Investigating diffuse radio emission with LOFAR: The complex merging galaxy cluster Abell 2069

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on behalf of the LOFAR surveys galaxy cluster group

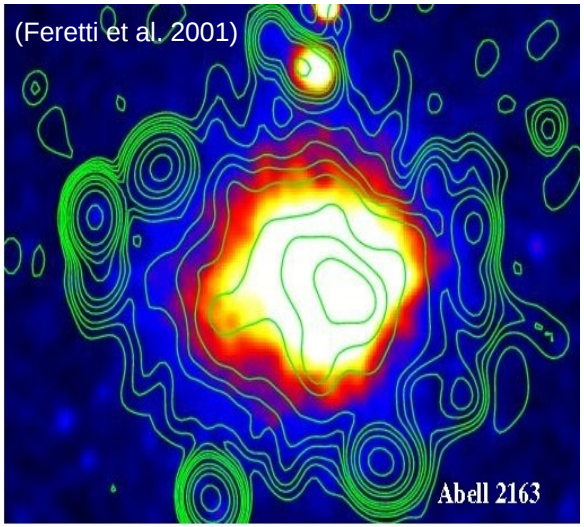
Radio halo emission in galaxy clusters

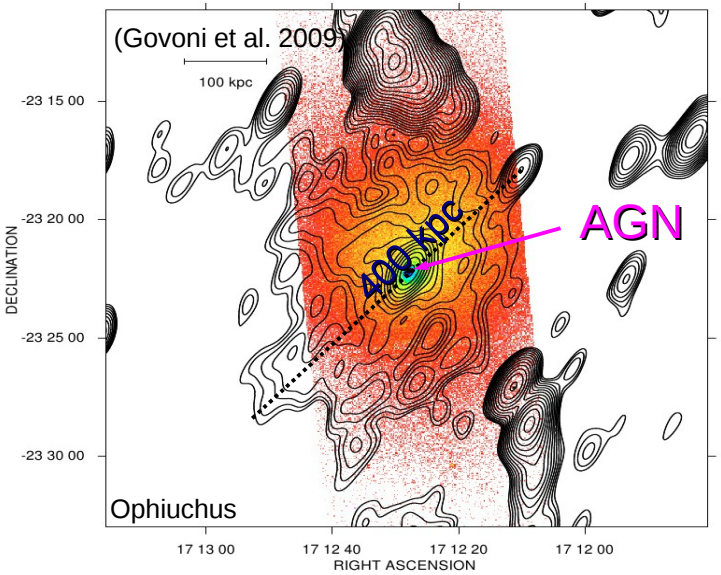
- **steep** spectrum: $\alpha \lesssim -1$ (can be bent)
- **centered** at the galaxy cluster
- regular, smooth shape
- **unpolarized**

	giant halo	**mini-halo**
occurrence	merging galaxy clusters	"cool-core" galaxy clusters
size scale	$\gtrsim$ 1 Mpc	$\lesssim$ 500 kpc
known objects	**> 42** (Feretti et al. 2012)	**15** (Giacintucci et al. 2014)

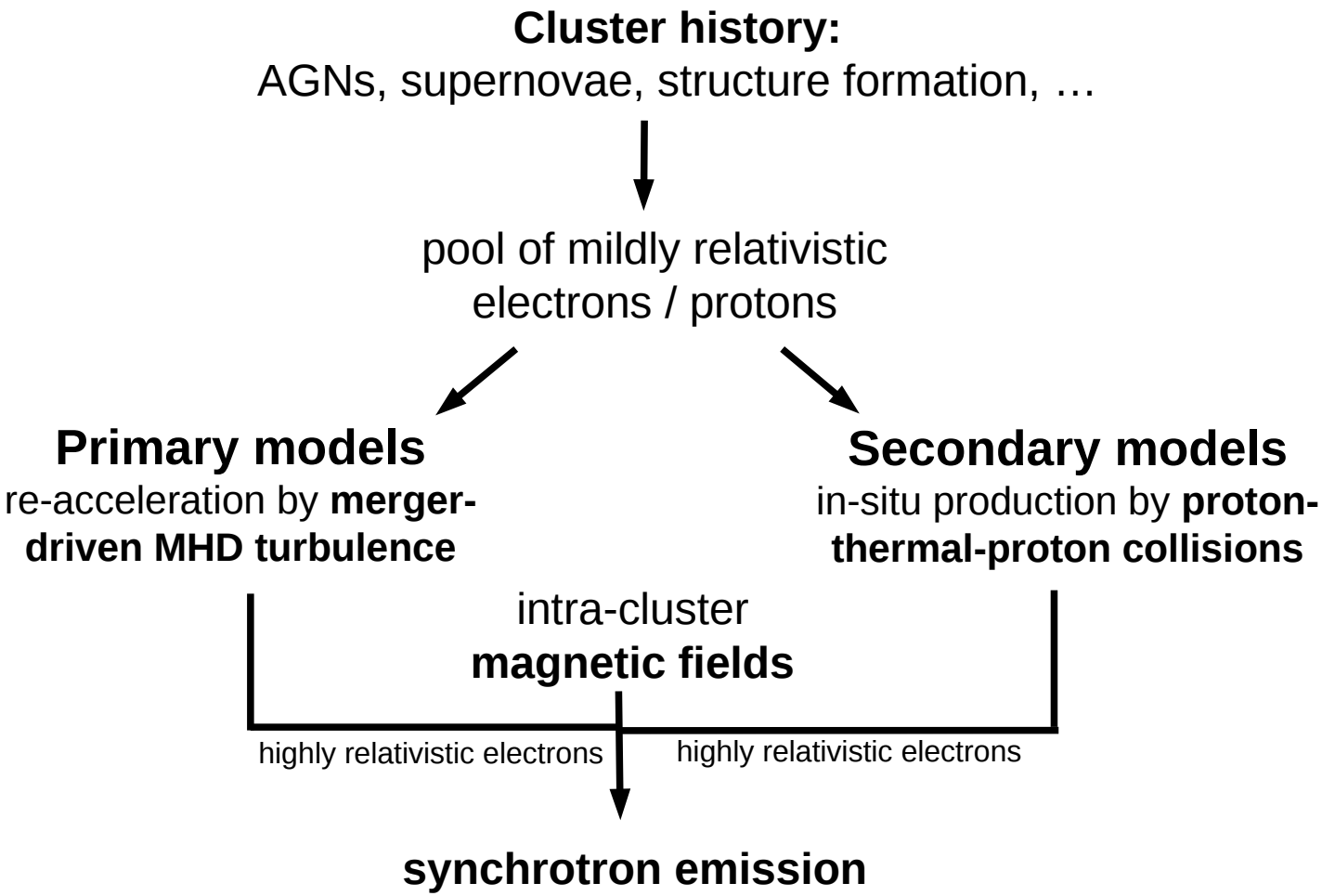
low surface brightness

no optical counterparts



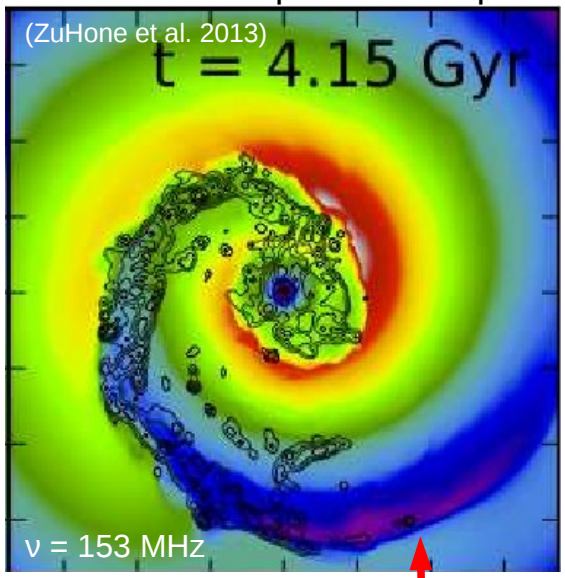


Origin of giant radio halos



Origin of radio mini-halos

simulated temperature map



cold front

cool-core clusters → **no** major merger-driven **turbulence**

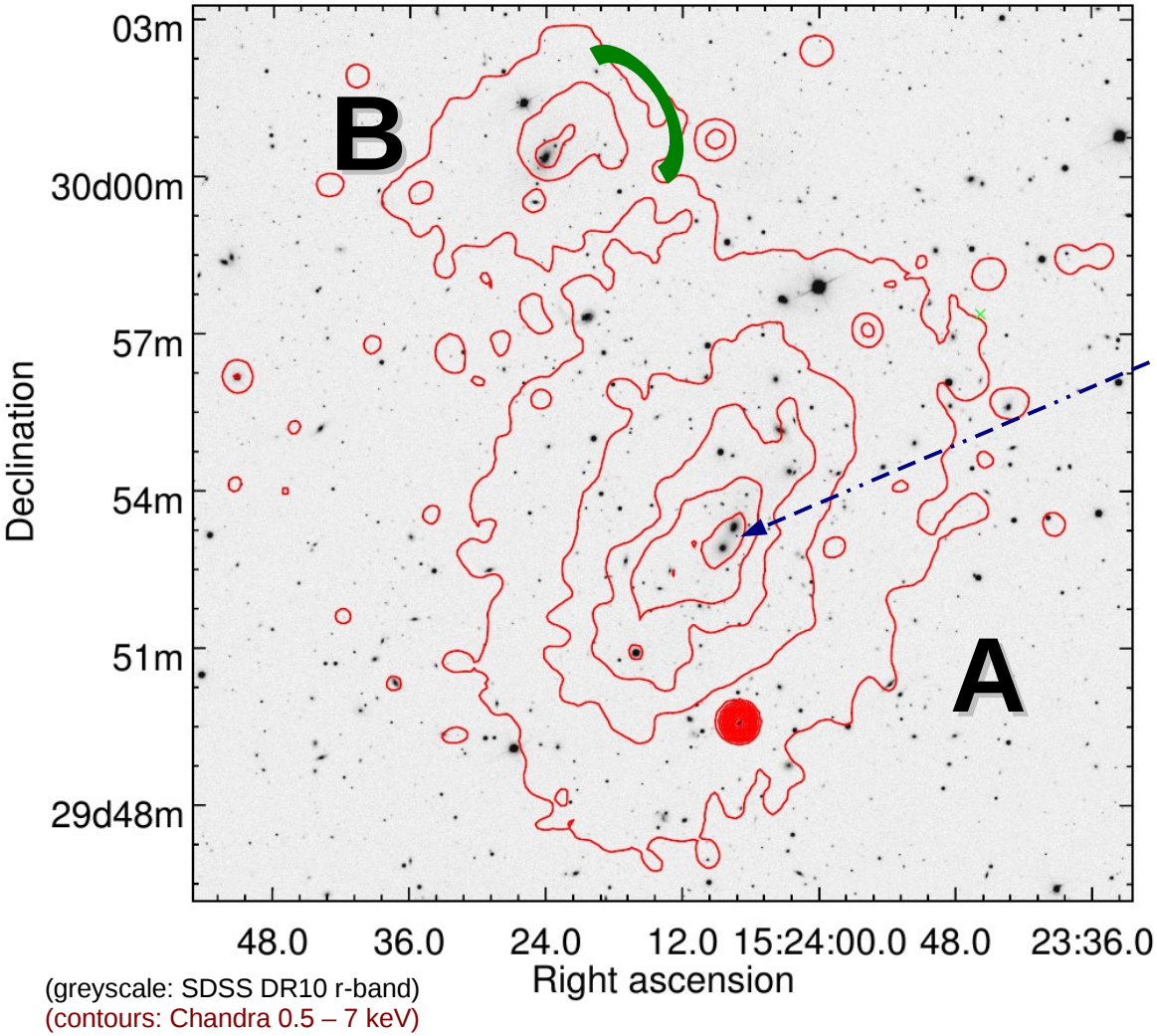
gas sloshing scenario:

- off-axis, minor, subcluster merger → cluster's cool-core **not** disrupted (Ascasibar and Markevitch 2006) (Churazov et al. 2003, Fujita et al. 2004)
- displace cool-core from DM peak

Primary model: gas sloshing → turbulence
Secondary model: gas sloshing → magnetic field amplification
(Pfrommer and Enßlin 2004, ZuHone et al. 2015)

Cluster details: Abell 2069

(z = 0.116)



(greyscale: SDSS DR10 r-band)
(contours: Chandra 0.5 – 7 keV)

- $L_X(0.1 – 2.4\ \text{keV}) = 5 \cdot 10^{44}\ \text{erg s}^{-1}$
- *two distinct components*

main component **A**
- elliptically elongated
- hosts two bright elliptical galaxies
- ➢ **major merger**

component **B**
- separated by ~ 1 Mpc
- peculiar velocity ~ 500 km s^{-1}
- presence of a **cold front**

(Owers et al. 2009)

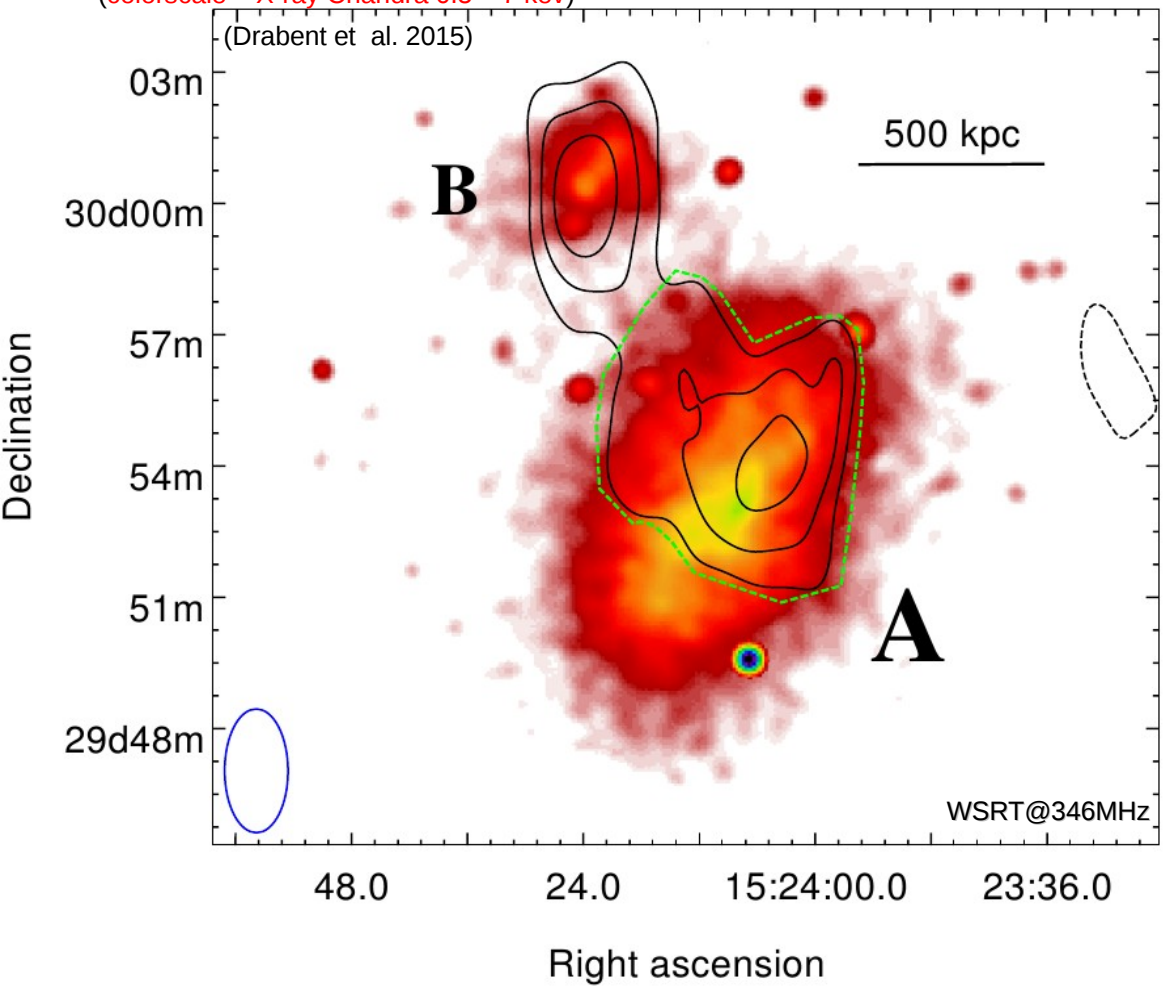
A ↔ B
- pre- or postmerger?

B
- **cold front** → gas sloshing?

Recovery of diffuse emission in Abell 2069

WSRT: 3 × 12 h @ 346 MHz (high sensitivity for diffuse emission)
GMRT: 4.8 h @ 322 MHz (to model and subtract compact sources)

(contours: [−3.0, 3.0, 4.2 , 6.0, 8.5, 12.0] mJy/beam, beam: 182'' × 91'', r.m.s.: 1.0 mJy/beam)
(colorscale – X-ray Chandra 0.5 – 7 kev)



main component **A**
- LLS ~ 750 kpc
- roughly elongated with X-ray
- peak flux is shifted to NW
- ongoing merger
- **giant radio halo**
- **flux density: 25 ± 9 mJy**

component **B**
- apparent size ~ beam width
- estimated LLS ~ 50 … 100 kpc
- **nature uncertain**
- **flux density: 15 ± 2 mJy**

LOFAR-observation

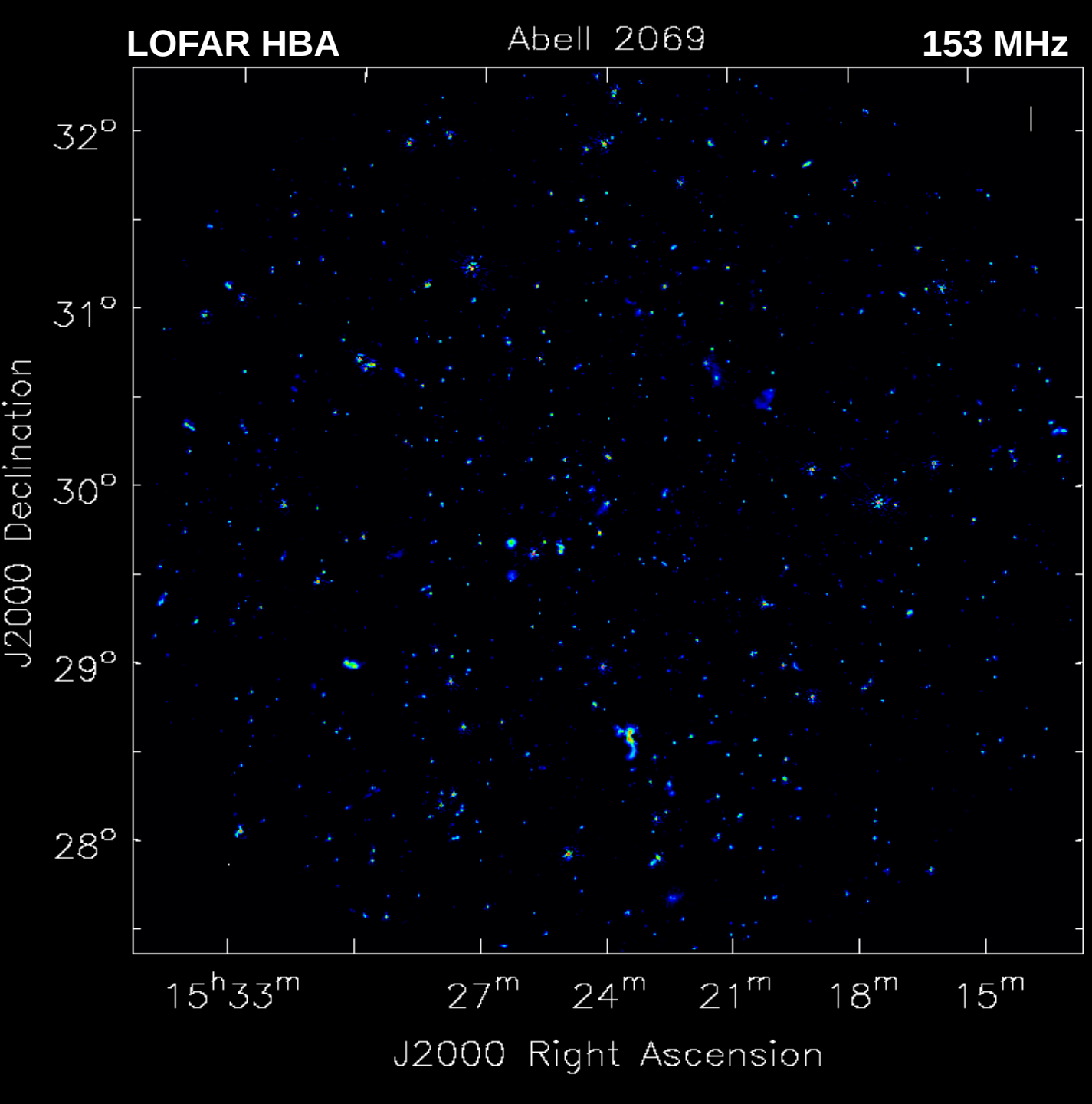
of Abell 2069

- ✔ **23 Core** Stations and **14 Remote** Stations
- ✔ Total observation **time**: **10 hours**
- ✔ **Frequency** band: **120-180 MHz**

Calibration procedure

- ➢ modified version of the prefacet pipeline
- ➢ facet-calibration is ongoing …

LOFAR „Superterp“ in Exloo, The Netherlands

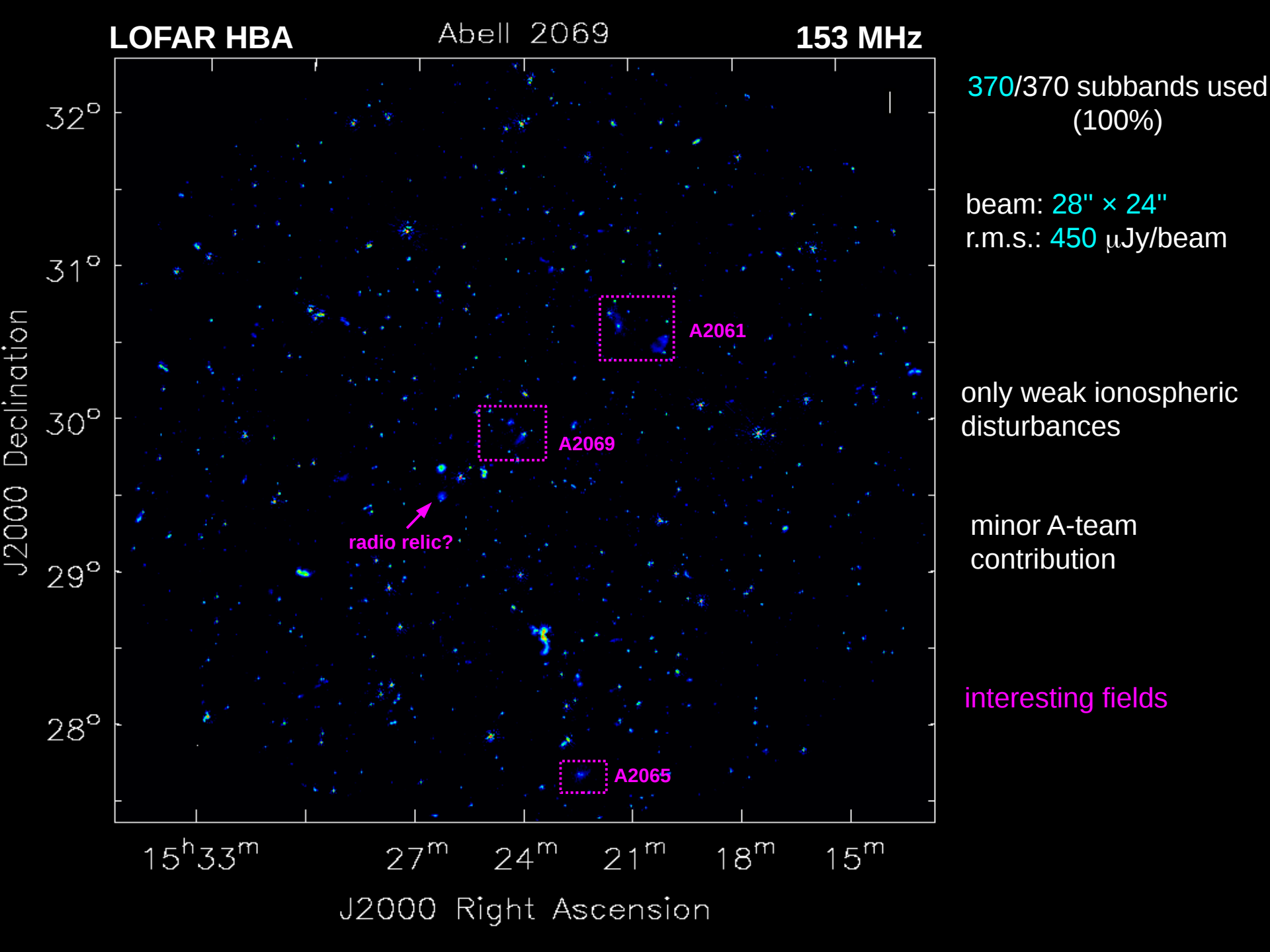


370/370 subbands used (100%)

beam: 28" × 24"
r.m.s.: 450 μJy/beam

only weak ionospheric disturbances

minor A-team contribution



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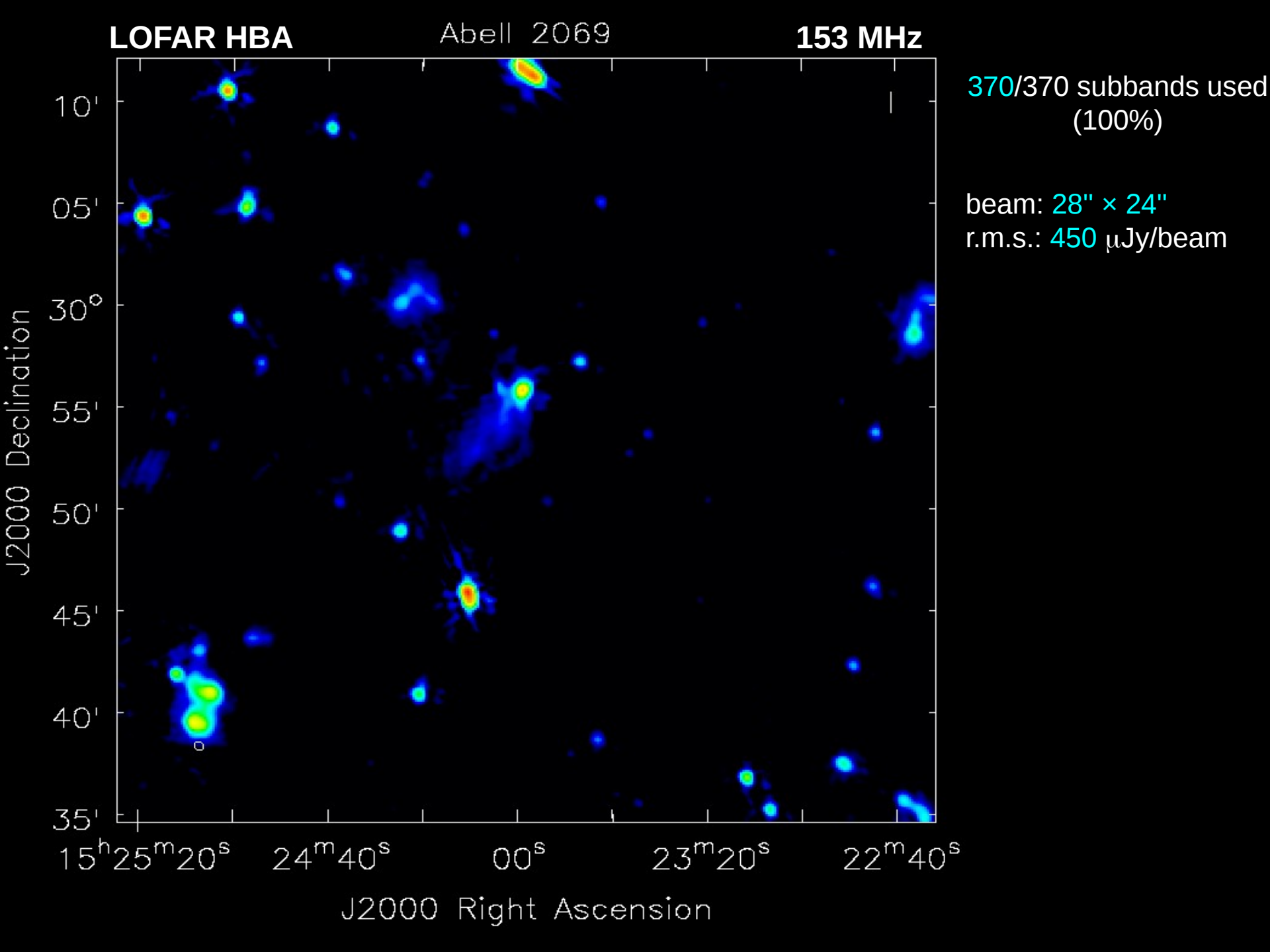
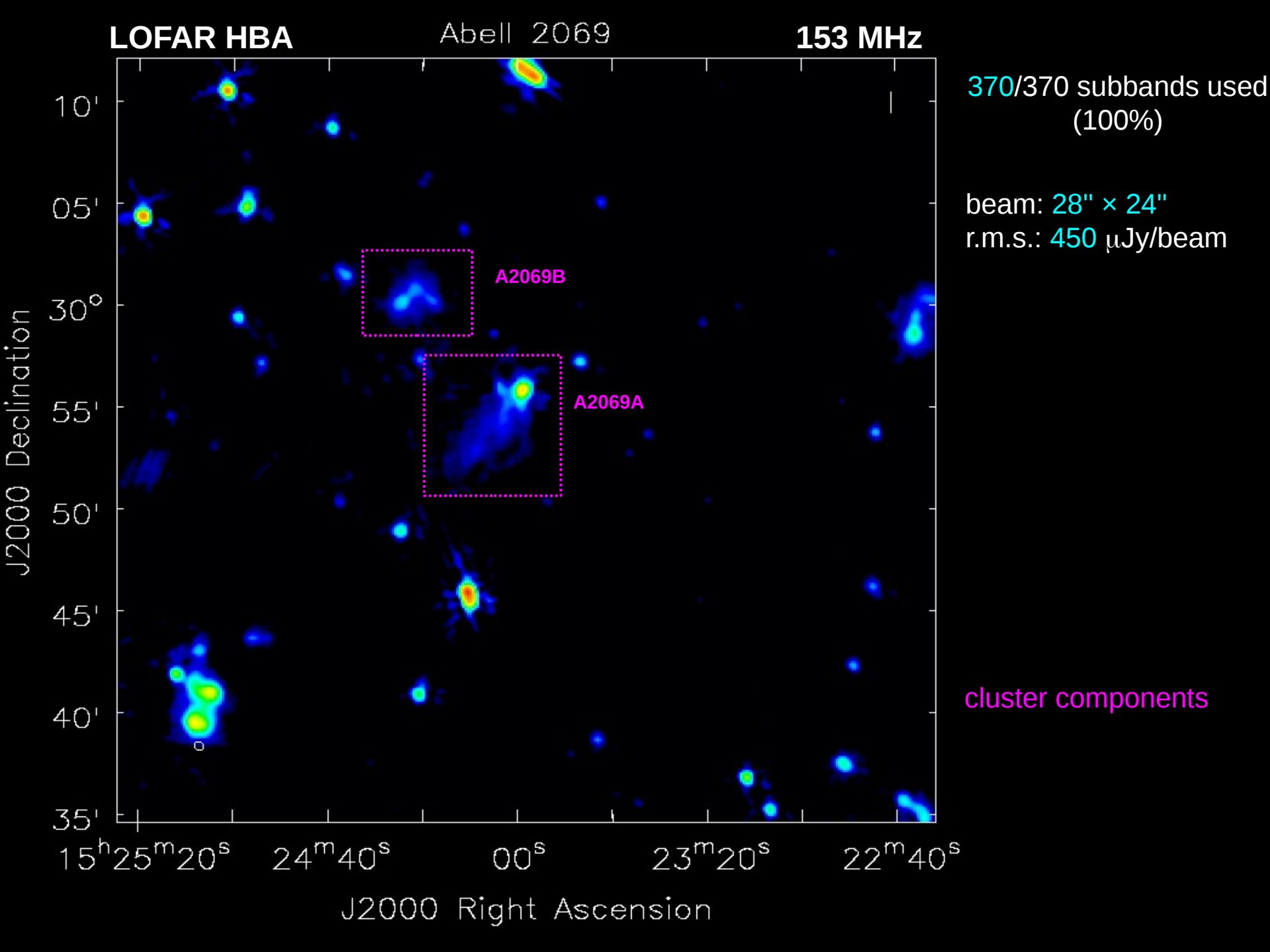
minor A-team contribution

interesting fields


LOFAR HBA
Abell 2069
153 MHz
370/370 subbands used
(100%)
beam: 28" × 24"
r.m.s.: 450 μJy/beam
10'
05'
30°
55'
50'
45'
40'
35'
J2000 Declination
15h25m20s
24m40s
00s
23m20s
22m40s
J2000 Right Ascension



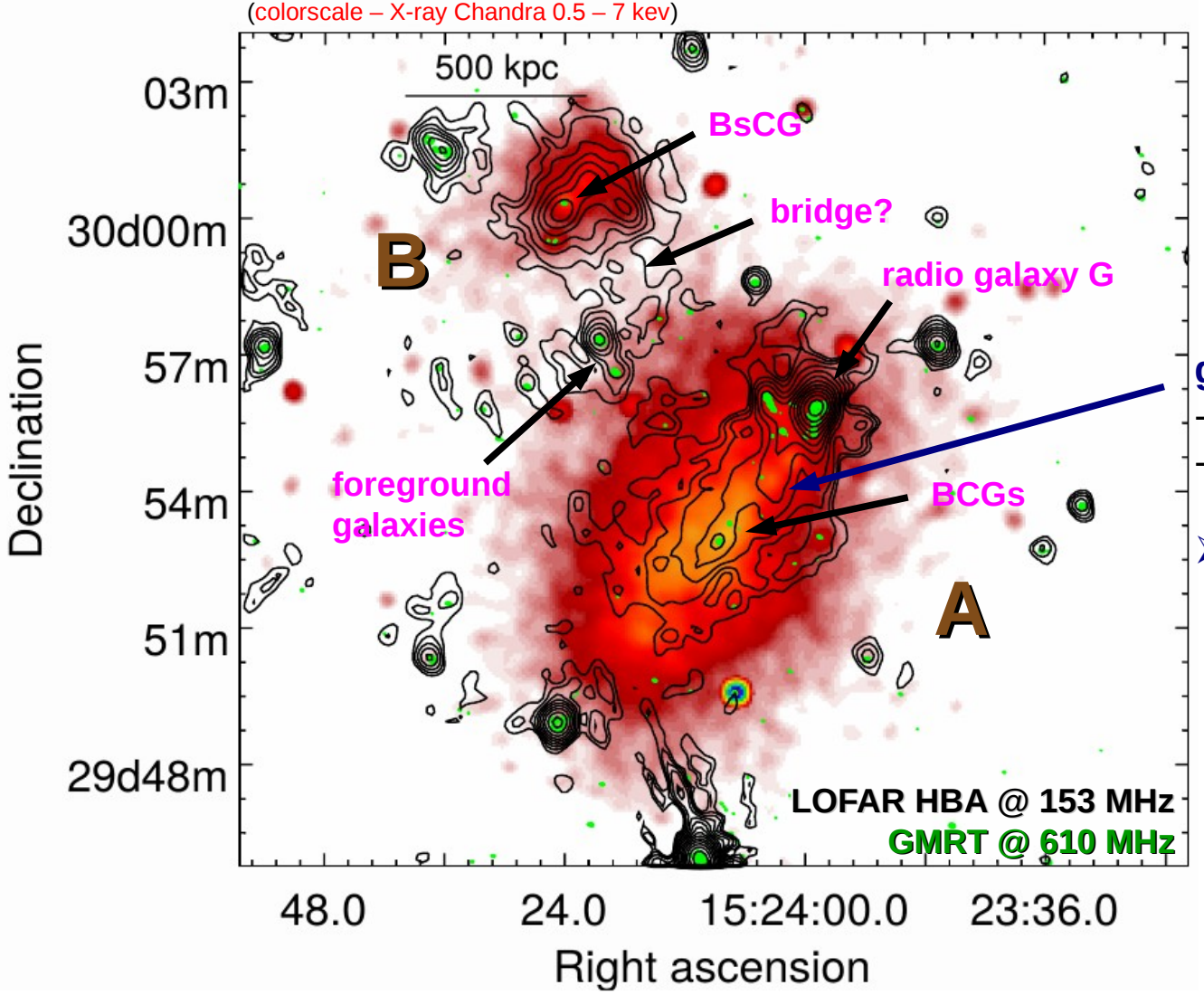
370/370 subbands used
(100%)

beam: 28" × 24"
r.m.s.: 450 μJy/beam

cluster components

LOFAR HBA – Abell 2069

(**GMRT 610 MHz:** [0.22,0.0.32,0.45,0.64,0.90], r.m.s.: 0.07 mJy/beam)
(LOFAR contours: [1.5,2,1,3.0,4.2,6.0,8.5,12.0] mJy, r.m.s.: 0.45 mJy/beam)
(colorscale – X-ray Chandra 0.5 – 7 kev)



beam: 28" × 24"
direction-independent only

giant radio halo A2069A
- LLS ~ 1 Mpc
- clearly aligned with X-ray

➢ **flux density: 146* ± 15 mJy**
(*conservative measurement)

LOFAR HBA – Abell 2069

(**GMRT 610 MHz:** [0.22,0.0.32,0.45,0.64,0.90], r.m.s.: 0.07 mJy/beam)
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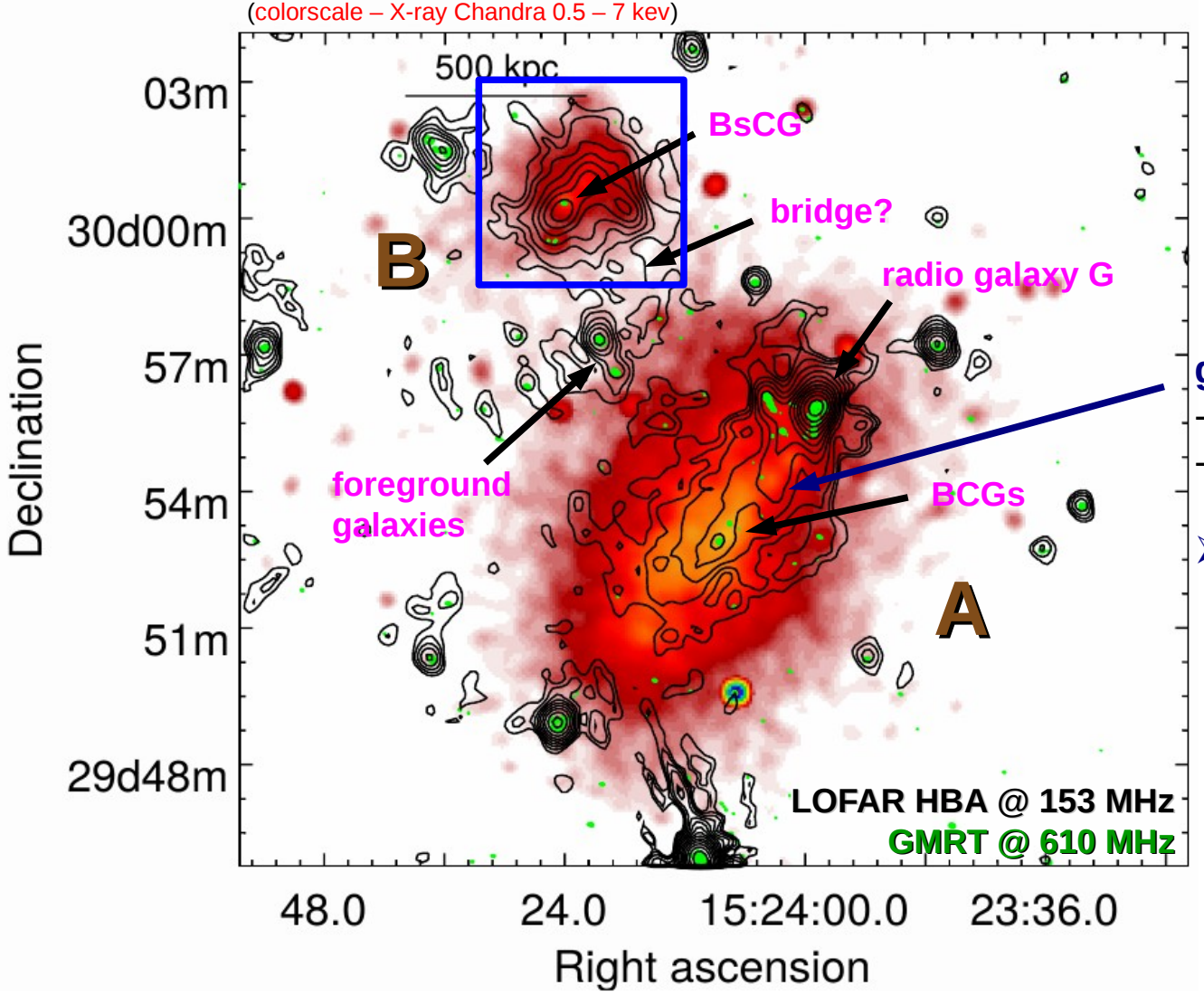


beam: 28" × 24"
direction-independent only

giant radio halo A2069A
- LLS ~ 1 Mpc
- clearly aligned with X-ray

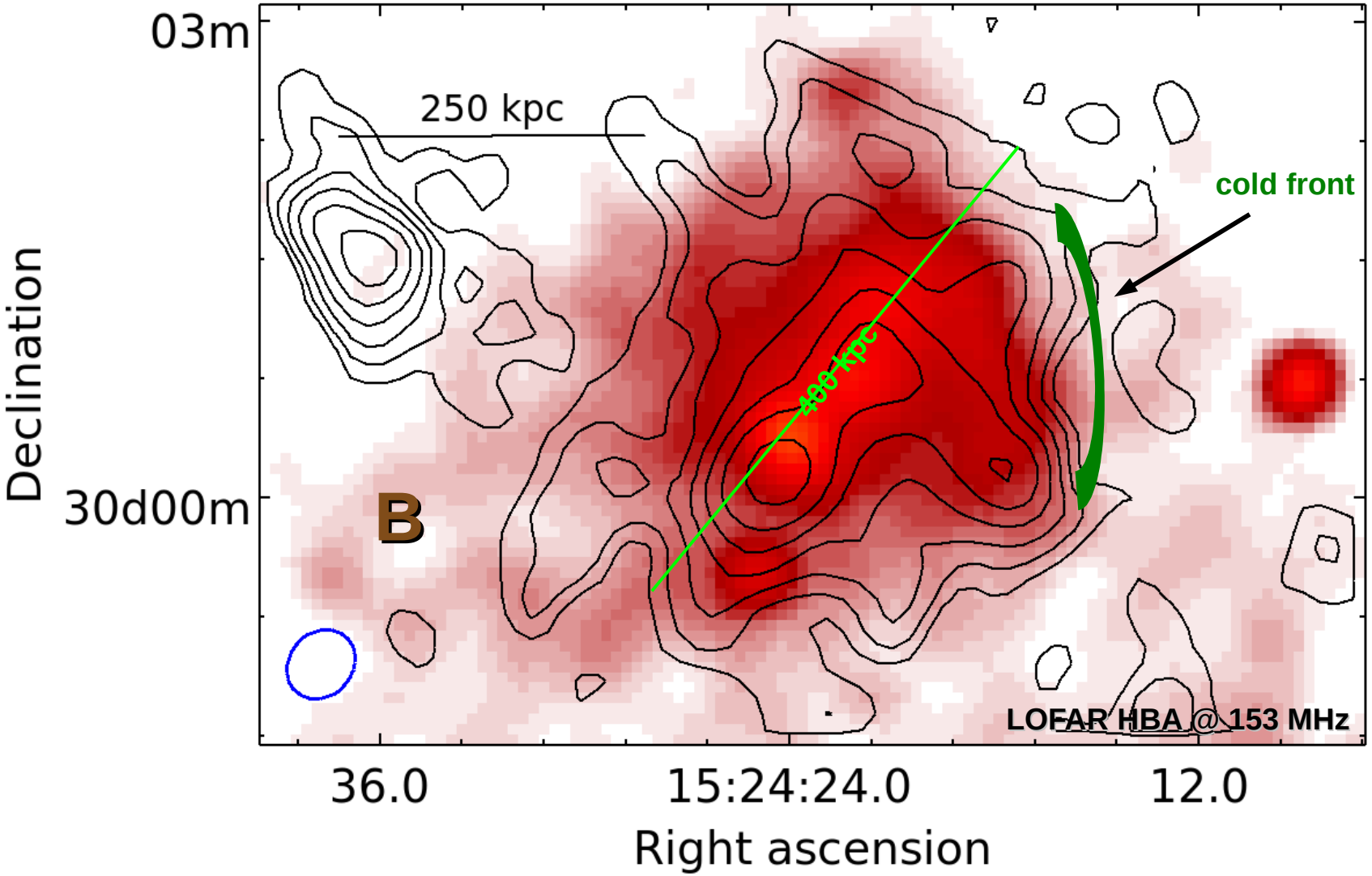
➢ **flux density: 146* ± 15 mJy**
(*conservative measurement)

emission A2069B uncertain

Constraining diffuse emission in Abell 2069 B

beam: 28" × 24"
recovered flux density: ~140 mJy

(LOFAR contours: [1.5,2,1,3.0,4.2,6.0,8.5,12.0] mJy, r.m.s.: 0.45 mJy/beam)
(colorscale – X-ray Chandra 0.5 – 7 kev)



Constraining diffuse emission in Abell 2069 B

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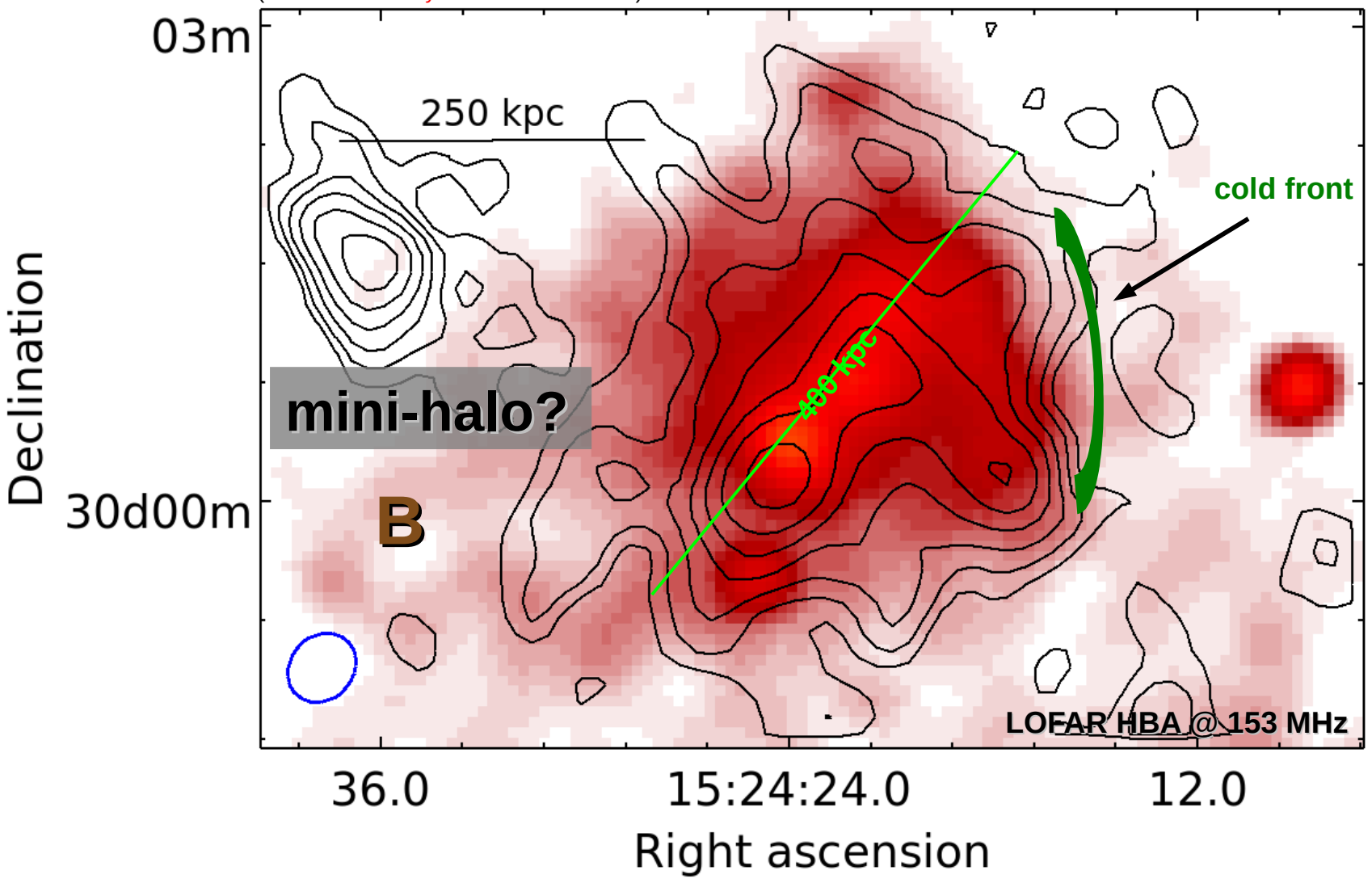
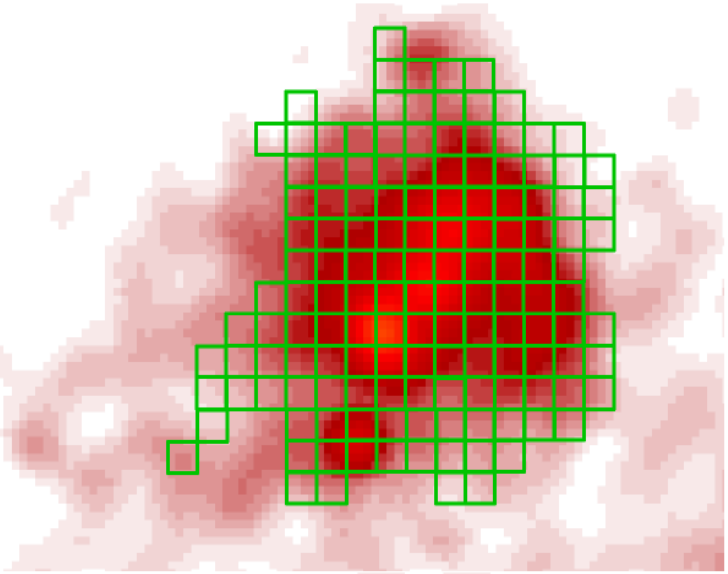
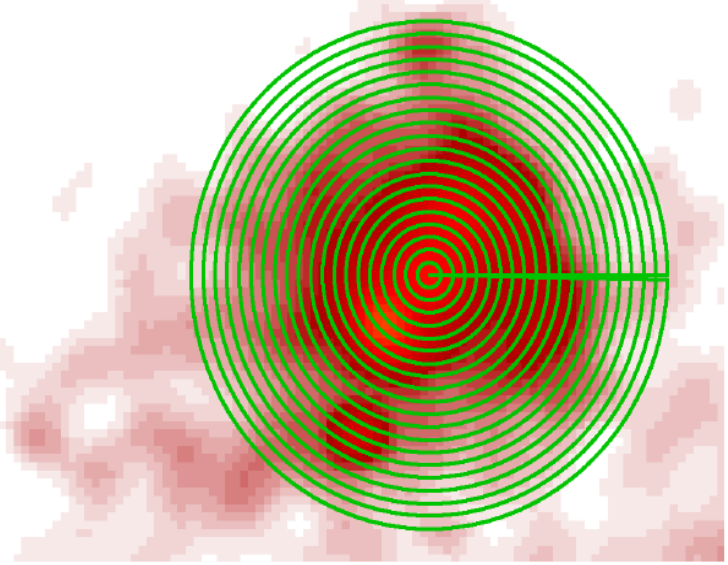
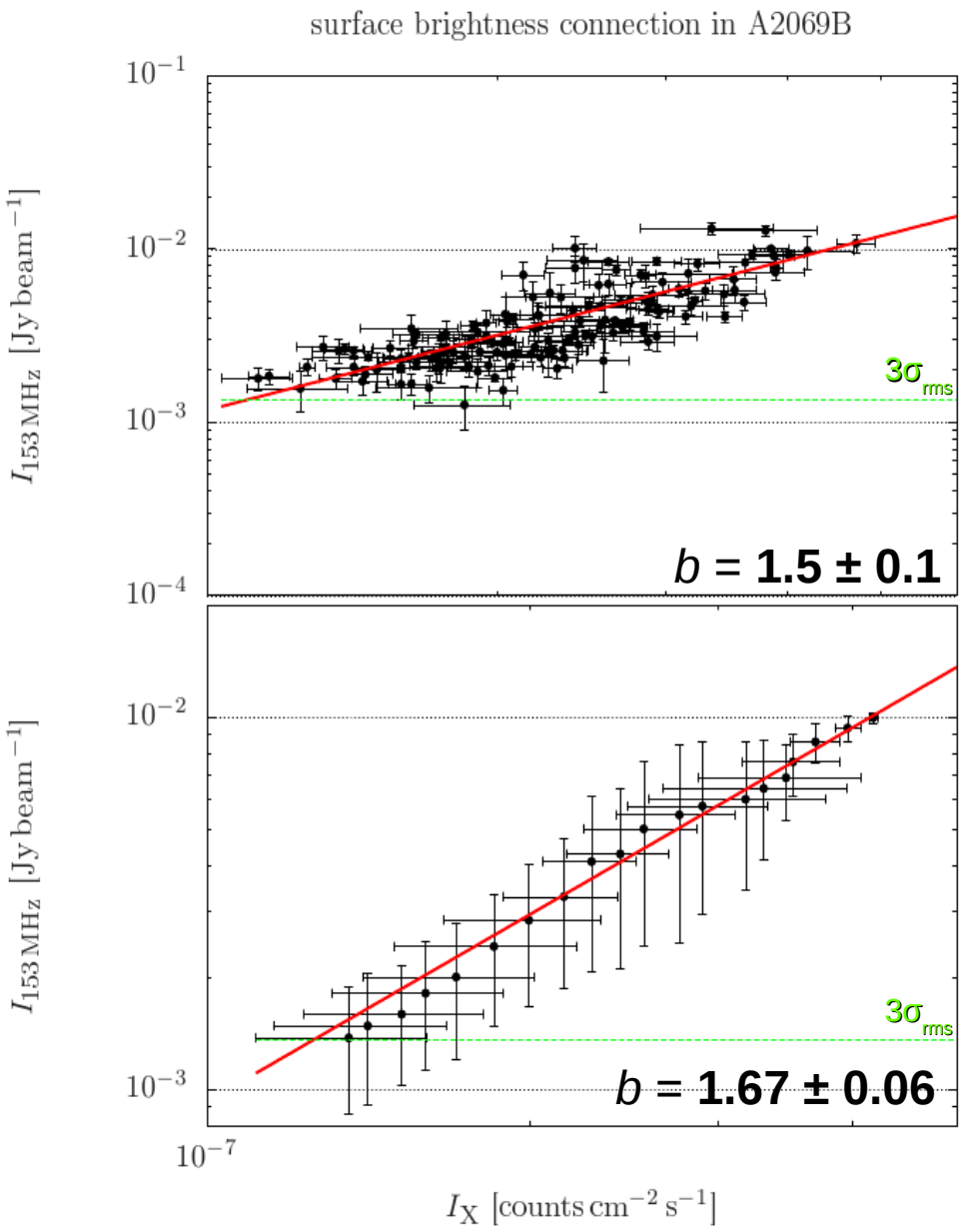


Is the diffuse emission in Abell 2069 B a mini-halo?

✔ **A2069B: mixed with ICM**







Comparison between radio and X-ray emitting gas

assumptions:
- isothermal, independent on position in cluster
- $\varepsilon_{\mathrm{CRe}} \propto \varepsilon_{\mathrm{th}}$, $\varepsilon_B \propto \varepsilon_{\mathrm{th}}$

(Govoni et al. 2001)

$$j_{\mathrm{Radio}}/j_{\mathrm{X}} \propto kT_{\mathrm{e}}^{3/2}$$

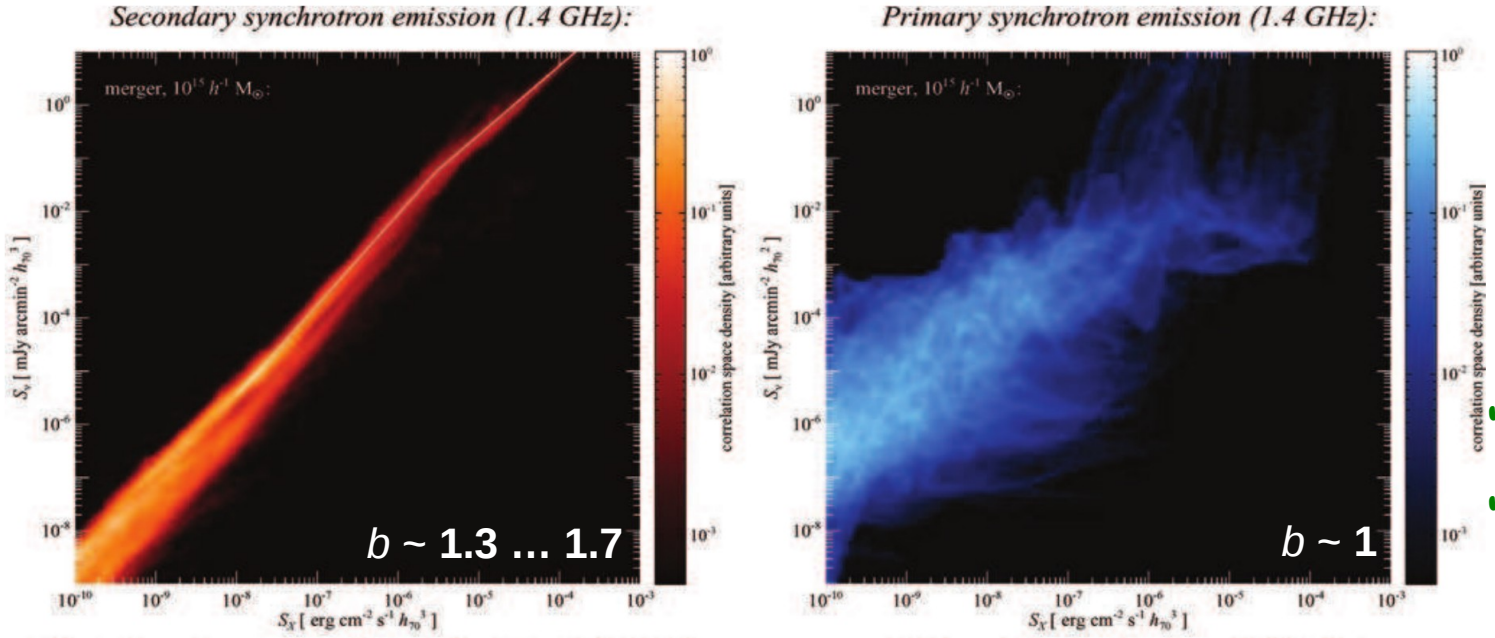
→ **linear relation**

hadronic origin:
- $\varepsilon_{\mathrm{CRe}} \propto \varepsilon_{\mathrm{th}}$

(Dolag & Enßlin 2000, Govoni et al. 2001)

$$j_{\mathrm{Radio}}/j_{\mathrm{X}} \propto kT^{1/2}\,\varepsilon_B/\left(\varepsilon_B + \varepsilon_{\mathrm{cmb}}\right)$$

→ **super-linear relation**
(in case of weak magnetic fields)



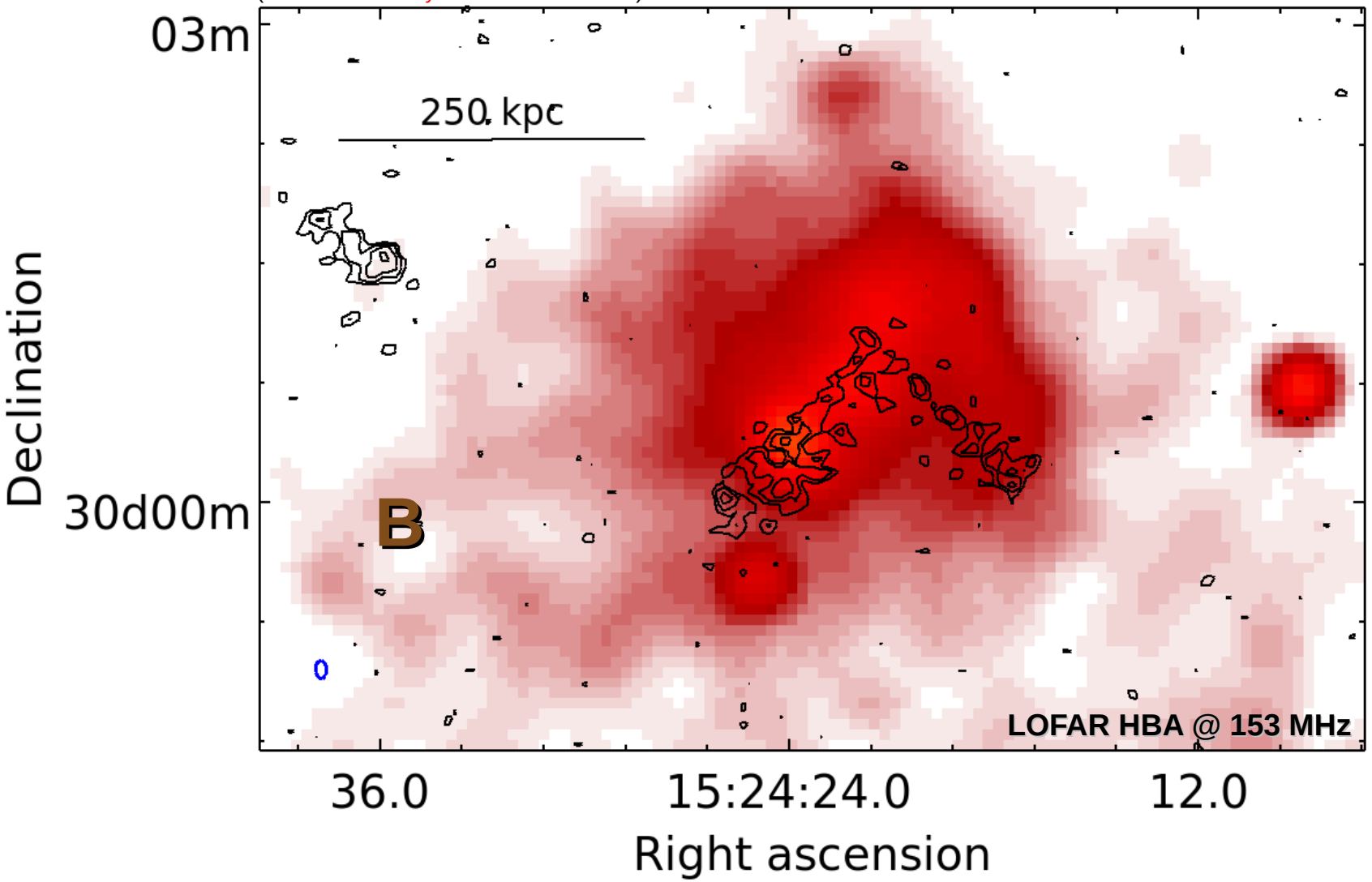
galaxy cluster merger simulation
(Pfrommer et al. 2008)

✔ **A2069B** supported by **secondaries**?
✔ **turbulence** present?

Is the diffuse emission in Abell 2069 B a mini-halo?

beam: 7" × 4"
recovered flux density: ~40 mJy

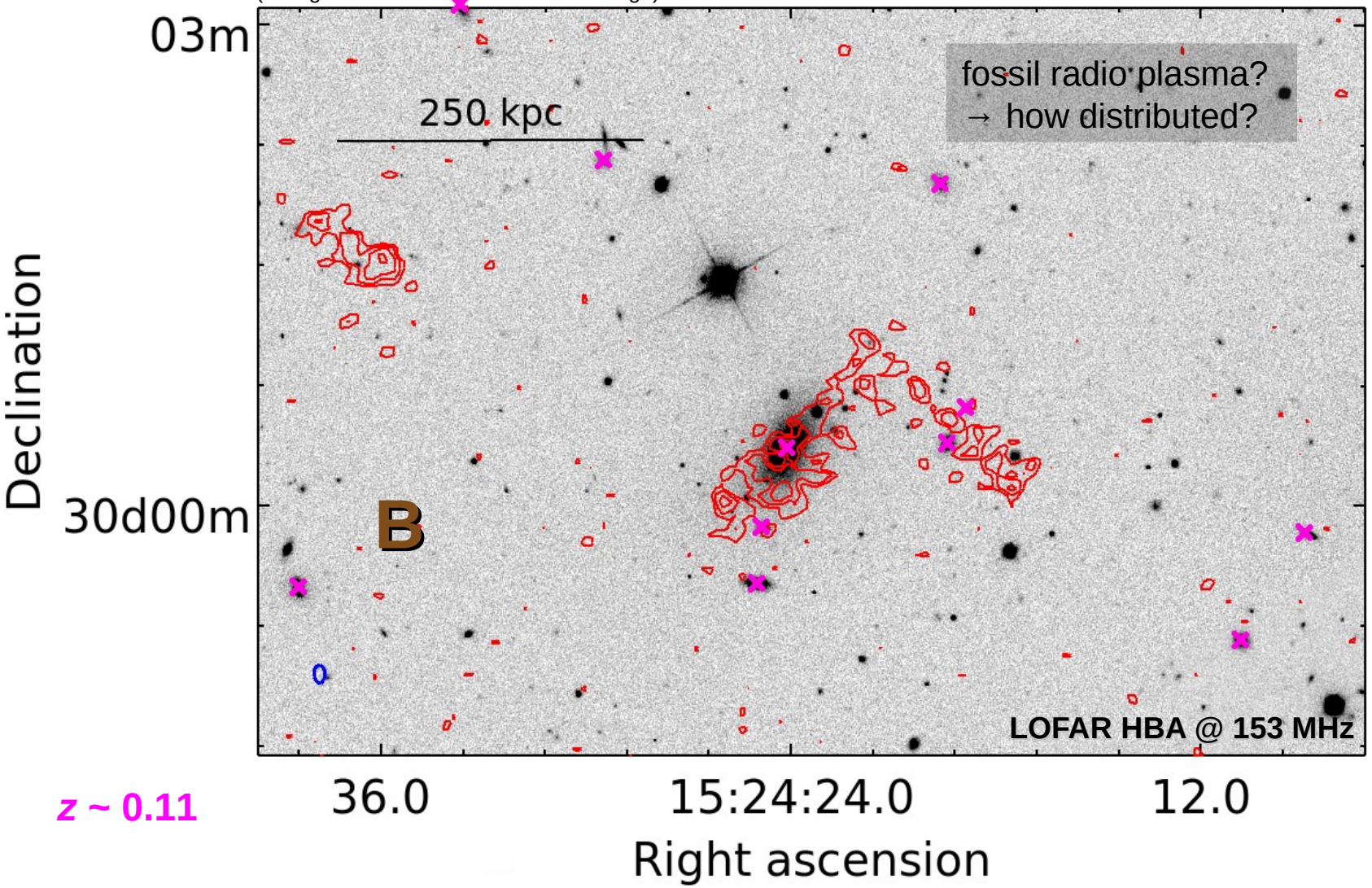
(LOFAR contours (slightly smoothed): [0.30, 0.42 , 0.60, 0.85] mJy, r.m.s.: 0.25 mJy/beam)
(colorscale – X-ray Chandra 0.5 – 7 kev)



Is the diffuse emission in Abell 2069 B a mini-halo?

beam: 7" × 4"
recovered flux density: ~45 mJy

(LOFAR contours (slightly smoothed): [0.30, 0.42 , 0.60, 0.85] mJy, r.m.s.: 0.25 mJy/beam)
(background – SDSS DR13 r-band image)



z ~ 0.11

Is the diffuse emission in Abell 2069 B a mini-halo?

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(LOFAR contours (slightly smoothed): [0.30, 0.42 , 0.60, 0.85] mJy, r.m.s.: 0.25 mJy/beam)
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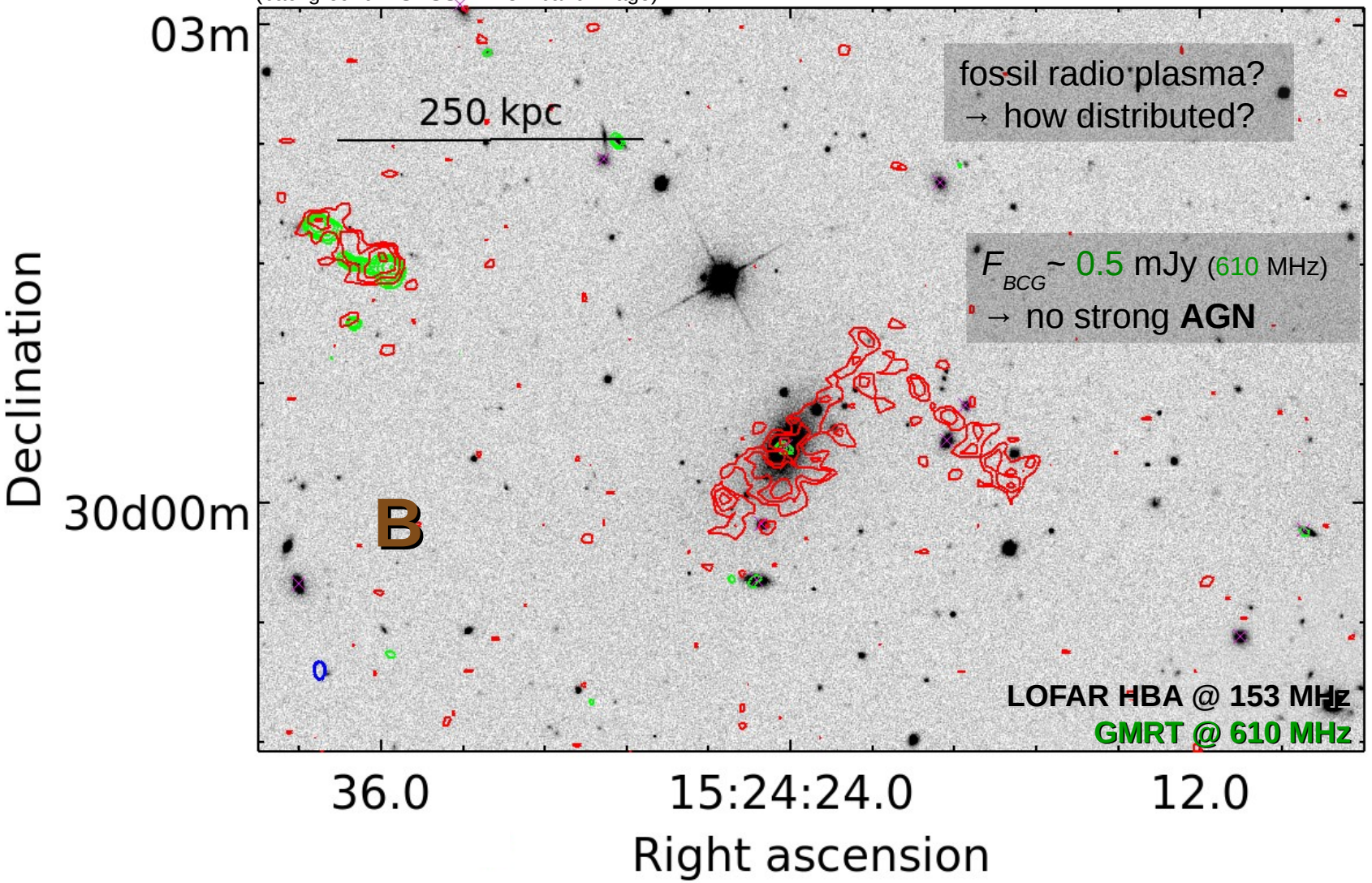
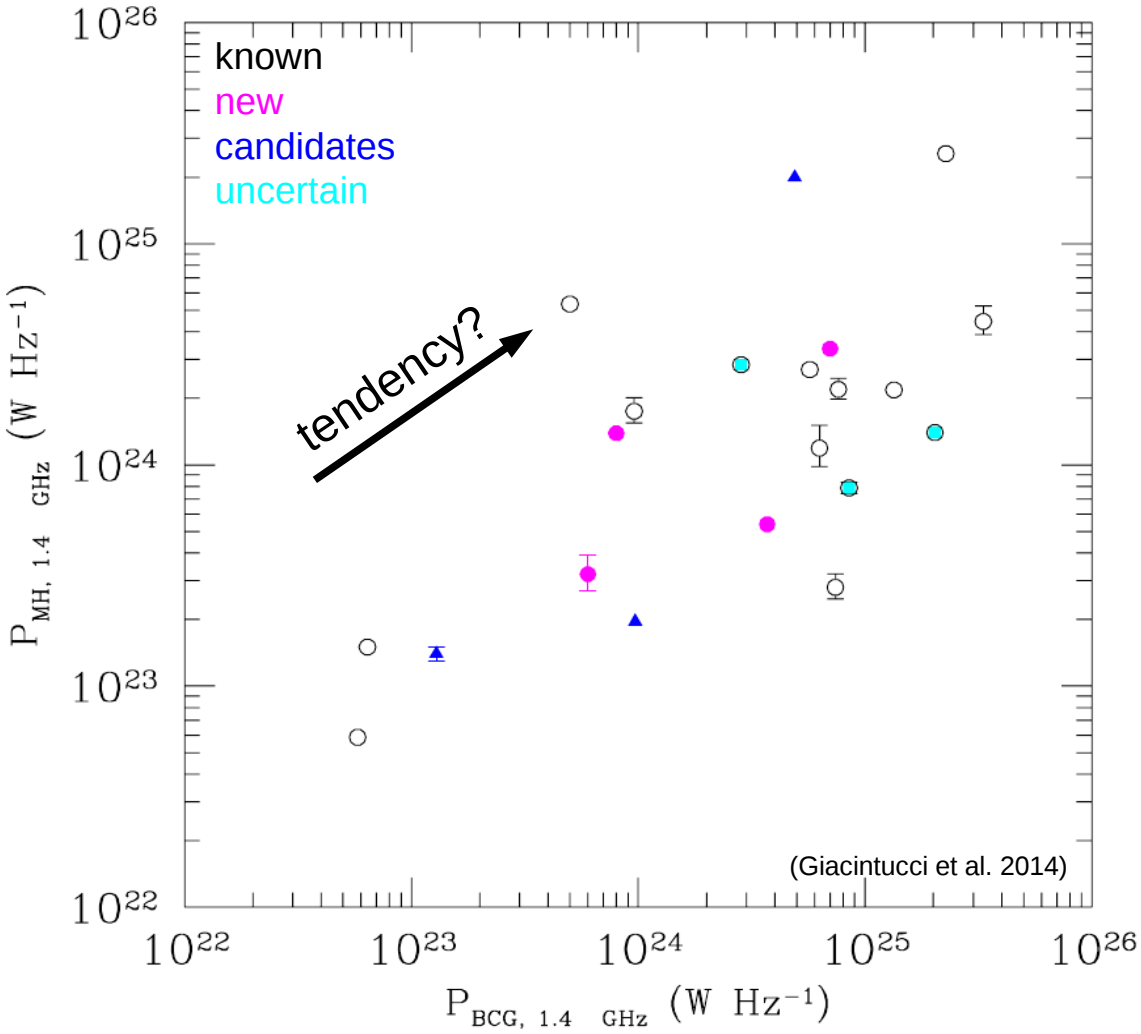


Radio mini-halos – BCG vs. radio power

BCG: potential source for seed electrons
→ redistributed and reaccelerated by **gas sloshing**
multiple cycles of activity

✗ **A2069B: very weak BCG emission**
→ "radio-off" state?
→ AGN duty cycle < cooling time

- "radio-off" mini-halo candidate: **A1413**
(Govoni et al. 2009)



Summary: Abell 2069

- ✔ clear confirmation of radio halo in main component **A**
  (morphology also better coincides with X-ray than previously)
- diffuse emission in component **B** shows clear signs for a **mini-halo**
  → potentially **first halo – mini-halo** system
  → indicate rather **complex dynamics**

location	flux density @ 153 MHz	classification
Abell 2069 **A**	**> 146 mJy**	**giant radio halo**
Abell 2069 **B**	**141 ± 15 mJy**	**mini-halo?**

Thank you for your attention!