Lal & Rao 2007

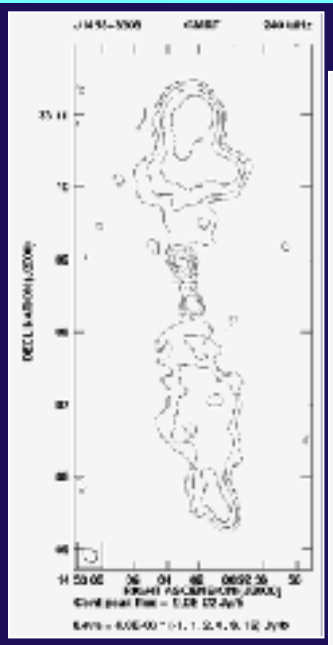


Field radio galaxies

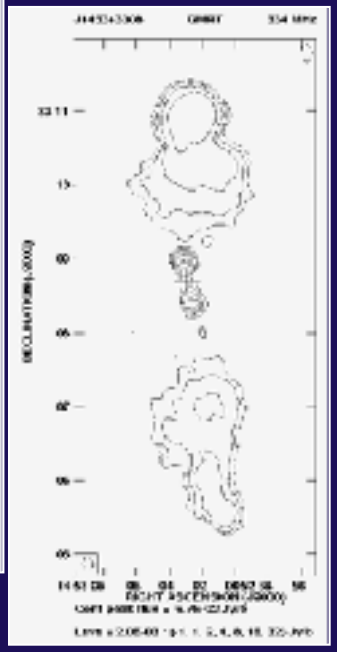
Remarkably similar radio morphologies at a large range of radio frequencies (Blundell 2008; Lal & Rao 2007, 2008).



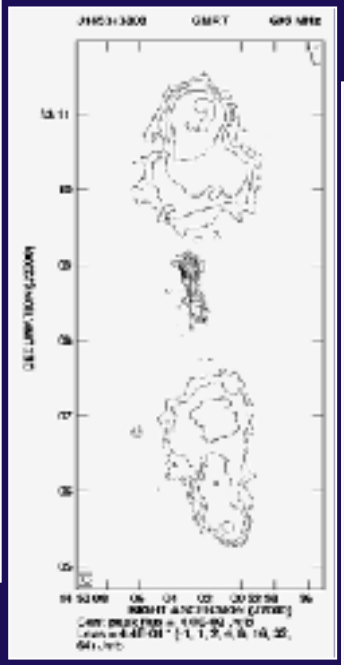
DDRG: J1453+330



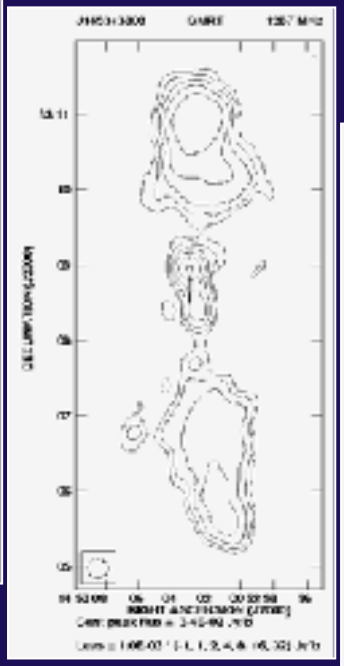
235 MHz, GMRT



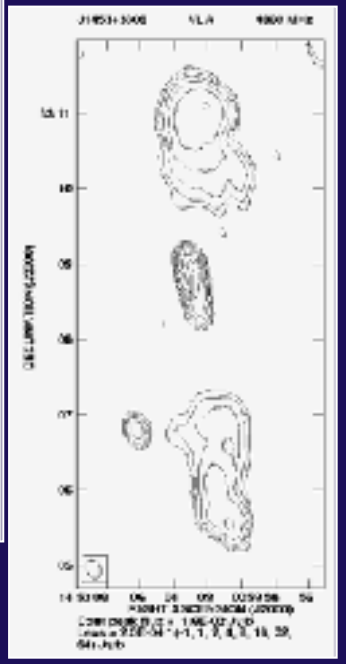
330 MHz, GMRT



610 MHz, GMRT



1420 MHz, GMRT



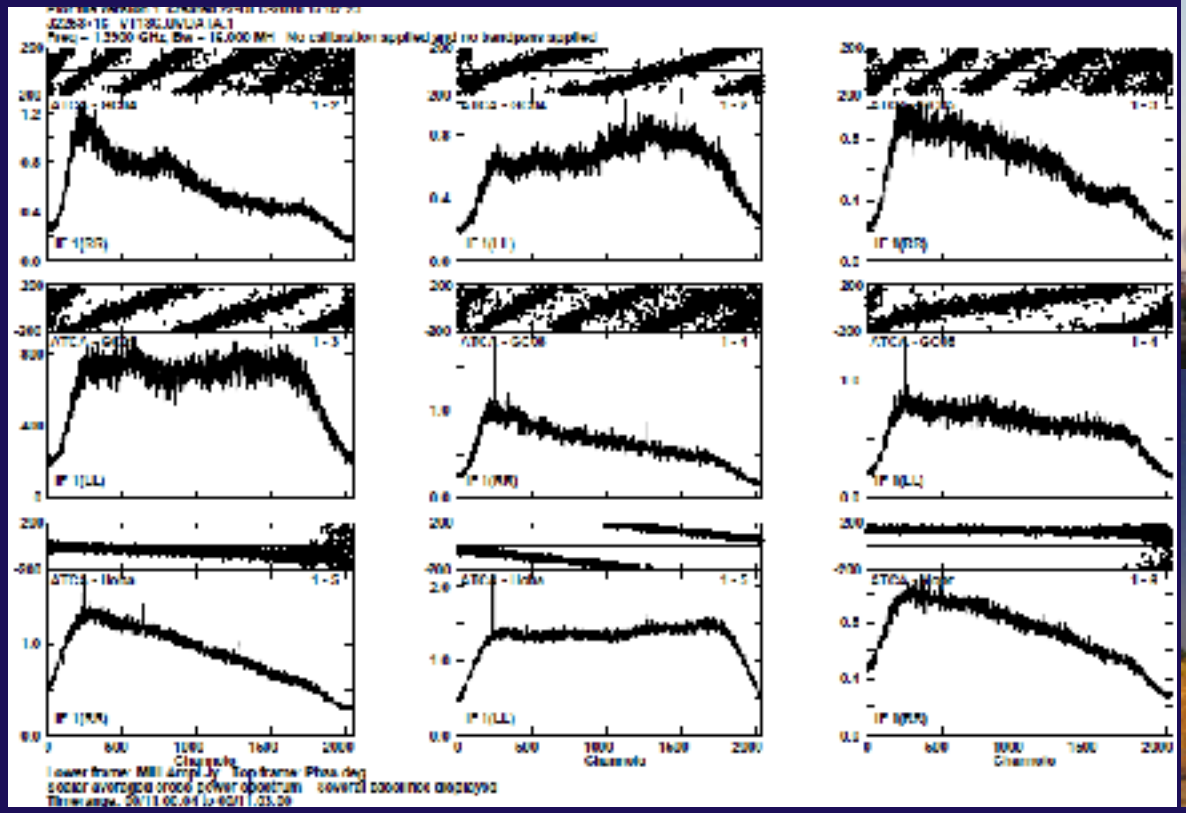
5.0 GHz, VLA

Konar et al. 2006

GMRT: VLBI station

15Dec2010: GMRT(4) + ATCA + MOPRA

- 3C 454.3, 1390 MHz, 16 MHz (BW)



Thank you for your attention!

The Giant Metrewave Radio Telescope is a powerful instrument to probe several astrophysical objects

The upgraded GMRT, even more powerful is available for users…