Exploring particle (re-)acceleration at low frequencies in merging galaxy clusters

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Collaborators: R. van Weeren, F. Andrade-Santos, H. Akamtsu, S. Randall, H. Röttgering, W. Forman, C. Jones, M.Rossetti, F. Gastaldello, G. Brunetti and the LOFAR collaboration

The Metre Wavelength Sky II — 22 March 2019

RADIO

RELIC

HALO

TAILED GALAXY

RELIC

FOREGROUND GALAXY (FRI)

MACS J0717.5+3745 Credit: Radio: NRAO/AUI/NSF

RELICS

- Located in the outskirts
- ~Mpc-size (elongated)
- Highly polarized
- Spectral index gradient towards the cluster center

HALOS

- Centrally located
- Mpc-size (roundish)
- Unpolarized
- “Homogeneous” steep spectral index

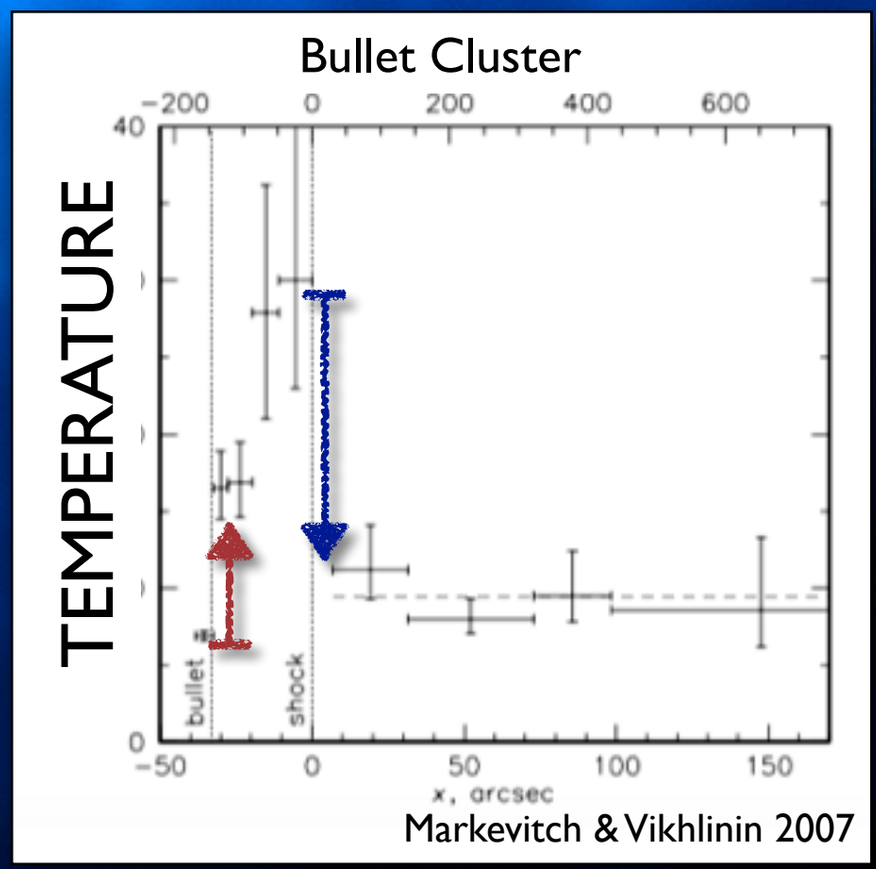
RADIO GALAXIES

- Tailed shape in galaxy cluster
- Lobed shape in the field
- Flat spectrum in the nucleus, steep spectra in the lobes

X-RAY

MERGERS

- Disturbed morphology
- One or more surface brightness and temperature discontinuities:
  - shock: $\Delta T < 1$
  - cold front: $\Delta T > 1$



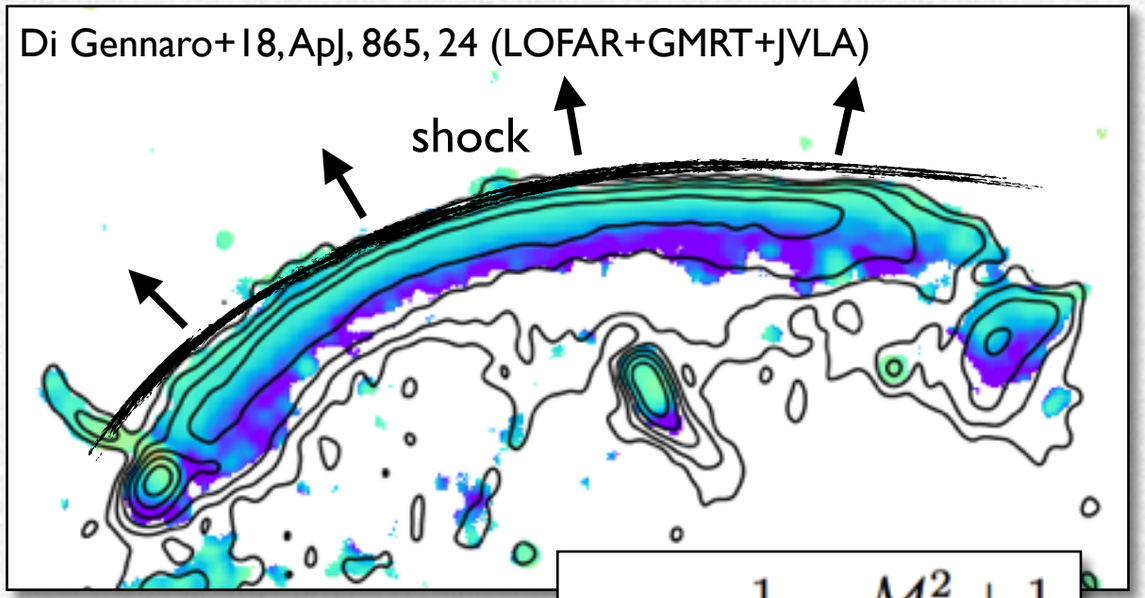
Credit: X-ray: NASA/CXC/SAO/R.J. van Weeren et al.;

Origin of the Diffuse Radio Emission

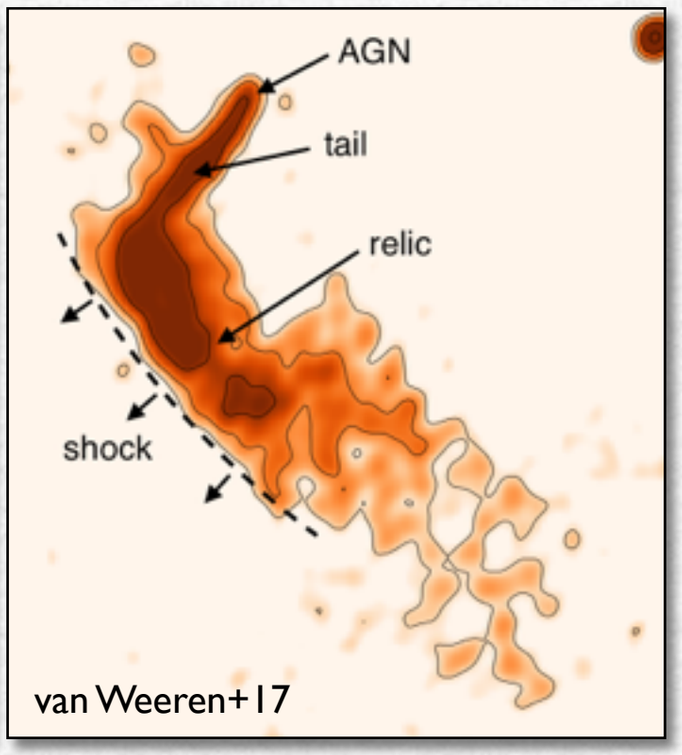
RELICS

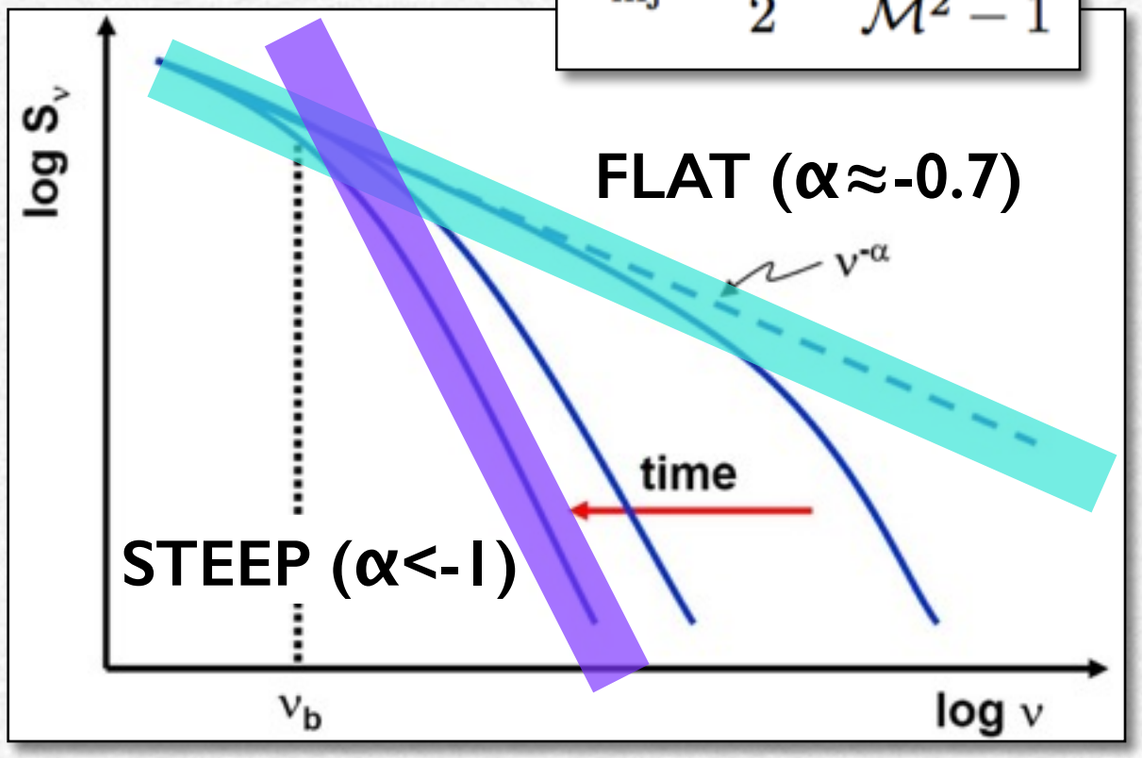
- Particles from thermal pool accelerated by multiple crossing of a shock front: **diffusive shock acceleration** (DSA, e.g. Ensslin+98)
  - ➡ "Simple", but not always efficient
- Old plasma **re-accelerated** by the crossing shock wave (e.g. Markevitch+05)
  - ➡ Efficient, but it needs tail-relic connection

THE "SAUSAGE" RELIC



$$\alpha_{\rm inj} = \frac{1}{2} - \frac{\mathcal{M}^2+1}{\mathcal{M}^2-1}$$





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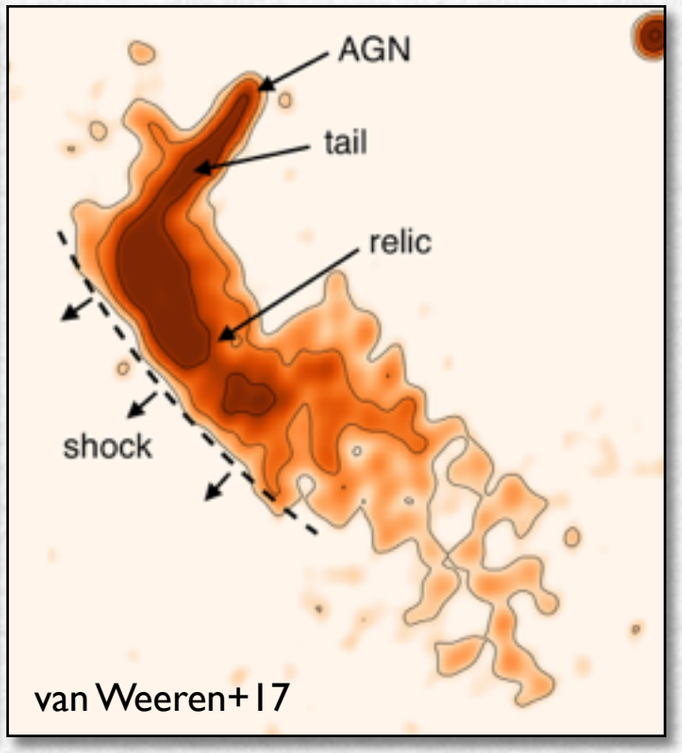
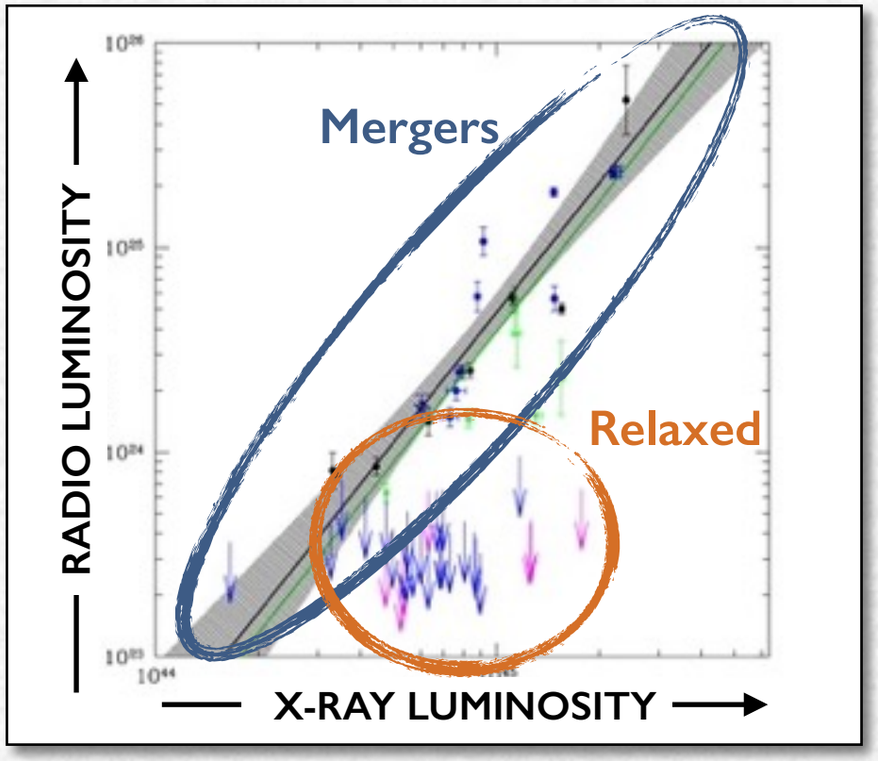


HALOS

- Cluster mergers generate turbulence which re-accelerate electrons (e.g. Brunetti+01)
  - ➡ Only in merging clusters
- Protons inside the cluster collide with thermal electrons (e.g. Ensslin+11)
  - ➡ In all galaxy clusters

Cassano+13



OPEN QUESTIONS

- What are the properties of relic-shocks ?

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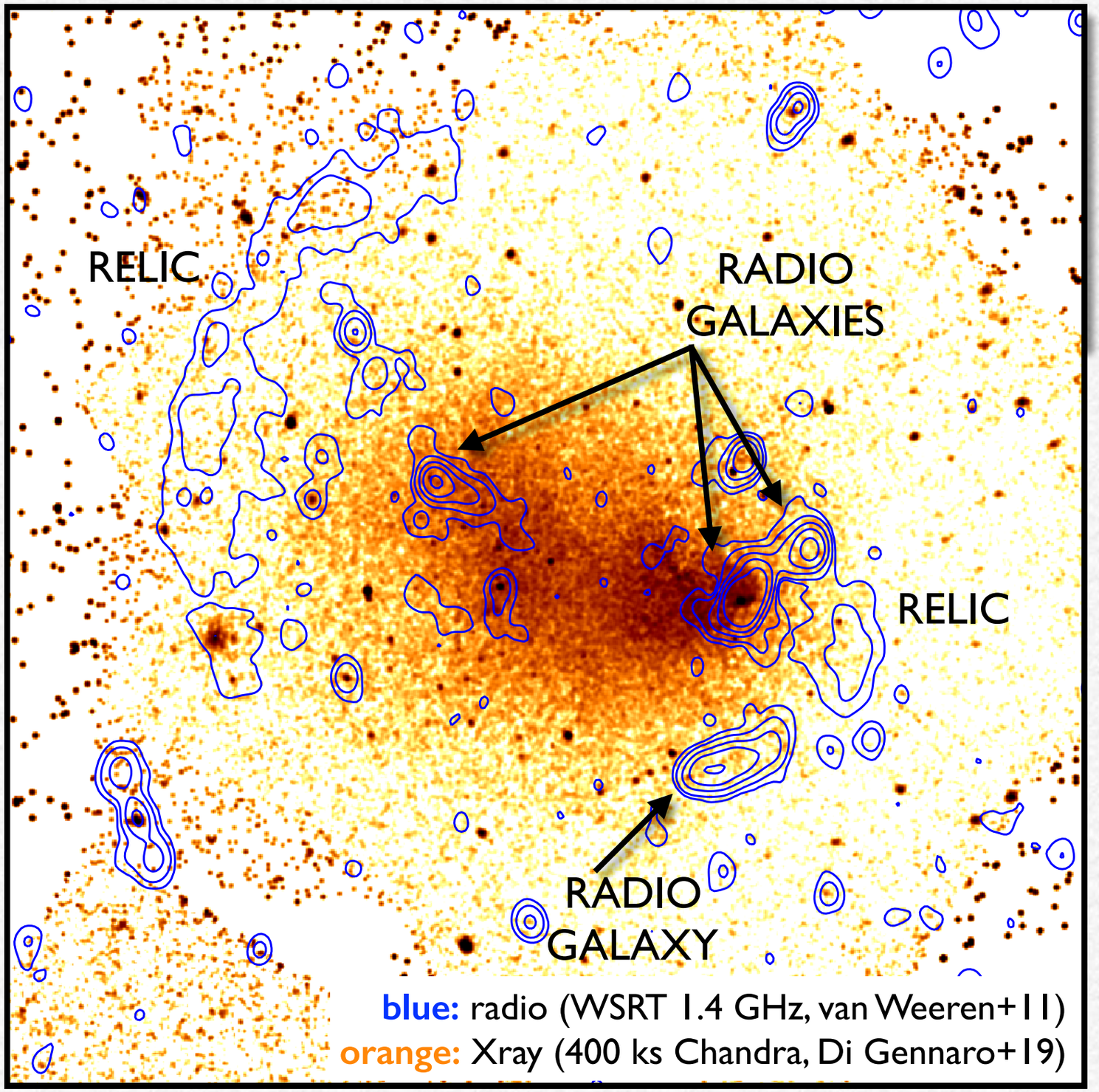
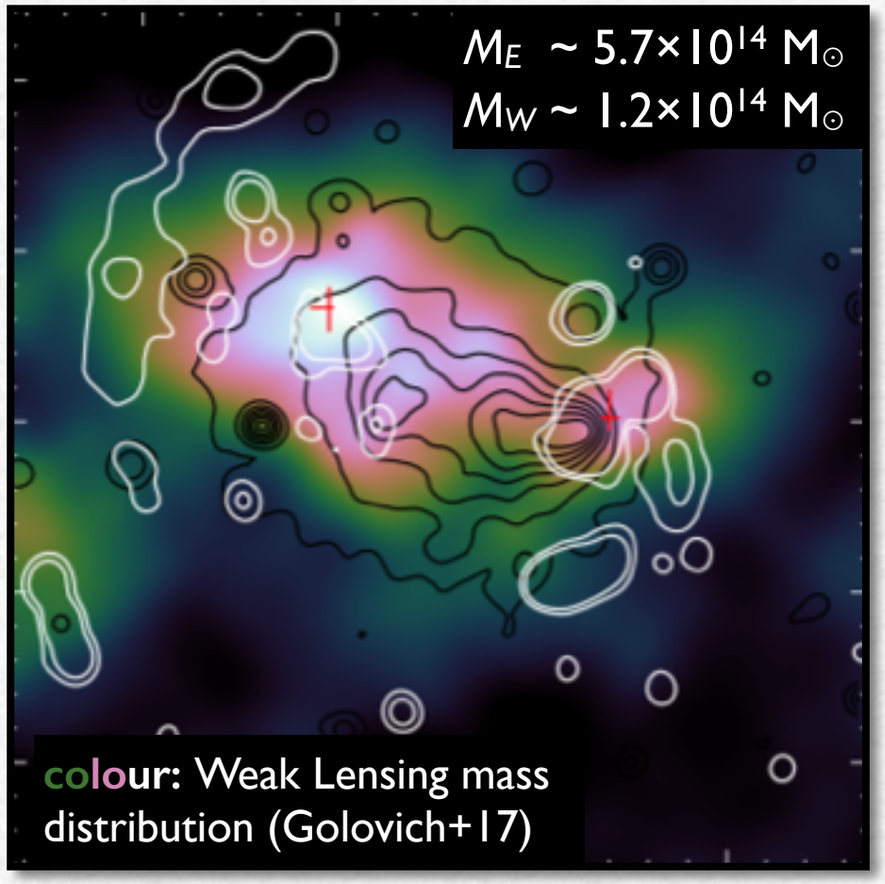
ZwCl 0008.8+5215

Di Gennaro+19, ApJ, 873, 64



- $z \approx 0.104$
- bullet-like merging system
- Eastern relic length ~ 1.4 Mpc
- Western relic length ~ 290 kpc
- No central diffuse emission (halo) detected so far
- inclination angle $i \lesssim 40°$



A SEARCH FOR SHOCKS

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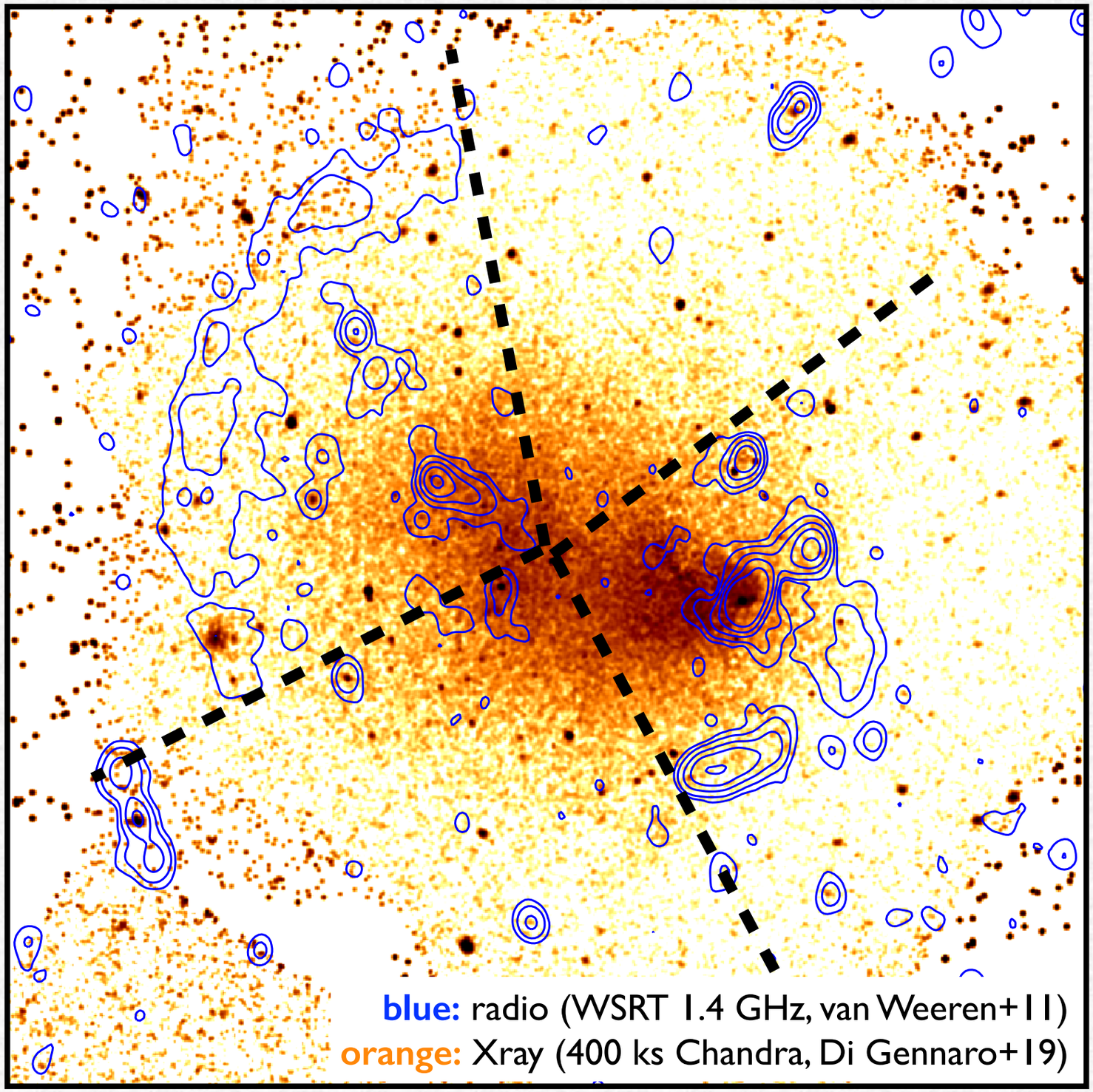

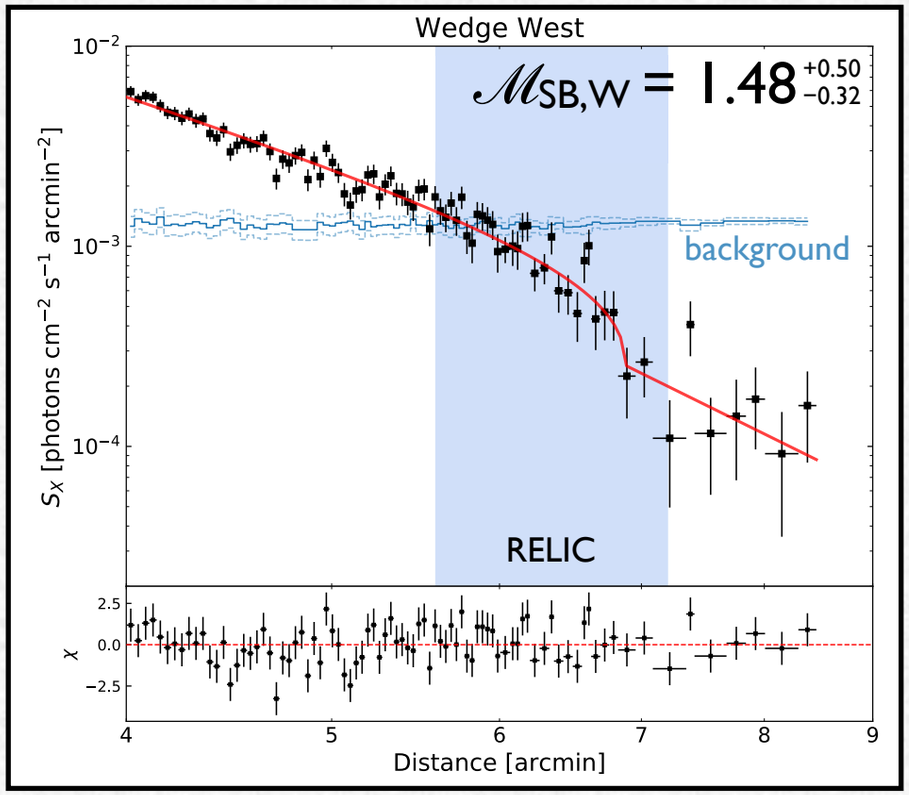

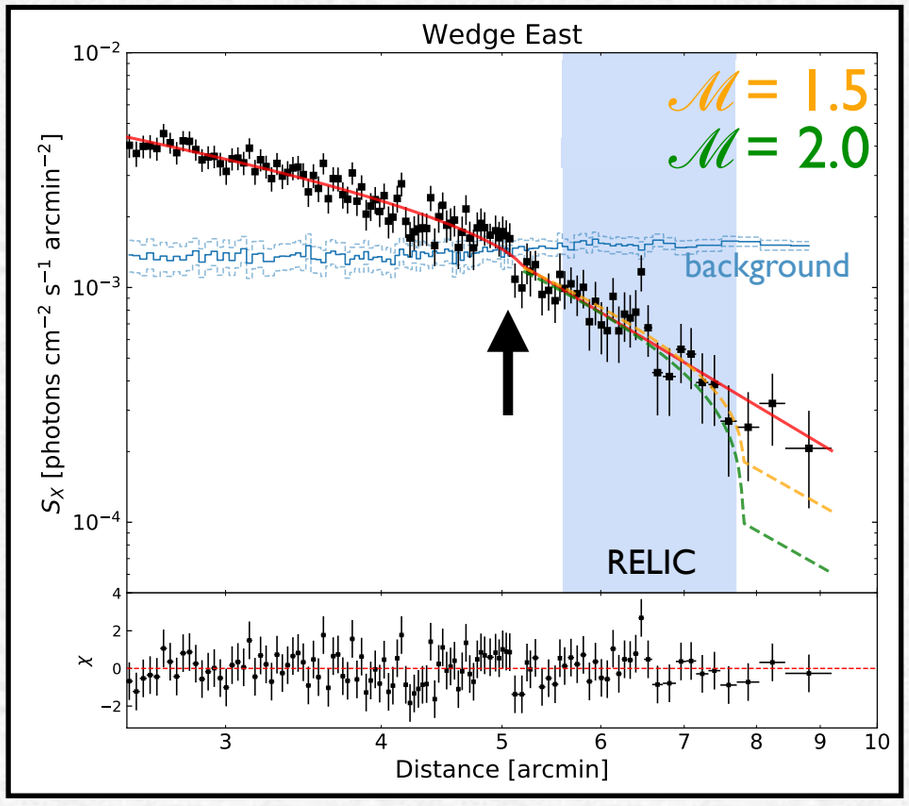

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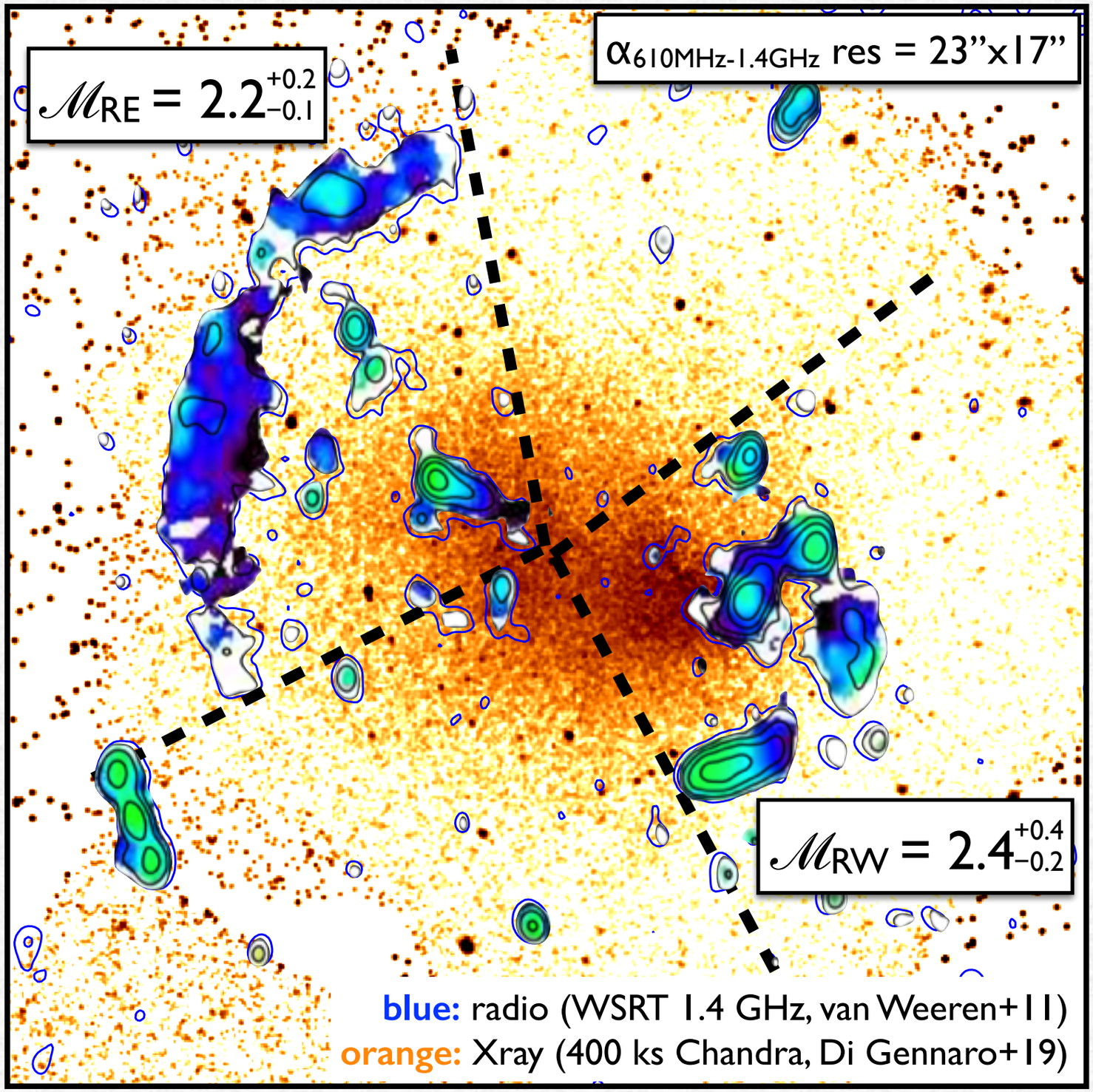

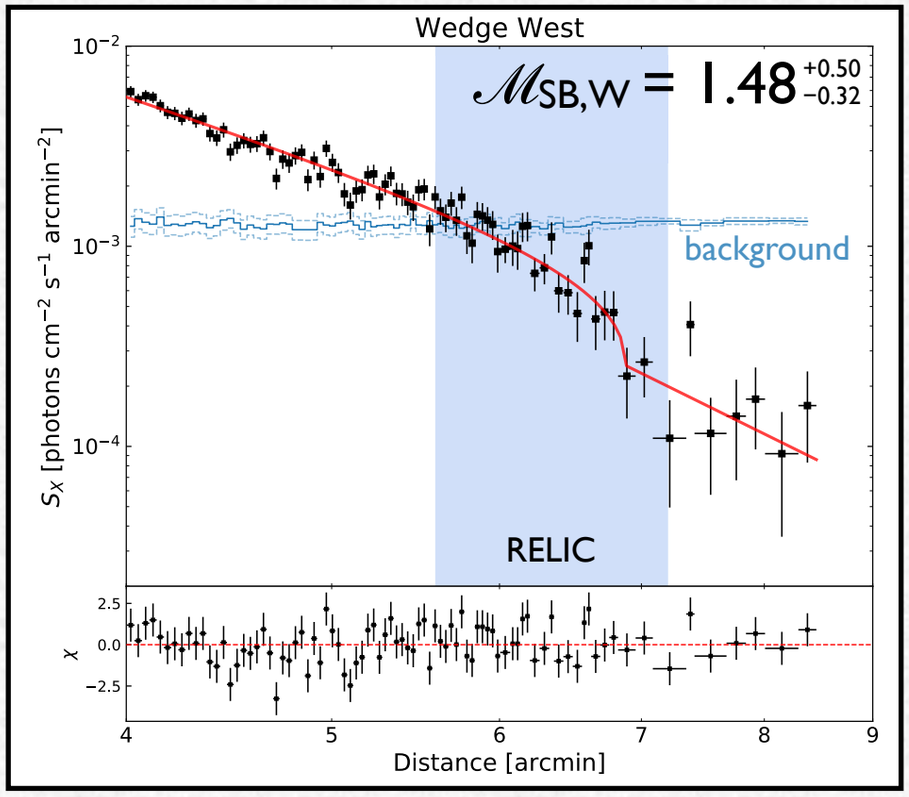

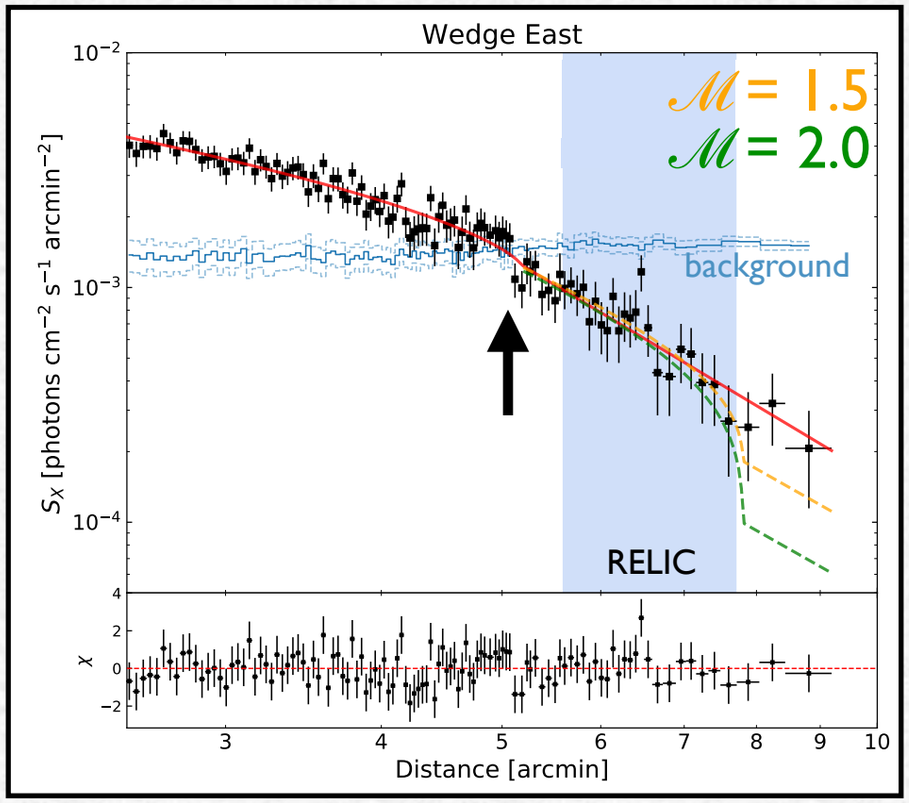

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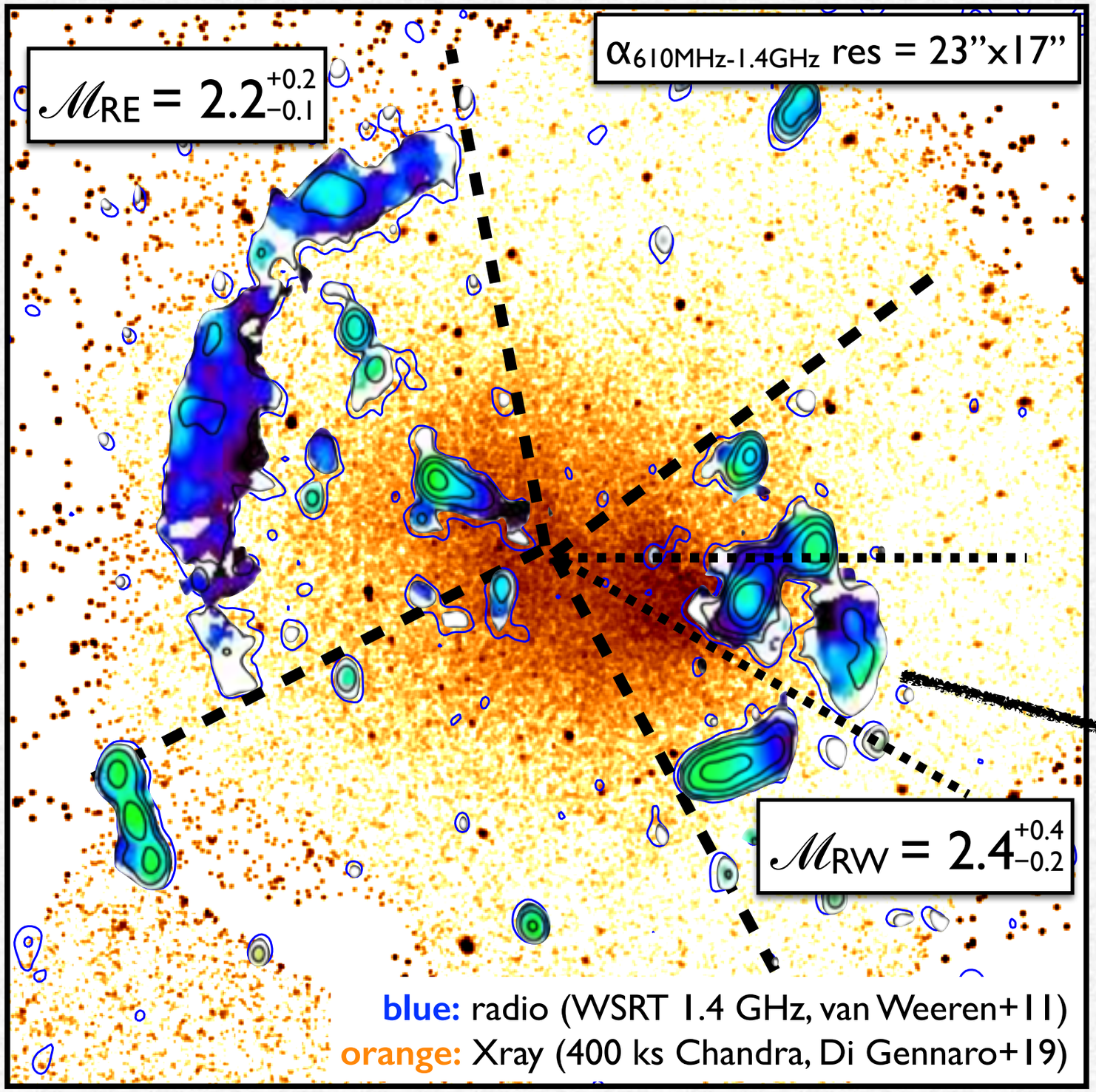
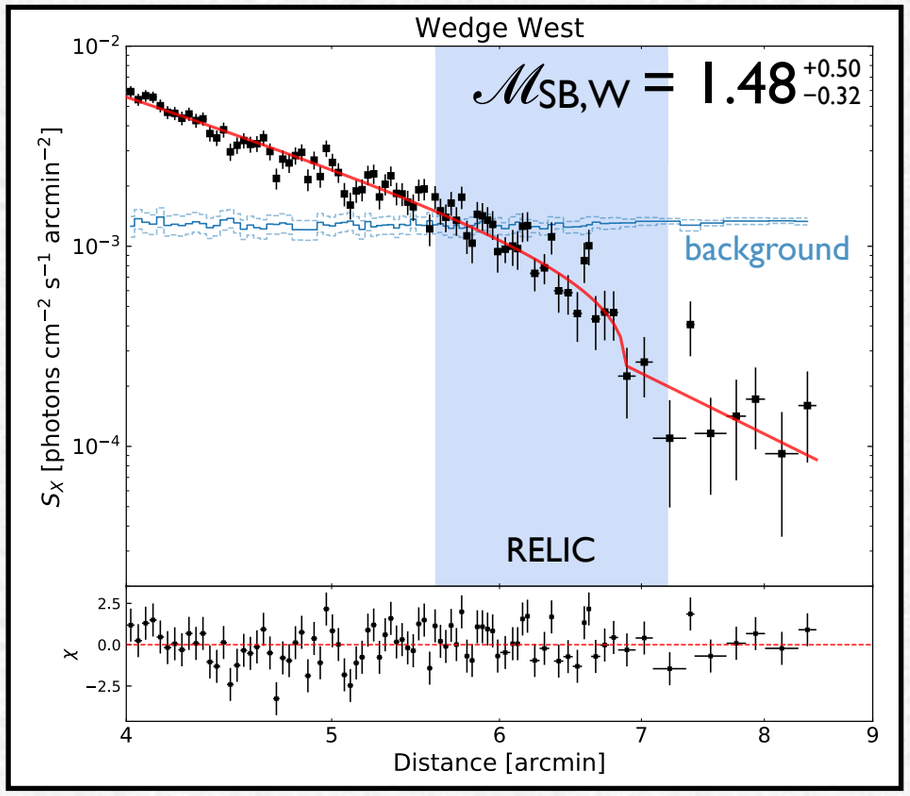
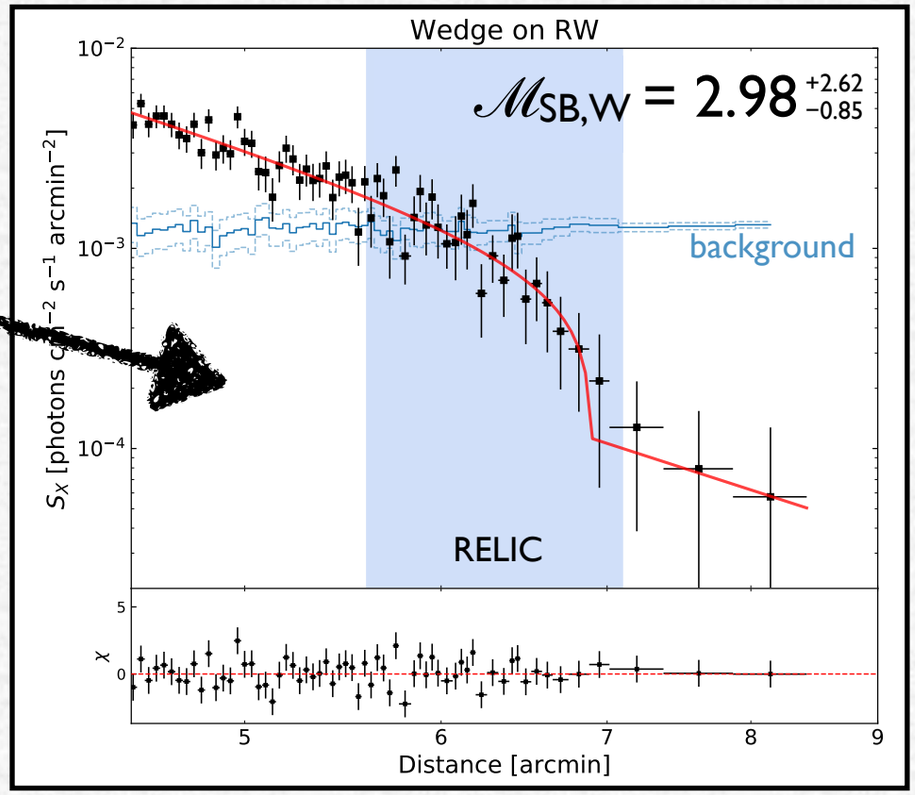
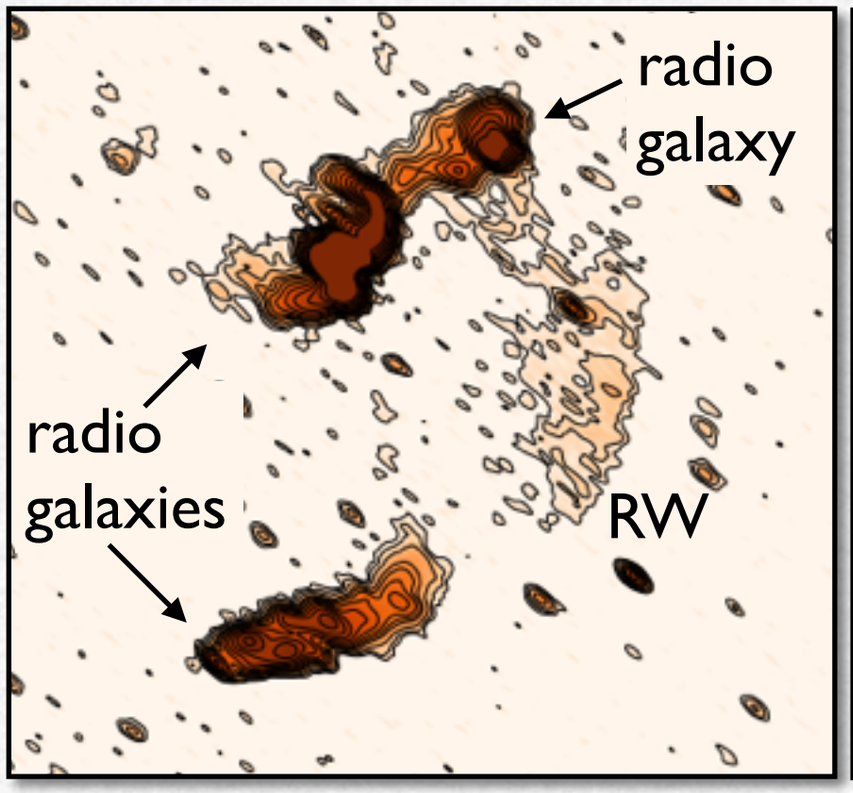






A CASE FOR RE-ACCELERATION ?

1-2 GHz JVLA (11”×4”)



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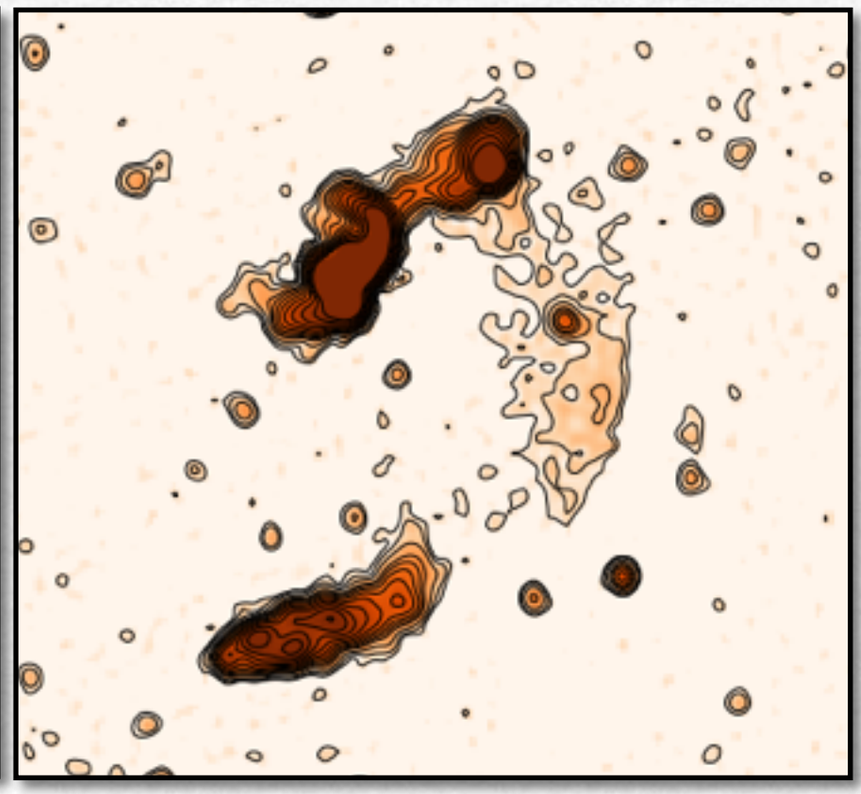

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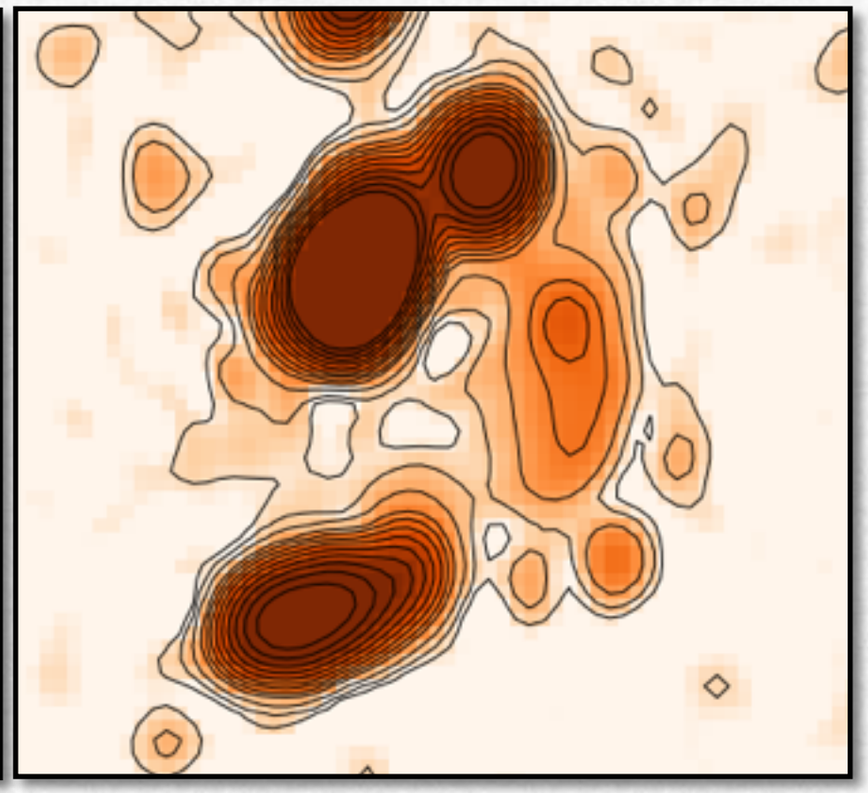

Di Gennaro+ in prep.

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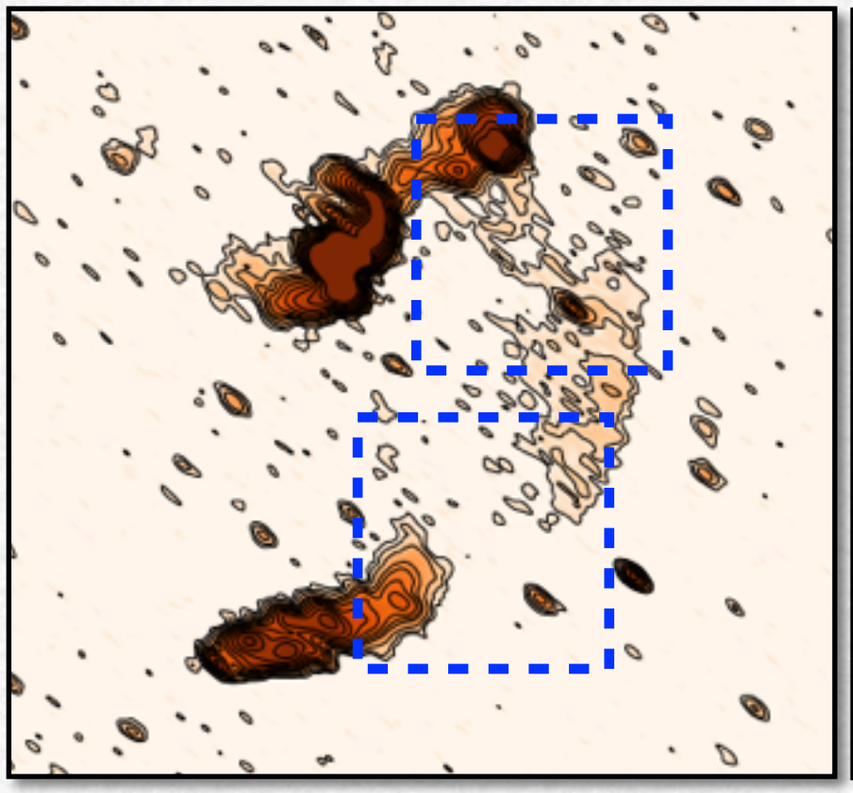

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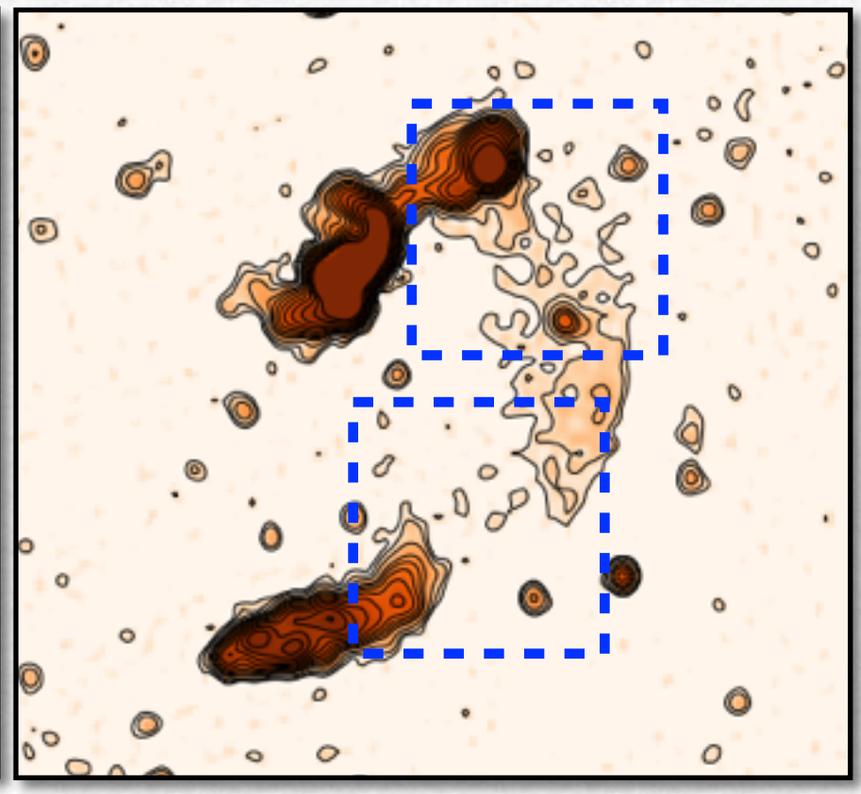

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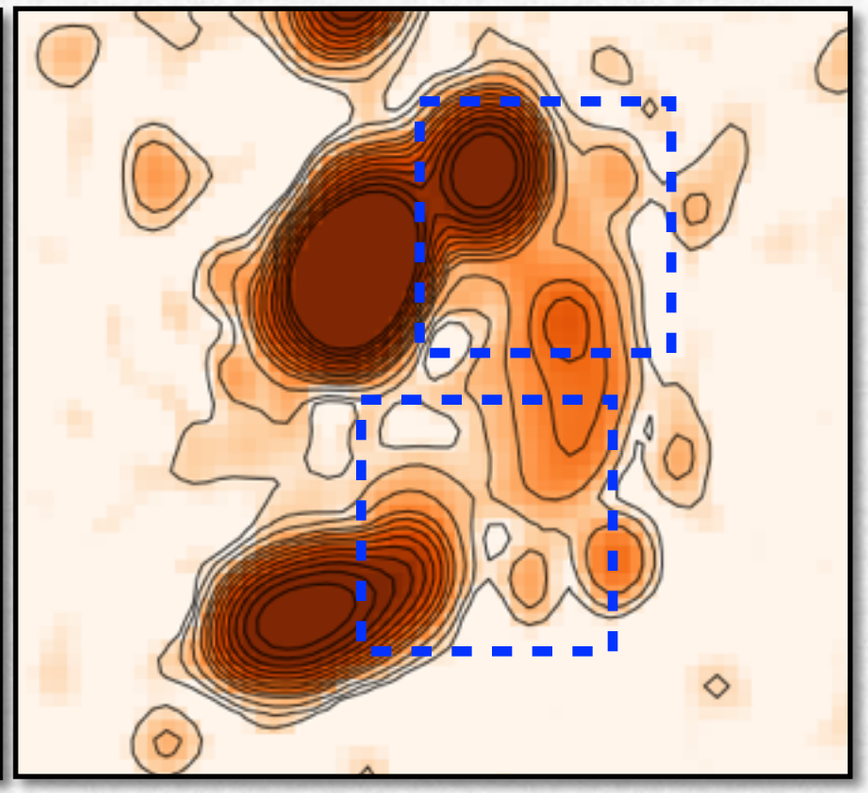

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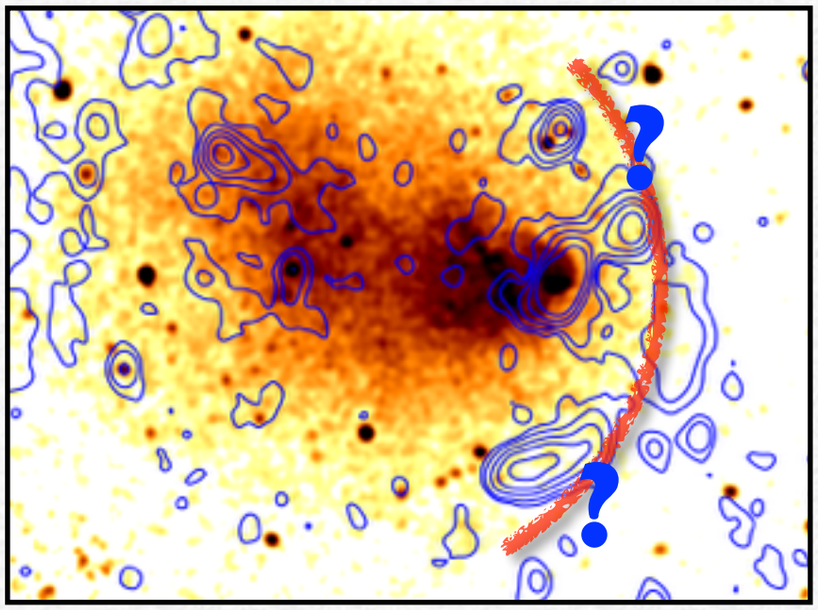
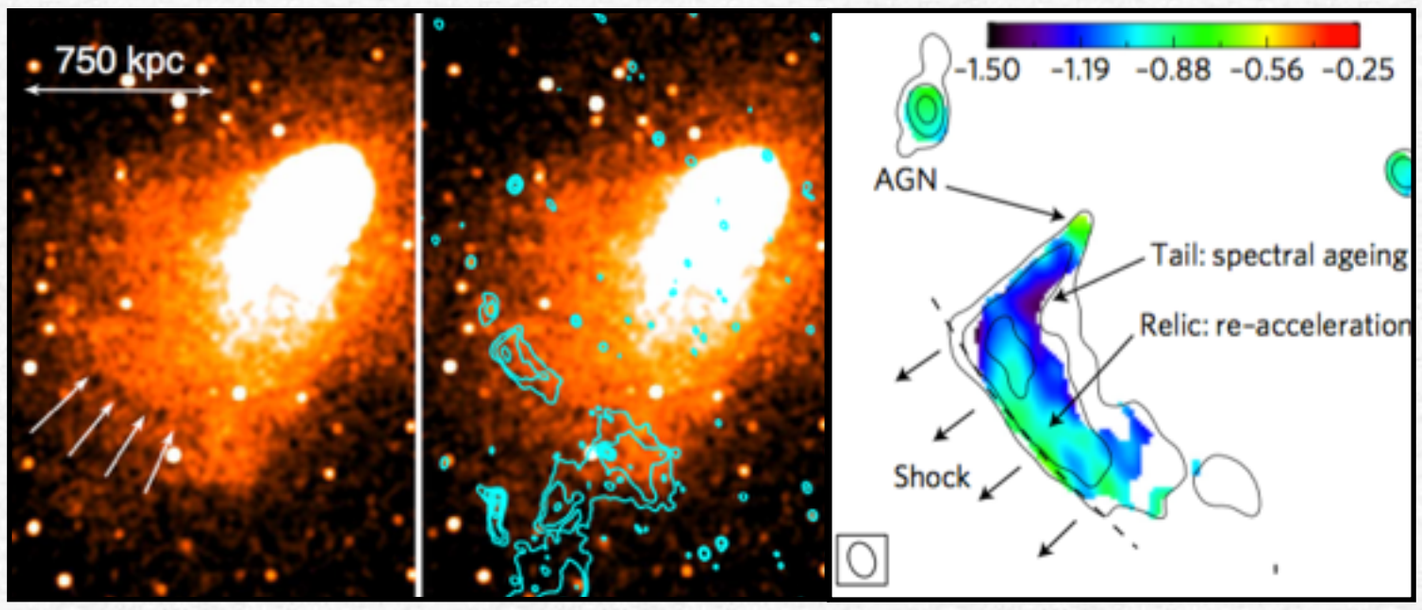
SOURCE FOR FOSSIL PLASMA ?



Abell 3411-3412 (van Weeren+17, Nat. Astr., F. Andrade-Santos in prep.)



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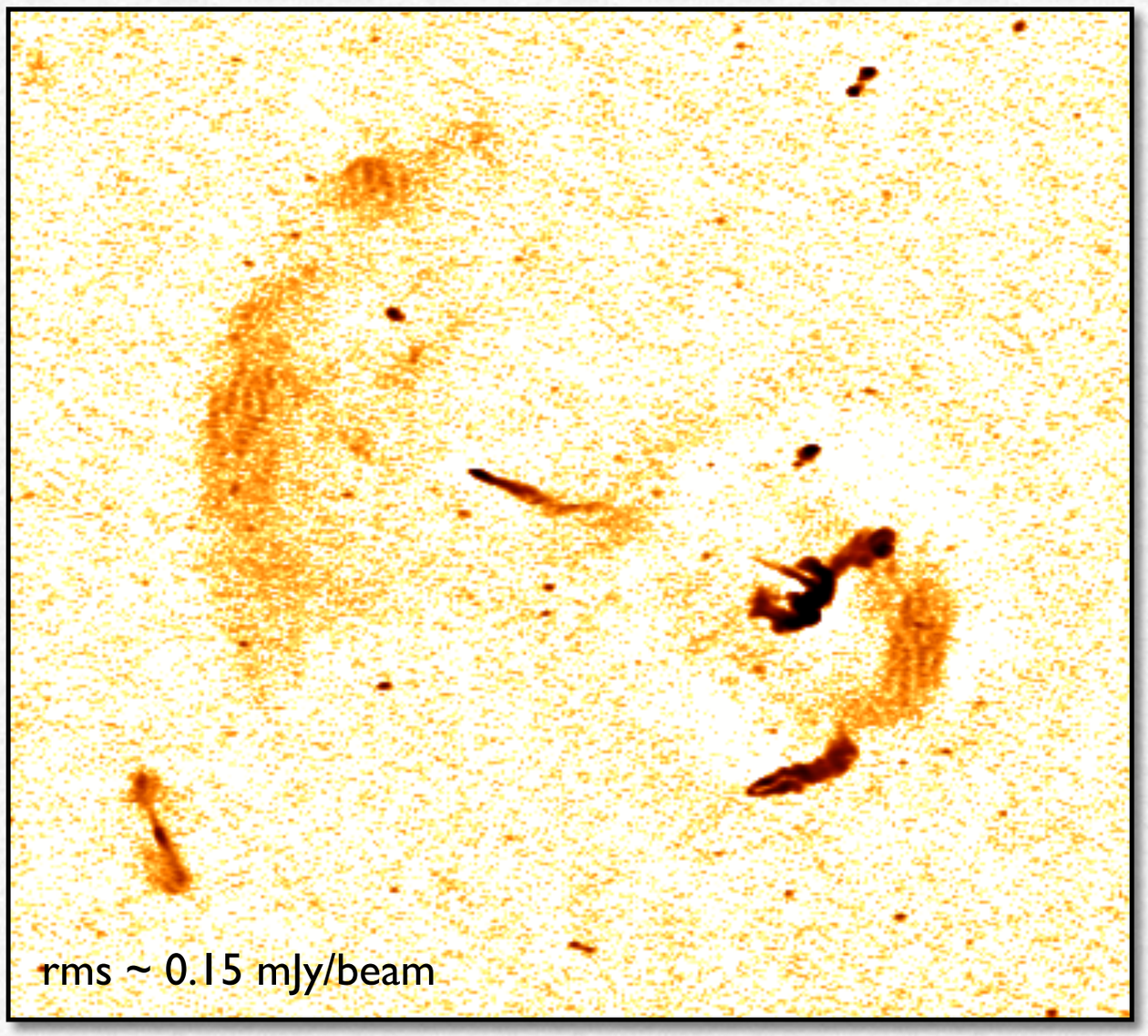
a work in progress…

<u>120-168 MHz — LOFAR</u>



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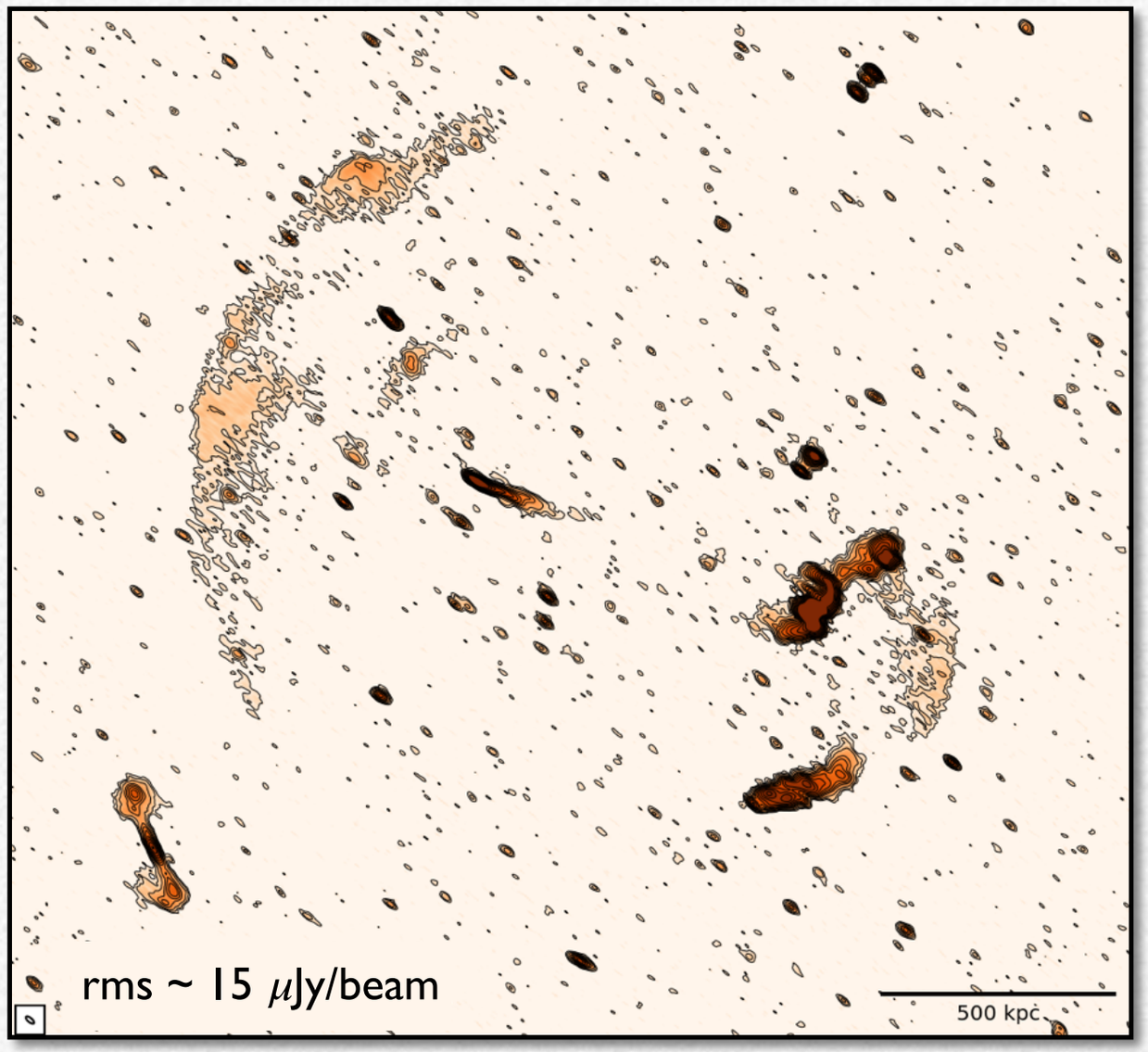

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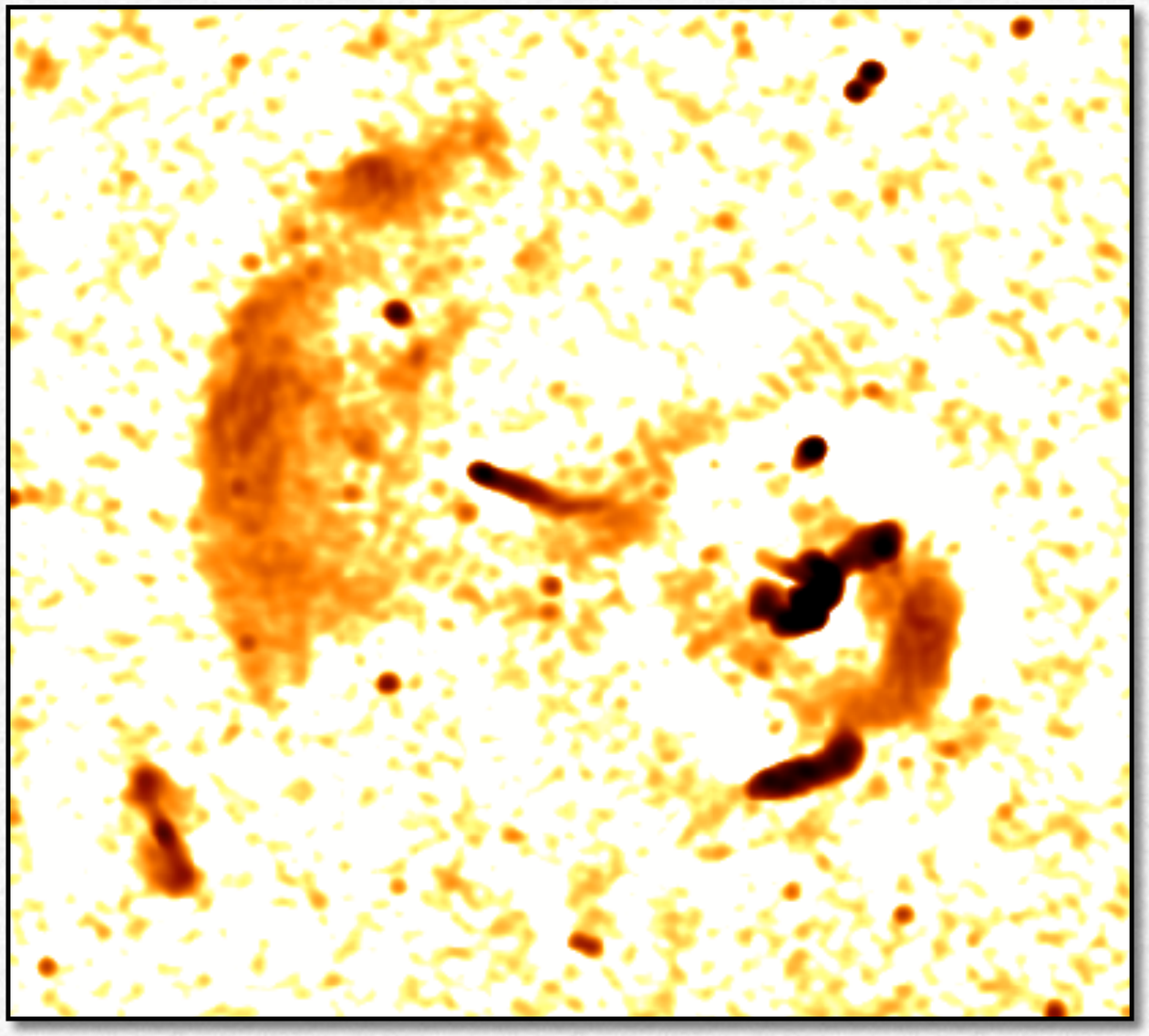

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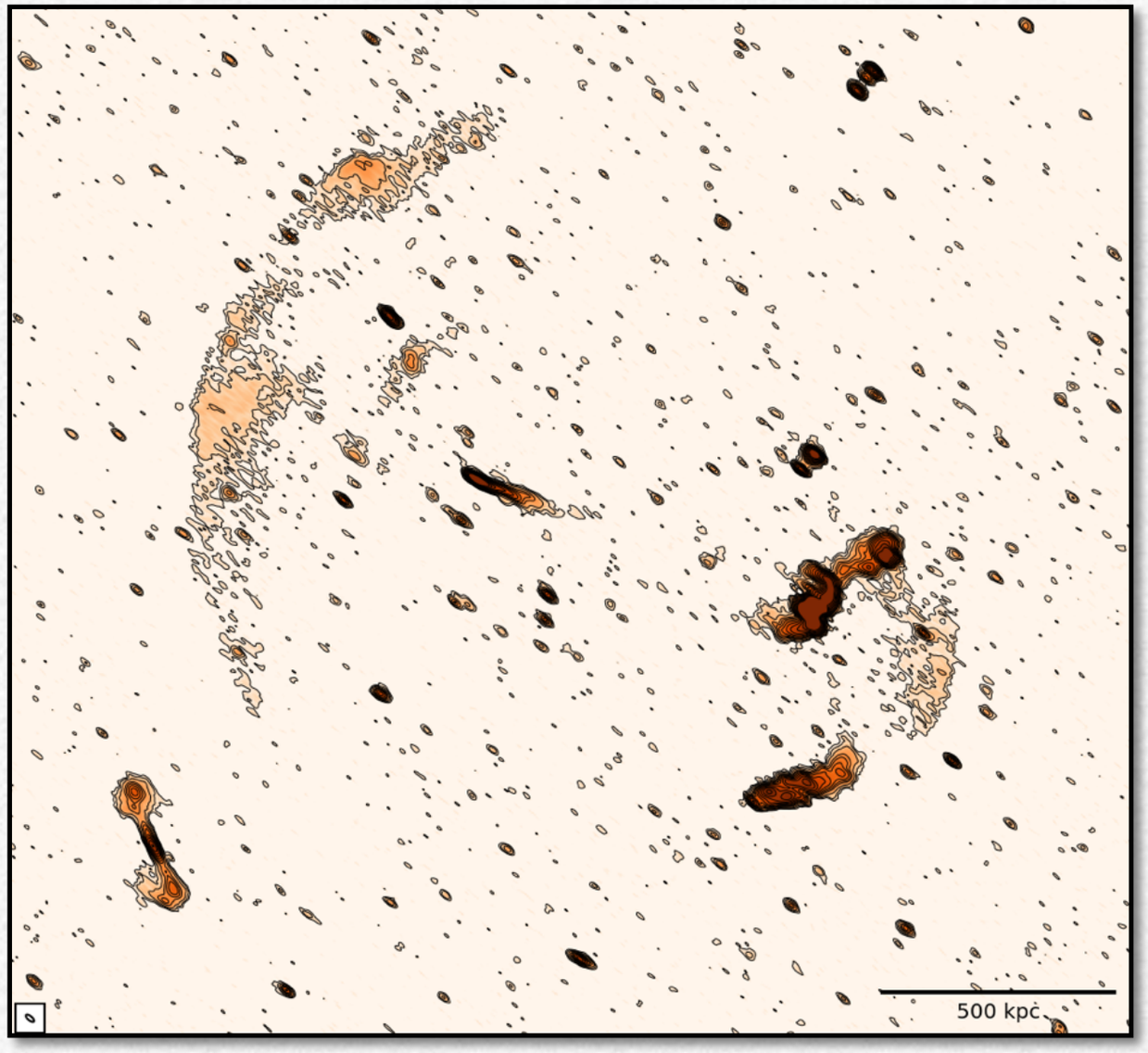

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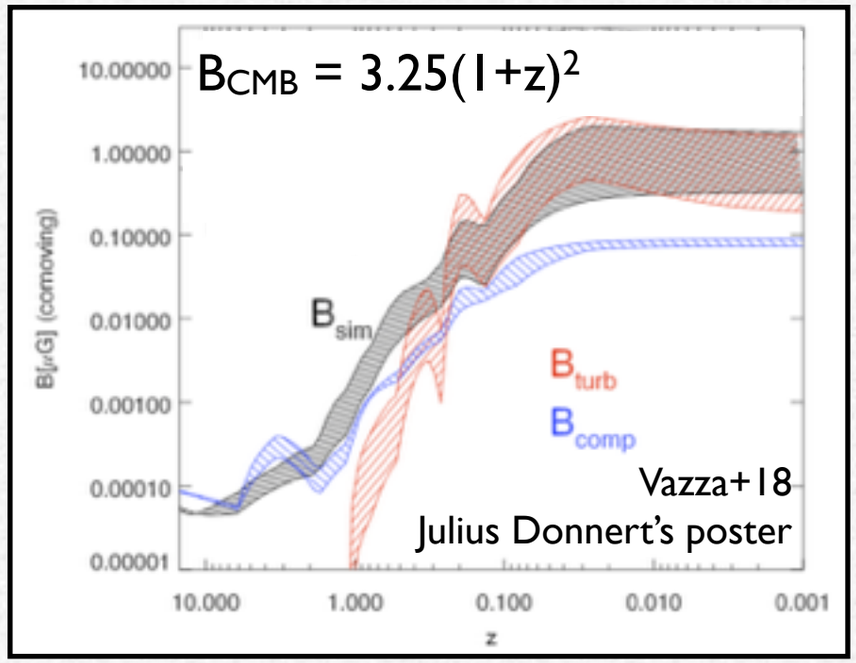
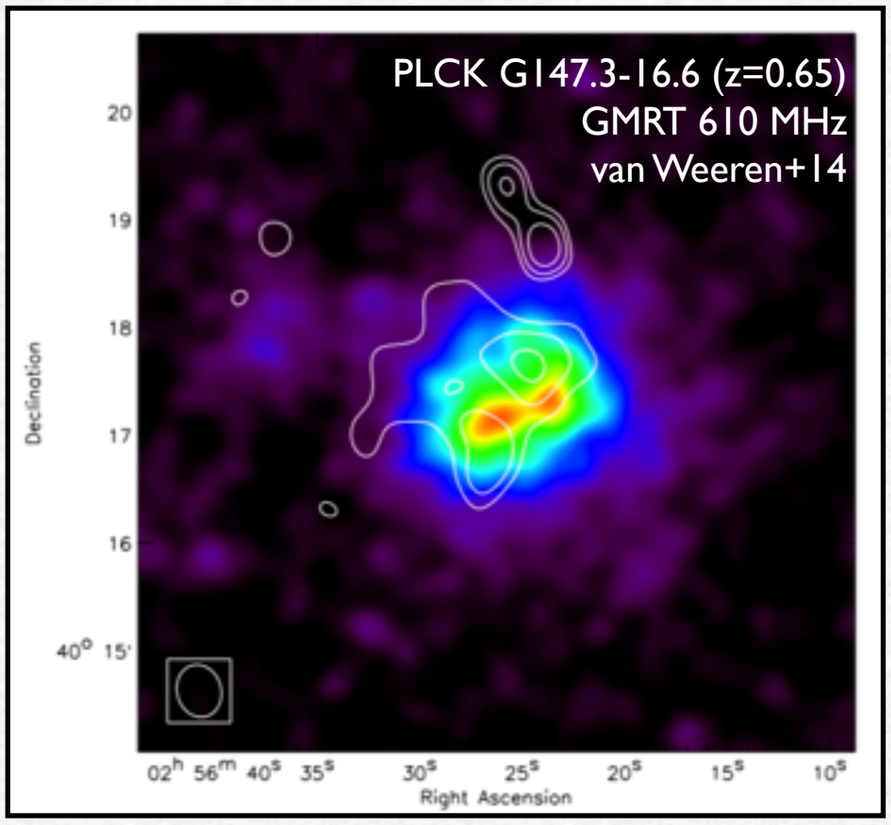
HIGH-REDSHIFT (z≳0.5) CLUSTERS

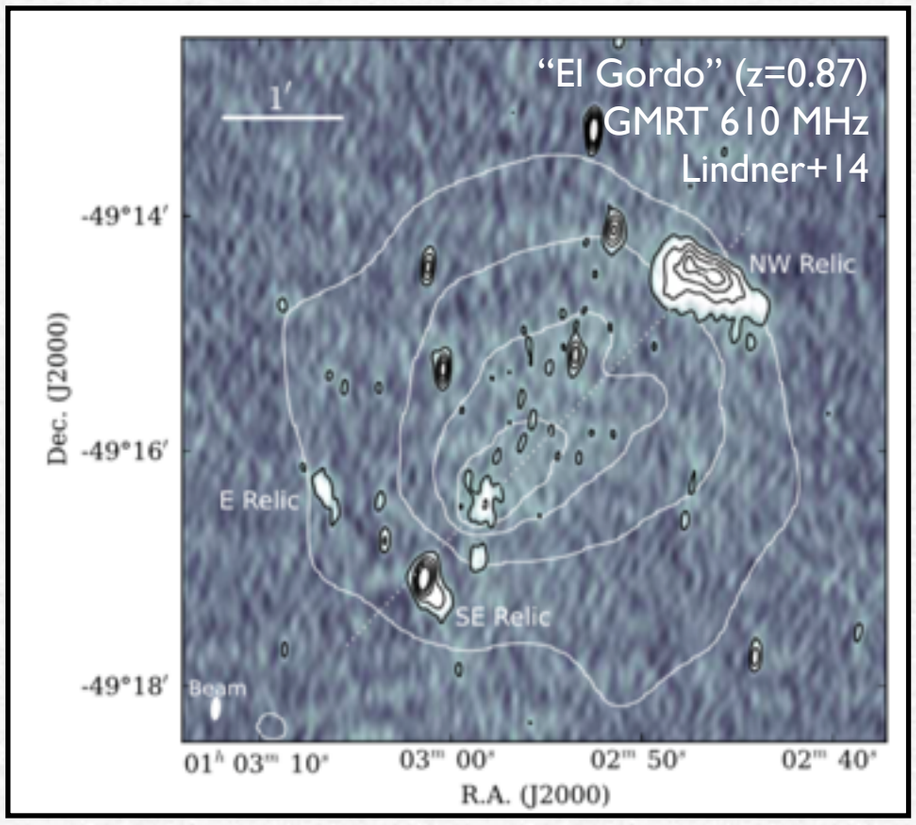
- **Observations:** limited by sensitivity and resolution from the previous generation of radio telescopes (now LOFAR and uGMRT)
- **Prediction:** occurrence rate at z>0.5 *should* be much lower than in low-z clusters due to IC losses + steep spectra (Cassano&Brunetti 05, Cassano+10)

a very simplistic view…



see also Donnert+18 for a recent review on magnetic fields in galaxy clusters





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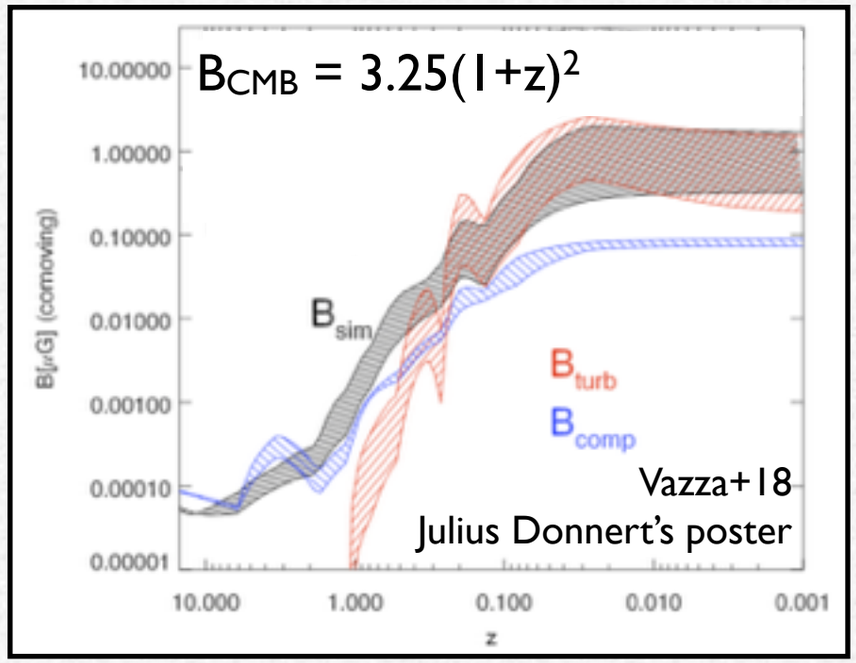

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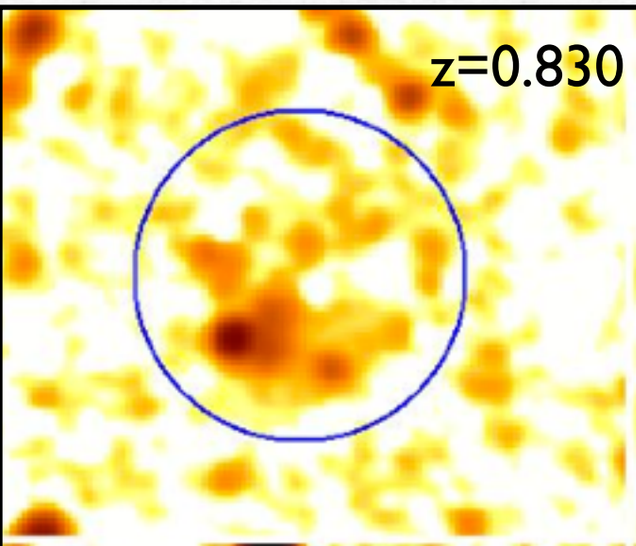
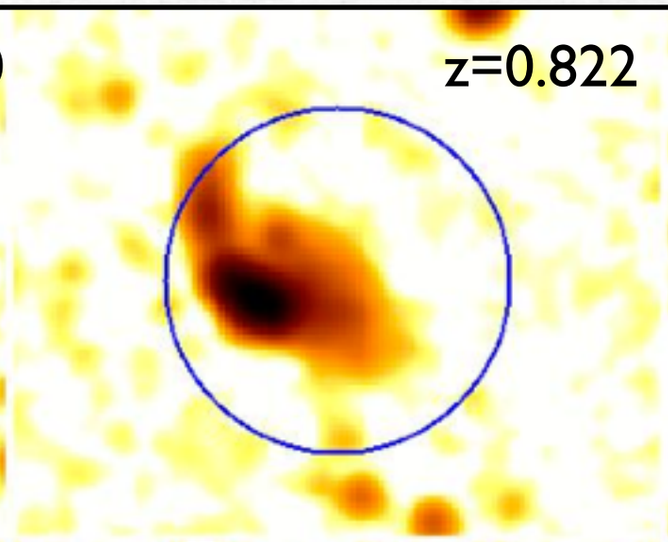
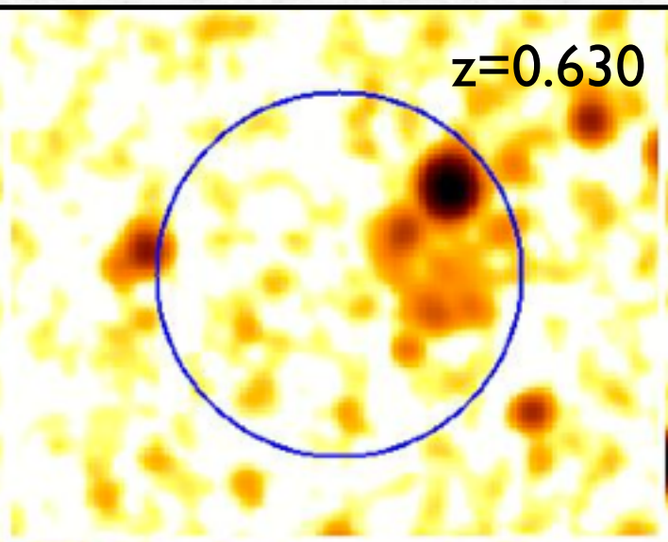
THE LOFAR (120-168 MHz) SAMPLE

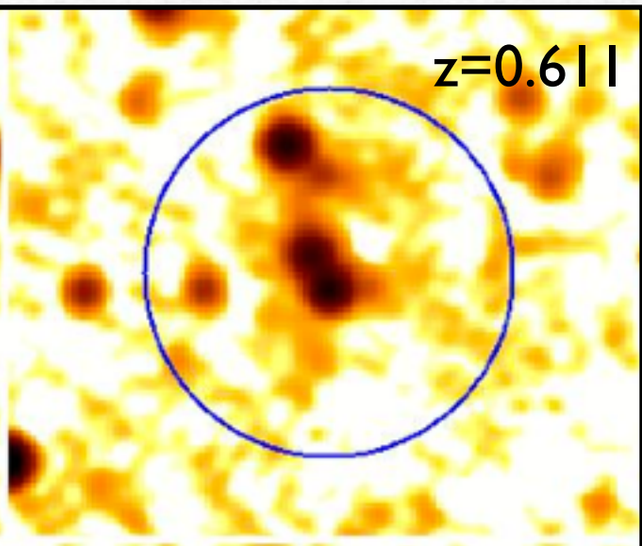
- $M_{SZ} > 7 \times 10^{14}\ M_{\odot}$ (latest Planck SZ Catalogue)
  - low-z surveys (z≲0.4) show that the fraction of halos is higher for massive clusters (Cuciti+15)
  - no selection effects towards "merging" systems
- DEC > 15 deg
- Xray (Chandra and/or XMM) available (PI: Rossetti)
  - thermal-non thermal comparison

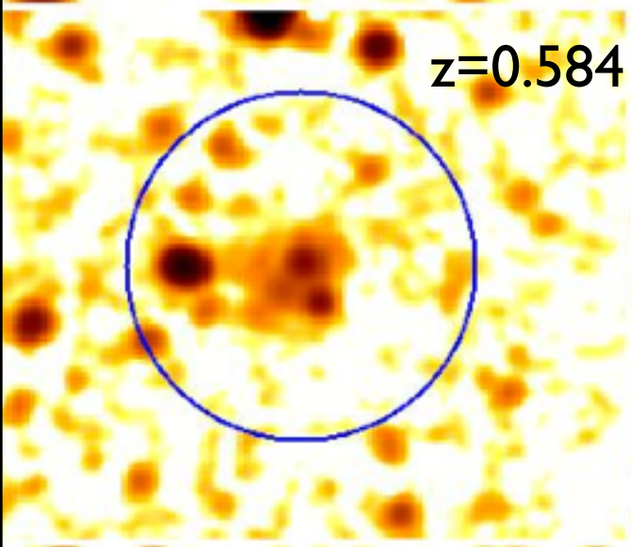
HIGH-REDSHIFT (z≳0.5) CLUSTERS
THE LOFAR SURVEY

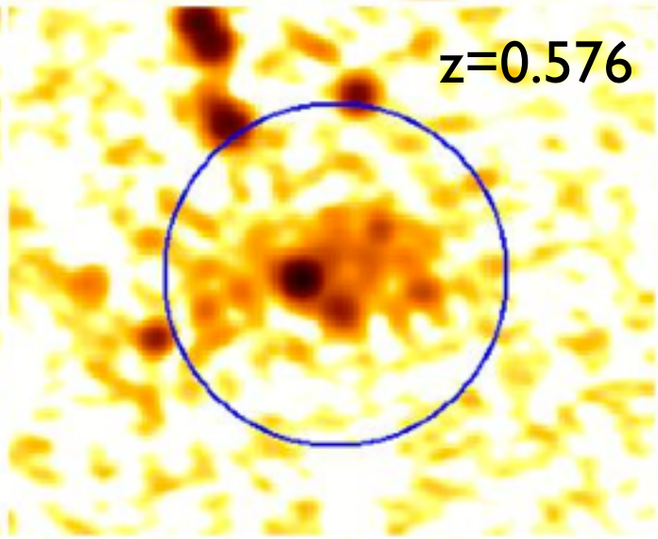


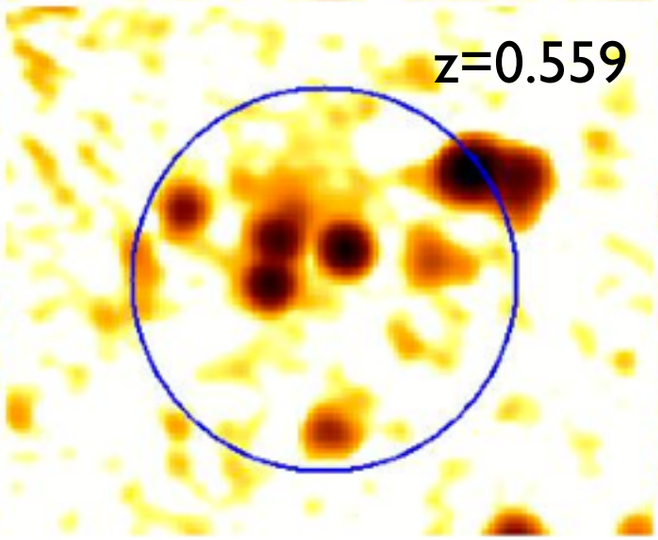


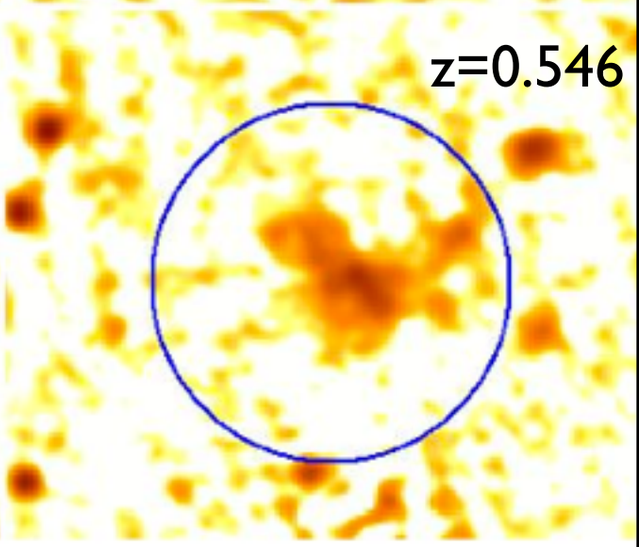


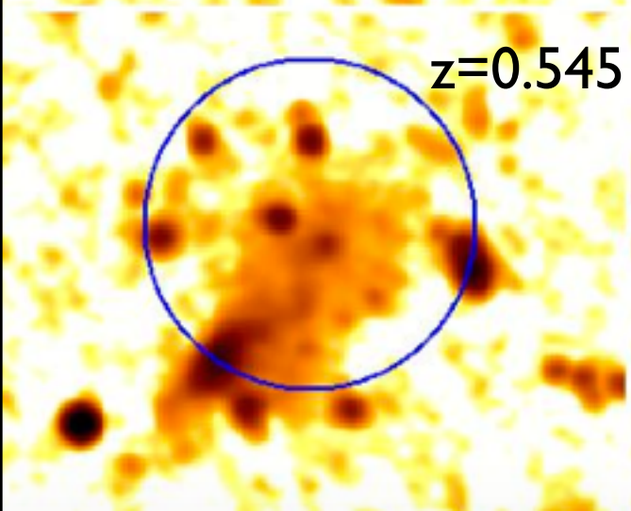


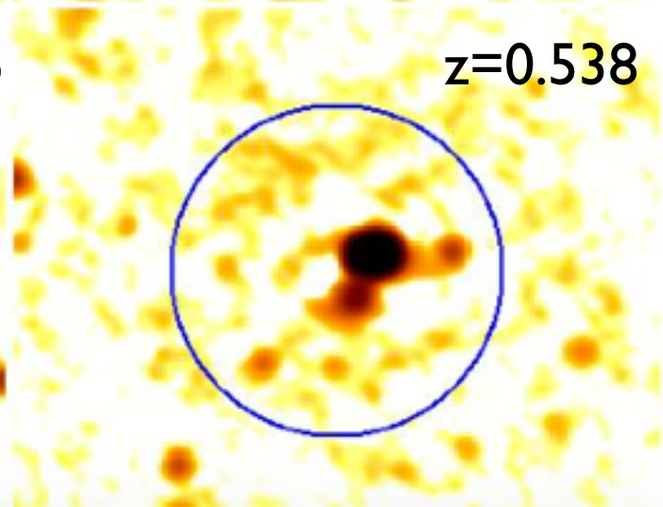












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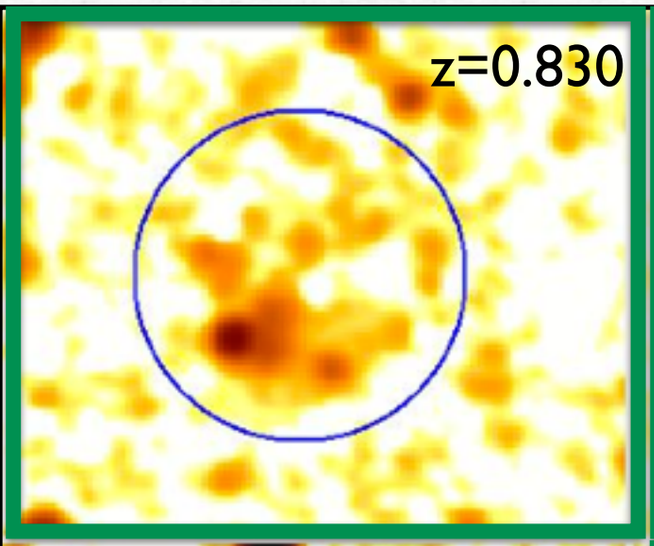

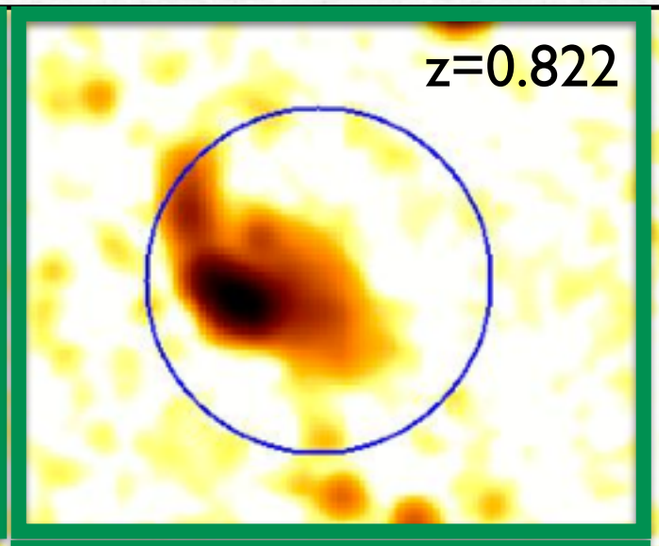

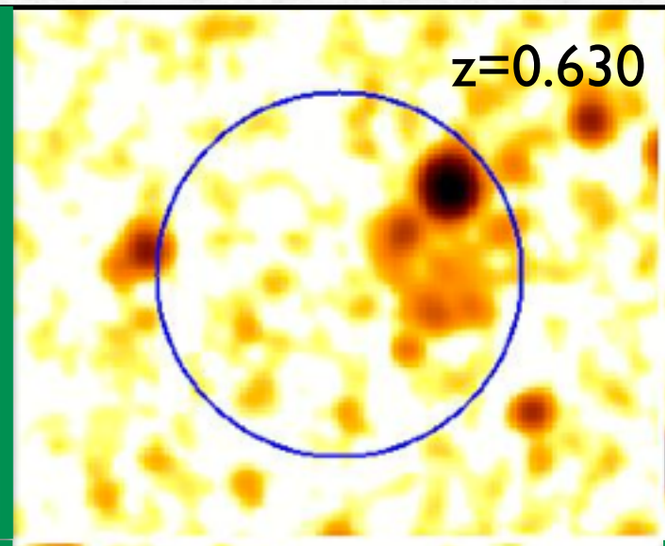

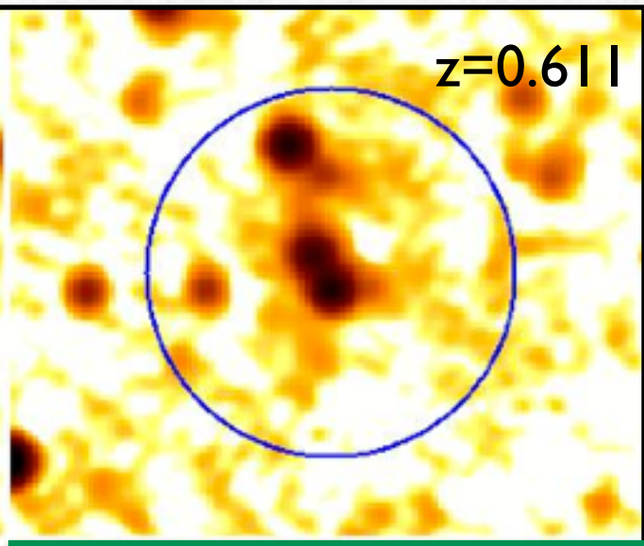

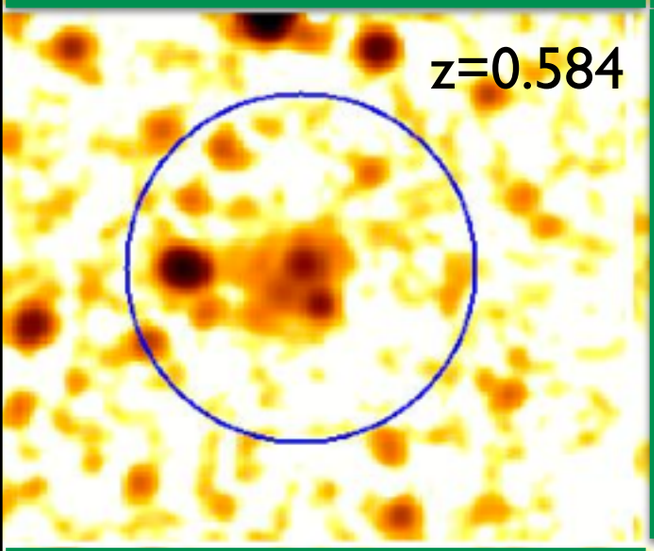

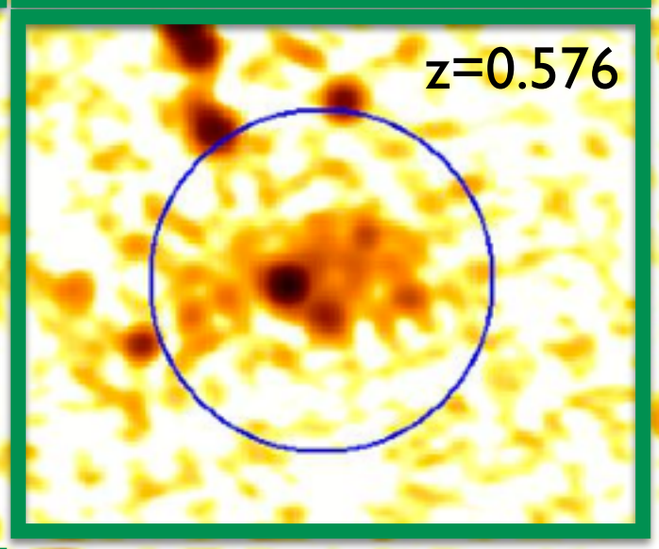

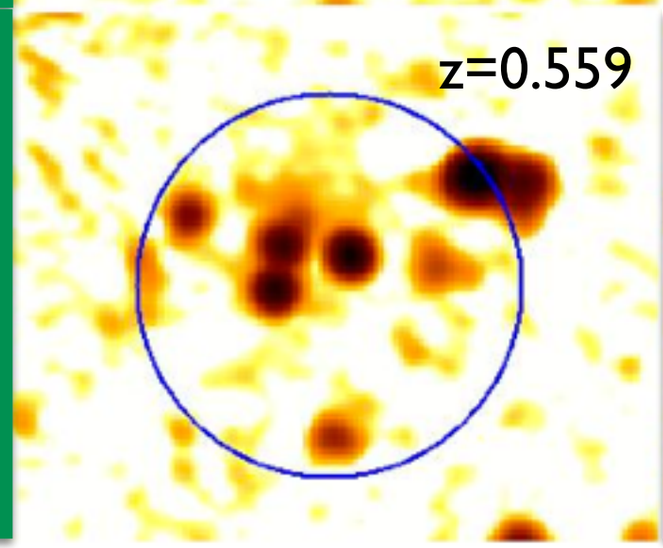

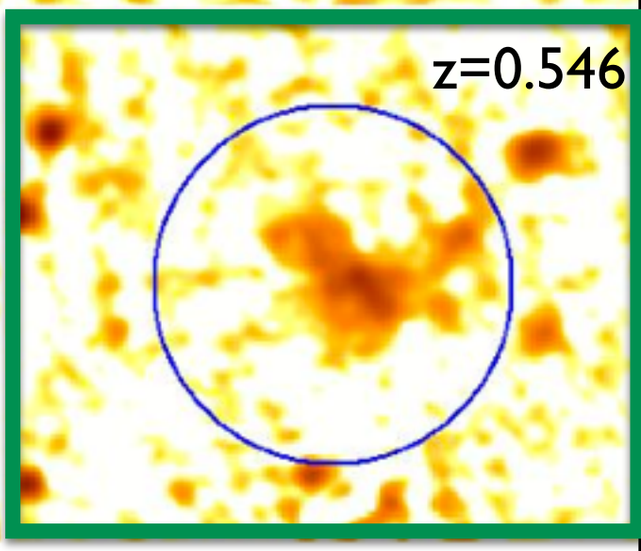

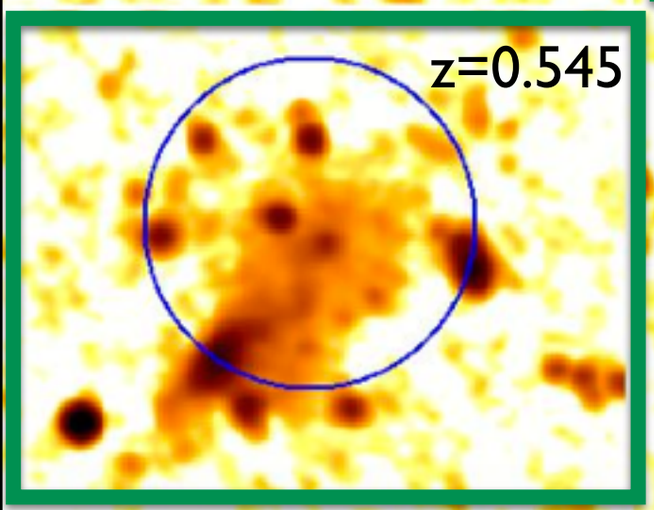

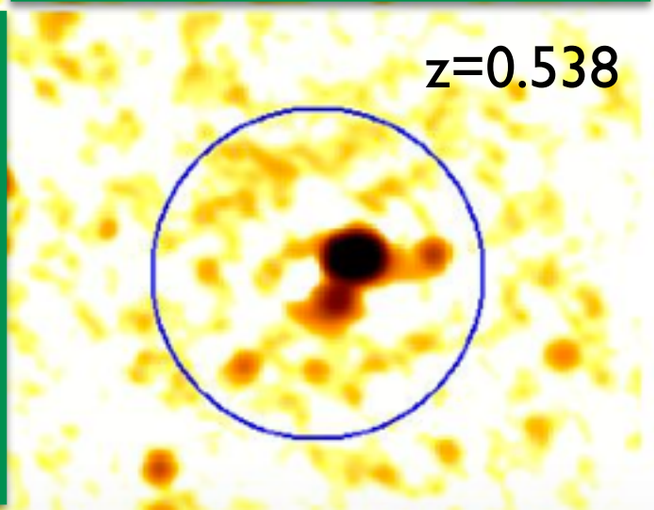

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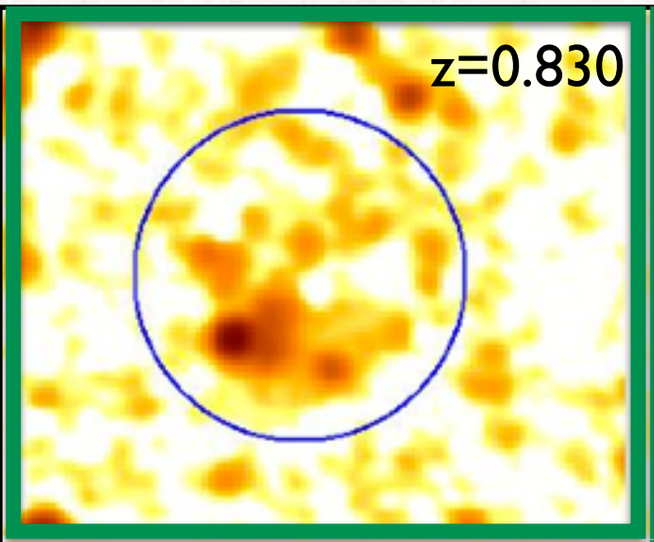
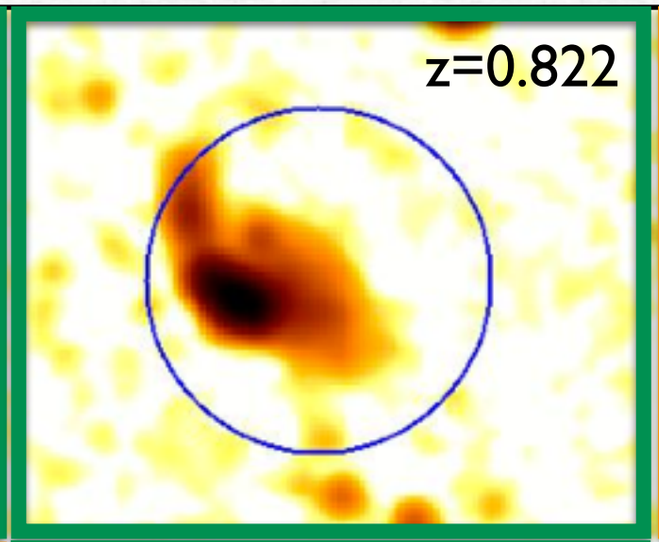
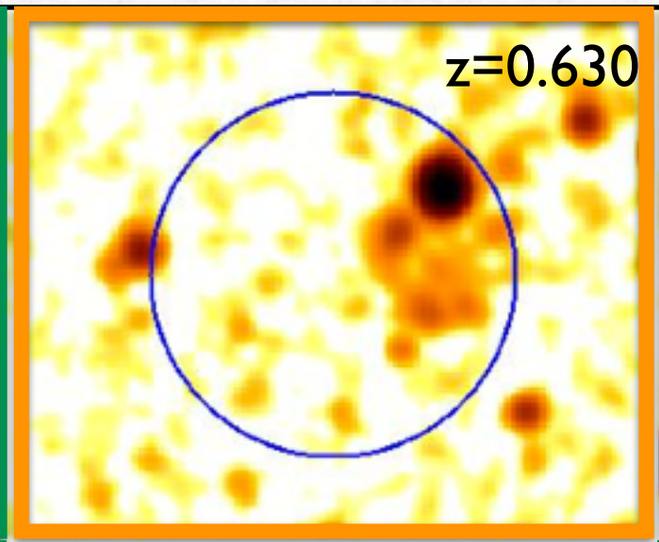
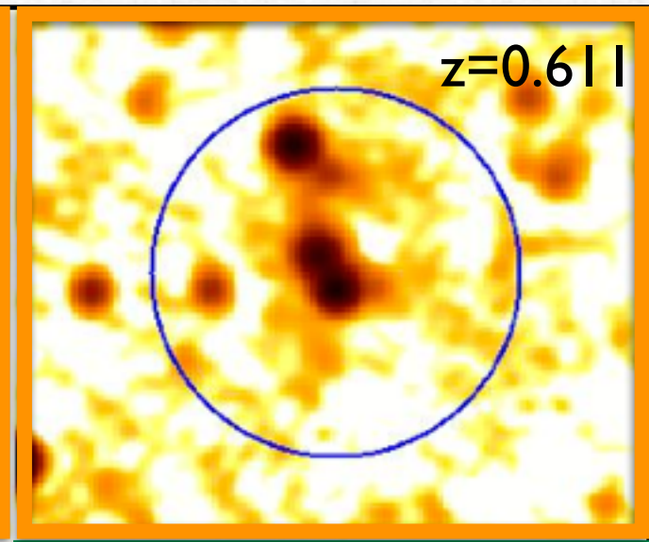
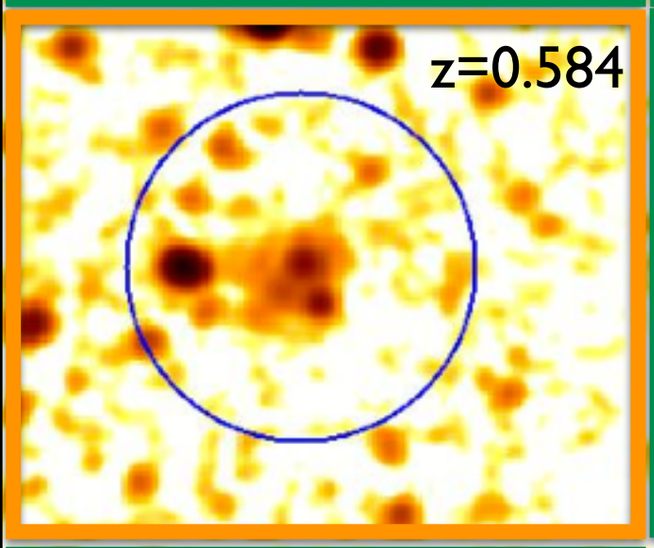
THE LOFAR SURVEY

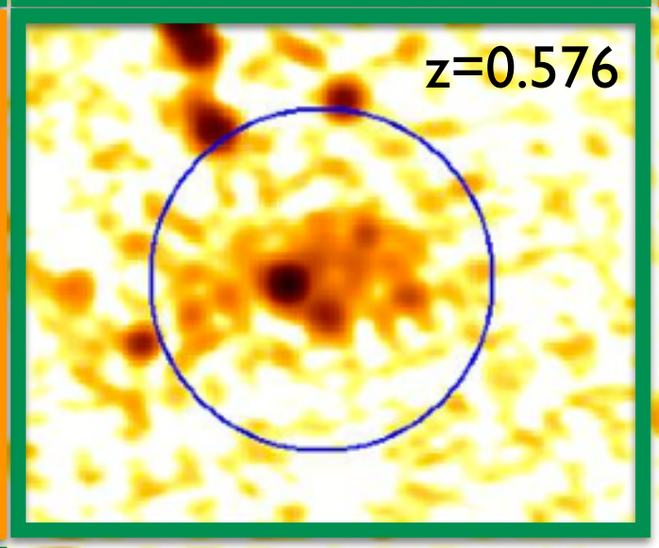


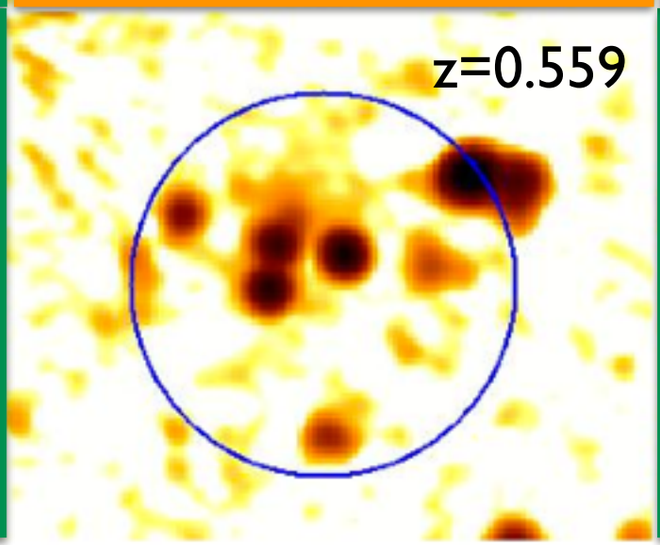


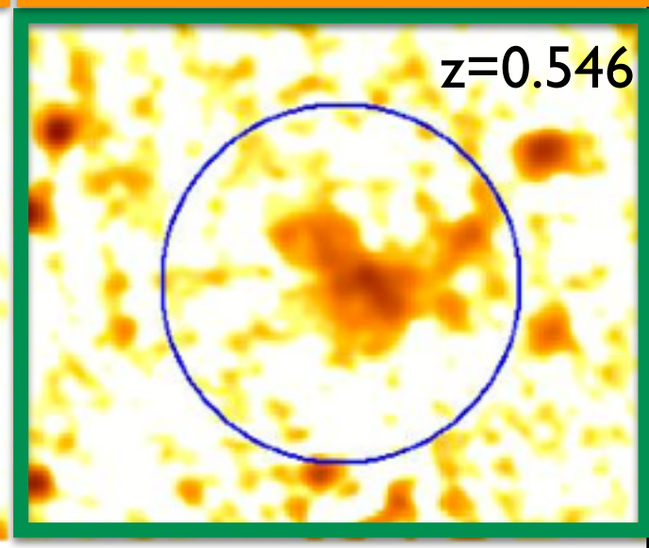


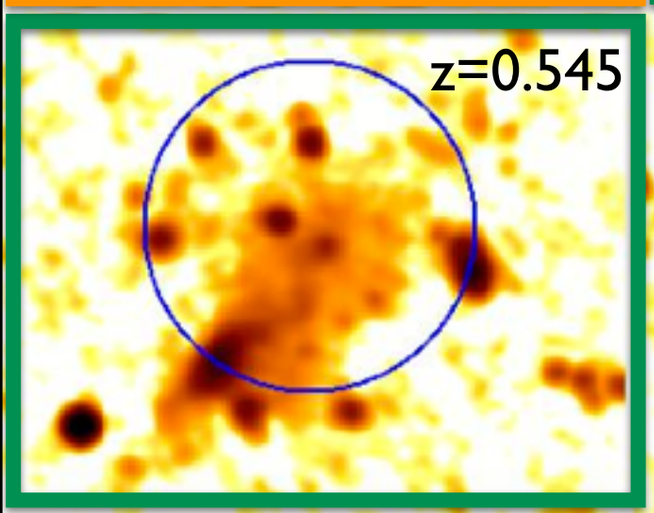


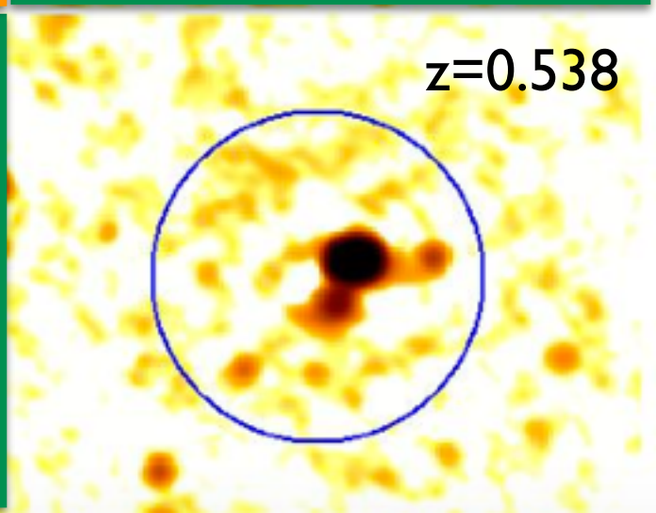












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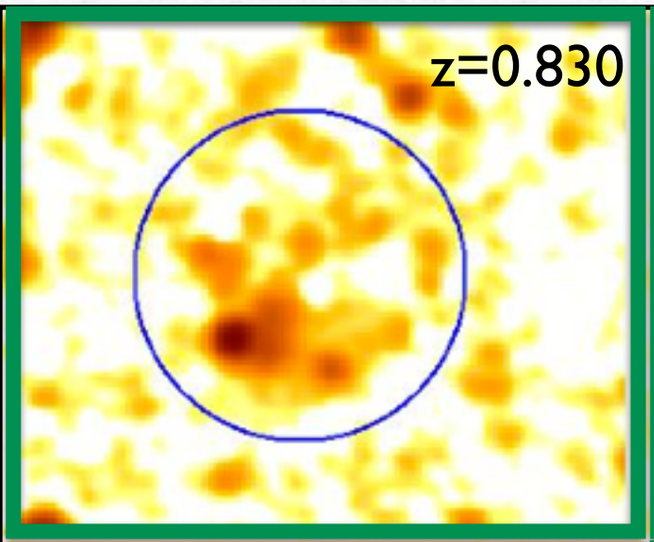

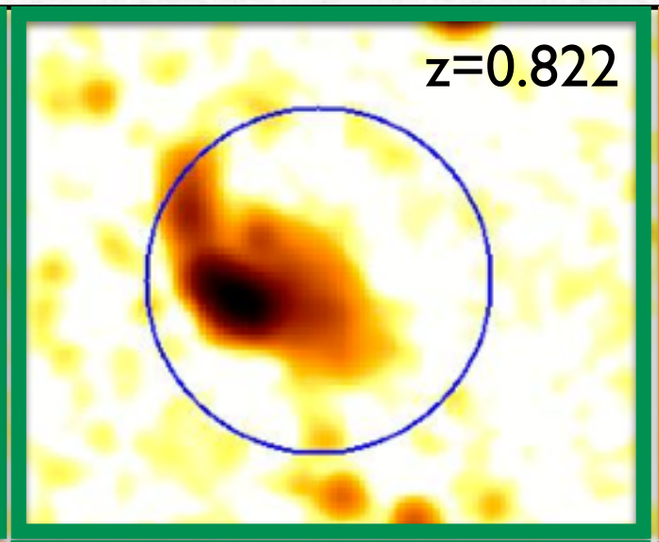

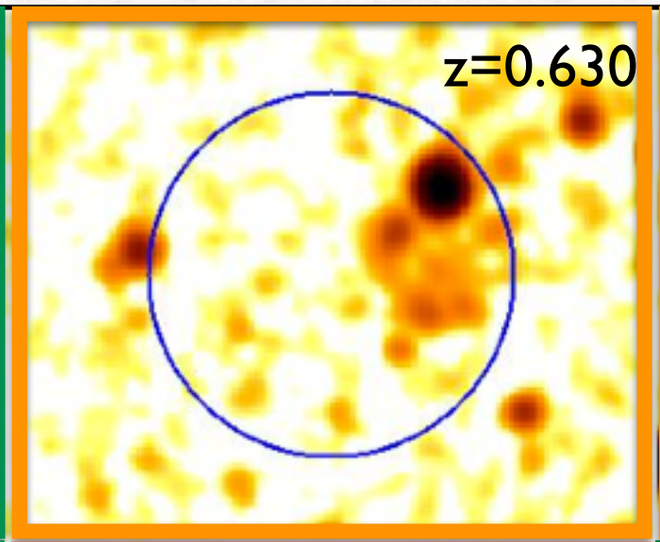

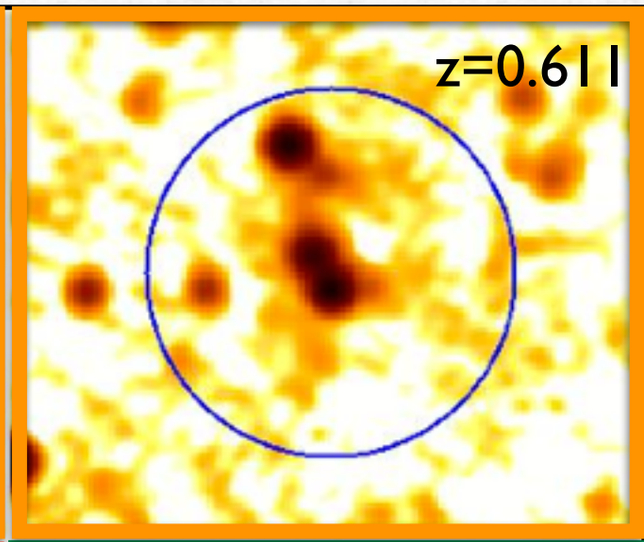

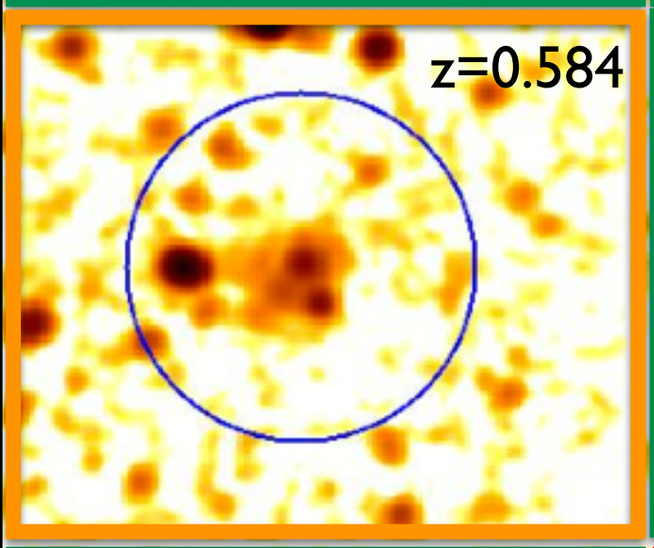

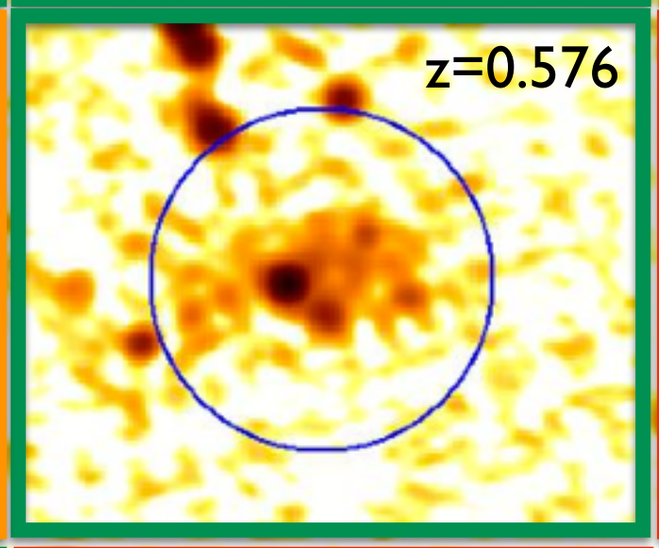

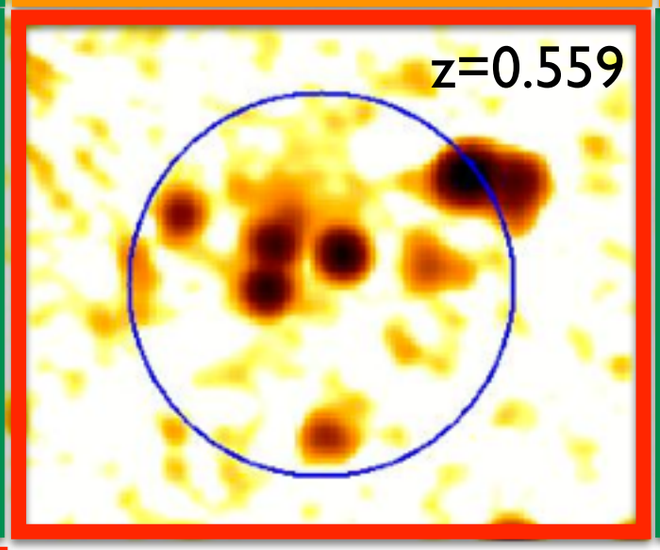

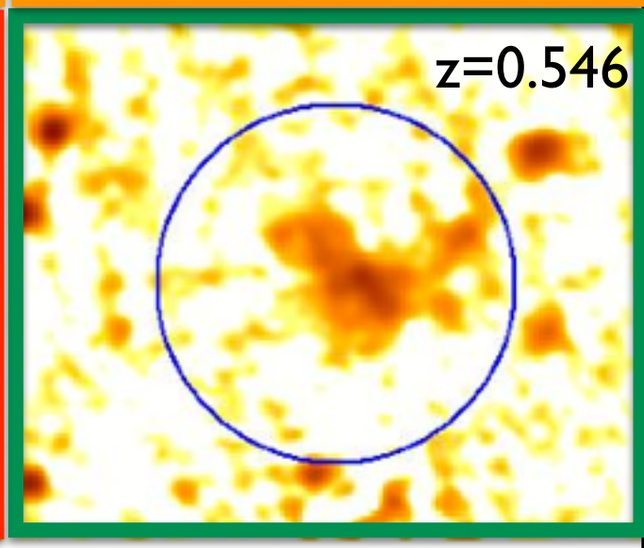

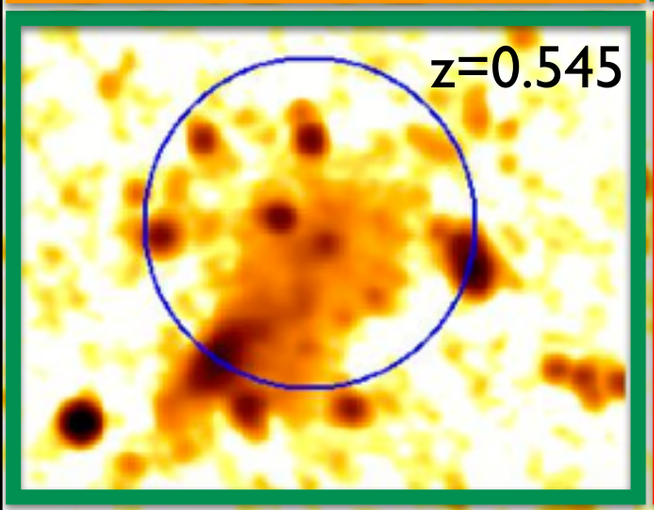

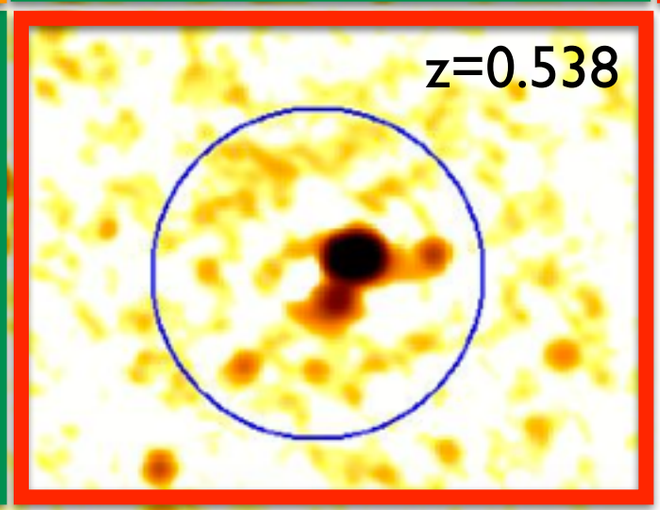

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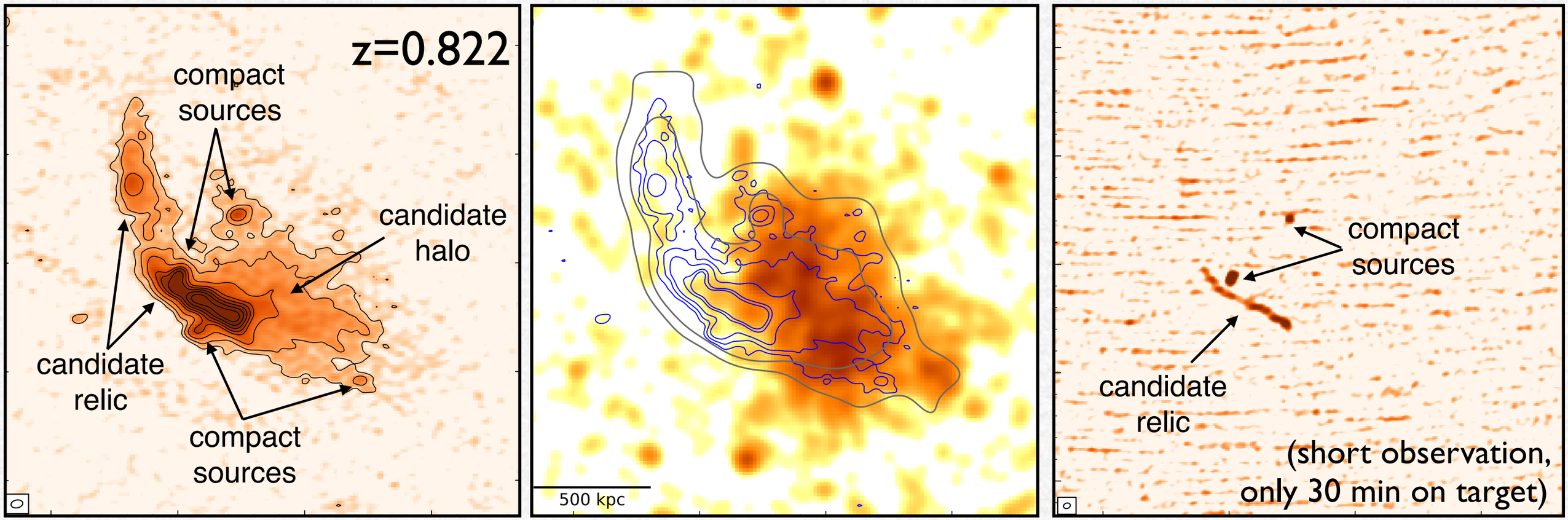
HIGH-REDSHIFT (z≳0.5) CLUSTERS

LOFAR (120-168 MHz) Chandra (20 ks) + LOFAR JVLA (1-2 GHz)



Di Gennaro+ in prep.

F_{relic} ~ 230 mJy
F_{halo} ~ 55 mJy

kT_{Xray} ~ 12 keV

F_{relic} ~ 6 mJy
$\alpha^{\mathrm{JVLA}}_{\mathrm{LOFAR}}$ ~ -1.4

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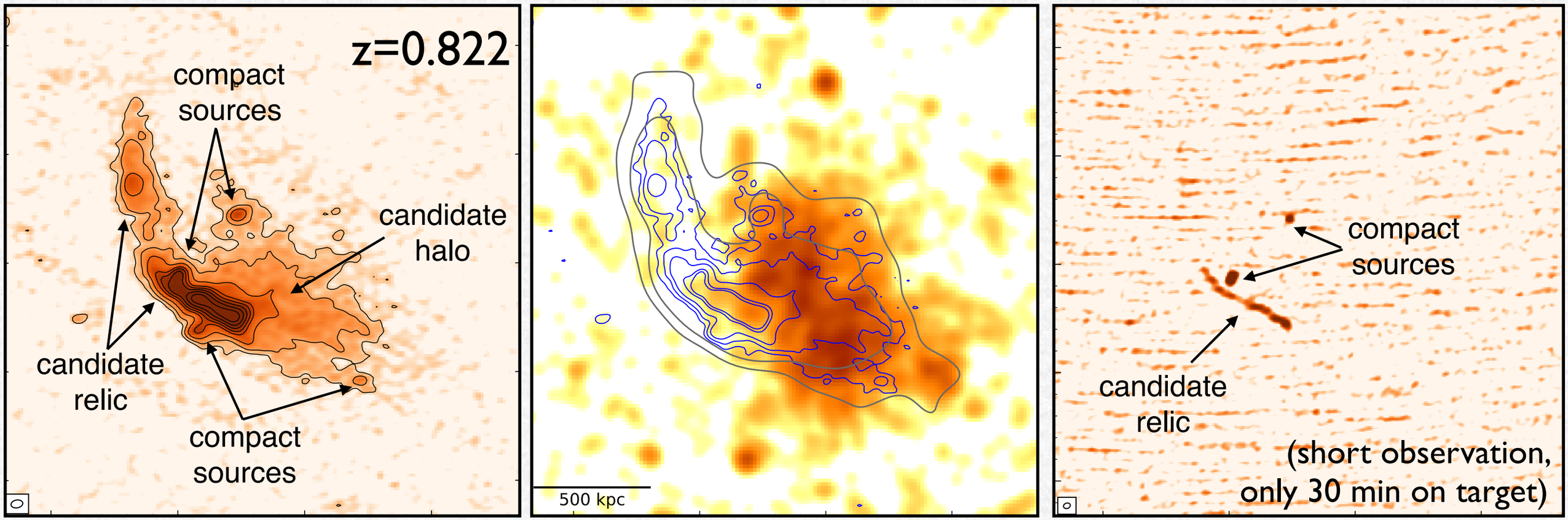

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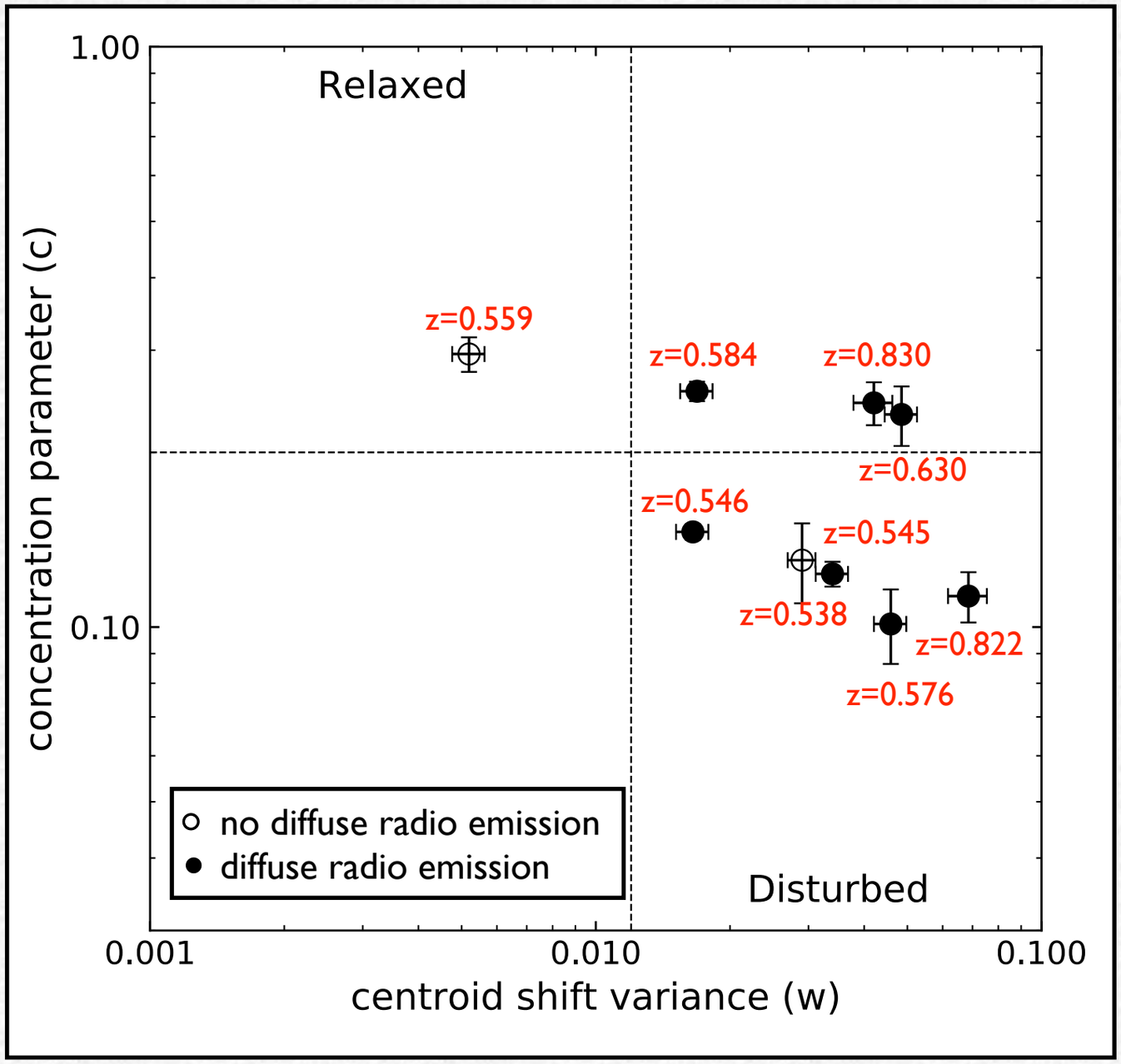
IMPLIES A MAGNETIC FIELD ≳10 μGauss AT z=0.822

HIGH-REDSHIFT (z≳0.5) CLUSTERS
THE X-RAY VIEW



Di Gennaro+ in prep.

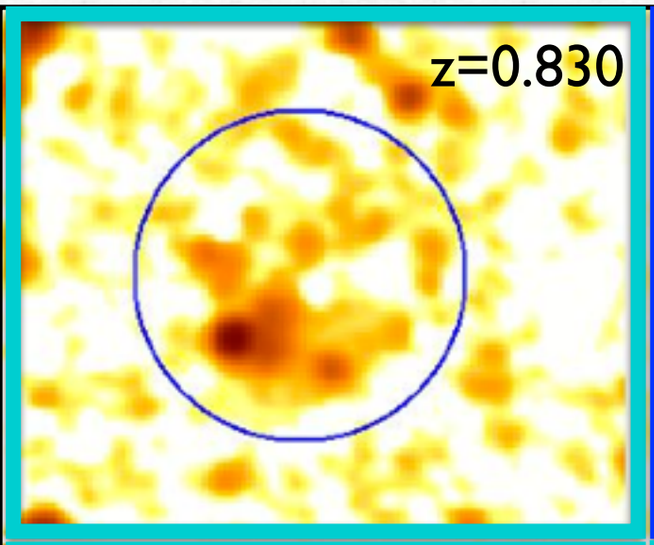
✓ Almost all the selected clusters appear to be in a "disturbed" gas phase

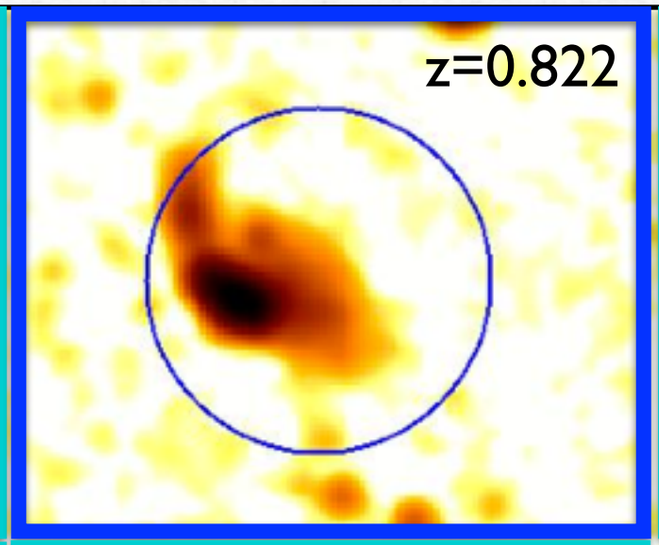
➡ expected, since at these z clusters are still forming

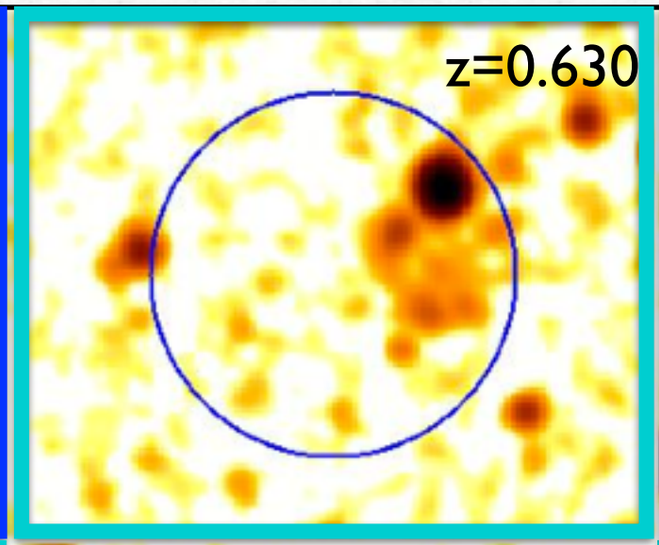
✗ **large** halo occurrence rate

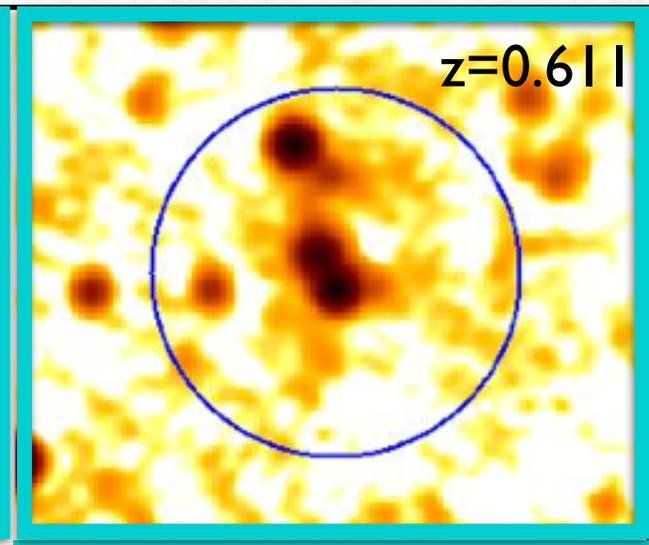
➡ in contrast with the predictions based on the current re-acceleration models (Brunetti +08, Cassano+10)

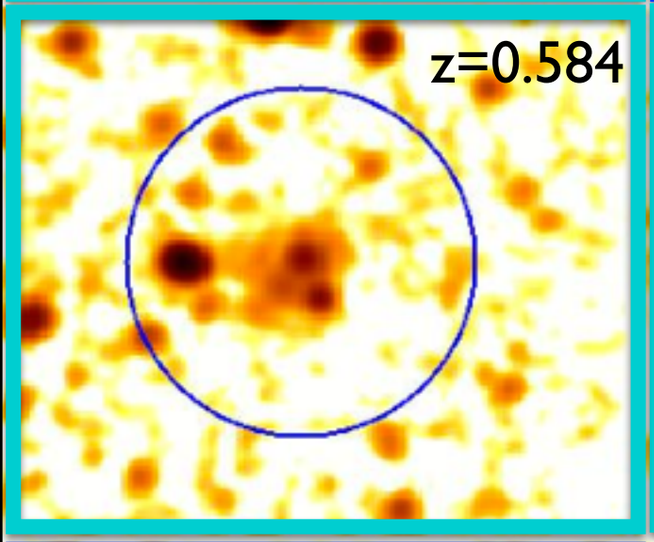
HIGH-REDSHIFT (z≳0.5) CLUSTERS

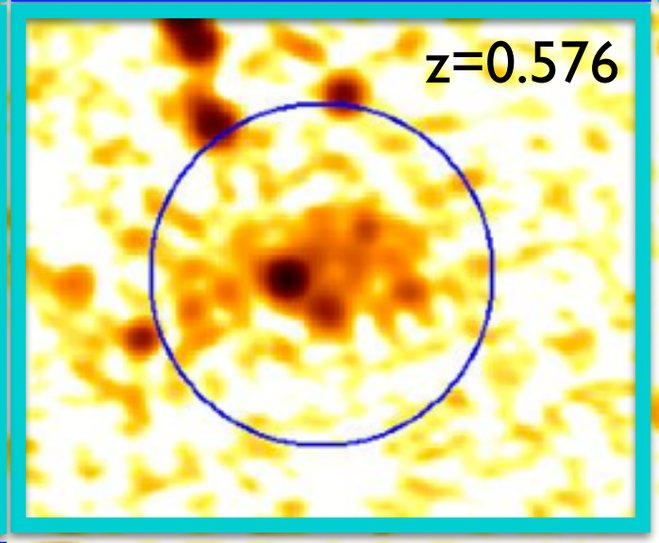


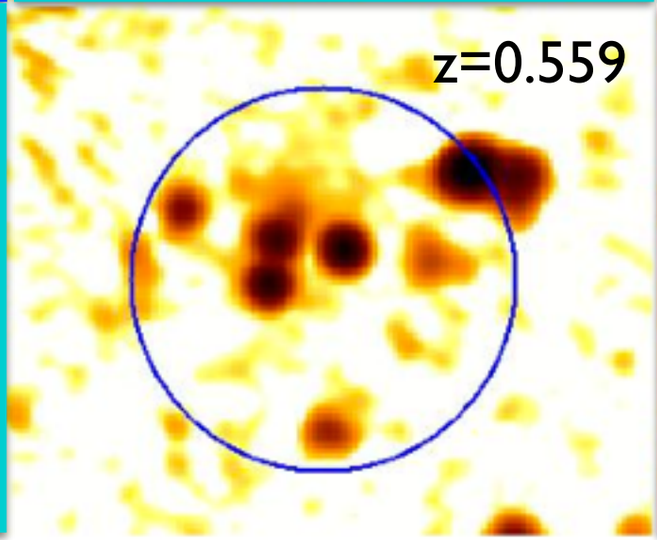


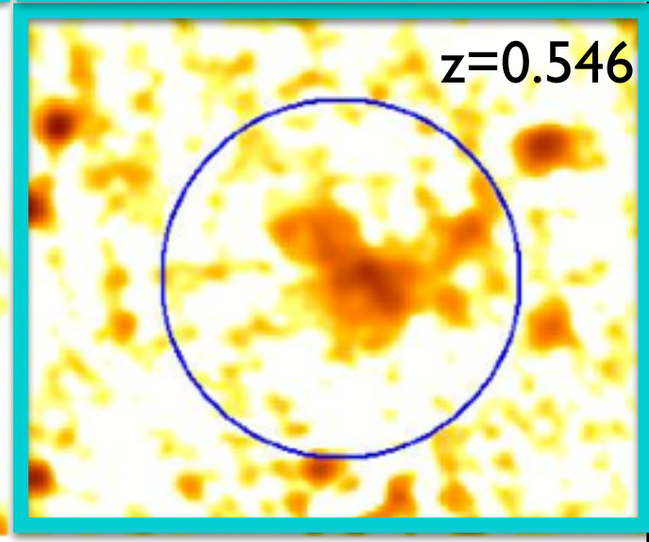


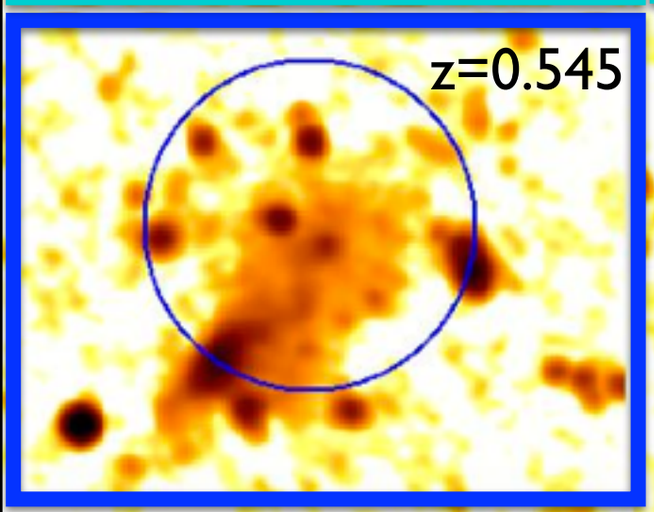


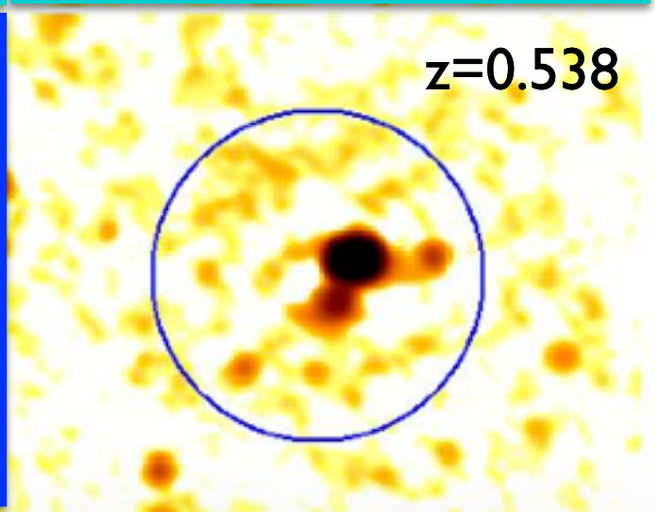












uGMRT FOLLOW-UP (PI: Di Gennaro)

- **band 4**
- **band 3+4** (z=0.822 and z=0.545)

JVLA FOLLOW-UP (PI: Di Gennaro)

- 1-4 GHz (z=0.822)

SUMMARY

- Deep Chandra (400 ks) and 1.4 GHz WSRT (van Weeren+11) observations of a double-relic cluster (ZwCl0008.8+5215)
  - ➡ ~1 Mpc-size shock in the West from the X-ray image
  - ➡ Western relic: re-acceleration of plasma from radio tail(s) ?
  - ➡ Eastern relic: no evidence of clear discontinuity

- LOFAR discoveries of several "disturbed" X-ray clusters at **z≳0.5** hosting diffuse radio emission: do they challenge the current (re)acceleration models ?
  - ➡ uGMRT (and JVLA) follow-up for spectral index studies

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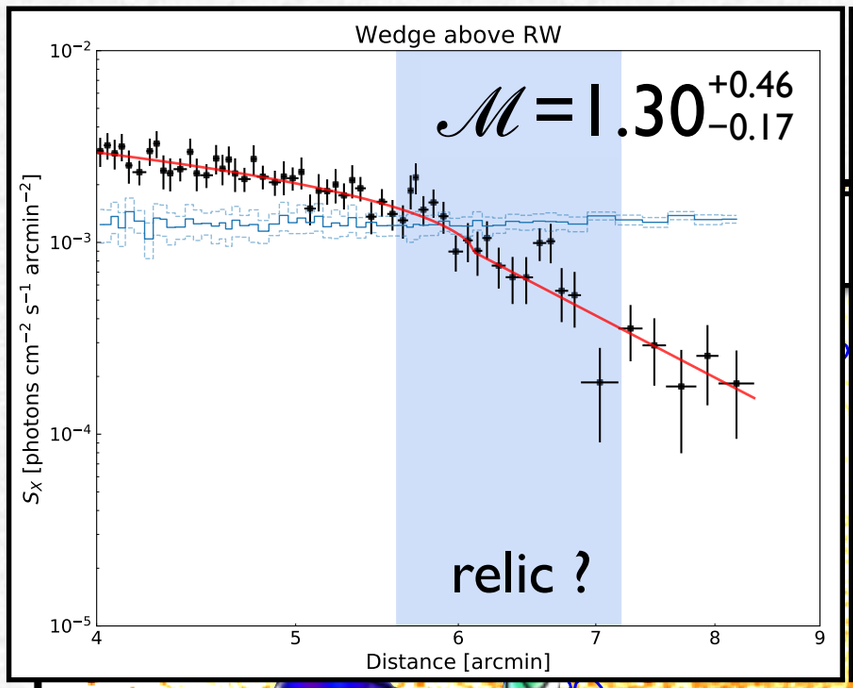
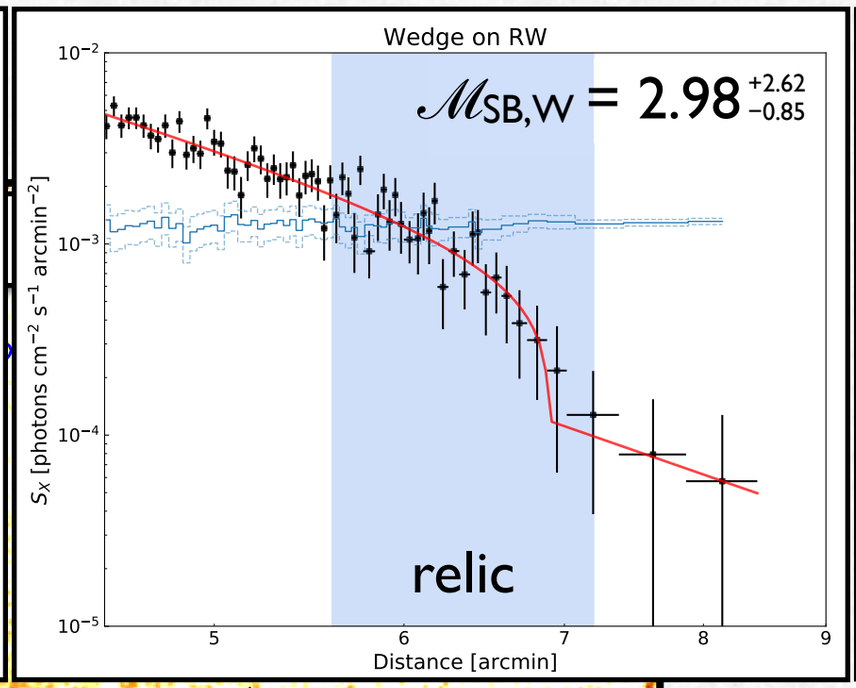
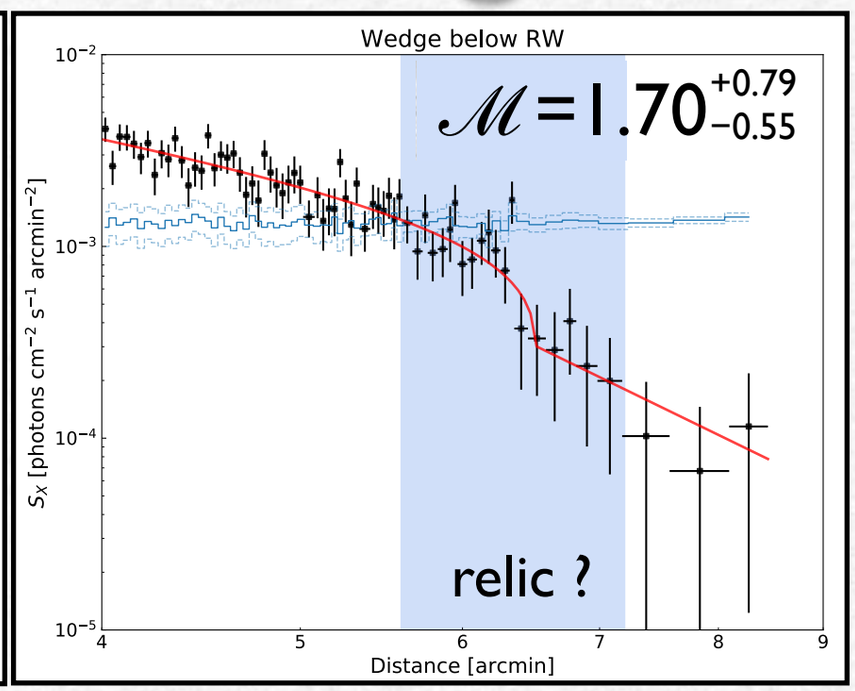
Thank you

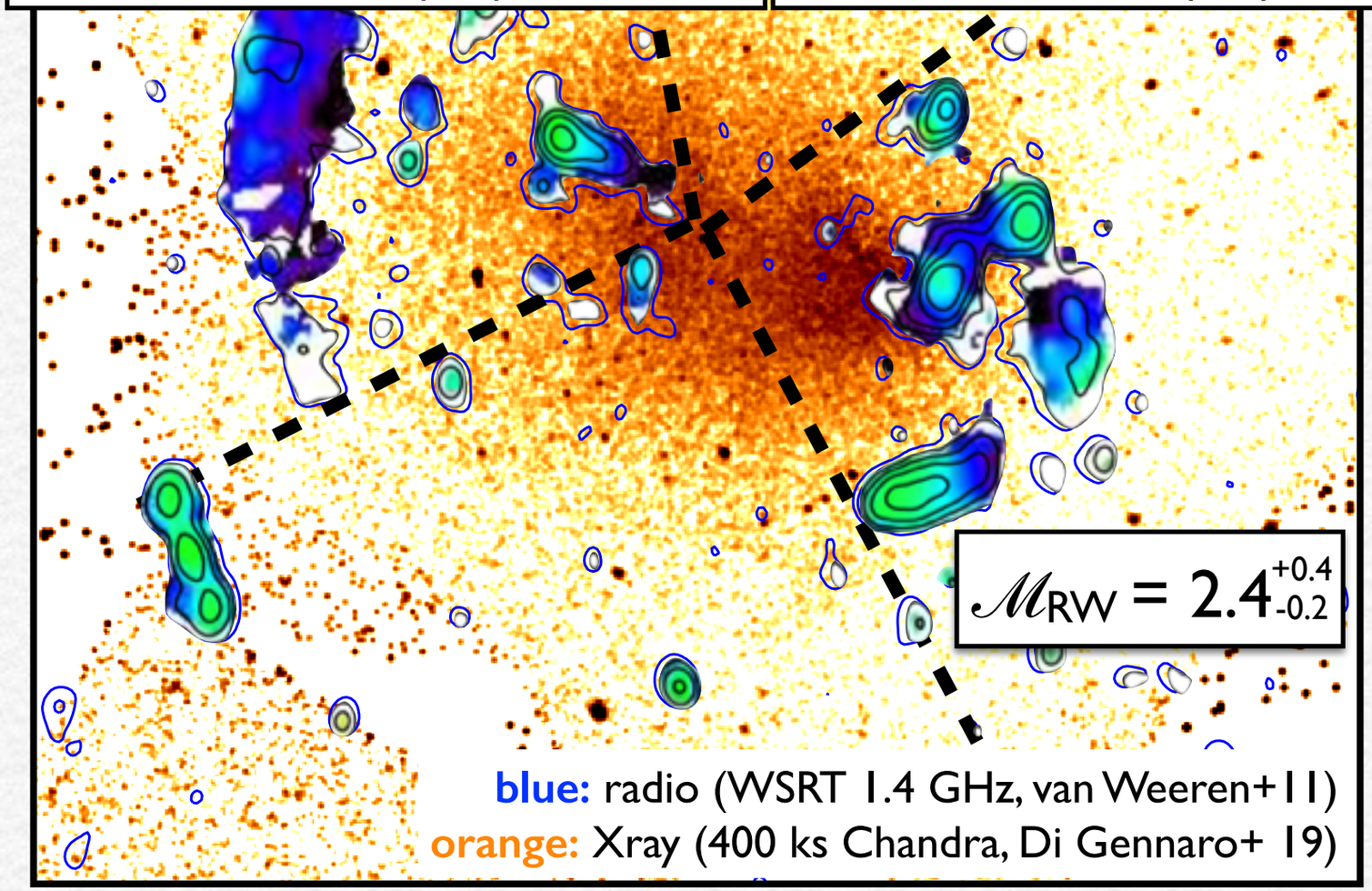
BACKUP SLIDES

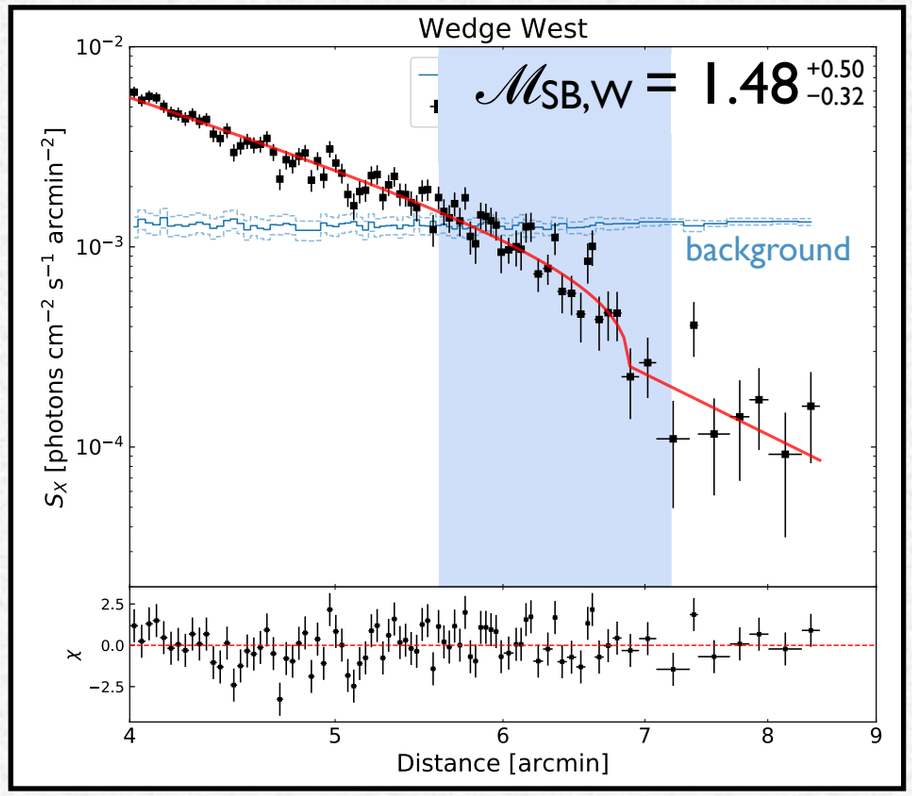
ZwCl 0008.8+5215: western edge





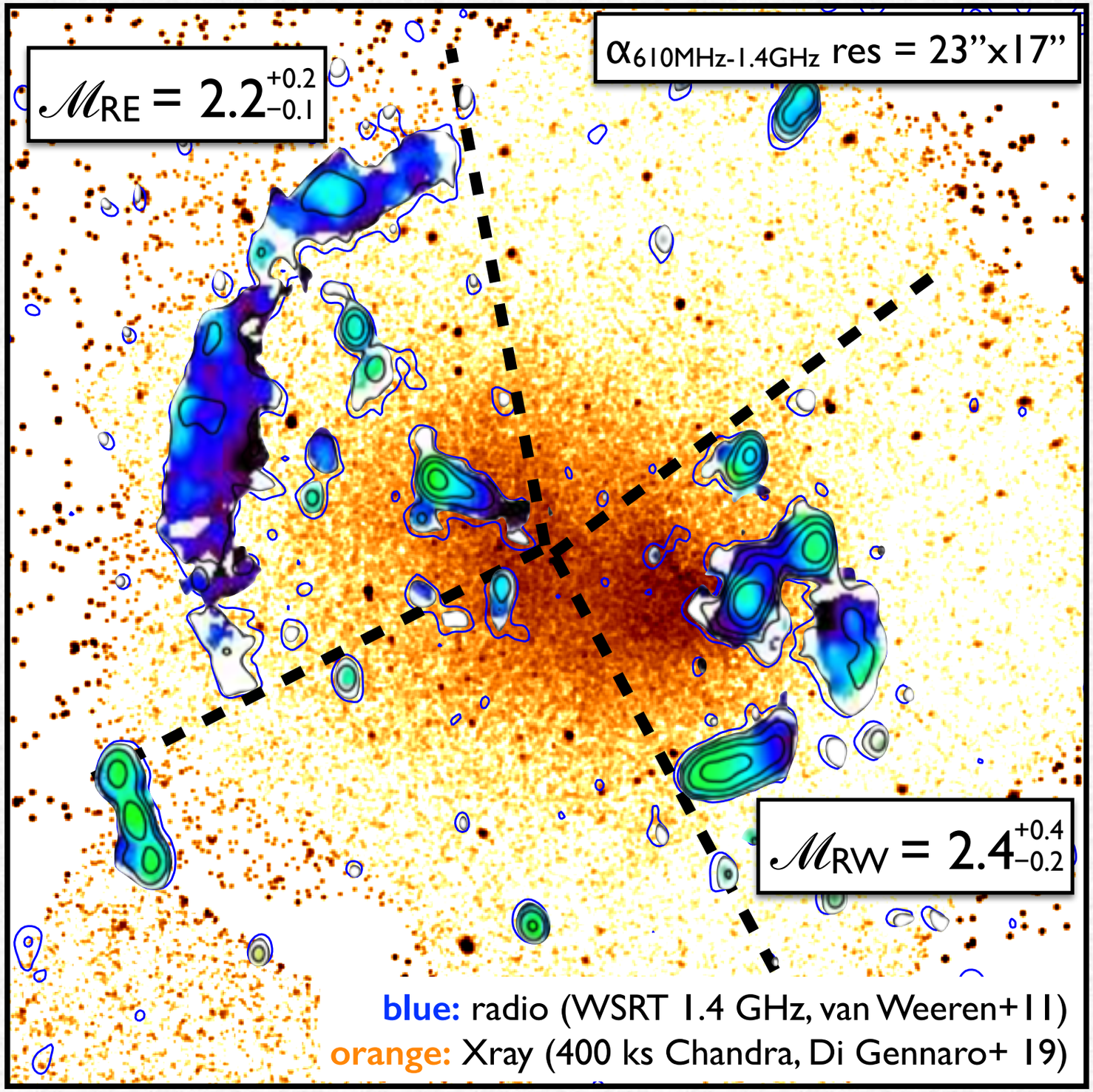


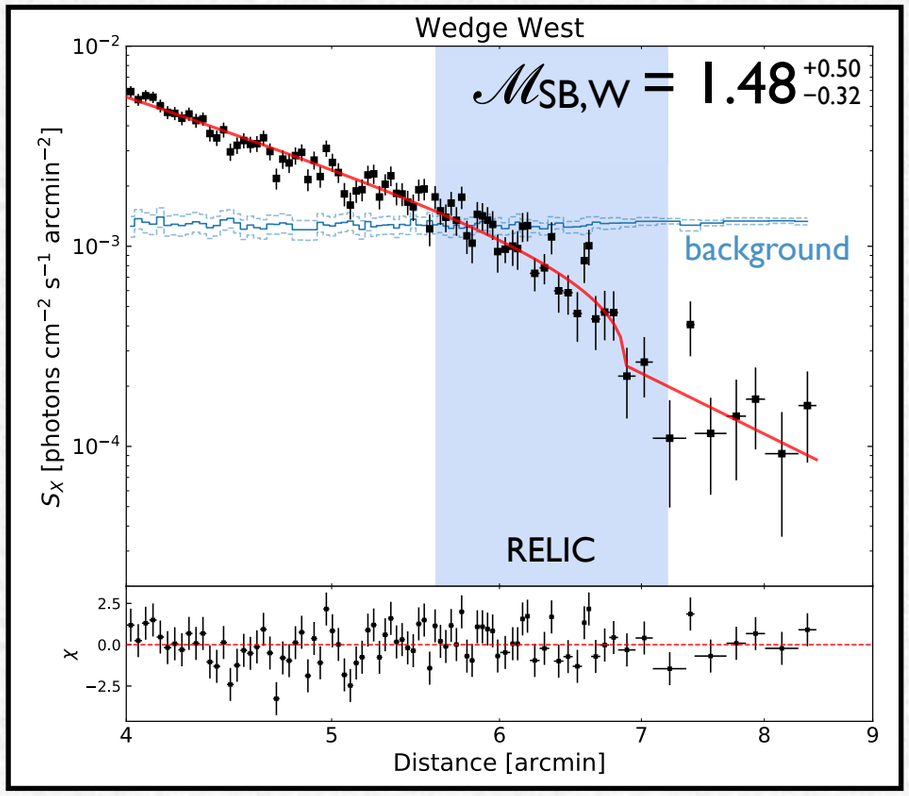


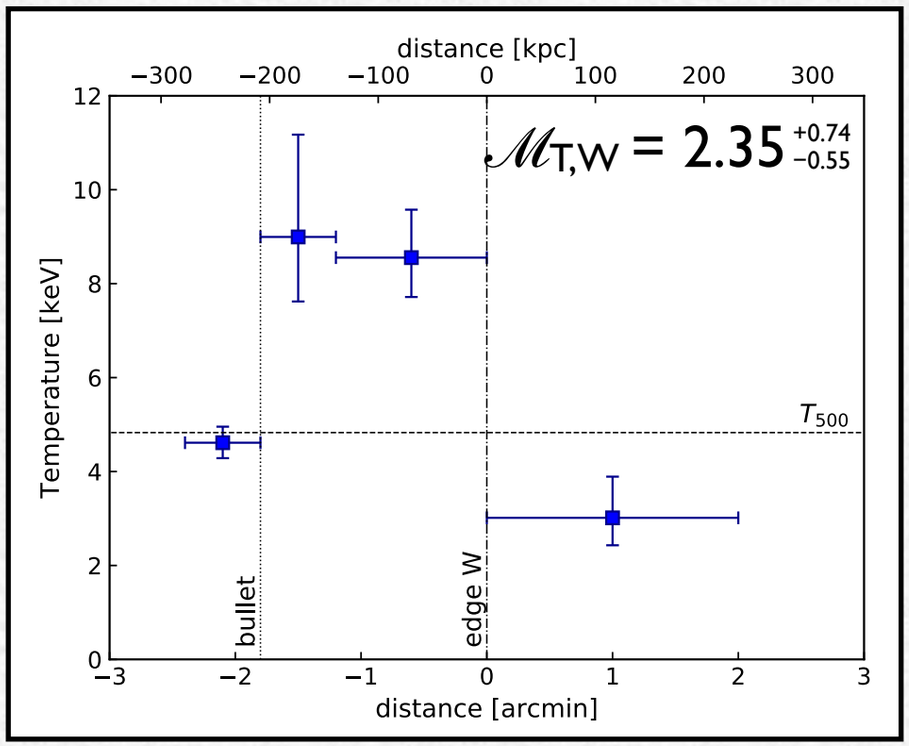


A SEARCH FOR SHOCKS

Di Gennaro+ 19, ApJ, 873, 64







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