Cluster of galaxies:

Our efforts using uGMRT

Dharam V. Lal, NCRA-TIFR

with due thanks to

Ishwara-Chandra C.H.

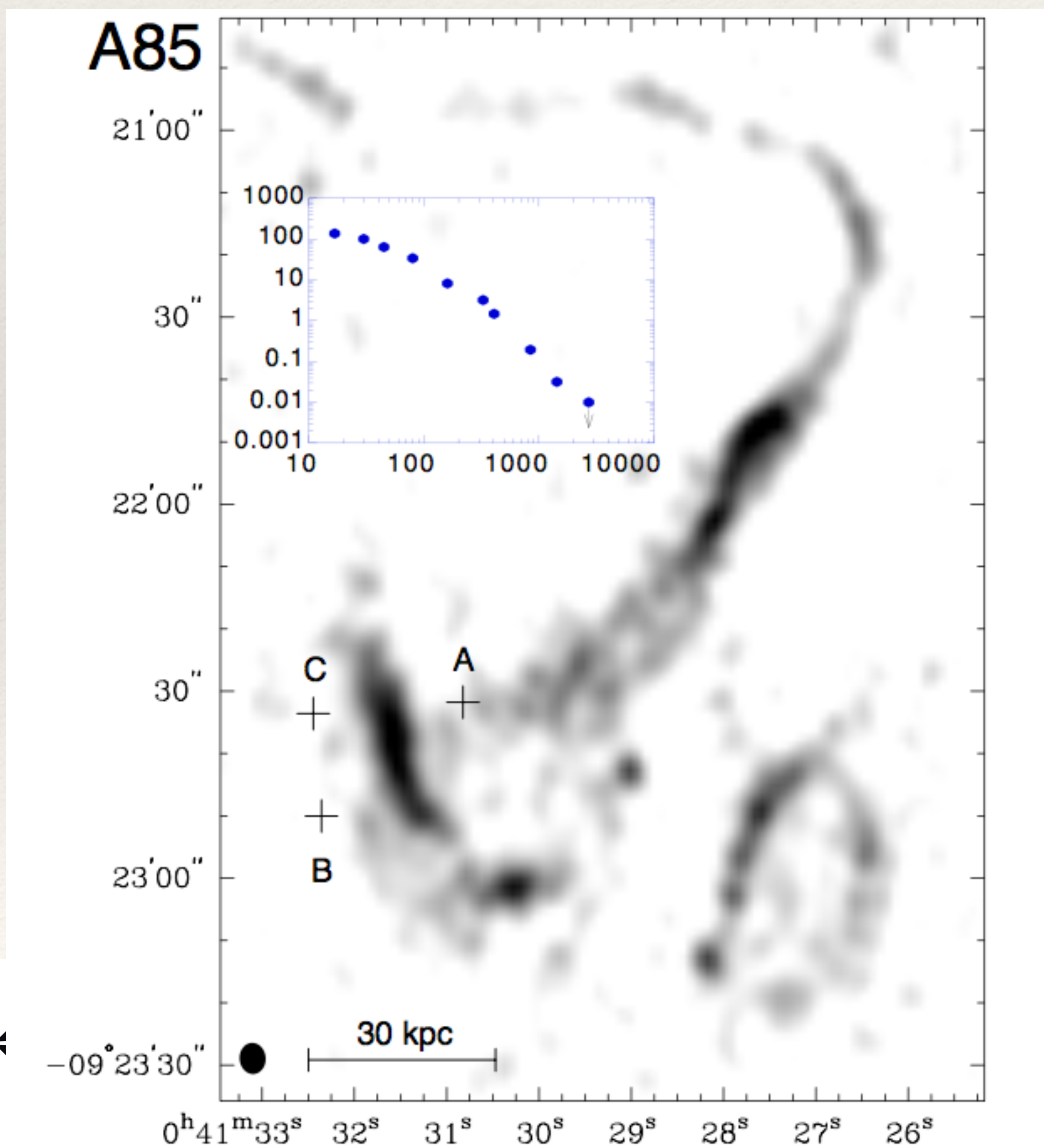
NCRA • TIFR

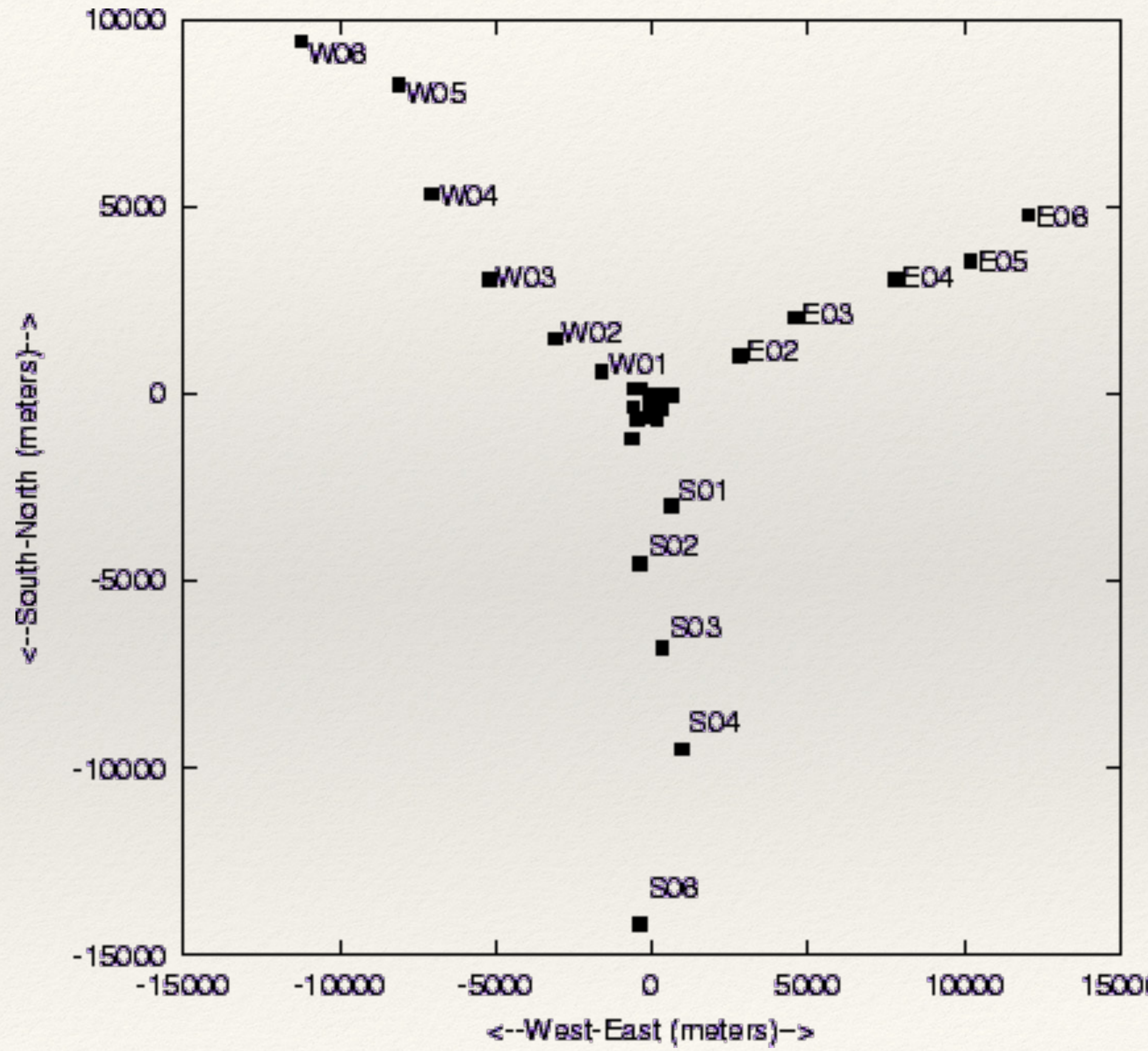
uGMRT as the testbed

A85 (Extreme radio relic / … / dead radio plasma)

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

- z = 0.079





Lal, D.V. ; ARDRA: Galaxies and clusters of galaxies

GMRT upgrade

uGMRT is a major upgrade of the GMRT

- **The fundamental goal is to improve**
  - **major observational capabilities of the original GMRT (bandwidth, UV-coverage, sensitivity).**
- This is a leveraged project - built upon existing infrastructure of the GMRT.
- Nearly seamless frequency coverage from 125 MHz to 1450 MHz
  - provided by 4 frequency bands
  - with new receivers.
- New correlator with 400 MHz bandwidth capability.
  - New digital / analog design to maximise instrumental stability and repeatability.
- Expectation - noise-limited, full-field imaging in all Stokes parameters for most observing fields.
- **The upgrade is now complete.**

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uGMRT as the testbed | 250-500 MHz

an early test of GWB

250-500 band synthesis on Coma

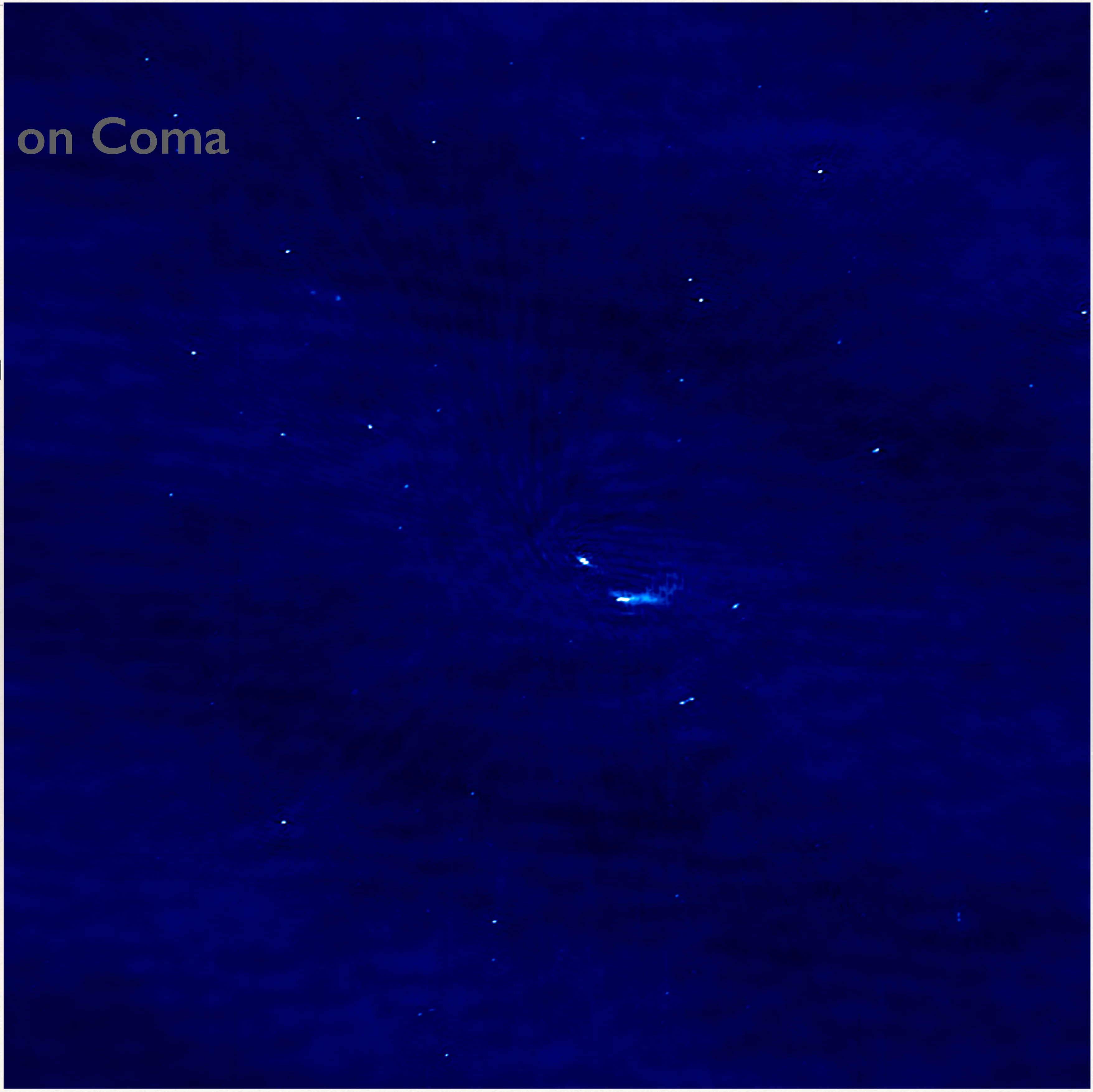
- 16 antennas
- 2048 channels
- 198.2 MHz bandwidth
- 9 x 30 min

DR ~327

RMS noise

- ~0.3 mJy/beam

this is ~22 x thermal



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uGMRT as the testbed | 250-500 MHz

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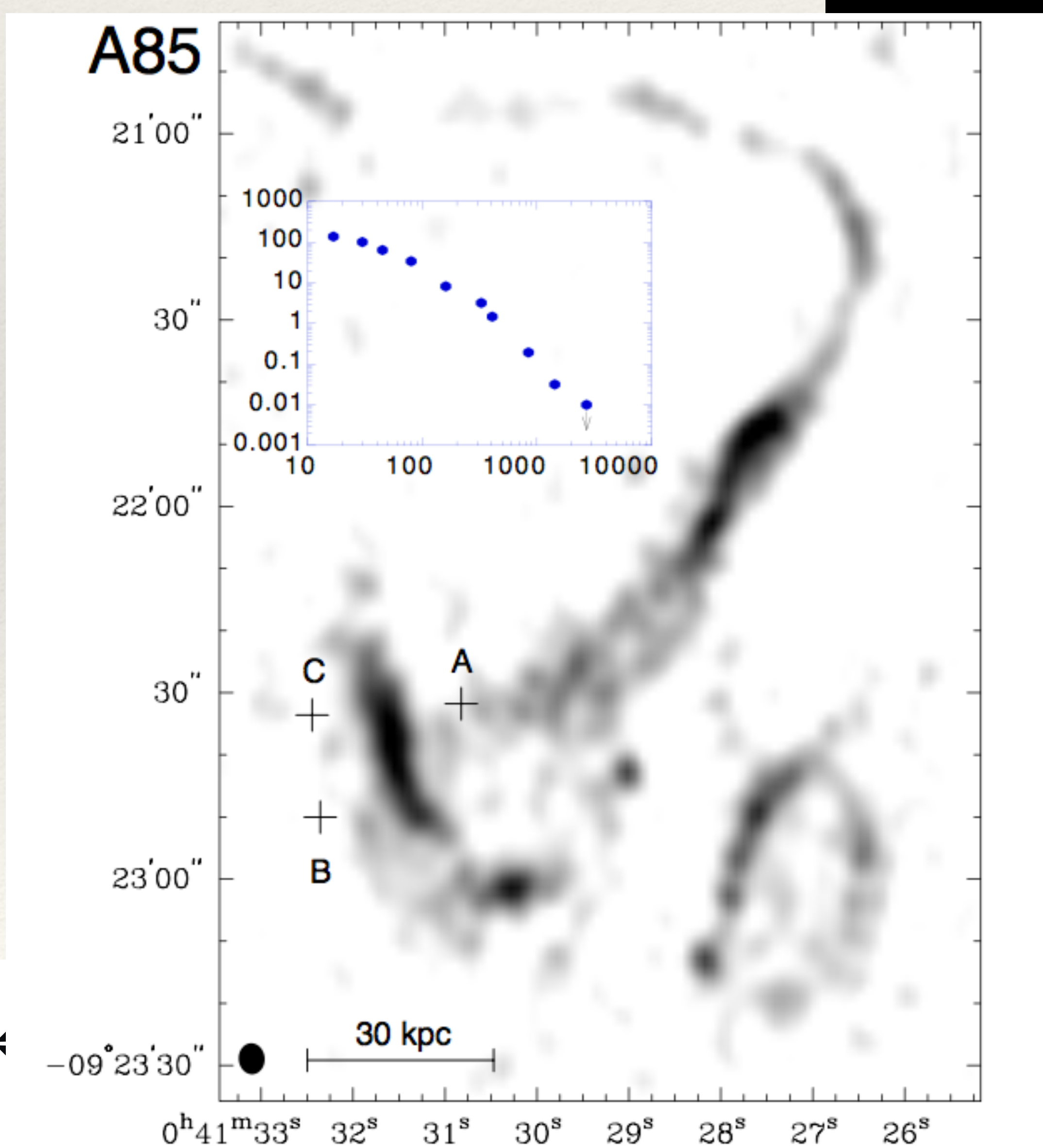
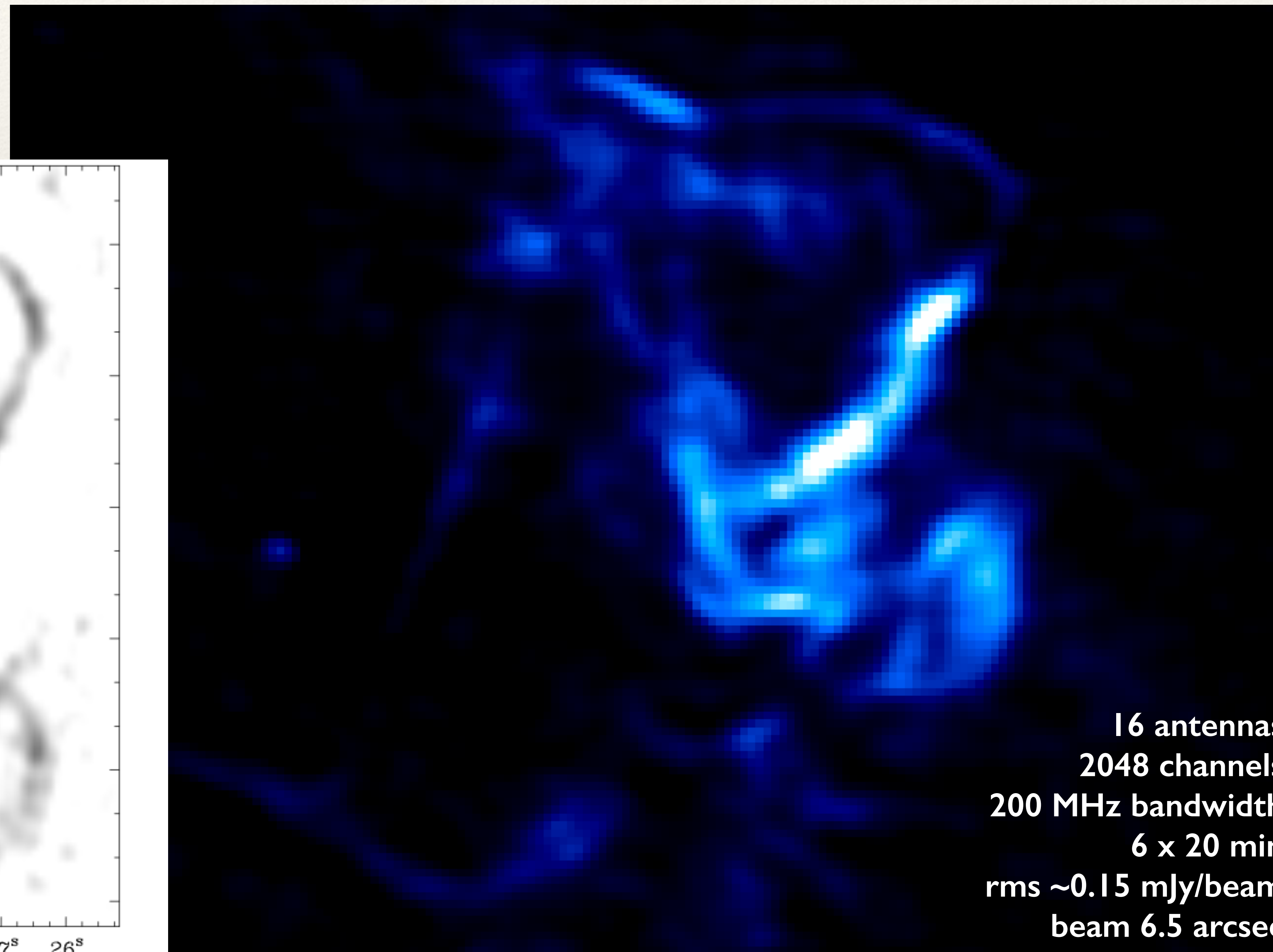
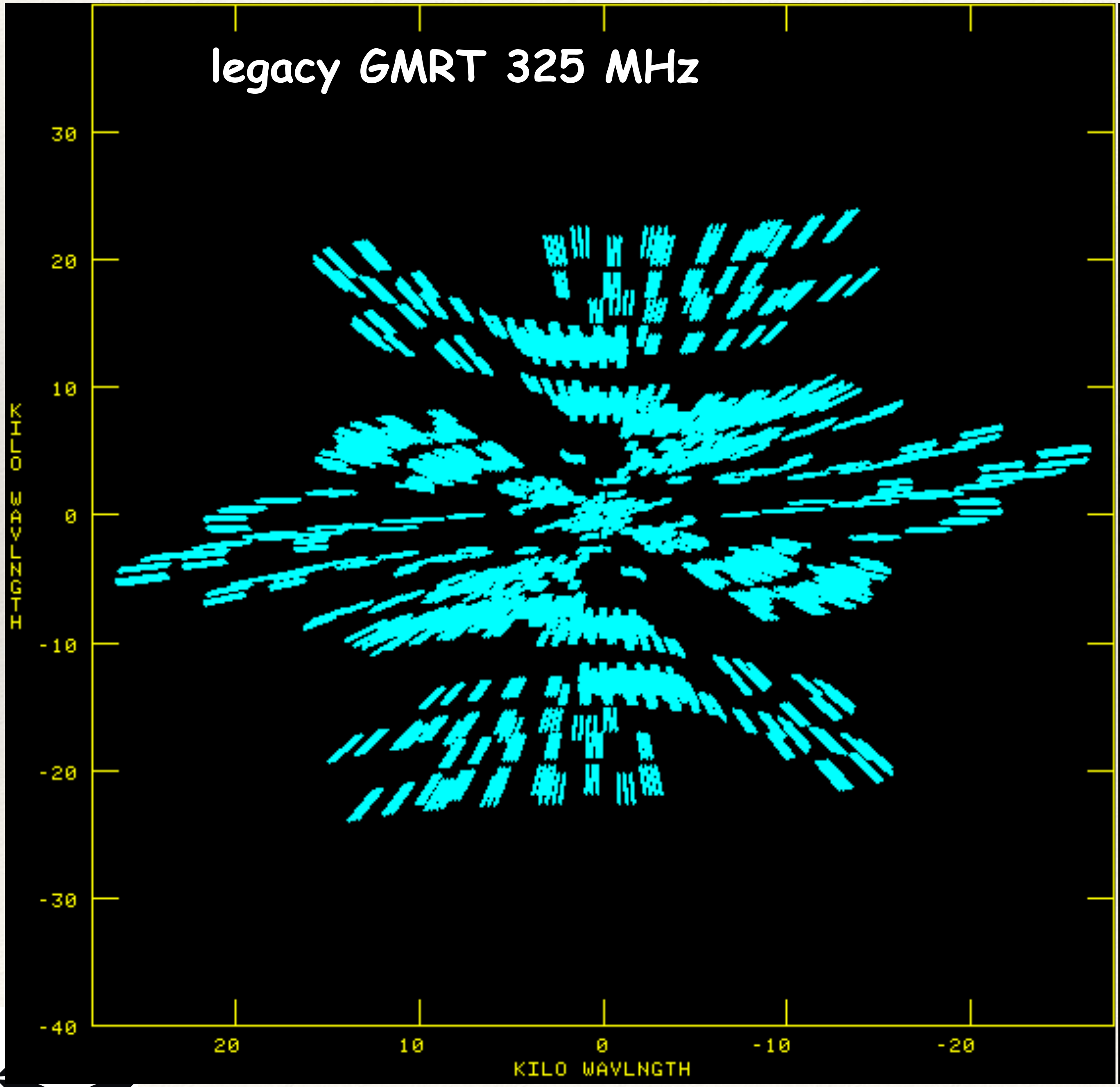
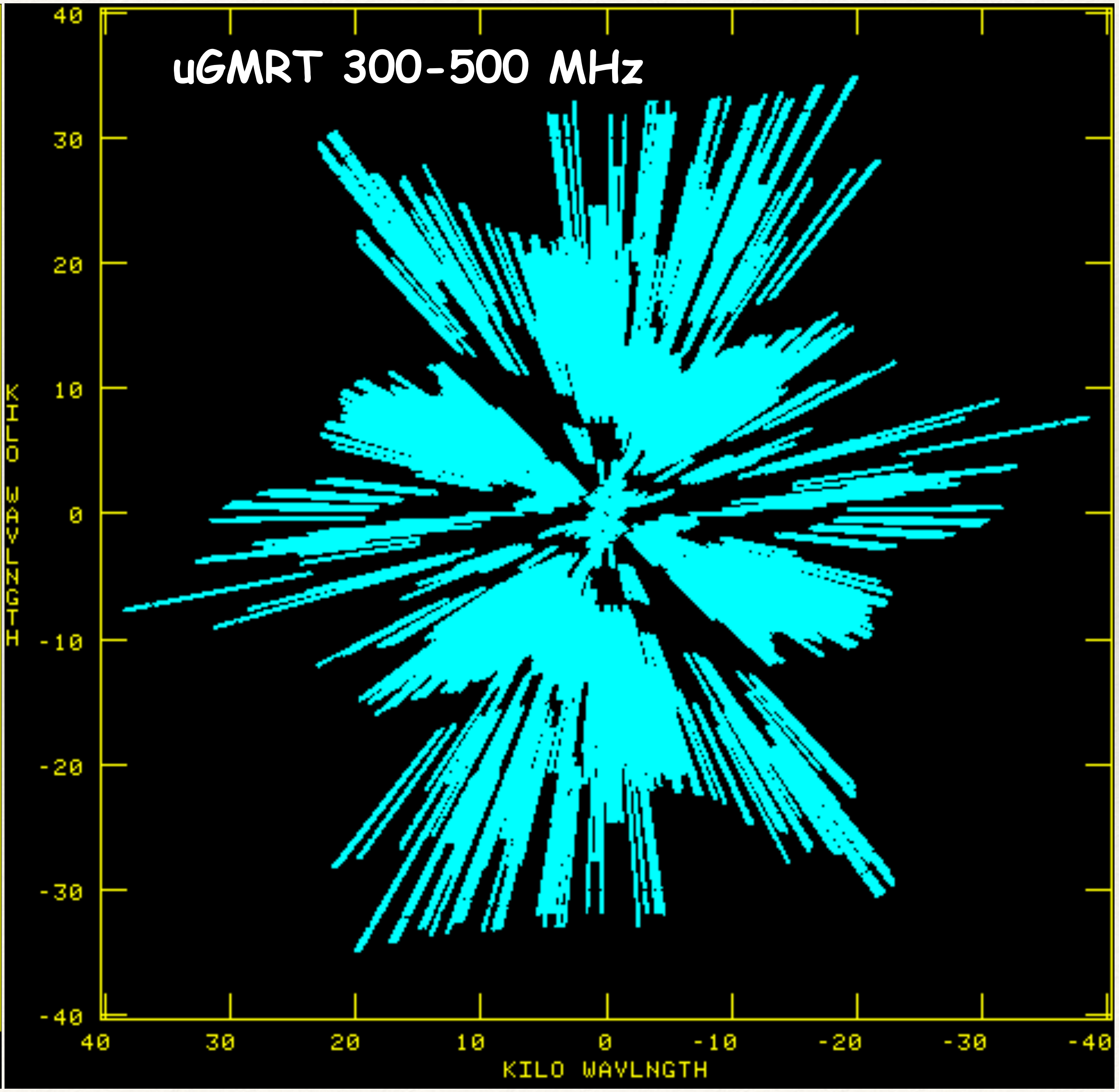




What is special in this "u"? | 250-500 MHz

A85 (Extreme radio relics / … / dead radio plasma)





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What would we learn?

Faint synchrotron radiation is an indicator of wide spread B-field

=> we study, both,

- feedback of outflows driven by galactic BHs and
- the gravitationally driven evolution of large-scale cosmic filament structure.

=> highlights the potential to use diffuse synchrotron emission to illuminate ICM energisation in both clusters and lower density regions invisible at other wavelengths.

Archetype Coma cluster in the nearby universe!

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Prior knowledge | Coma cluster

352 MHz, WSRT image:134 x 68 arcsec² (Brown & Rudnick 2011)

408 MHz, DRAO+Arecibo: ~135 arcmin radio 'cloud' (Kronberg+ 2007)

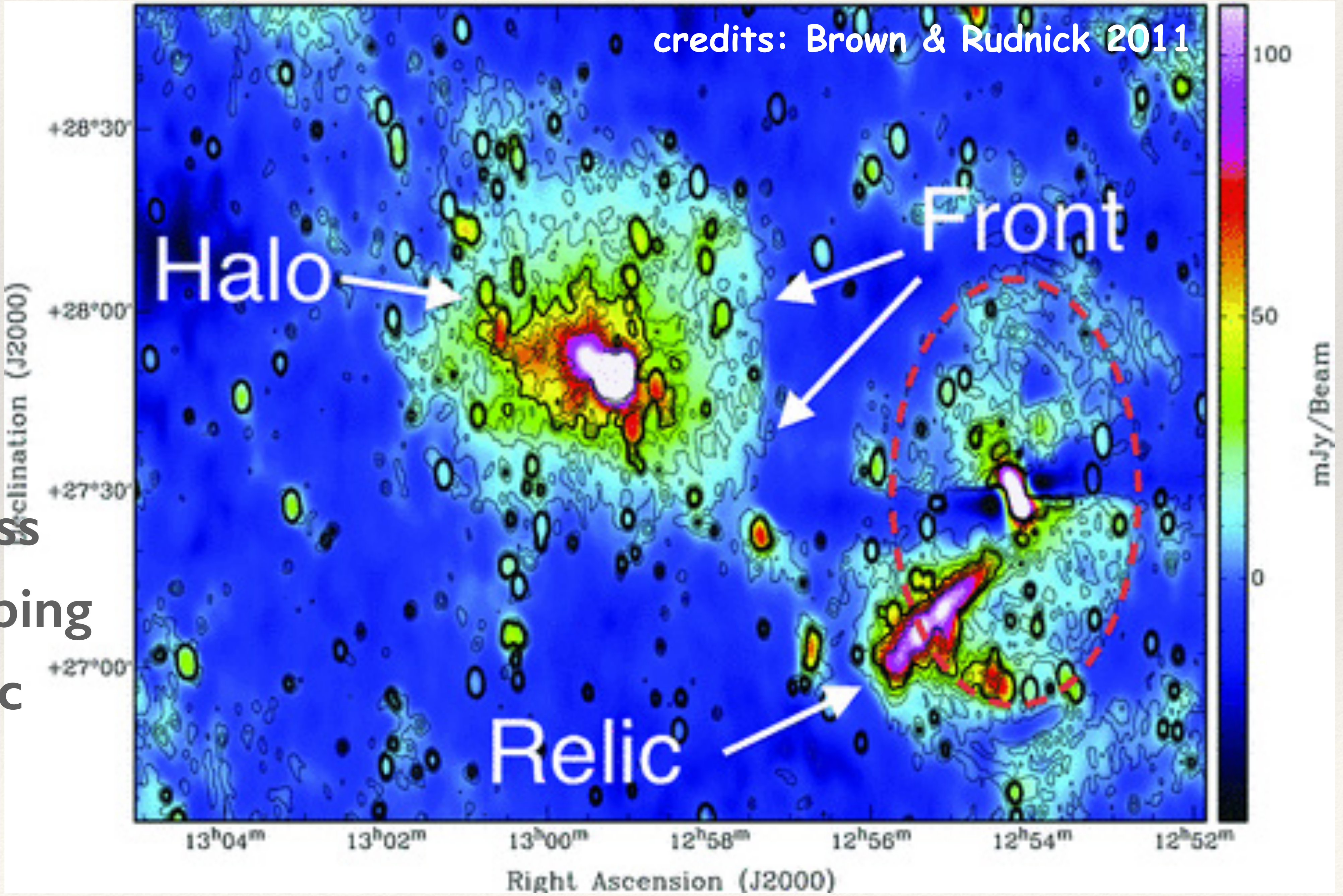
150 MHz, WSRT: radial steepening of spectral index (Pizzo 2010)

Abell 1656

z = 0.0235

469 pc/arcsec

existence of low surface brightness emission enveloping the halo and relic (Kronberg+ 2007)



What images do we need?

Deep images containing all information on all spatial scales,

information of bright / faint point-sources,

information of low-surface brightness diffuse emission,

(information of polarisation structure)

…

We want

high-fidelity images in all Stokes as function of frequency

- fidelity: best high-dynamic range images
- and noise as low as ~ μJy levels.

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GMRT: D

No. of antennas

26-28

No. of pol'n

1-2

No. of channels

64-256

Band-width

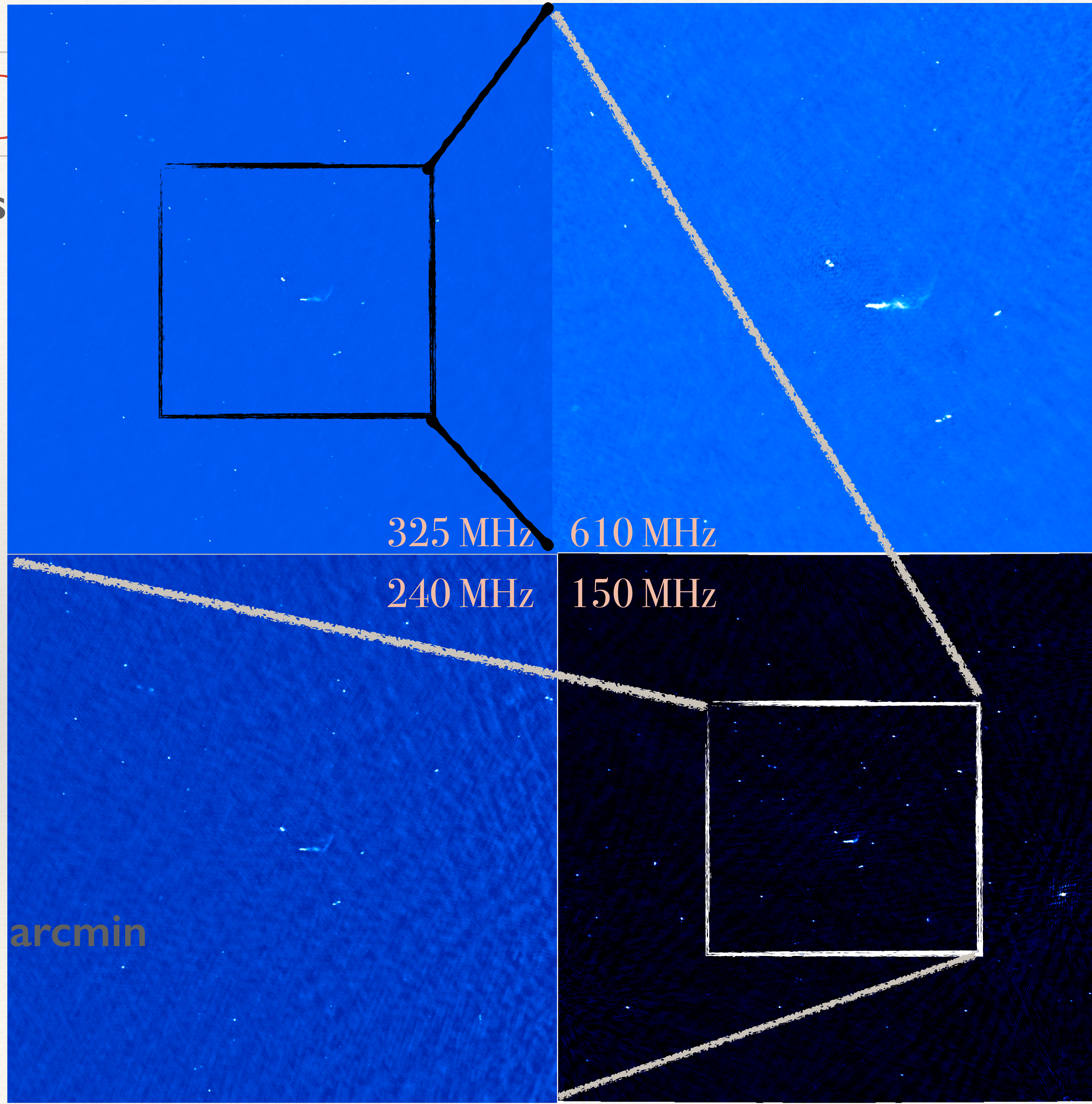
7-15 MHz

t_{int} (on-source)

2.0 - 2.5 hr

FoV

43/81/114/186 arcmin



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GMRT: Data reduction | 610 MHz

Shown here - 610 MHz

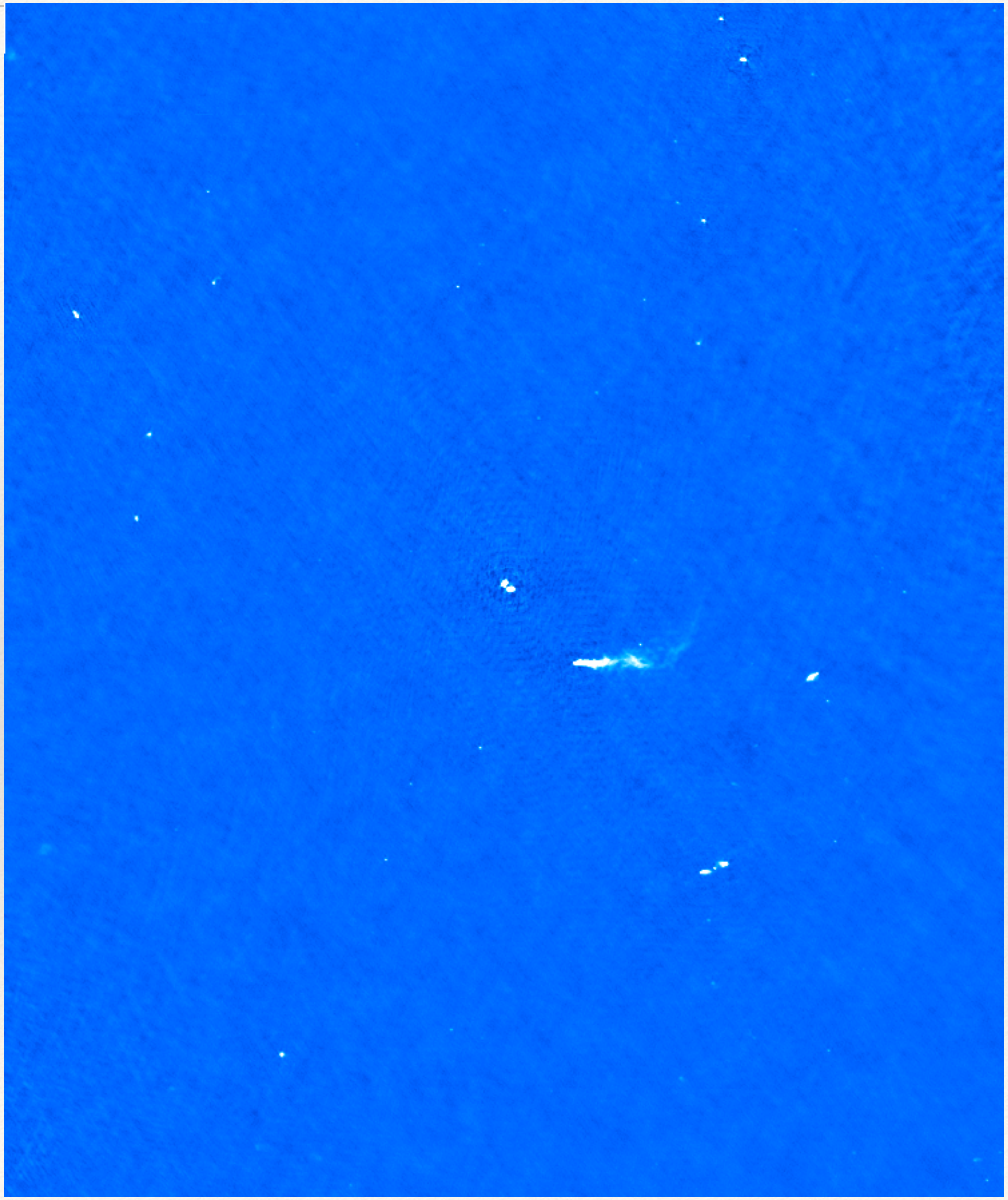
- 27 antennas
- 128 channels
- 15.0 MHz bandwidth
- 5 x 30 min (1 pol.)
- FoV 43 arcmin

DR ~ 716

RMS noise

- ~0.1 mJy/beam
- ~4.9 arcsec beam

this is ~3 x thermal



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GMRT: Data reduction | 325 MHz

Shown here - 325 MHz

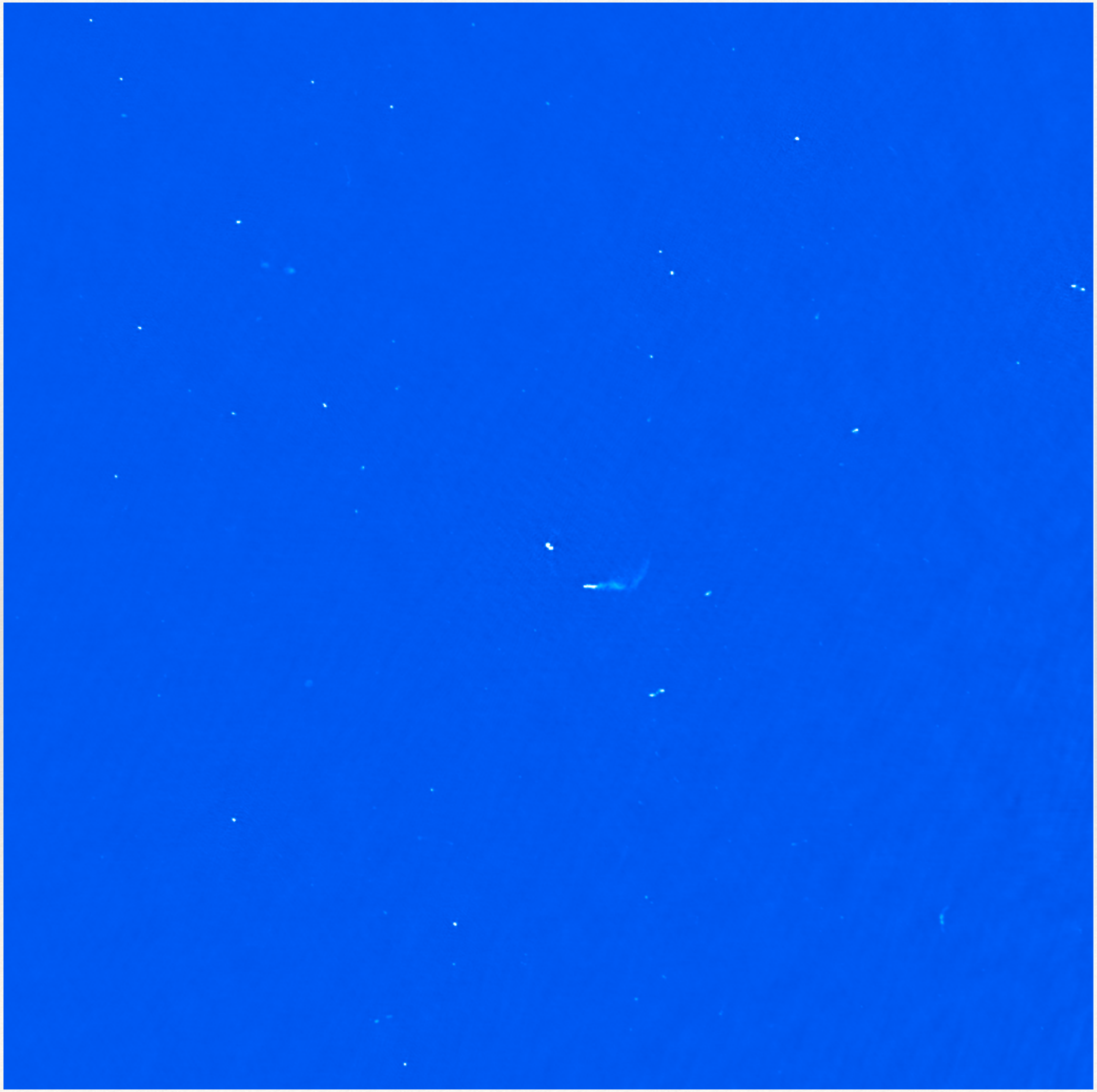
- 28 antennas
- 128 channels
- 14.8 MHz bandwidth
- 4.5 x 40 min (2 pol.)
- FoV 81 arcmin

DR ~ 653

RMS noise

- ~0.35 mJy/beam
- ~8 arcsec beam

this is ~9 x thermal



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GMRT: Data reduction | 240 MHz

Shown here - 240 MHz

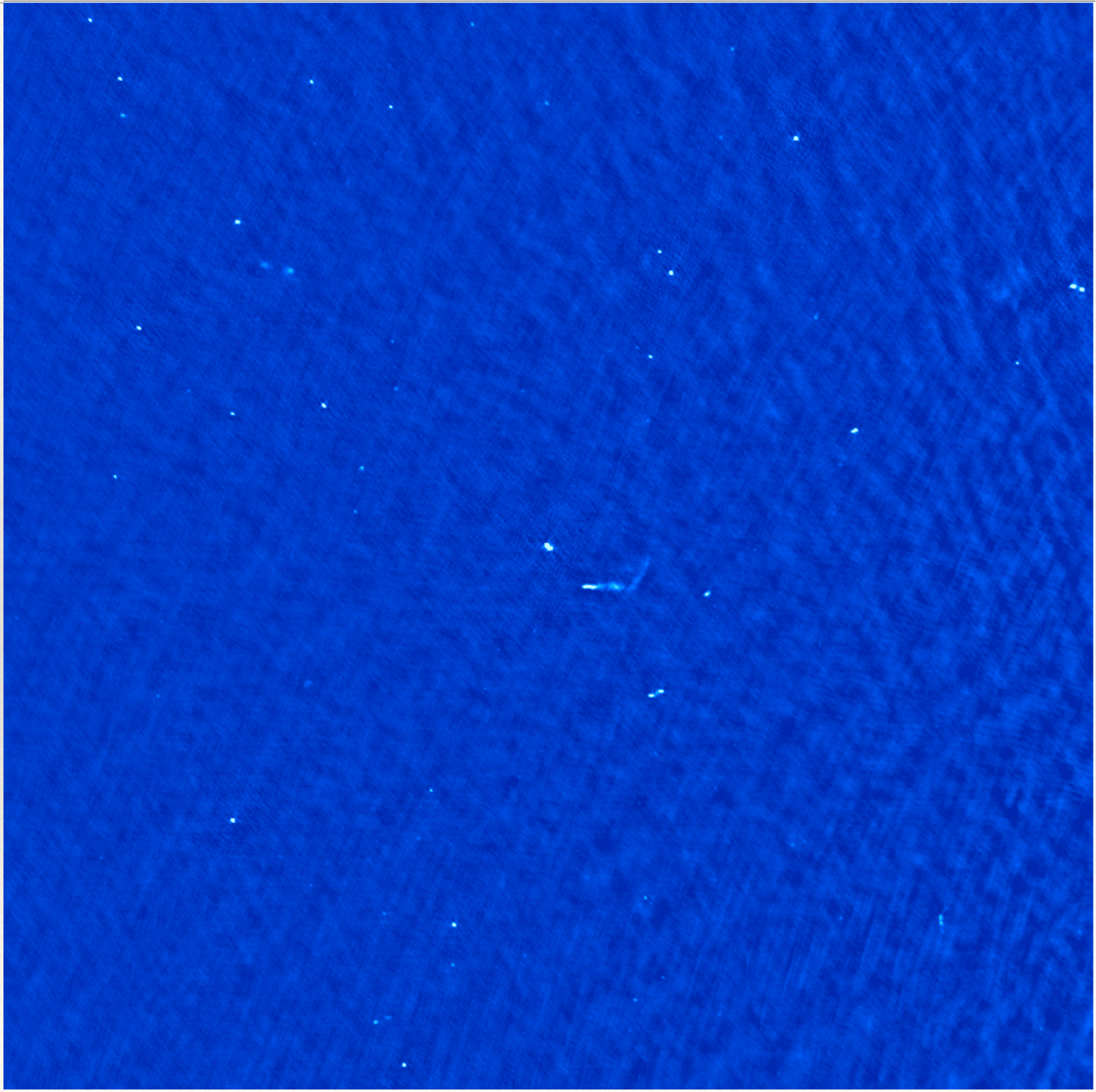
- 26 antennas
- 64 channels
- 5.2 MHz bandwidth
- 5 x 30 min (1 pol.)
- FoV 114 (81) arcmin

DR ~ 295

RMS noise

- ~1.1 mJy/beam
- ~10.8 arcsec beam

this is ~7 x thermal



GMRT: Data reduction | 150 MHz

Shown here - 150 MHz

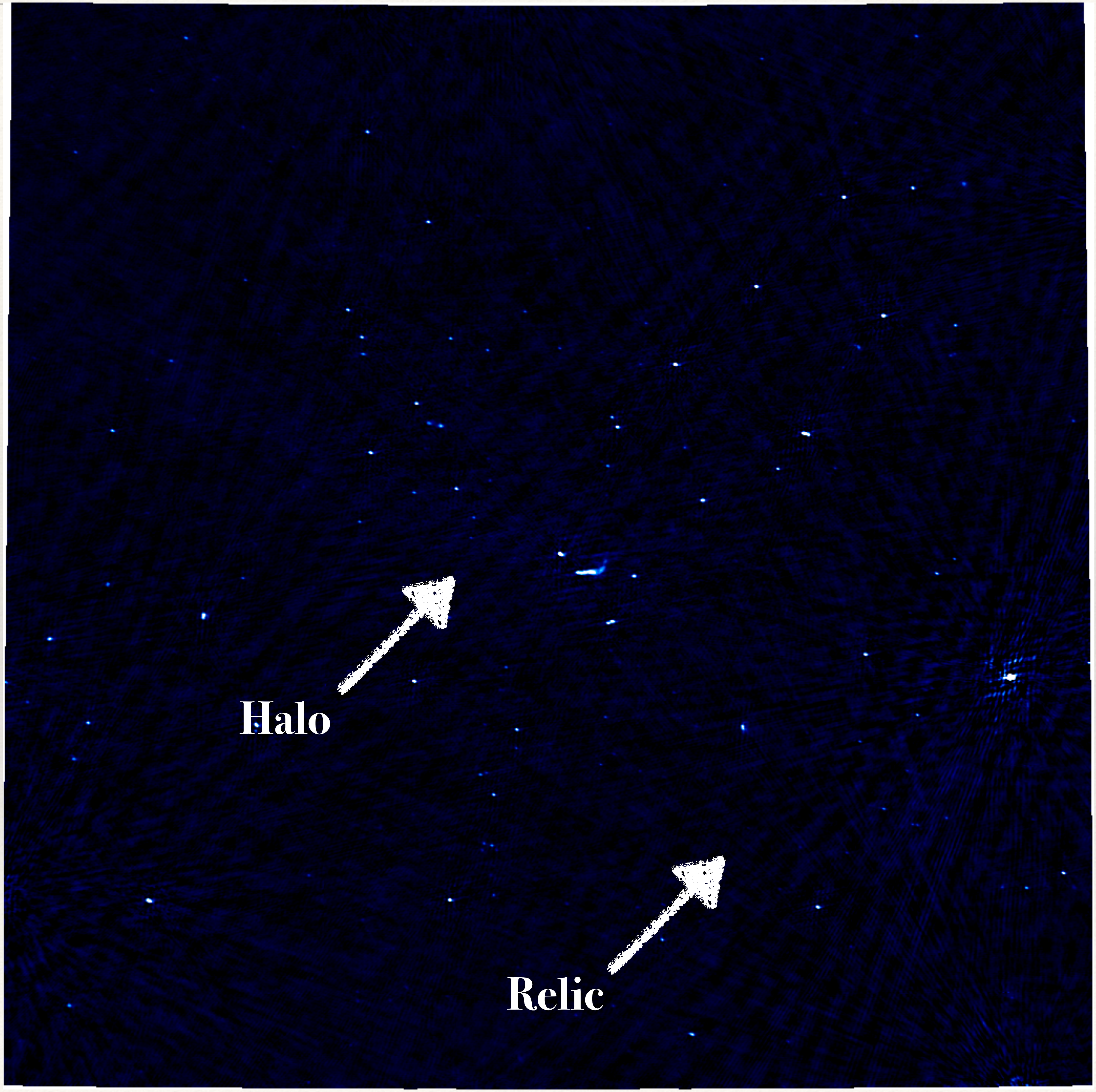
- 27 antennas
- 128 channels
- 14.2 MHz bandwidth
- 7 x 20 min
- FoV 186 (177) arcmin

DR ~ 678

RMS noise

- ~5.4 mJy/beam
- ~21.8 arcsec beam

this is ~20 x thermal



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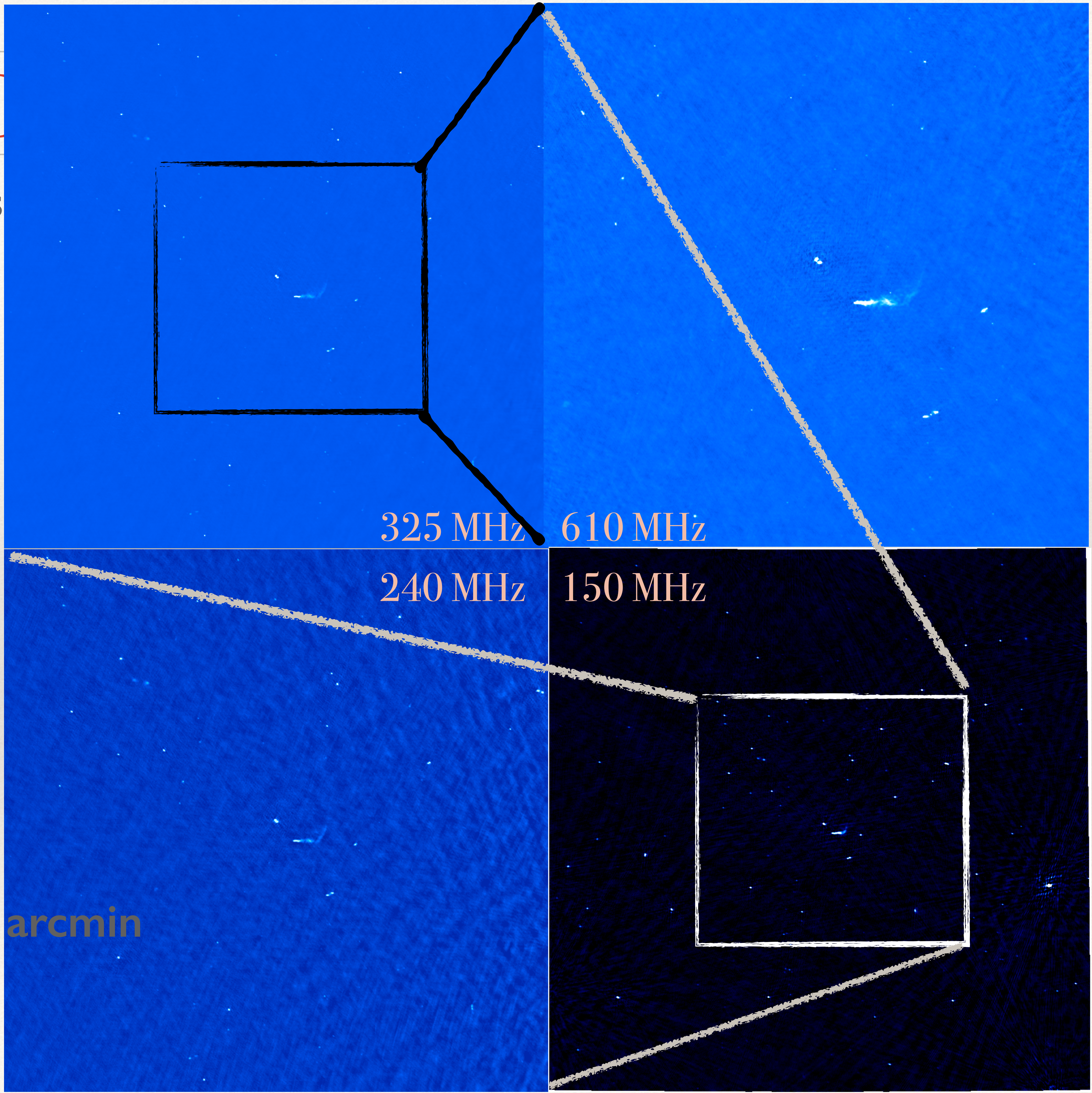
GMRT: D

No. of antennas
  26-28
No. of pol'n
  1-2
No. of channels
  64-256
Band-width
  7-15 MHz
t_{int} (on-source)
  2.0 - 2.5 hr
FoV
  43/81/114/186 arcmin



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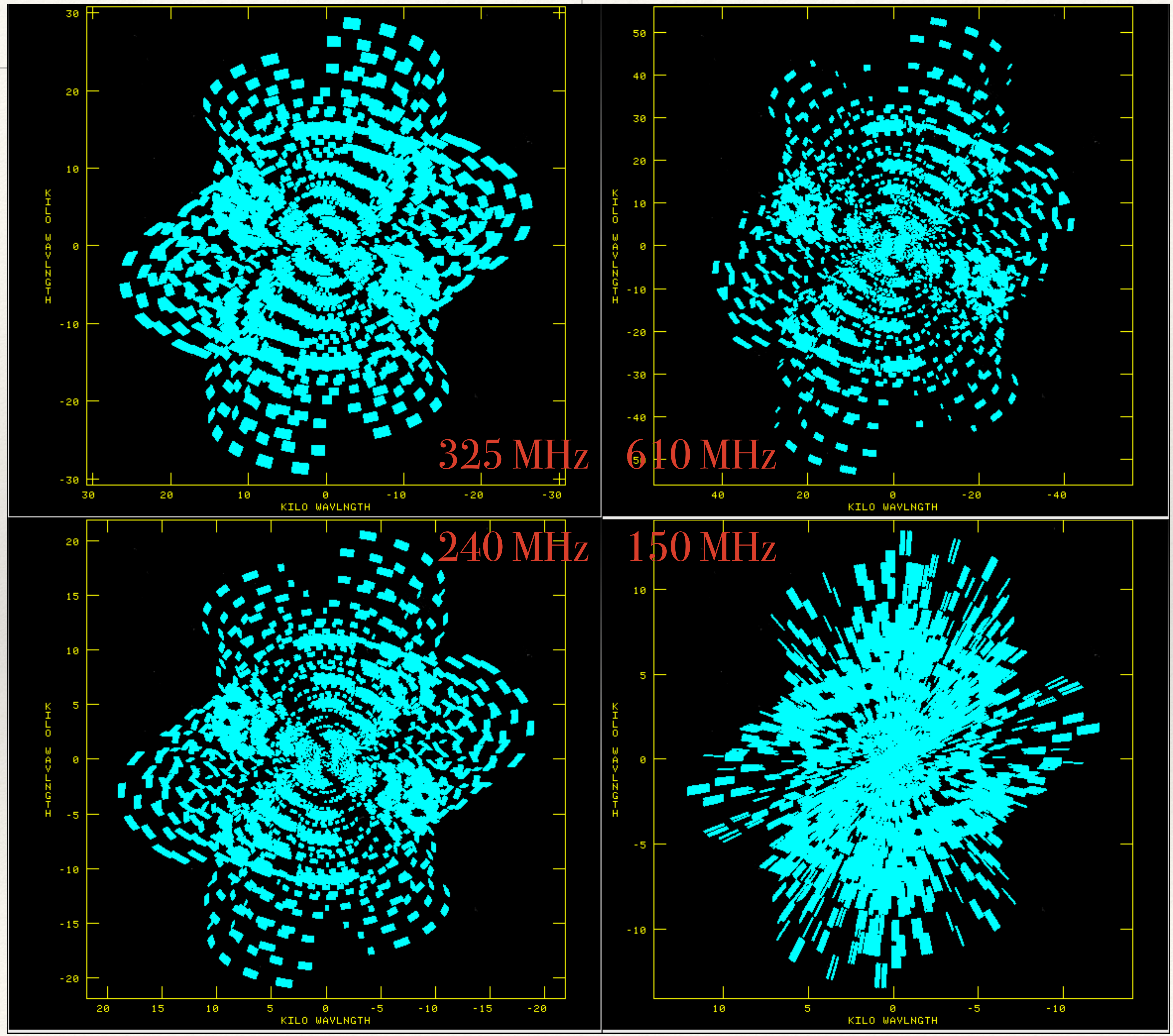
GMRT

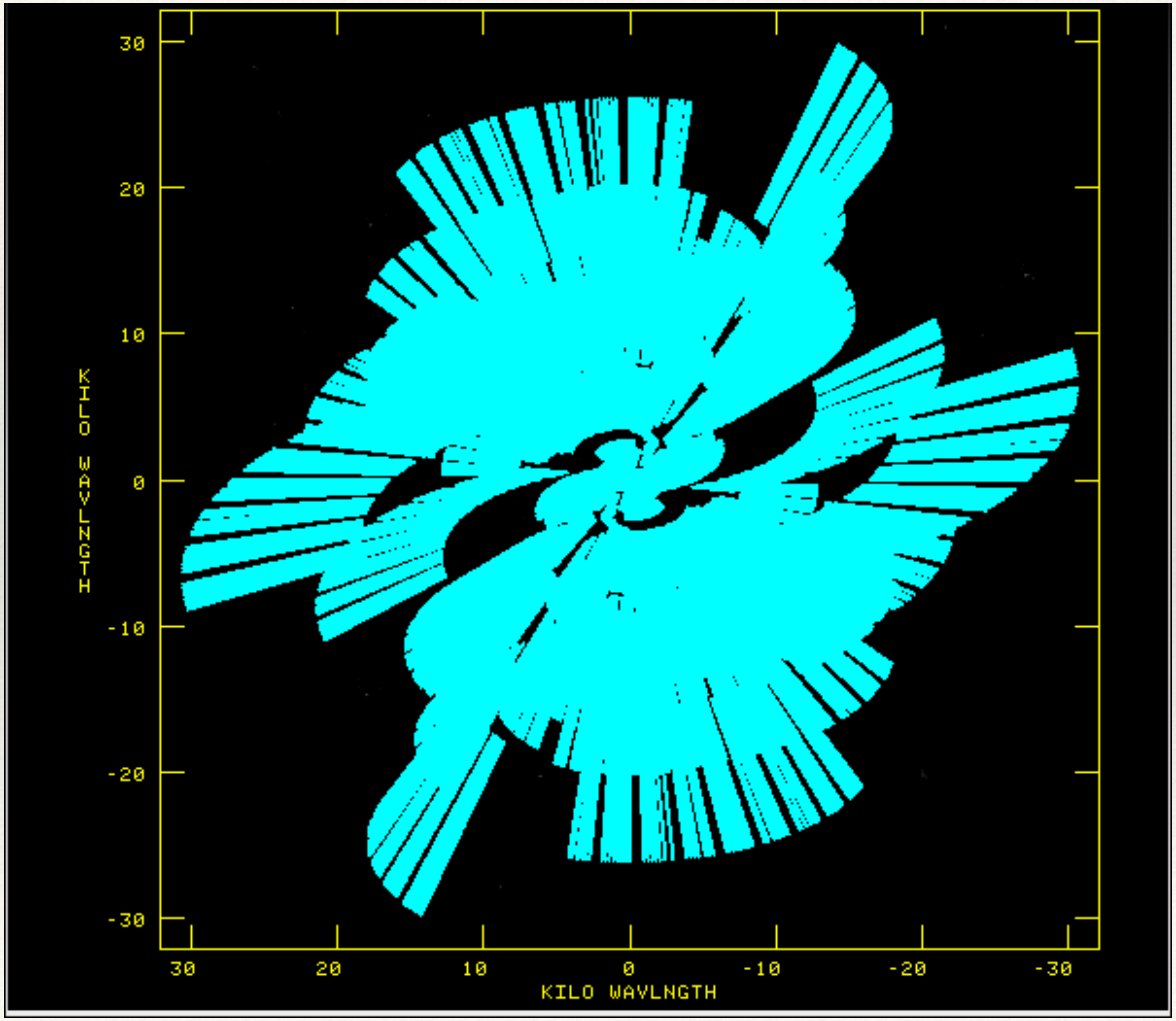


u-GMRT | 250-500 MHz

Shown here - an early test of GWB

250-500 band synthesis on Coma

- 16 antennas
- 2048 channels
- 198.2 MHz bandwidth
- 9 x 30 min



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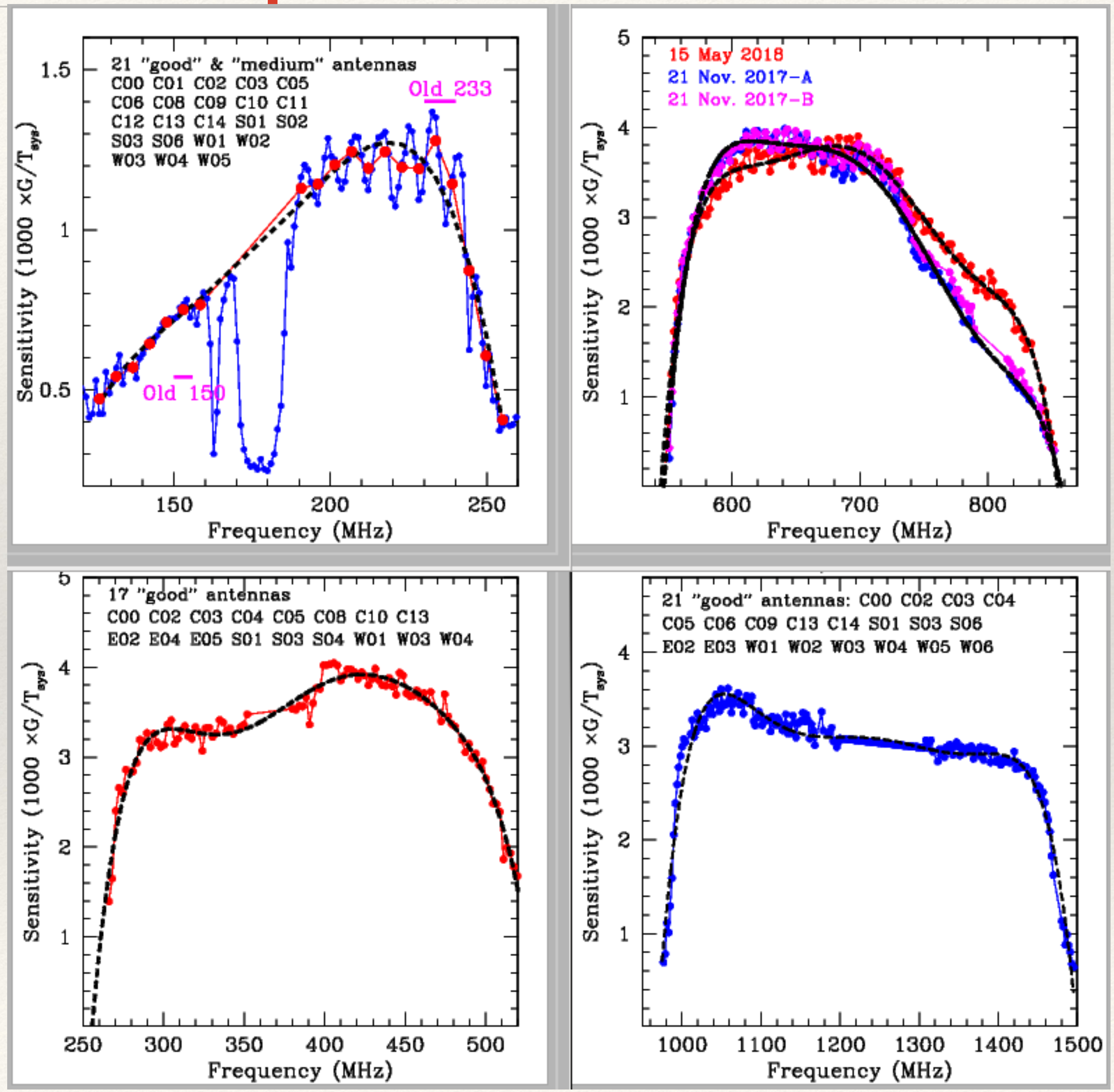
uGMRT: bandshapes



credits: Nissim Kanekar

NCRA • TIFR

uGMRT

Shown here - 250-500 MHz

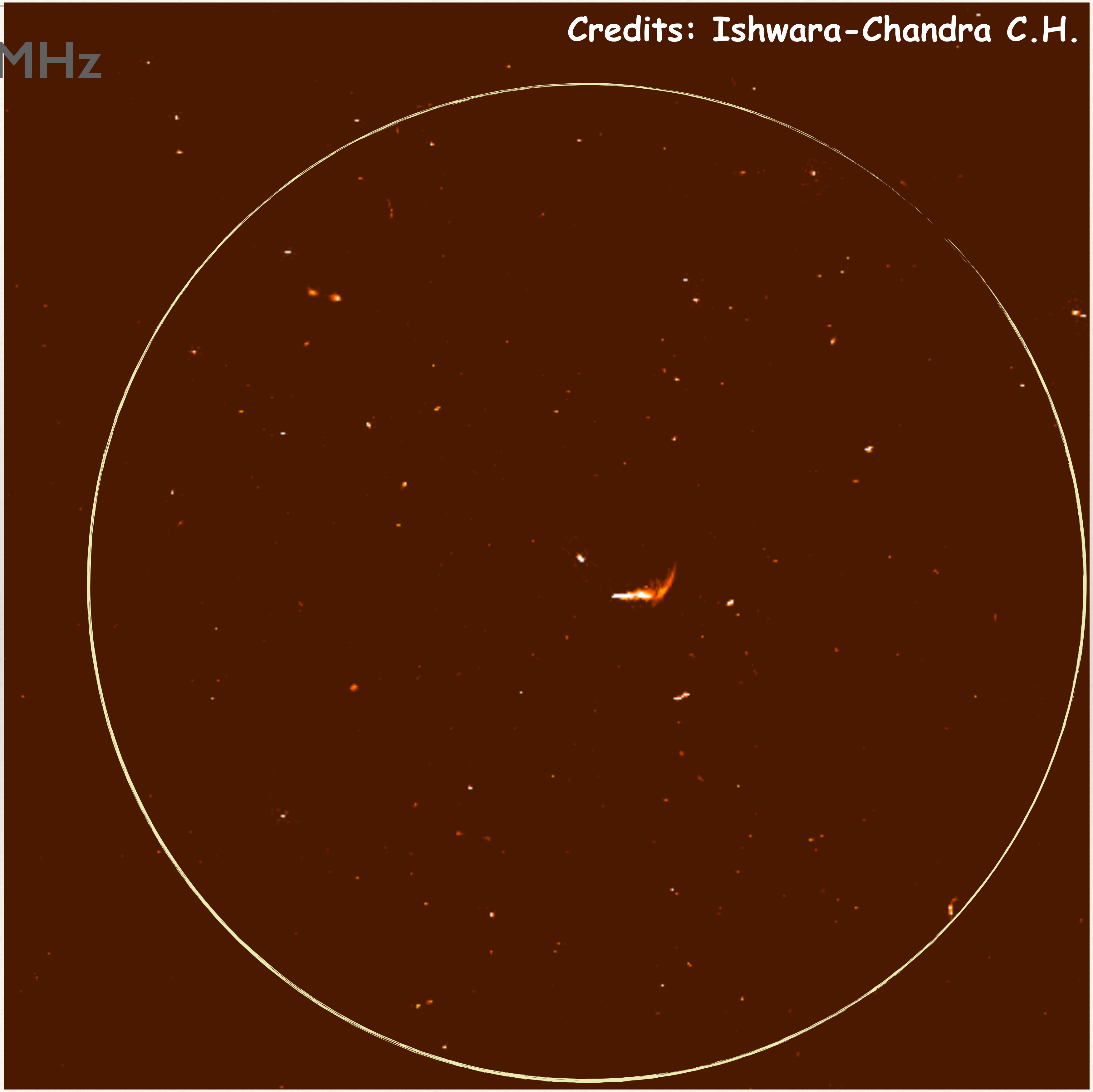
- 28 antennas
- 2048 channels
- 198 MHz bandwidth
- 4 x 30 min
- FoV ~80 arcmin

DR ~ 3460

RMS noise

- ~0.028 mJy/beam
- ~5.5 arcsec beam

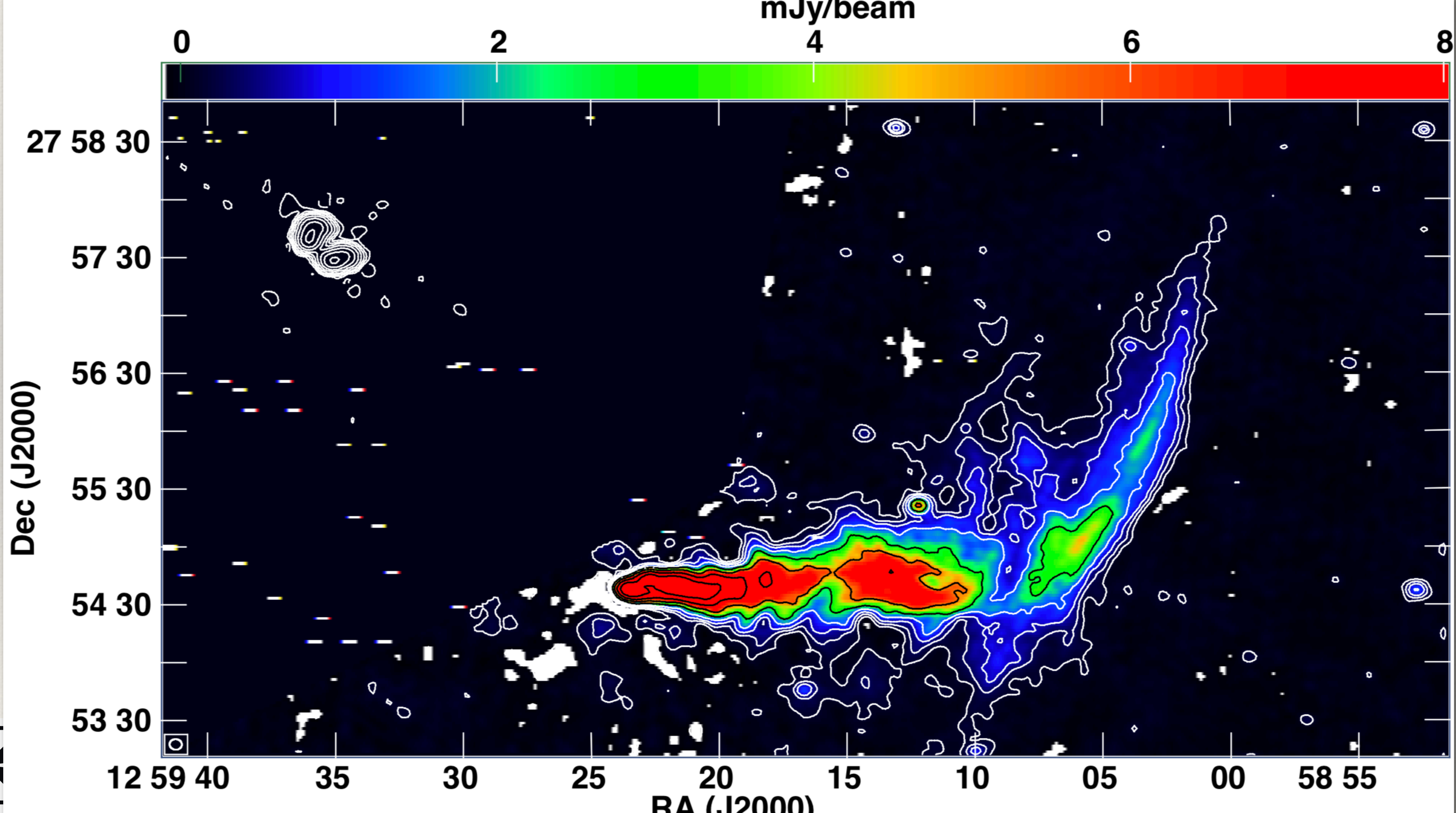
this is ~2.5 x thermal



uGMRT

NGC 4869: head-tail radio source

Credits: Ishwara-Chandra C.H.



GMRT: Data analysis

Thanks to large field-of-view, high sensitivity, high resolution!

- ~30 radio galaxies that are associated with Coma,
- 2 of them for the first time,
- detailed paper (Kim et al. 1994) lists all sources.
- …

Next, if we account for all these sources, subtract these out then we should detect the diffuse (extended halo) emission.

GMRT: Data analysis | 150 MHz

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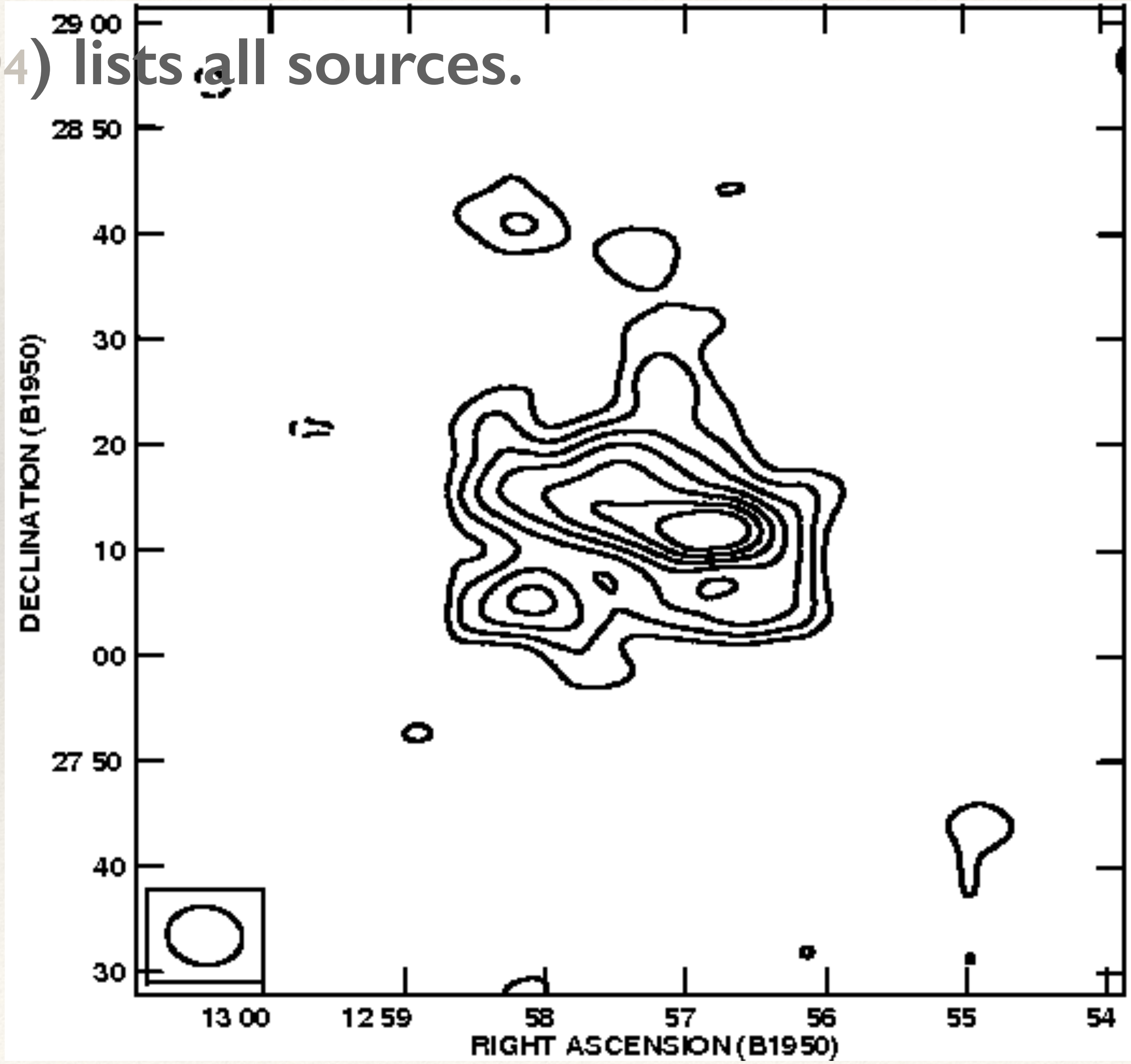
- 150 MHz

~50 arcmin extent

9.8 +/- 0.3 Jy

$\alpha_{(408-150)}$ 0.77 +/-0.08



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uGMRT: Data analysis | 250-500 MHz

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Halo emission | Coma cluster

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- 150 MHz

  ~50 arcmin extent

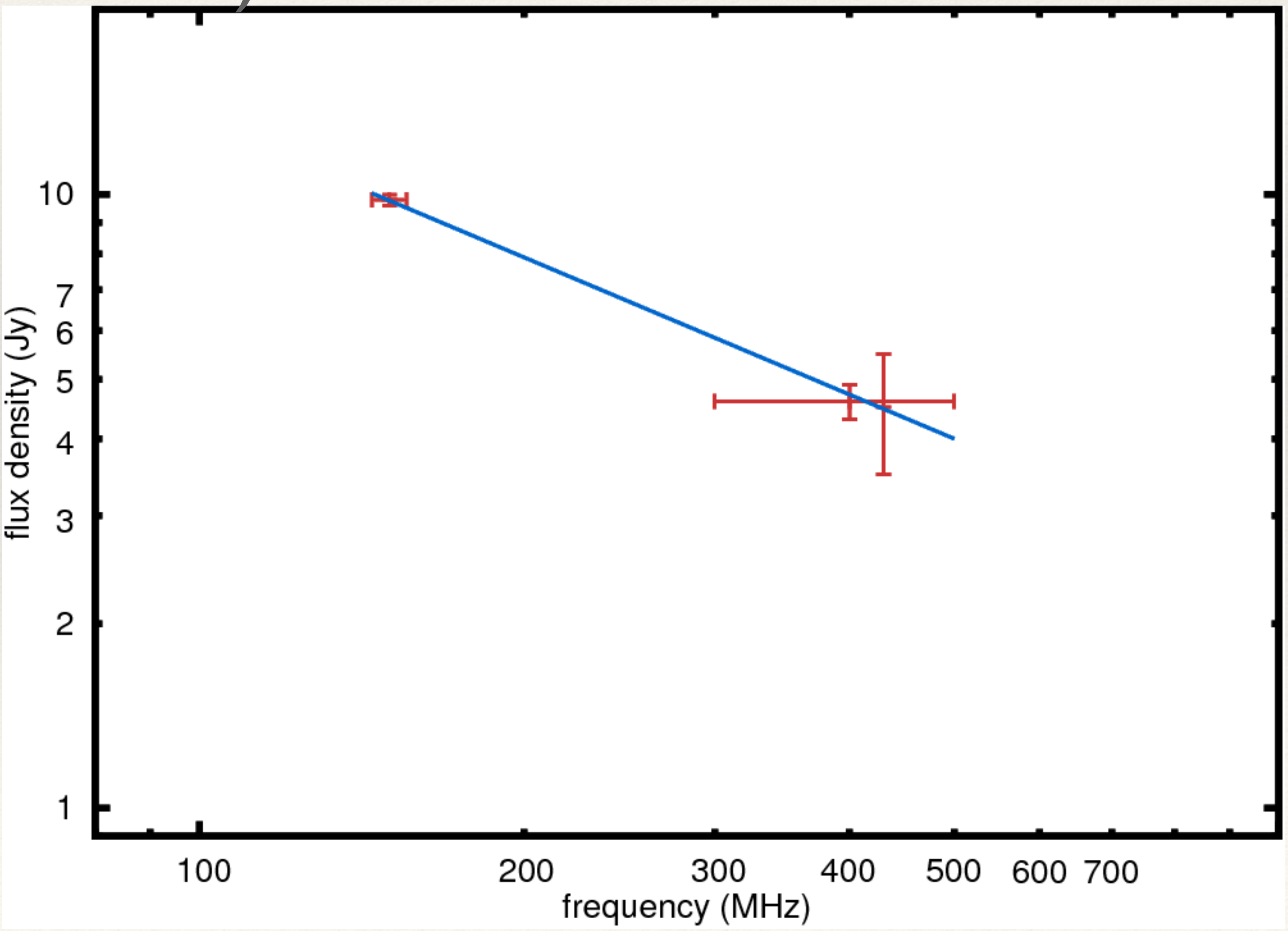
  9.8 +/- 0.3 Jy

  $\alpha_{(408-150)}$ 0.77 +/-0.08

- 250-500 MHz

  40-50 arcmin extent

  4.6 +/-0.4 Jy



The story so far | Coma cluster

A high resolution, high sensitivity, low radio frequency view of the Coma cluster

Deepest images (and dynamic range does not change with freq.)

A clear detection of Coma halo emission at several radio frequencies

Challenges:

- direction-dependent errors
- antenna pointing errors
    - variation of amplitude/phase within the primary beam
- atmosphere phase gradients

Imaging using uGMRT

With the new capabilities of the upgraded GMRT

- full frequency coverage across several bands
- from 2048 to 16348 frequency channels
- dual polarisation
- raw data occupies ~25GB (5.3 sec, 16 ant, 2 pol, 2k ch, 7.5 hr)

Imaging challenges

We need fast efficient, 'correct', easy-to-use deconvolution

…

Much work lies ahead to understand / control these…

Imaging using uGMRT | Thank you!

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