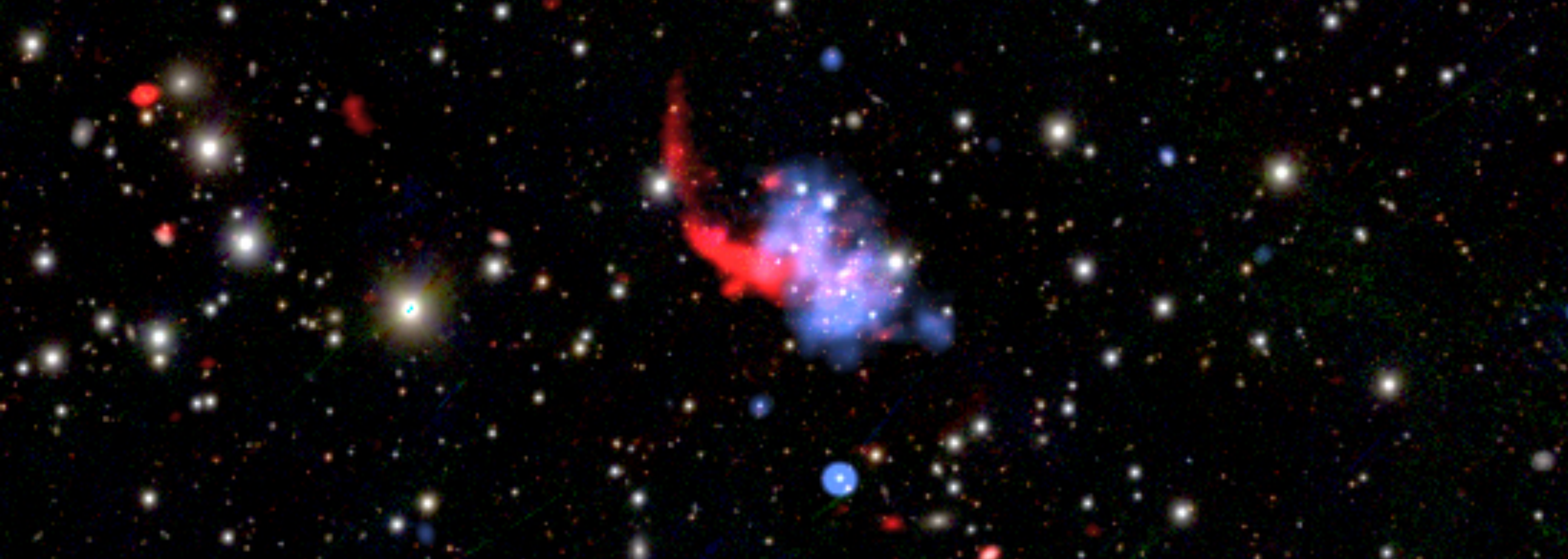
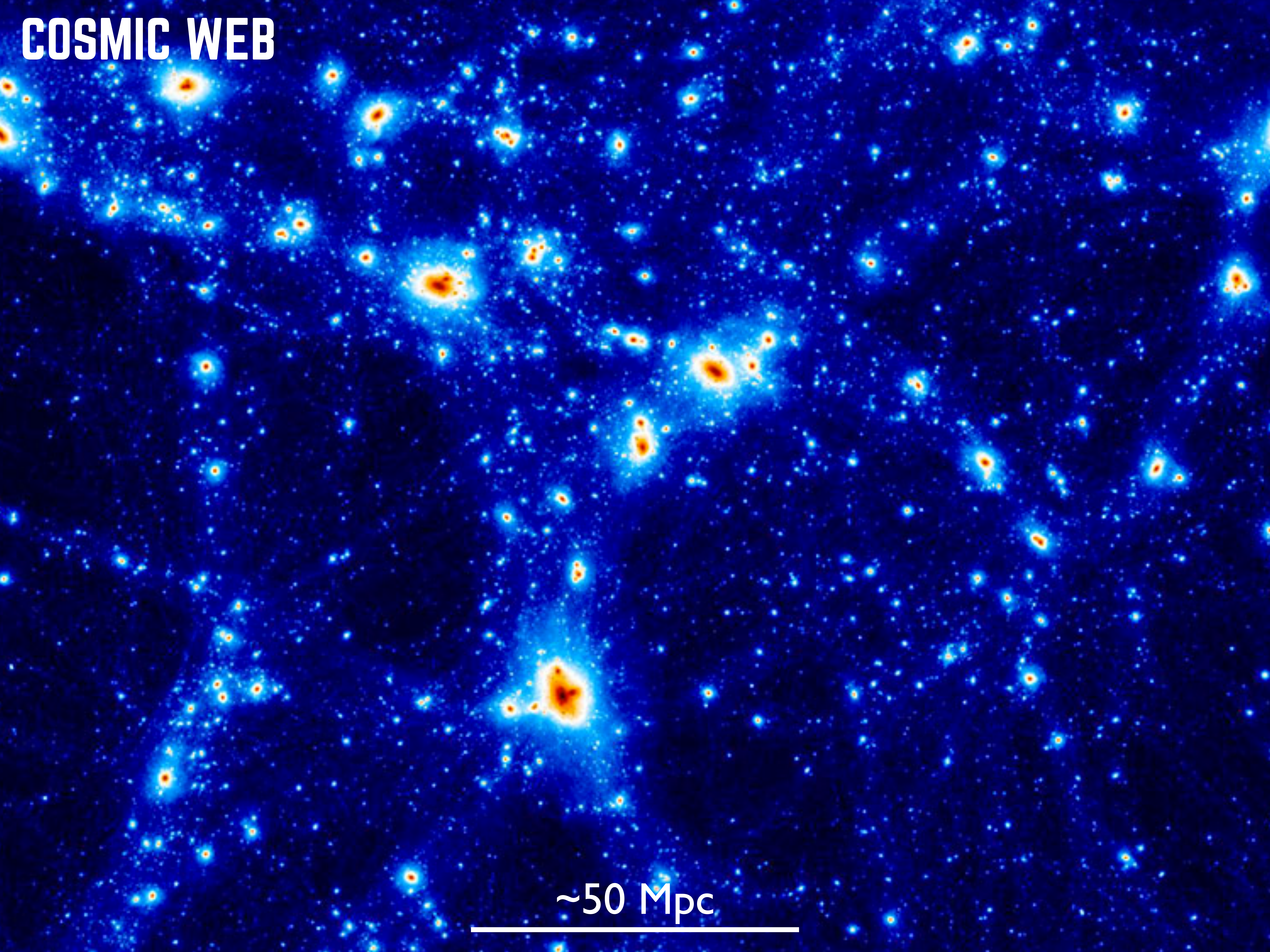
MAGNETIC AMPLIFICATION AT FILAMENTS KNOTS IN THE DISTANT UNIVERSE

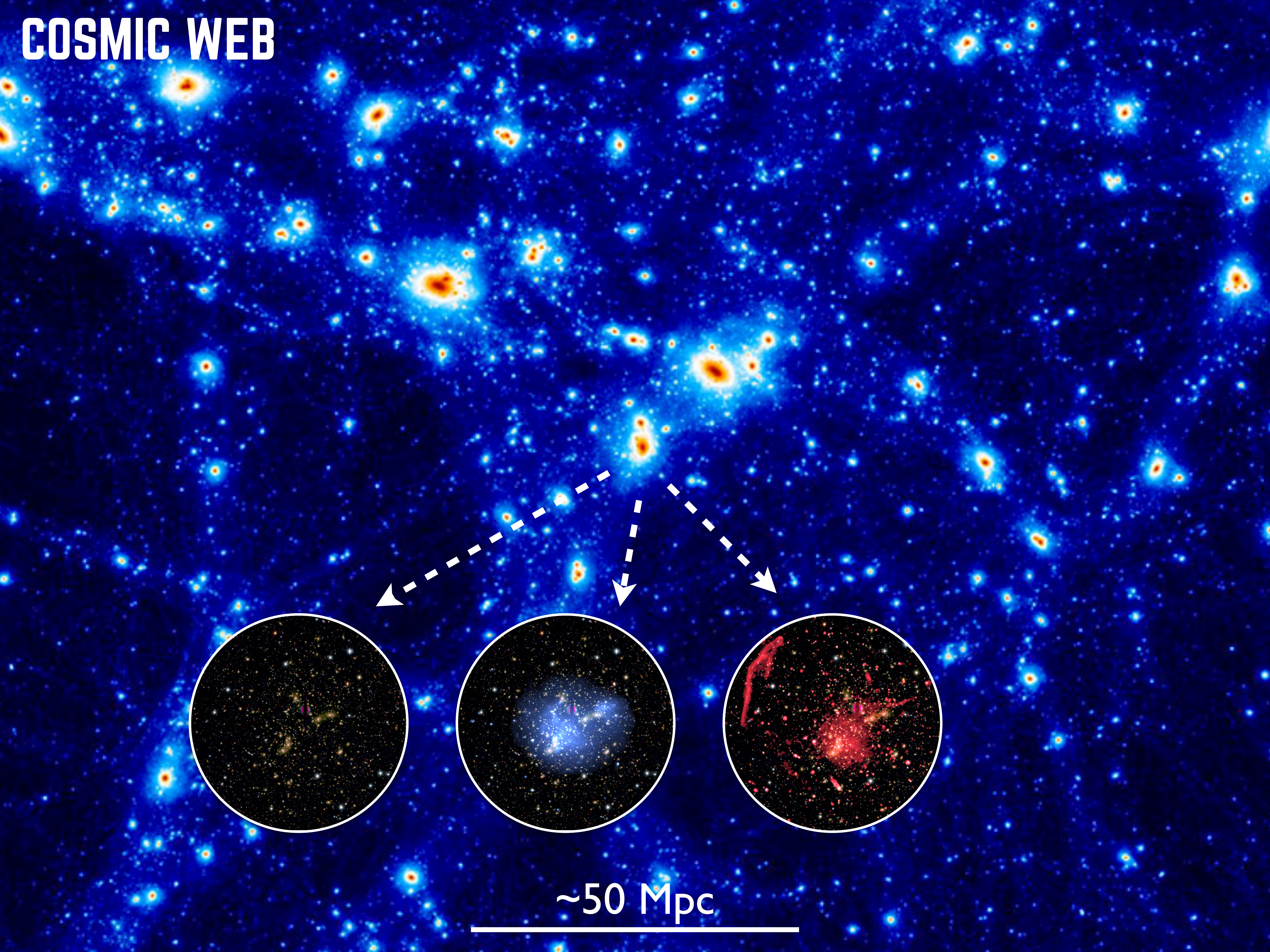


GABRIELLA DI GENNARO
ALEXANDER VON HUMBOLDT FELLOW
gabriella.di.gennaro@hs.uni-hamburg.de

Cosmic Magnetism in Voids & Filaments
26 January 2023

UNIVERSITÄT HAMBURG

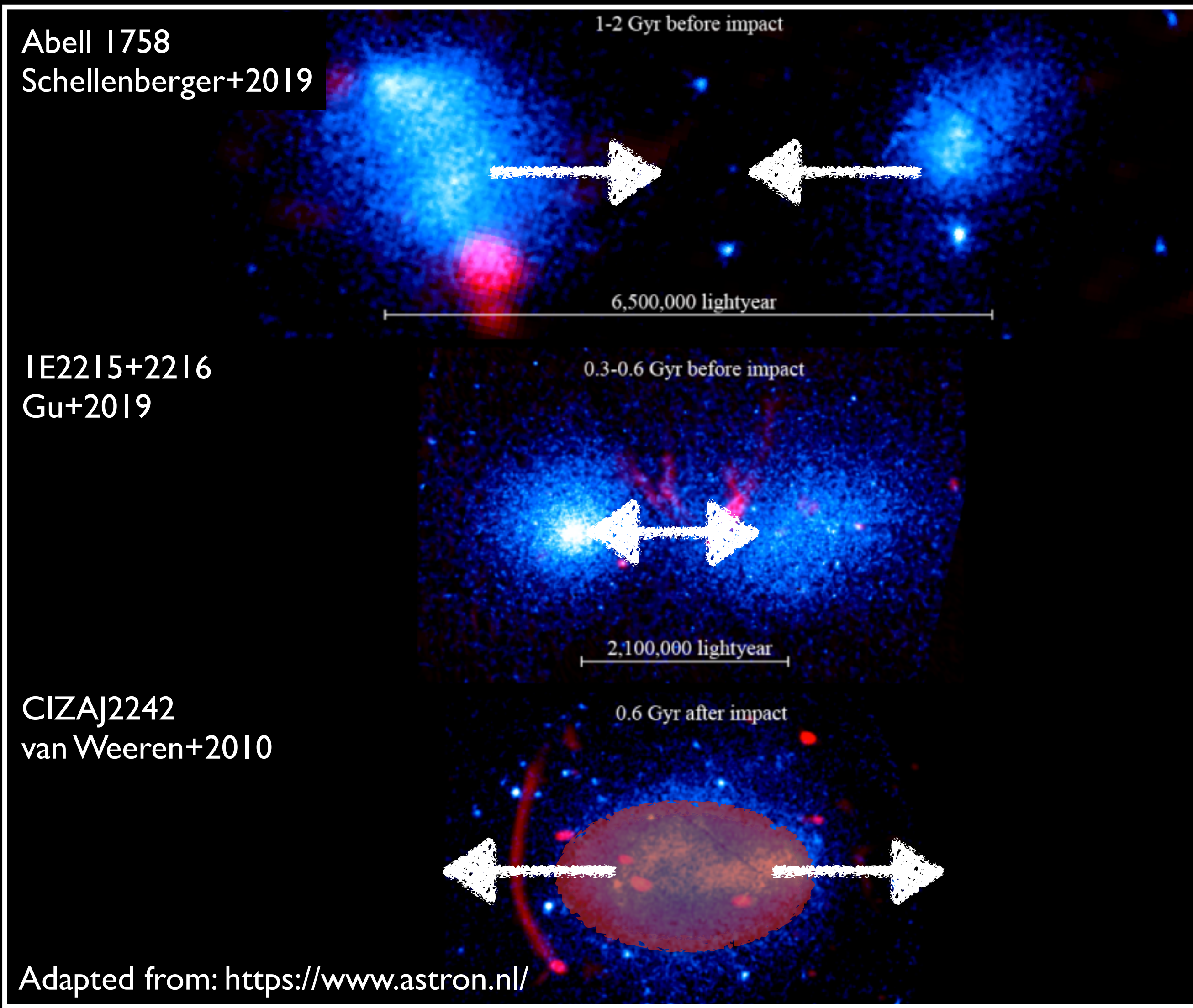

COSMIC WEB
~50 Mpc

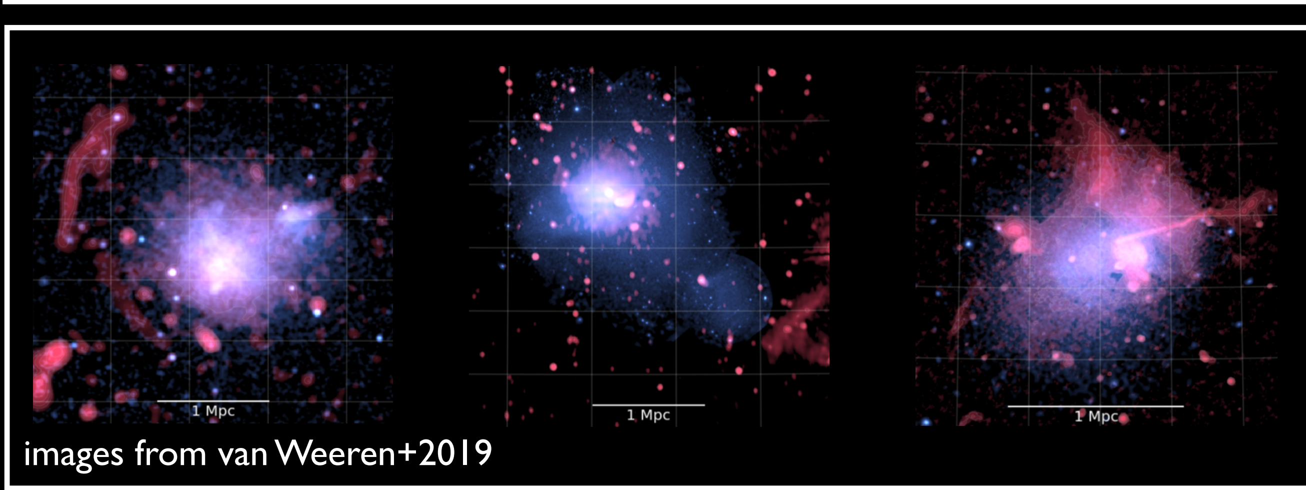

COSMIC WEB
~50 Mpc

RADIO HALOS: A GENERAL PICTURE

X-RAY: thermal gas (ICM)

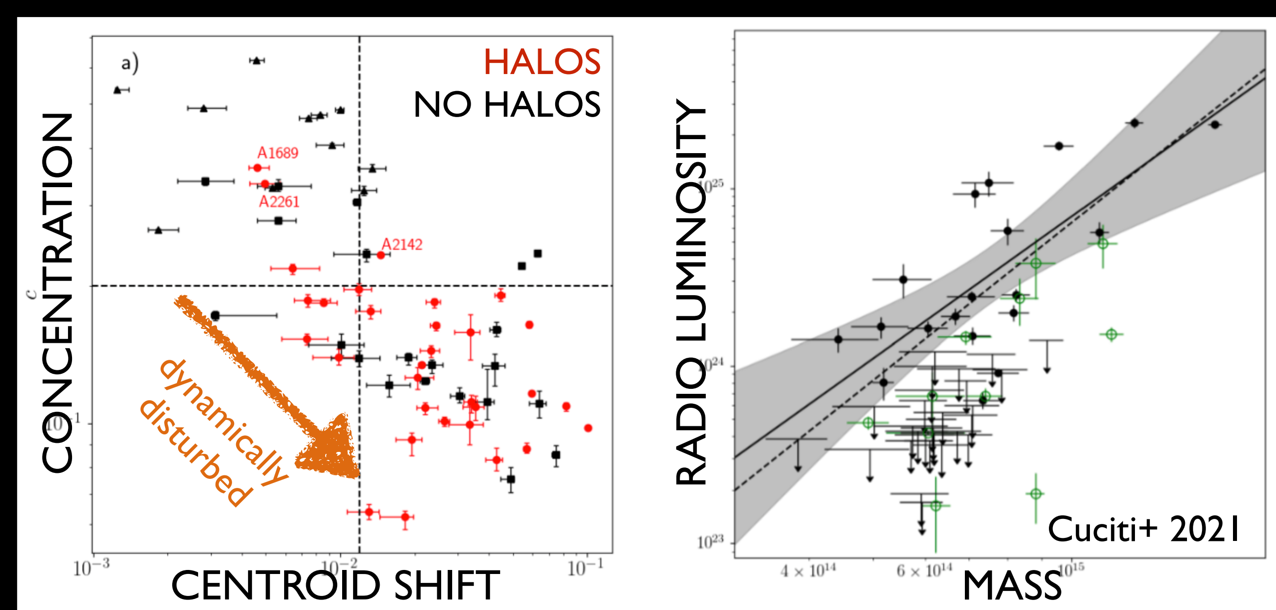
RADIO: CRs ($\gamma_L \gg 10^3$) + magnetic field (~few μGauss)





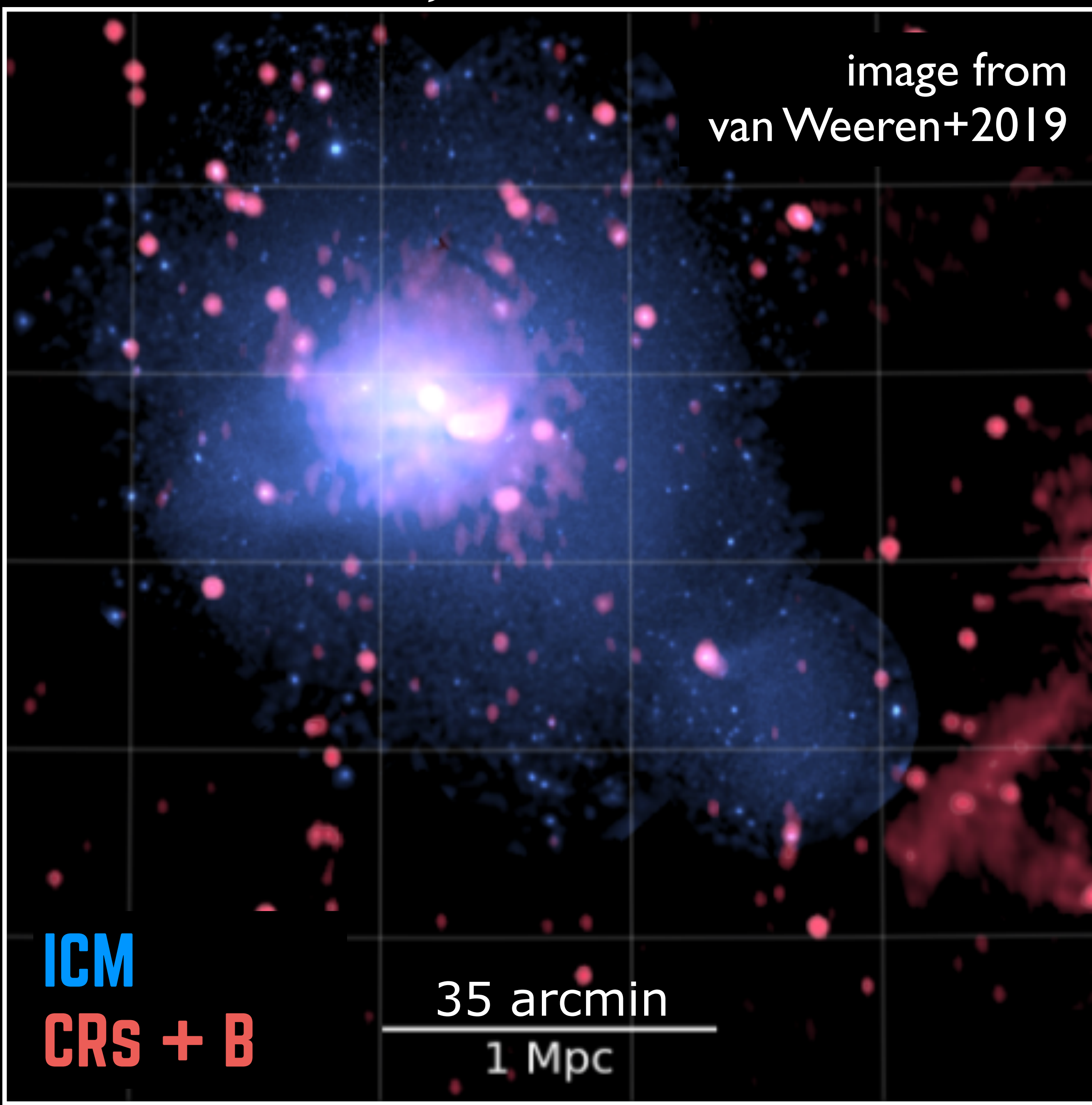
- **<u>Re-acceleration</u>** of electrons (e.g. Brunetti+2001) and secondary particles (proton-proton collisions, e.g. Brunetti+2017) due to *magneto-hydrodynamical turbulence*
  ➡ Ultra-steep spectrum radio halos

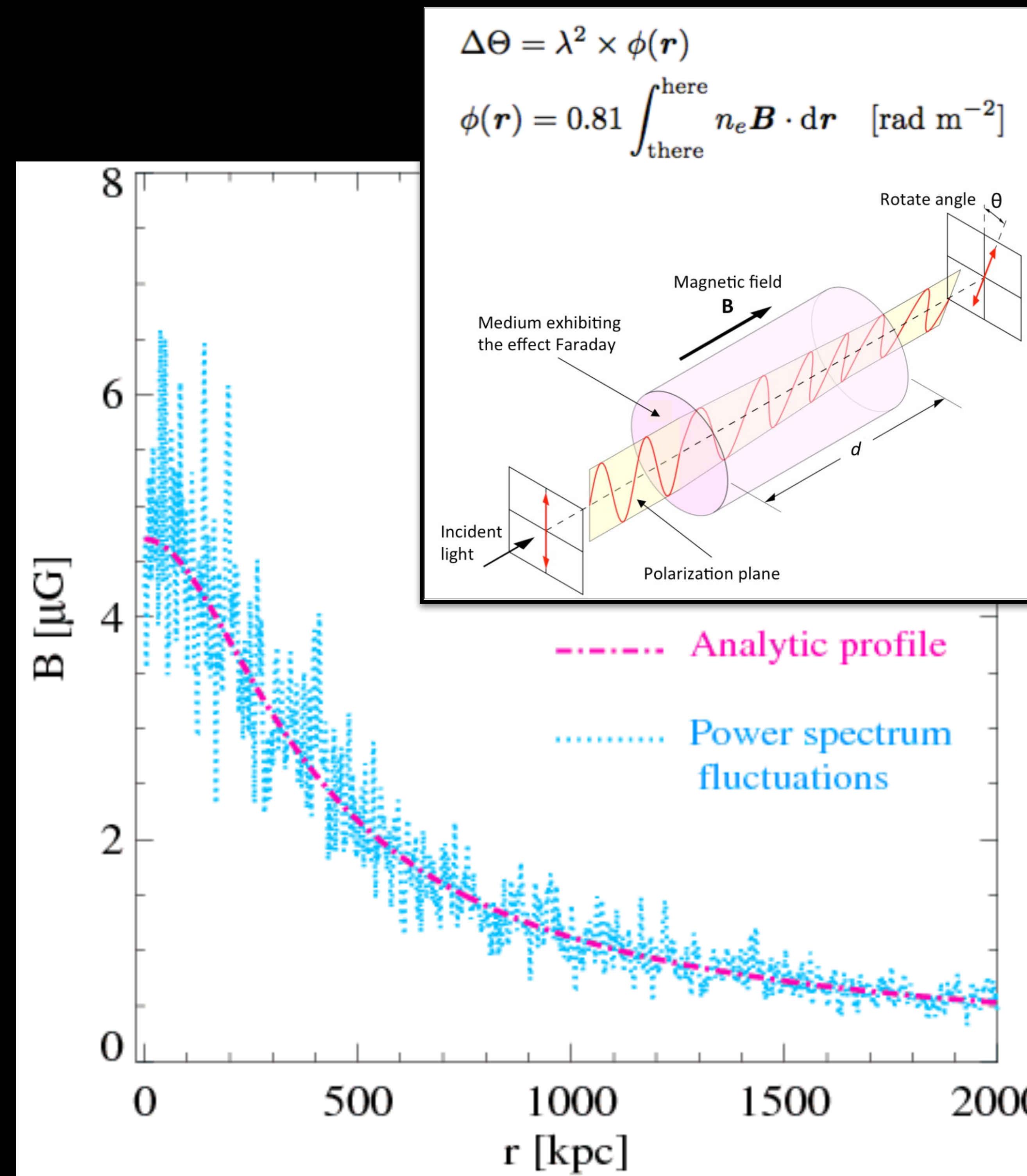
- **<u>Small-scale dynamo</u>** is triggered by *magneto-hydrodynamical turbulence* and amplifies magnetic fields (e.g. Donnert+2018)



HOW DO WE DETERMINE MAGNETIC FIELDS IN CLUSTERS ?

Coma (z=0.023)
Bonafede+2010, 2020





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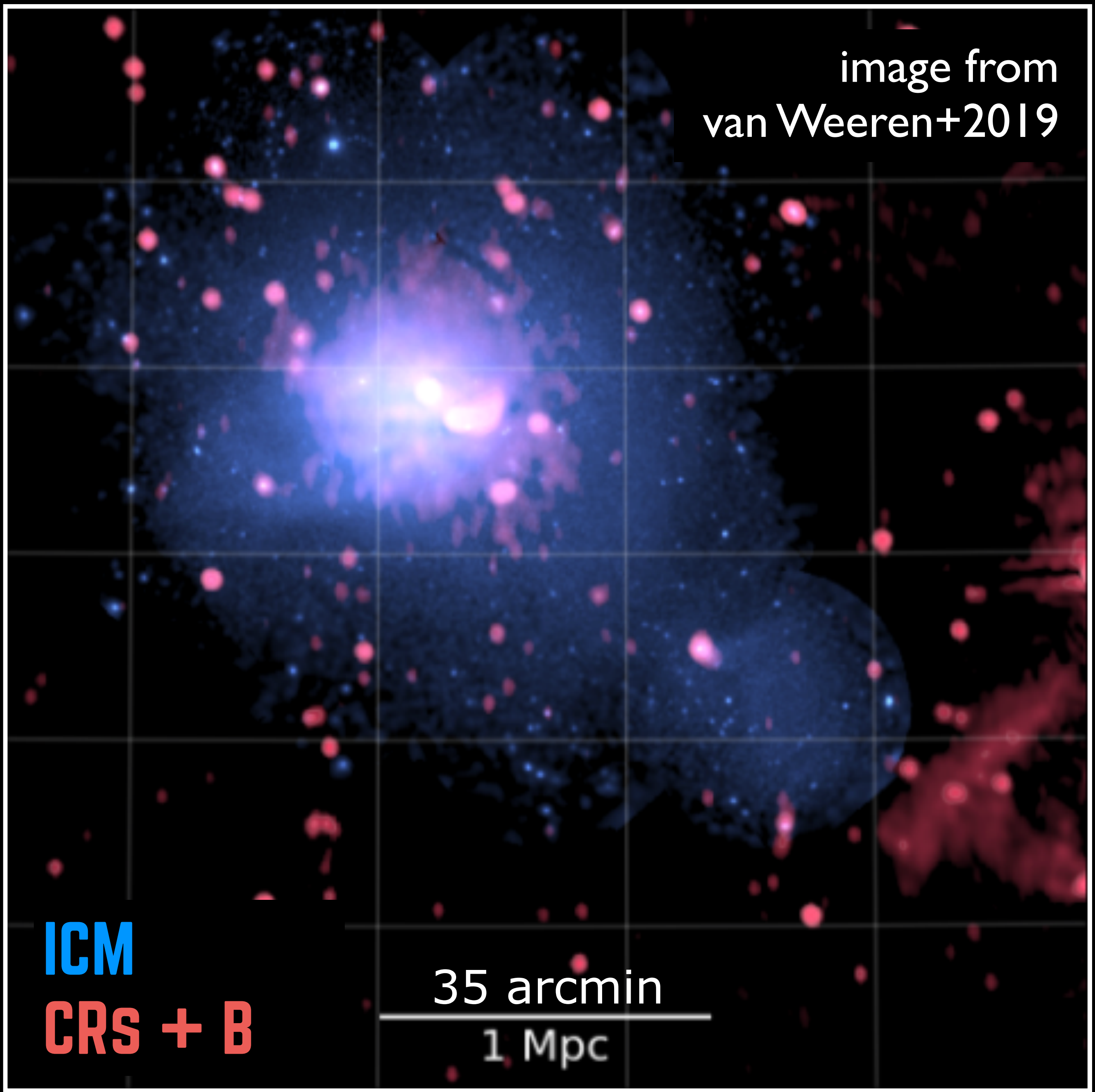
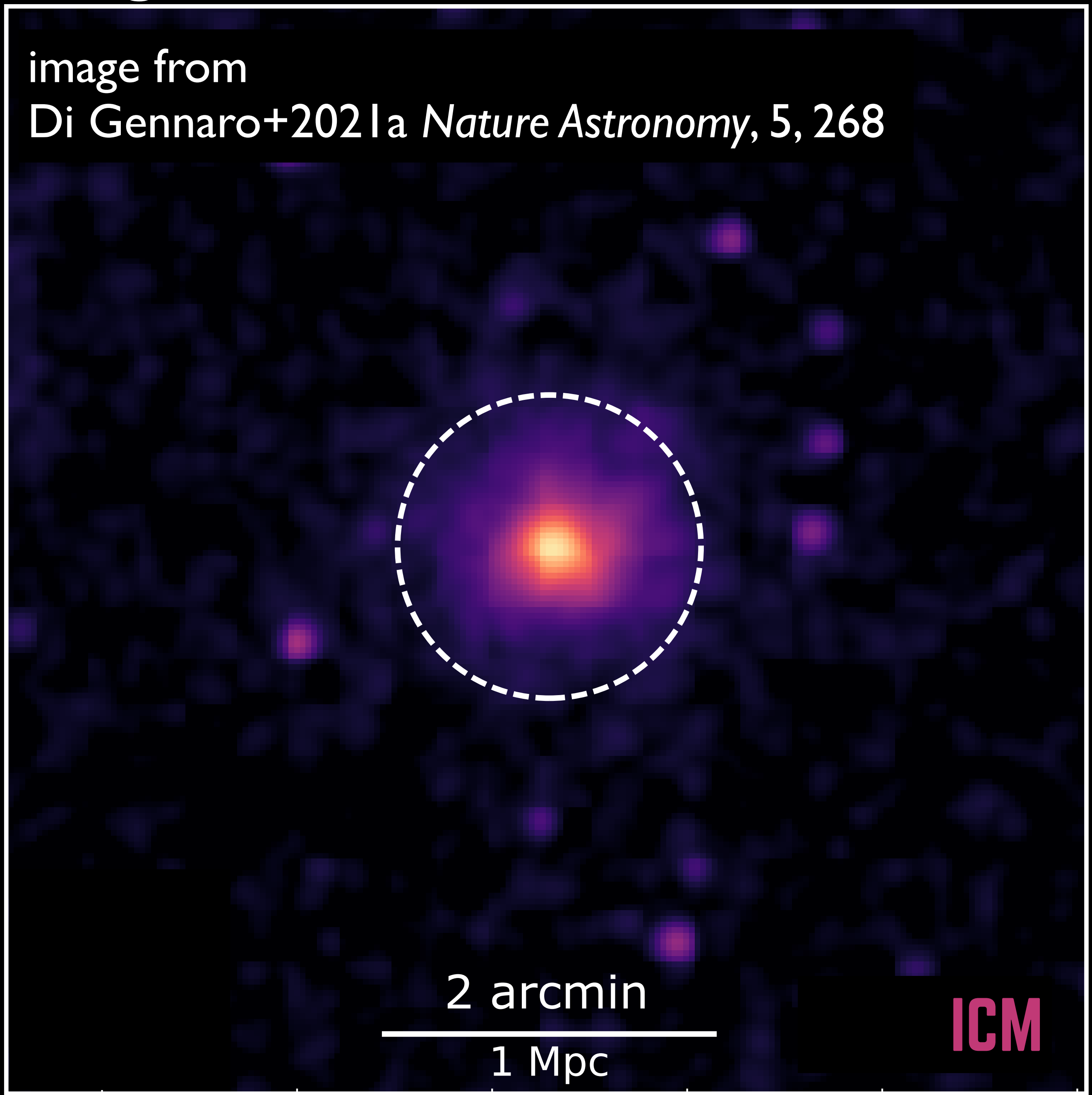


PSZ2G160.83+81.66 (z~0.9)
Maughan+2007



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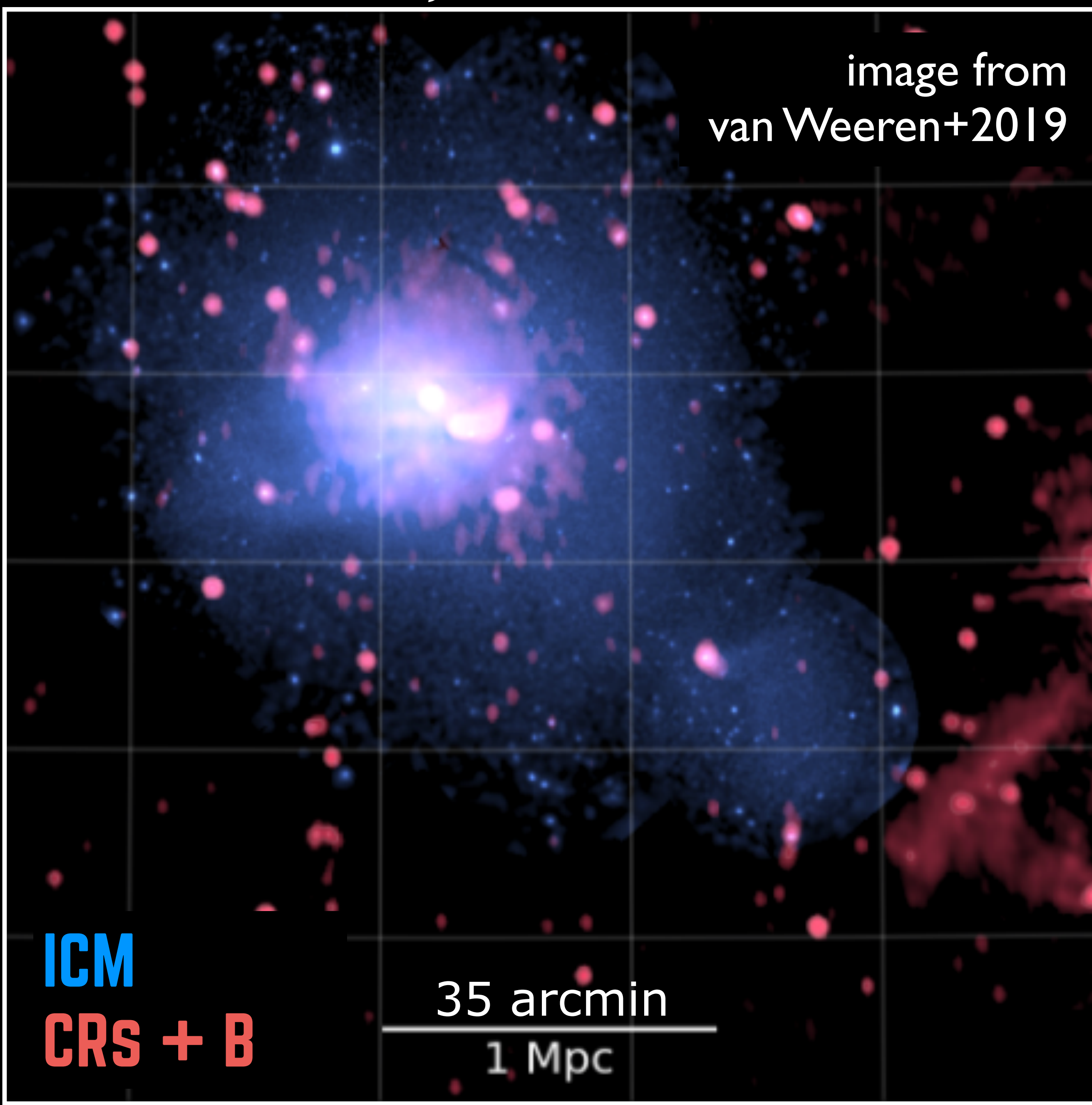

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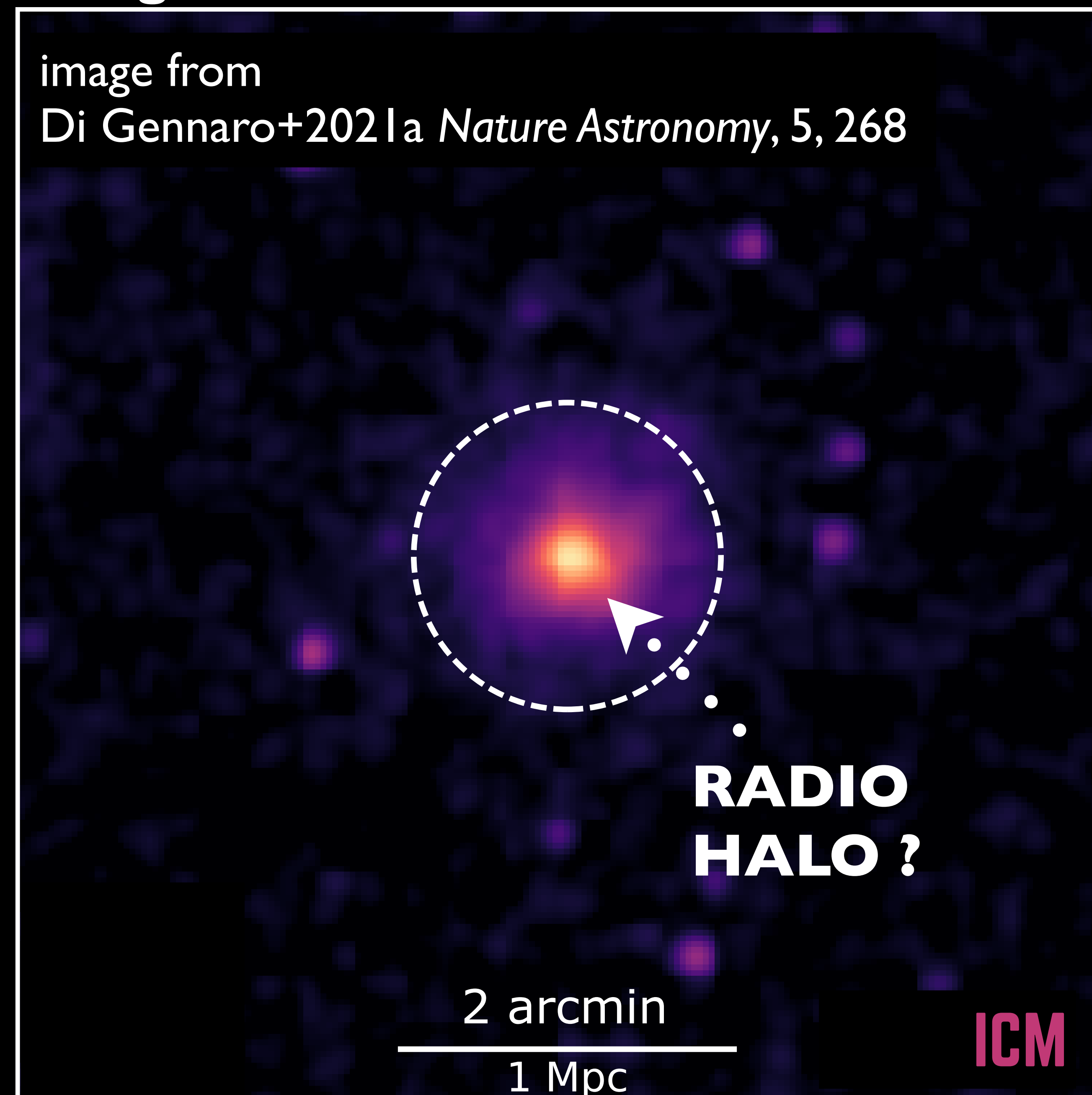
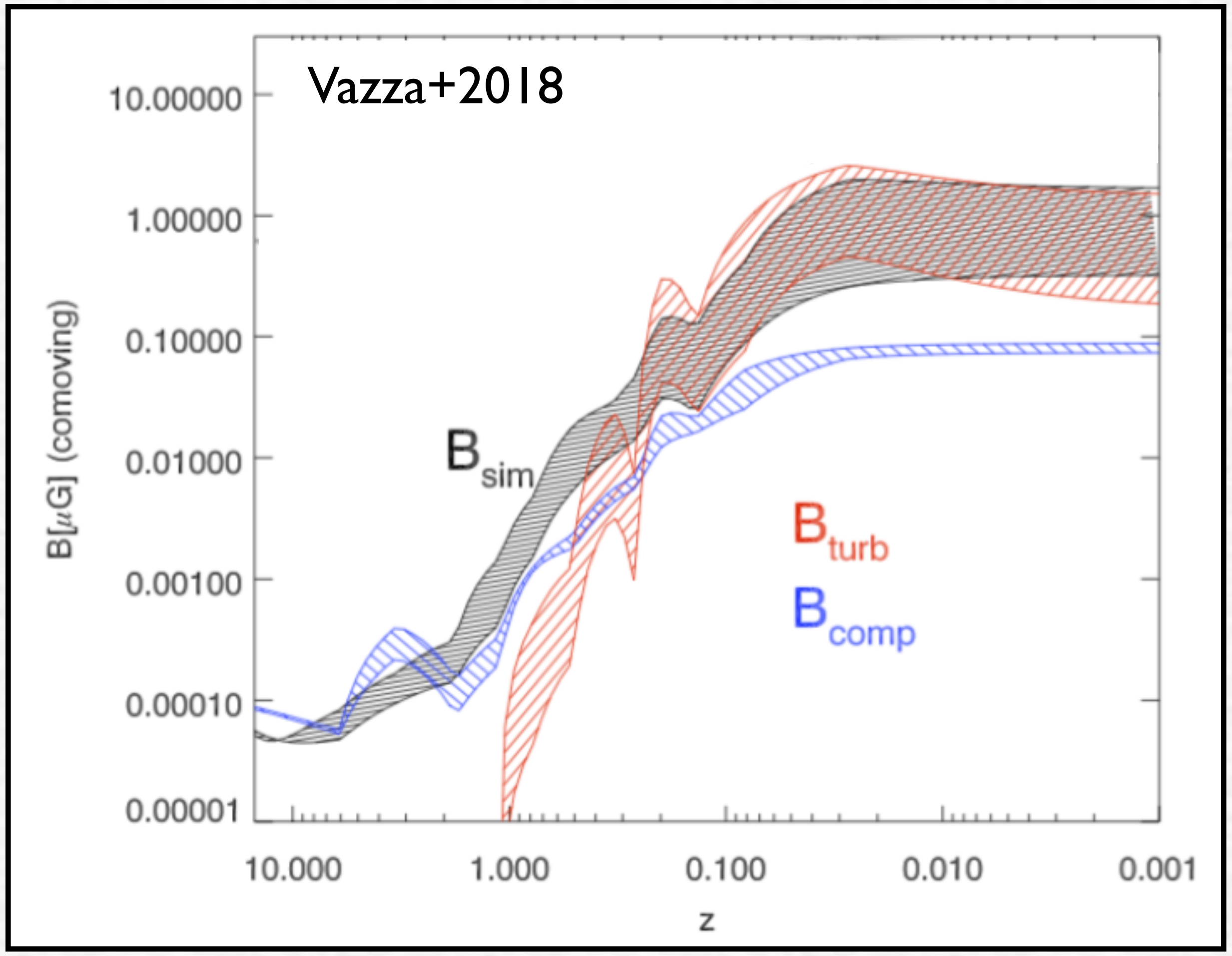
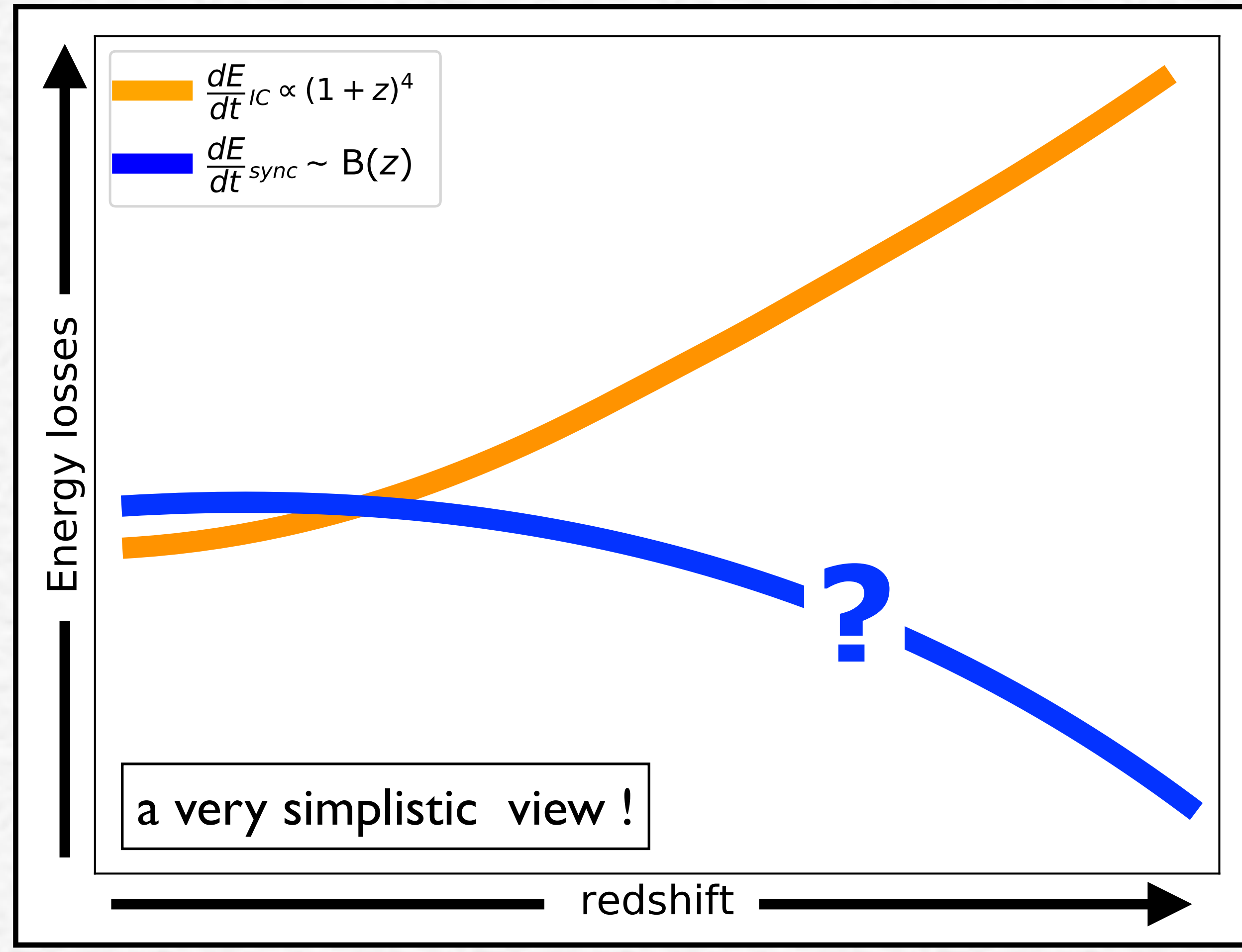


DETECTION OF RADIO HALOS AT HIGH z

MAGNETIC FIELD
EVOLUTION



ENERGY LOSSES (SYNCHROTRON + IC)
EVOLUTION

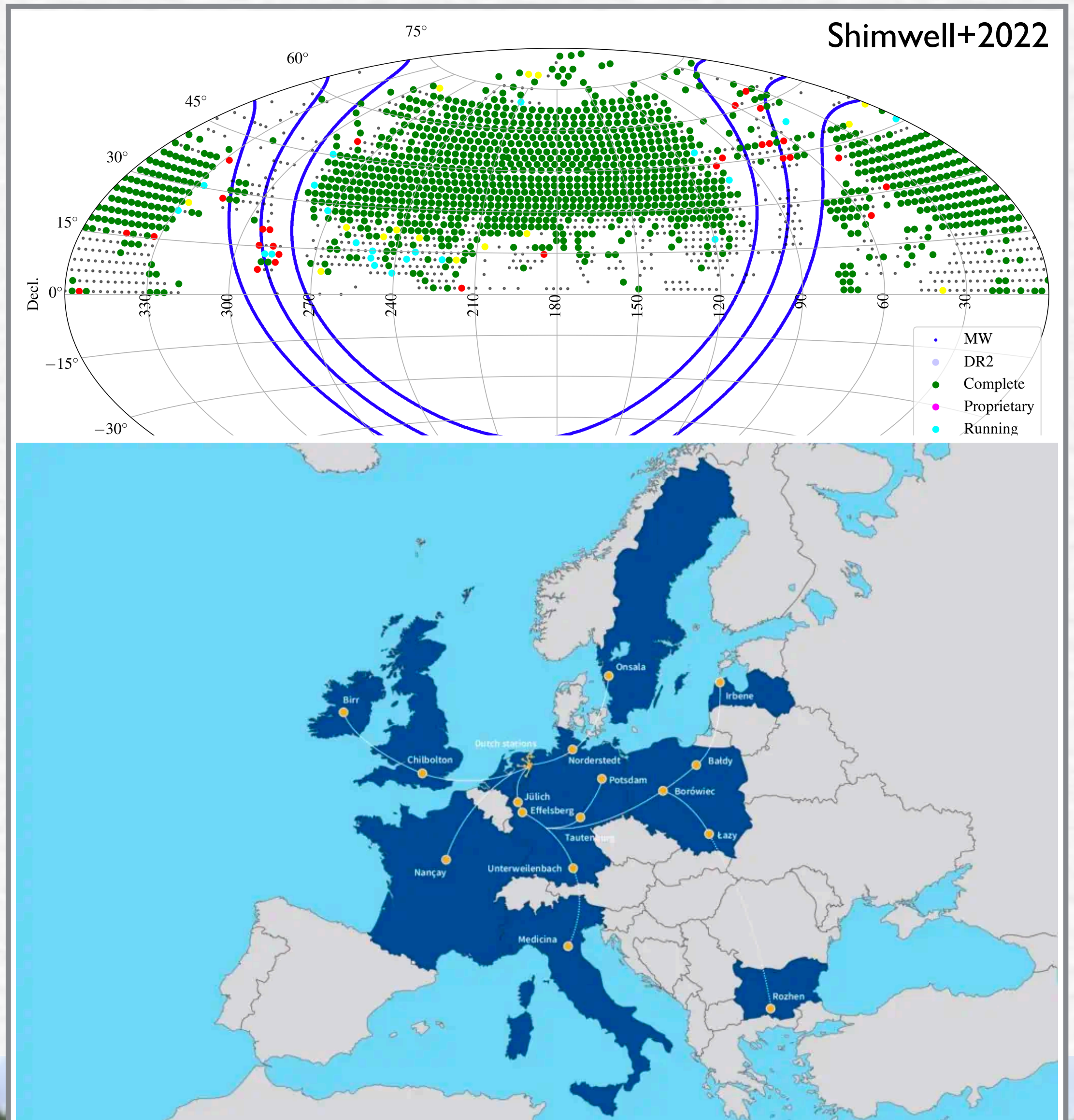


- **<u>Predictions:</u>** occurrence rate at <u>*GHz frequencies is lower*</u> than in low-z clusters due to IC losses and they should have steeper spectra, $\alpha \lesssim -1.5$ (Cassano & Brunetti 2005, Cassano+2010)

- **<u>Observations</u>** lack because such an emission is very faint and the old generation of radio telescopes is not sensitive enough

DETECTION OF RADIO HALOS AT HIGH z

THE PLANCK SZ-LOFAR (120-168 MHz) SAMPLE



- Latest Planck SZ Catalogue
  ➡ no bias on the dynamical state of the cluster (e.g. Rossetti+2017)
- No cluster mass threshold
  ➡ no bias on the most powerful radio sources (e.g. Cuciti+2015,2021ab)
- $z \geq 0.6$
  ➡ no upper limits (but Planck is up to z~1)
- DEC > 20 deg
  ➡ match the best LoTSS sensitivity (Shimwell+2017,2019,2022)

DETECTION OF RADIO HALOS AT HIGH z

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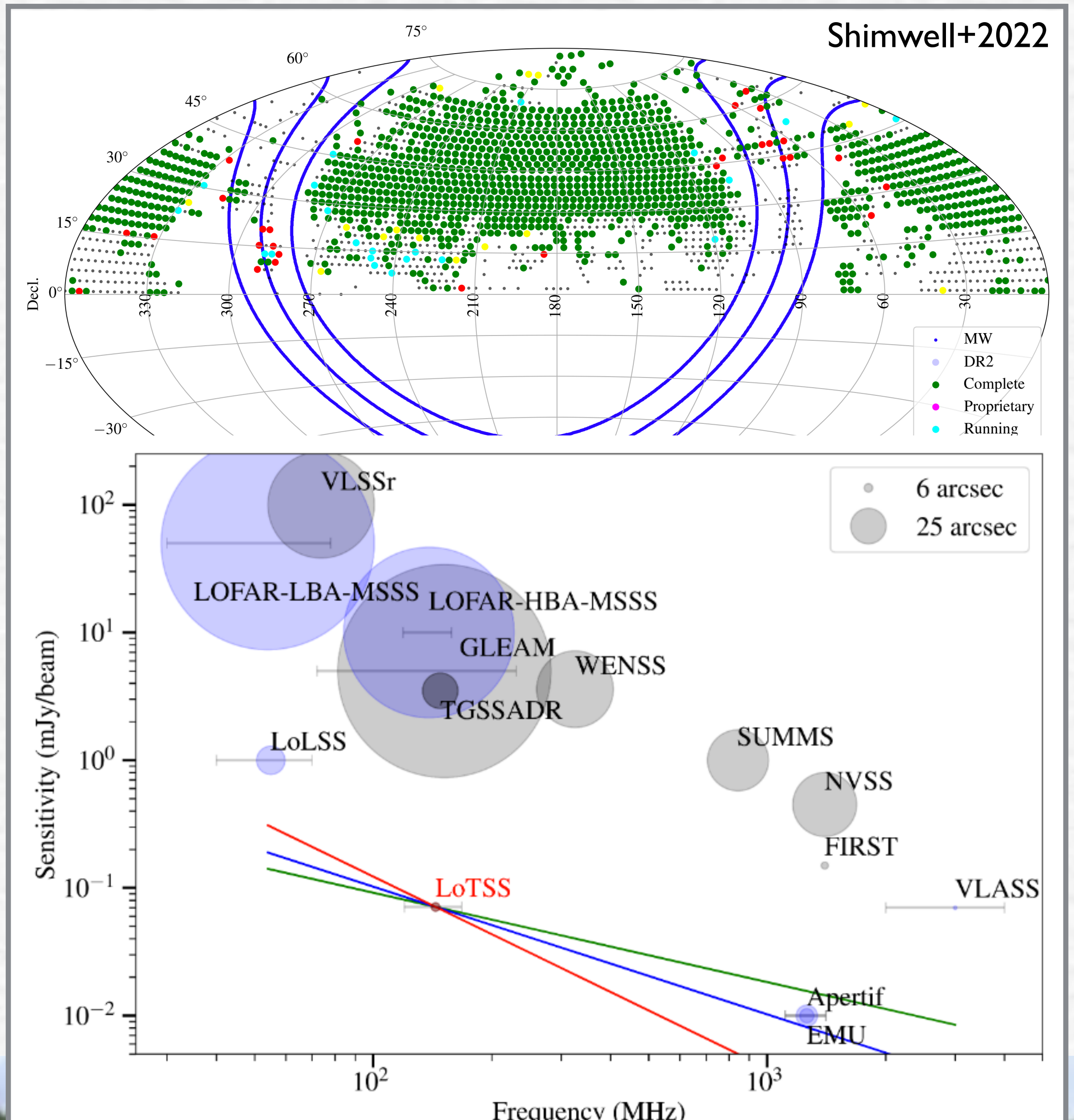

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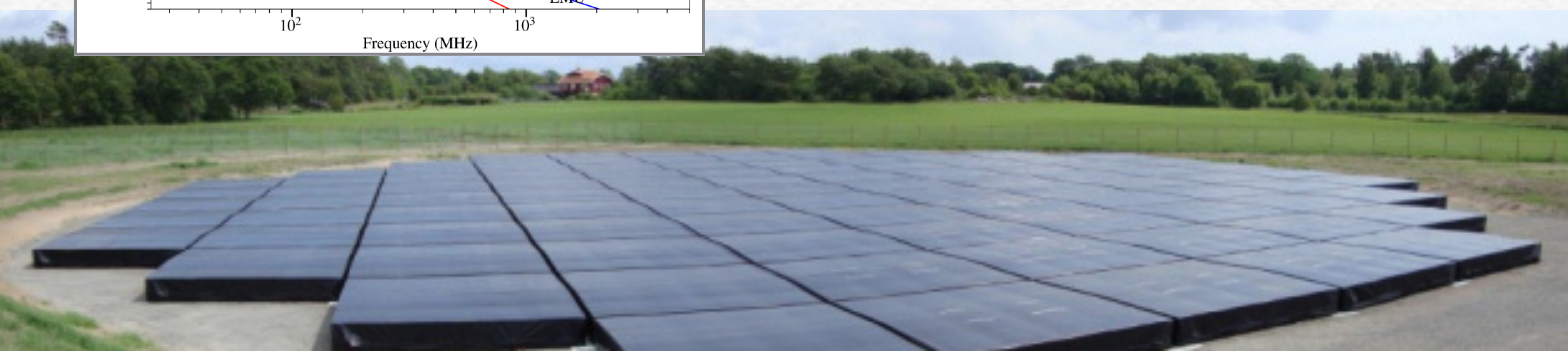

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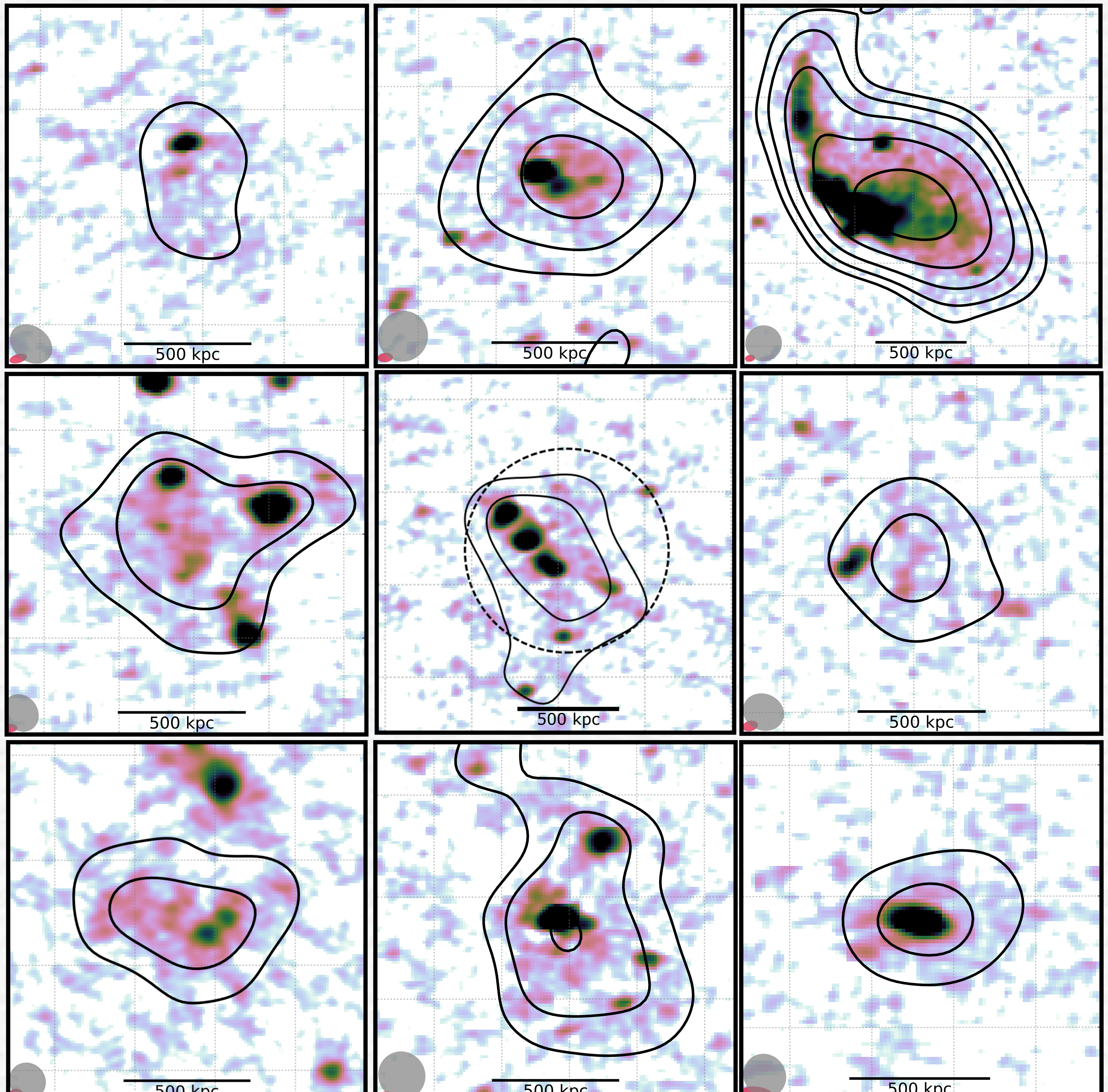
Di Gennaro+2021a, Nat. Astron., 5, 268



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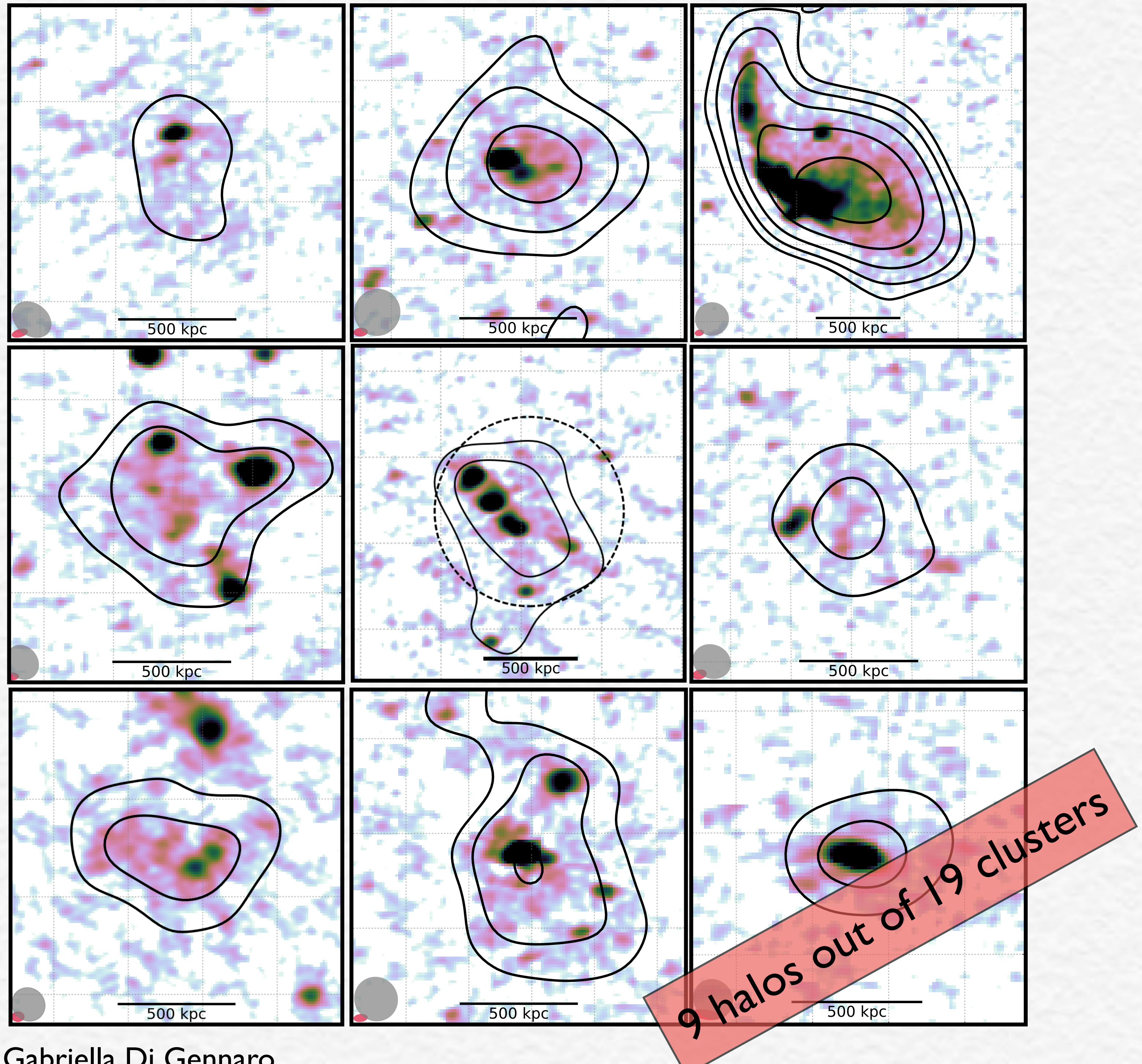

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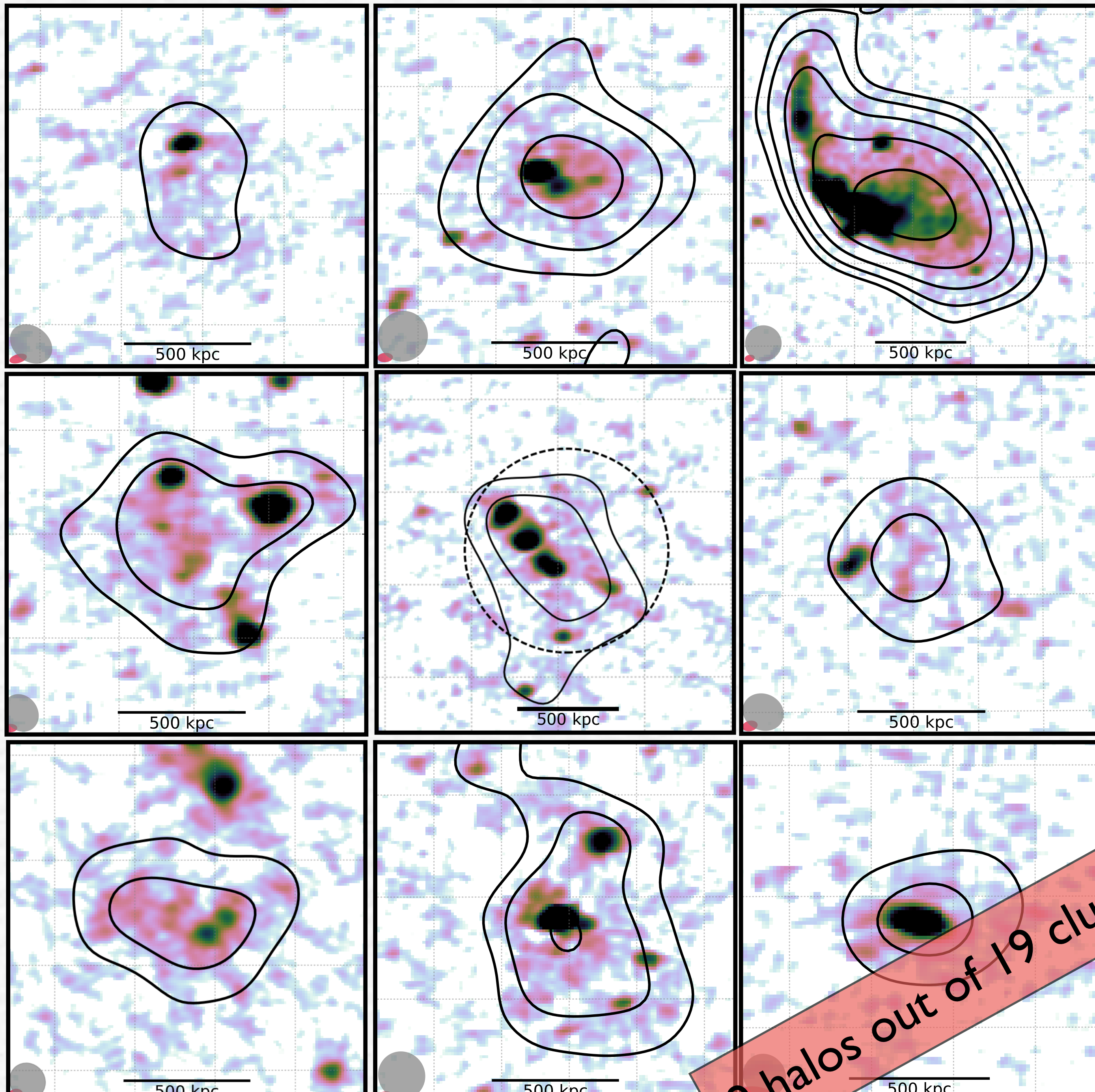

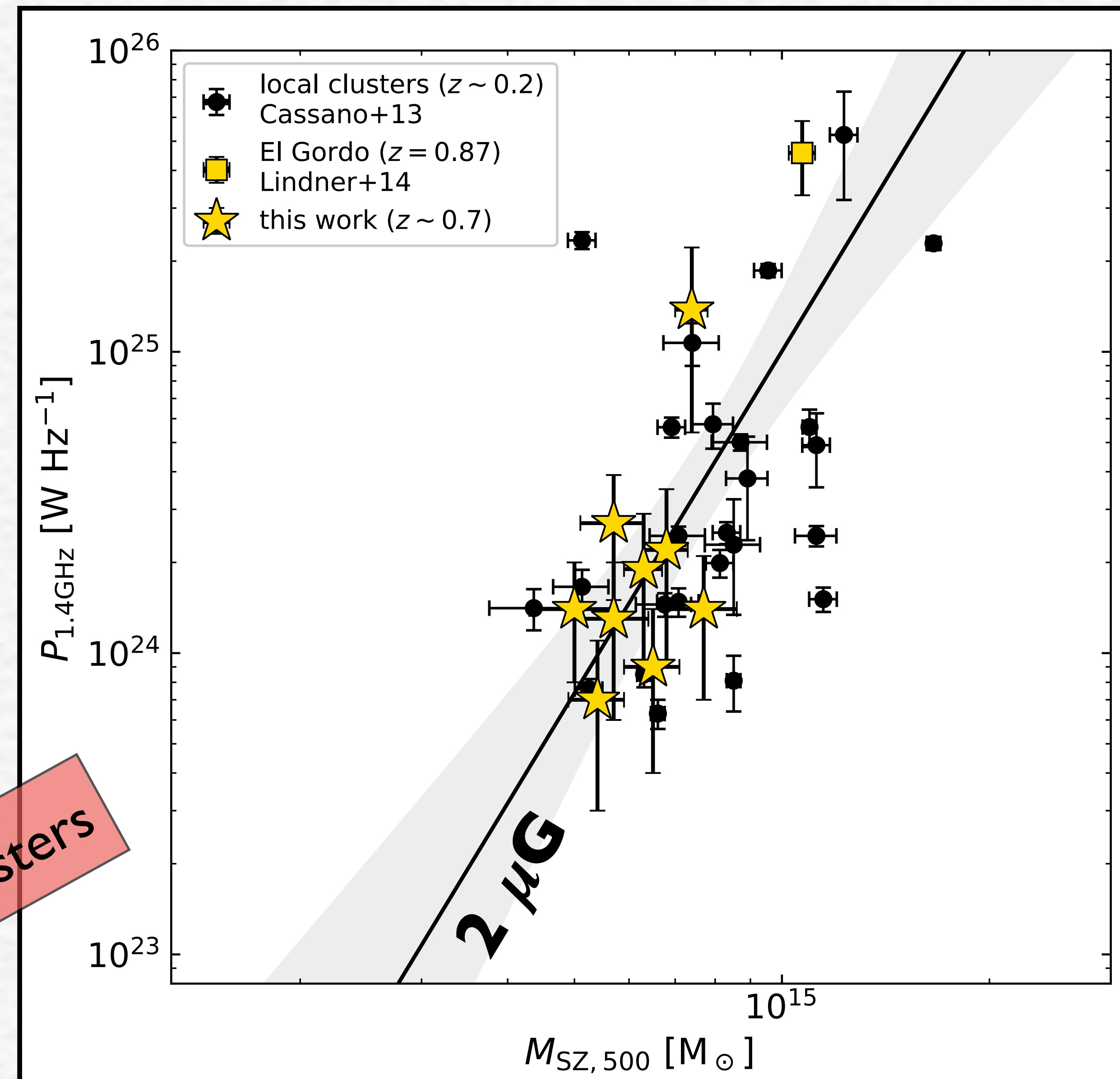

9 halos out of 19 clusters

DETECTION OF RADIO HALOS AT HIGH z

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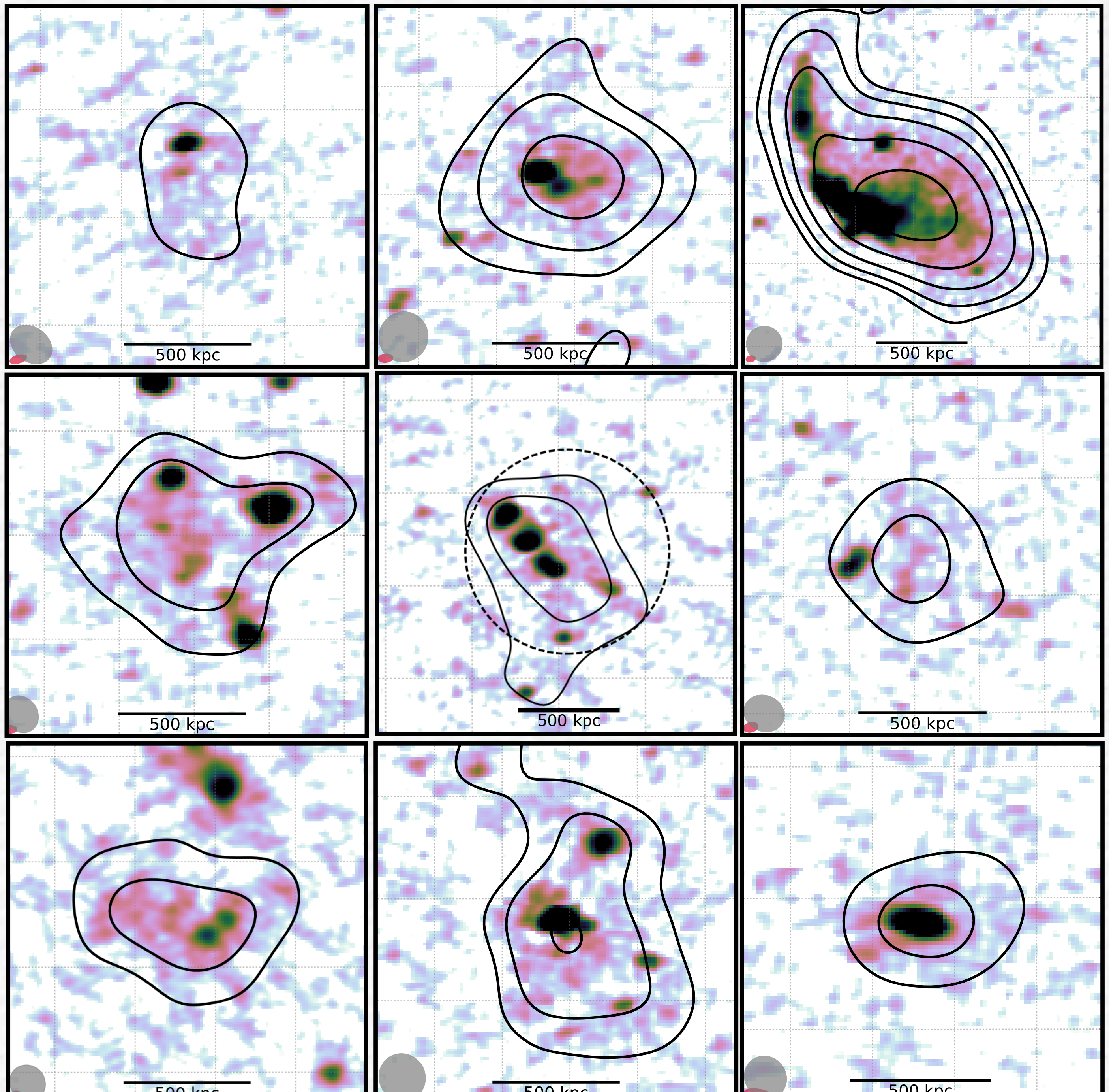
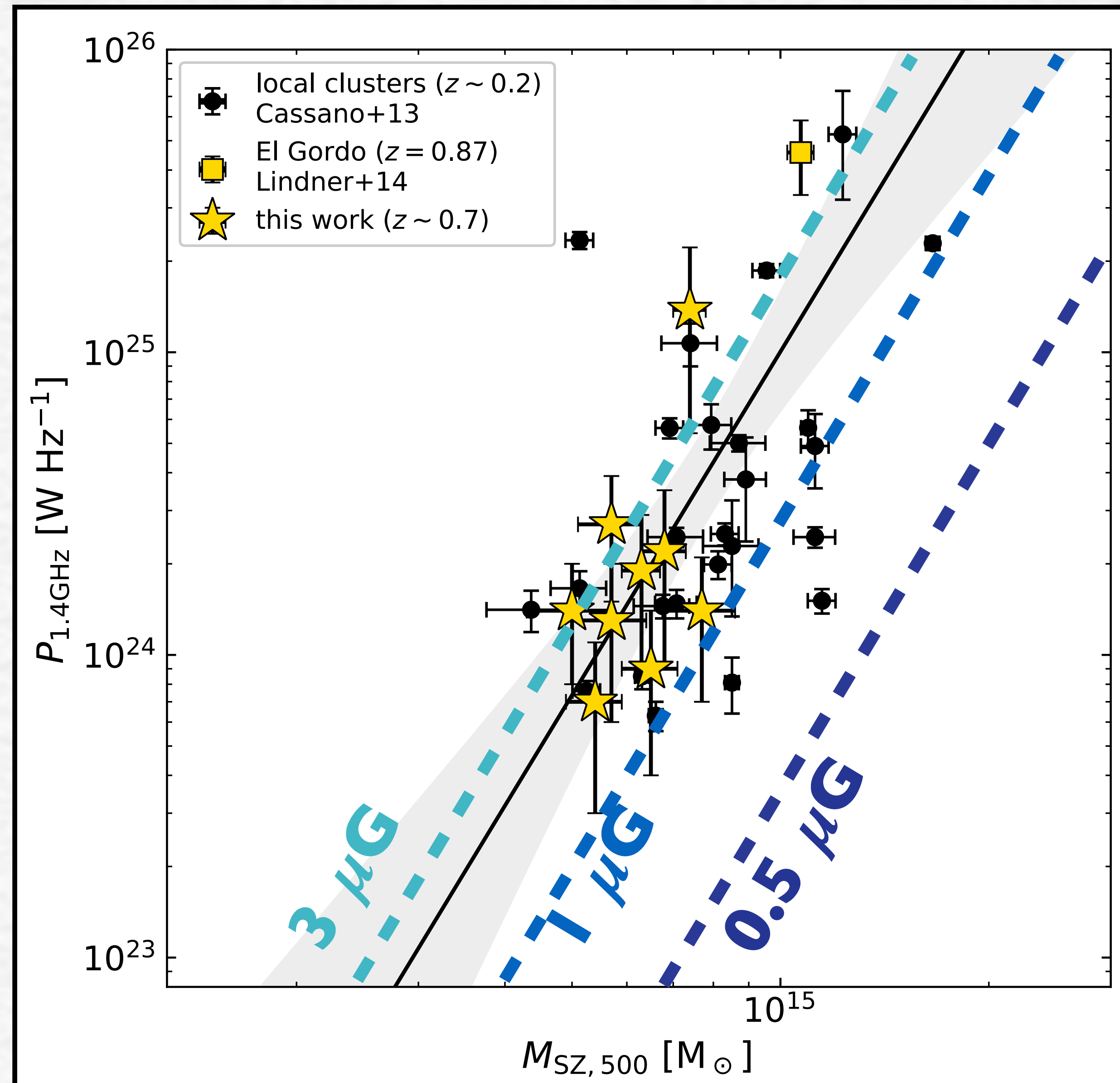
Di Gennaro+2021a, Nat. Astron., 5, 268



RE-ACCELERATION THEORY

$$P_{\rm rad} \propto \eta_{\rm rel} \frac{\rho v_t^3}{L_{\rm inj}} \frac{B^2}{B^2 + B_{\rm CMB}^2}$$



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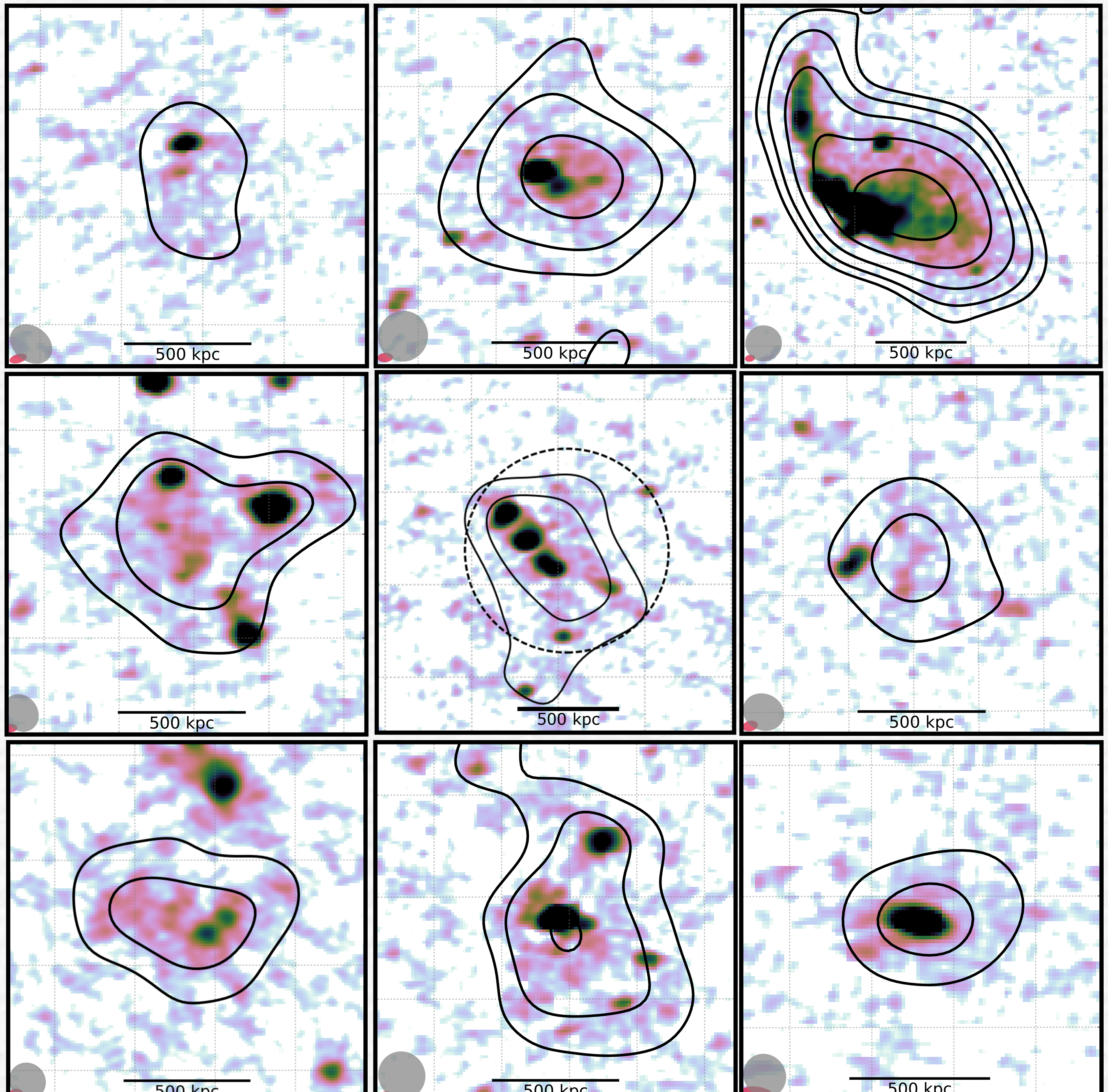
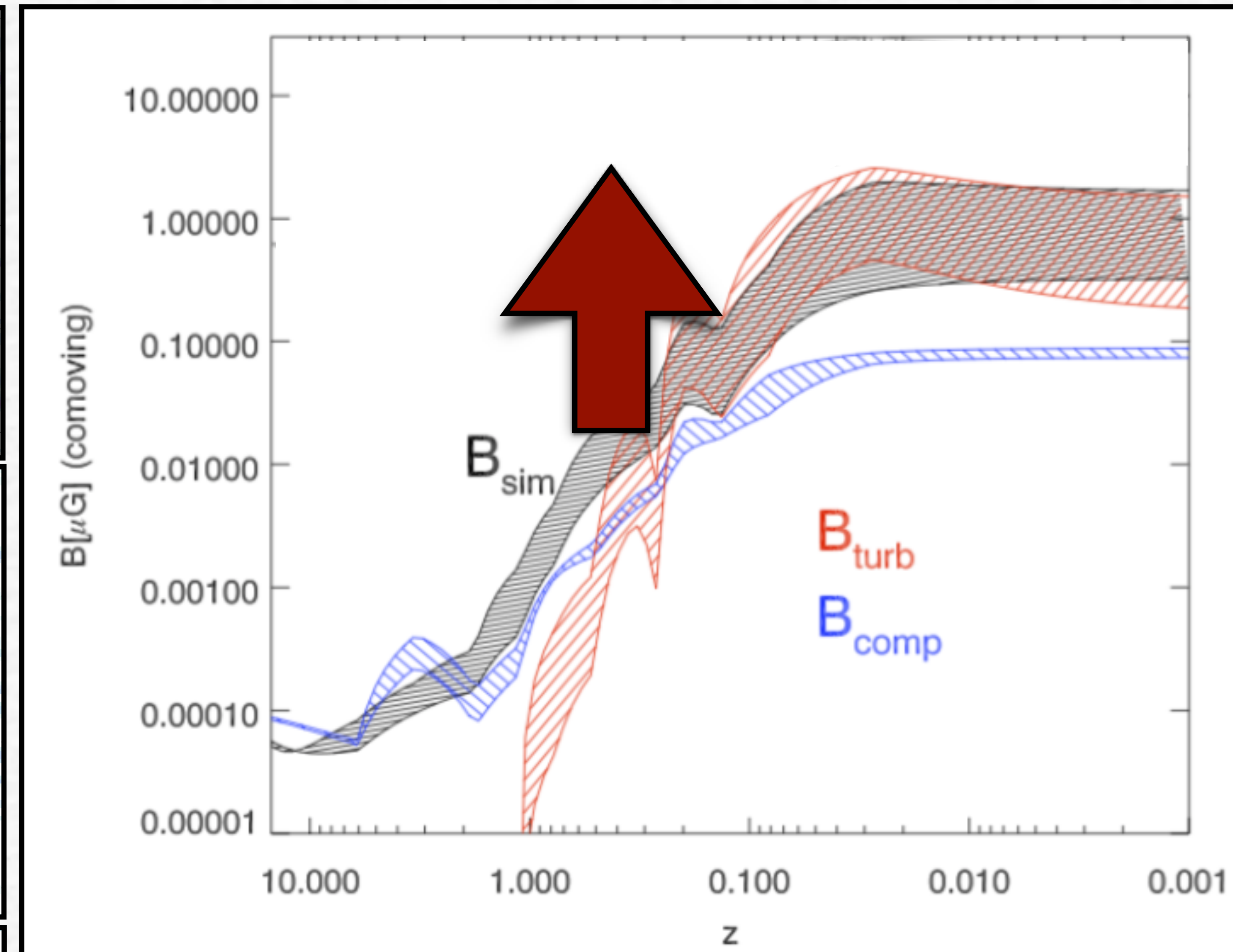
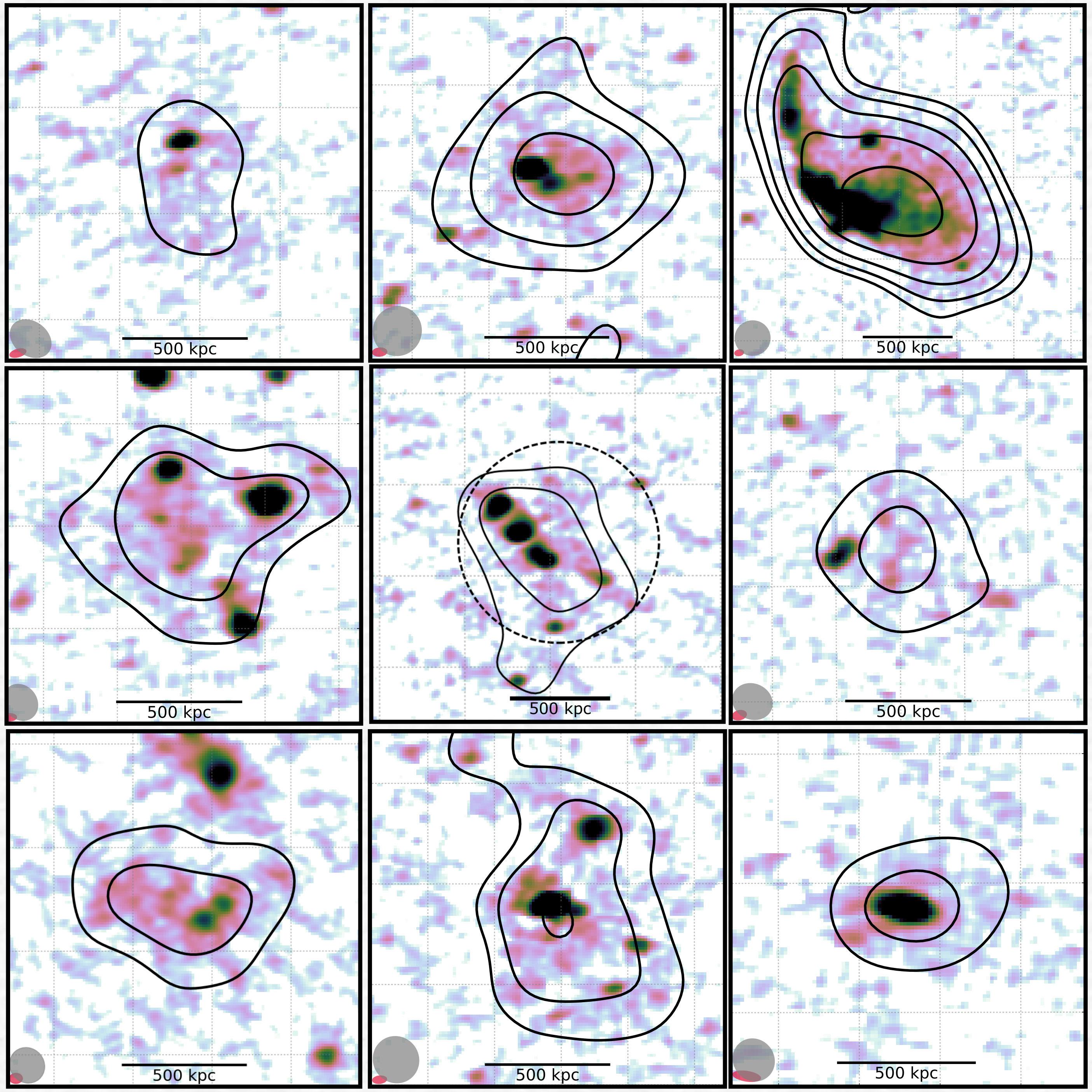




Cluster magnetic fields at z~0.7 have similar strengths to those at z~0.2 (1-few μG)

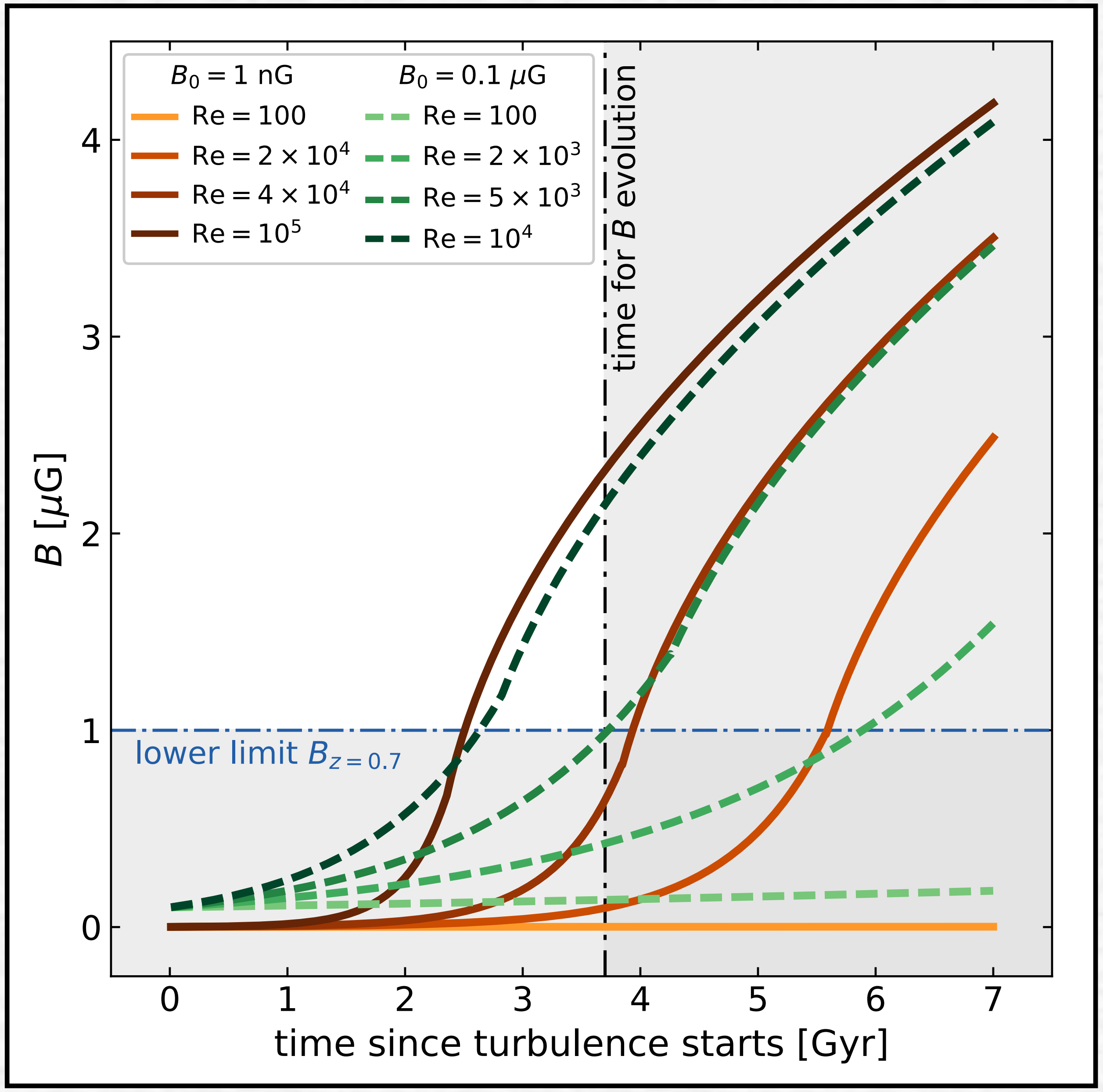
HOW CAN WE BUILD SUCH STRONG MAGNETIC FIELDS AT HIGH z ?

Di Gennaro+2021a, Nat. Astron., 5, 268



$$B^2(t) \sim B_0^2 \exp(t\,\Gamma)$$
$$\Gamma = \mathrm{Re}^{1/2} v_t / (30 L_{\rm inj})$$

small-scale dynamo following Beresnyak 2012



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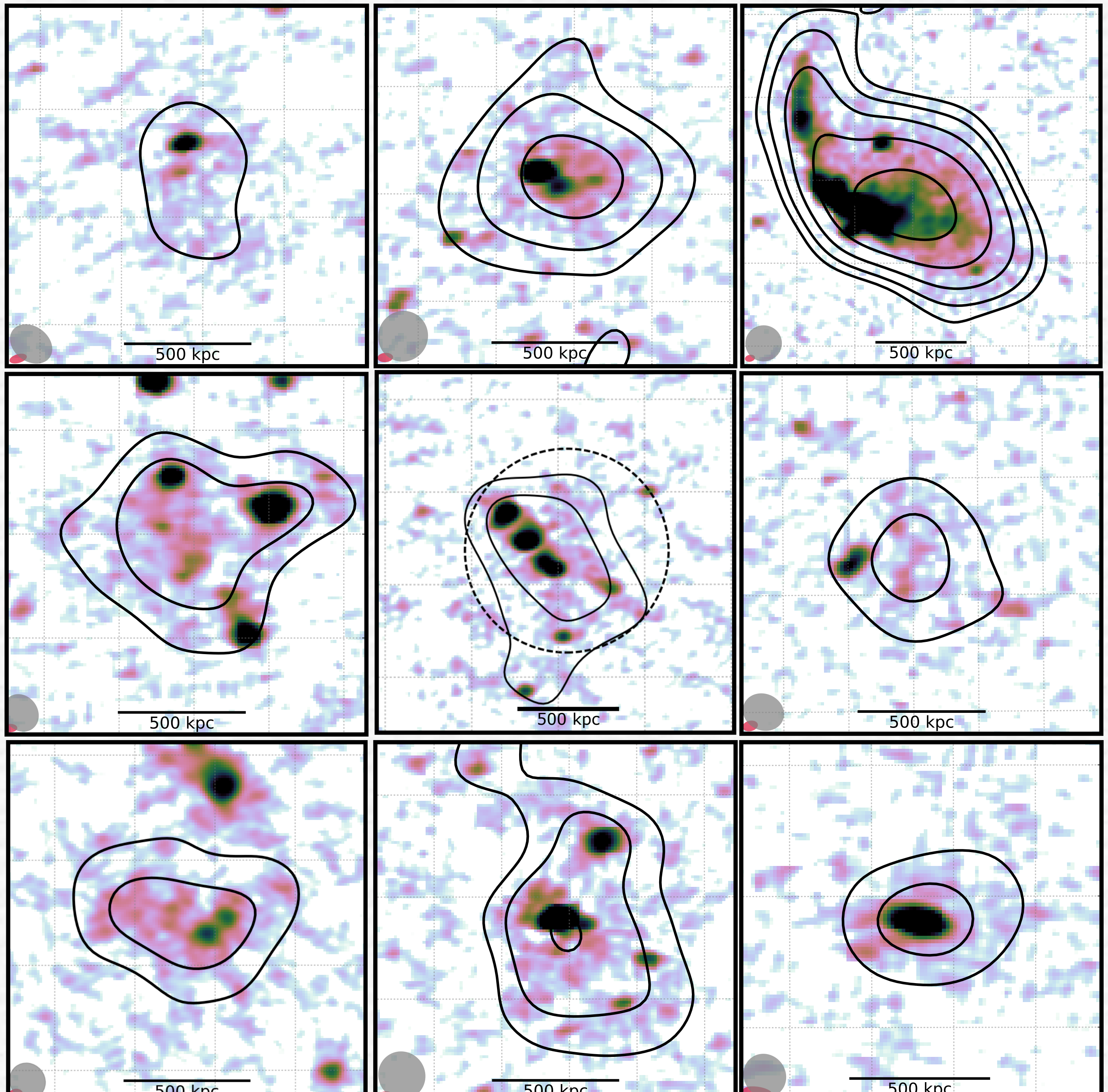

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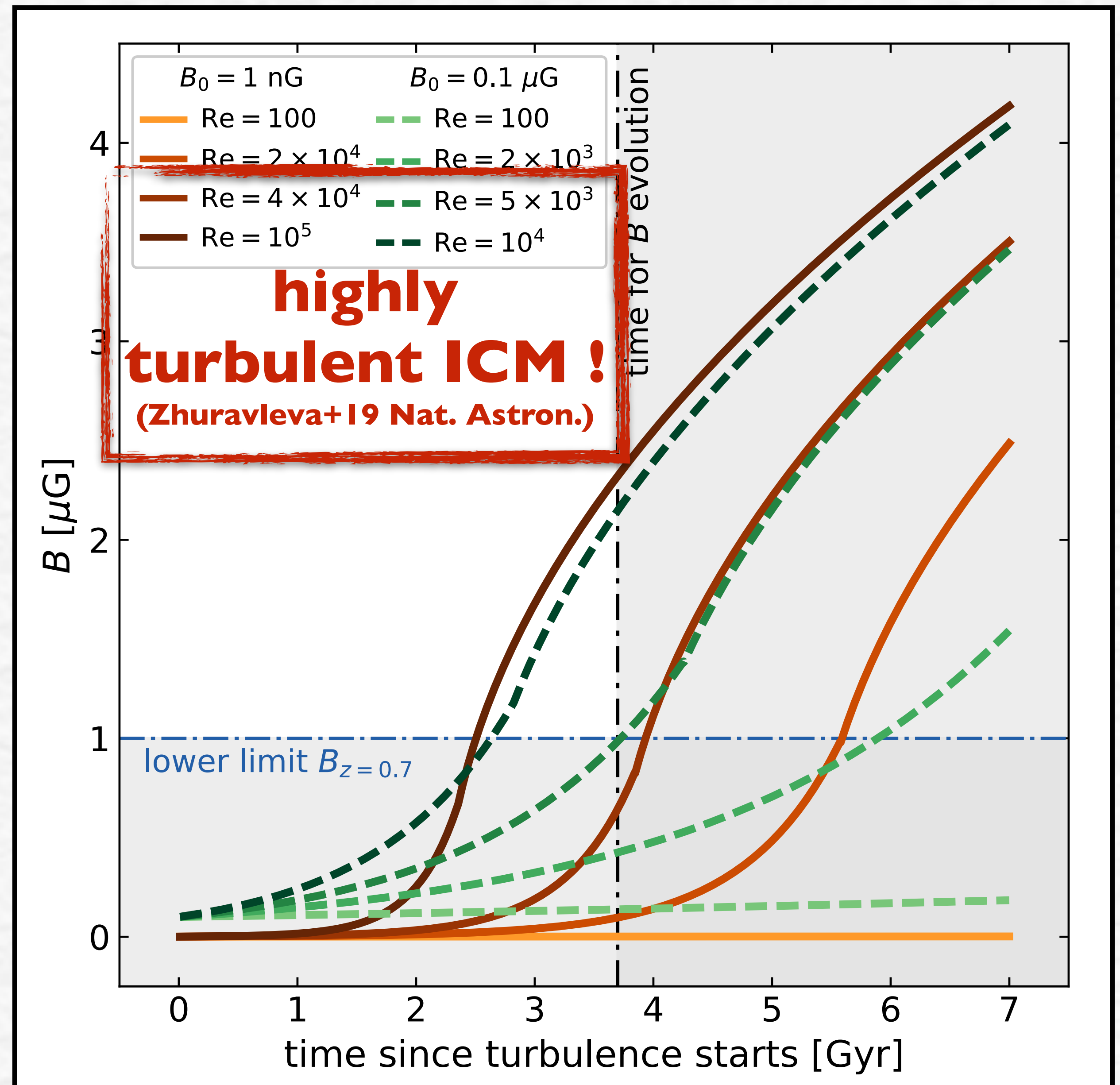
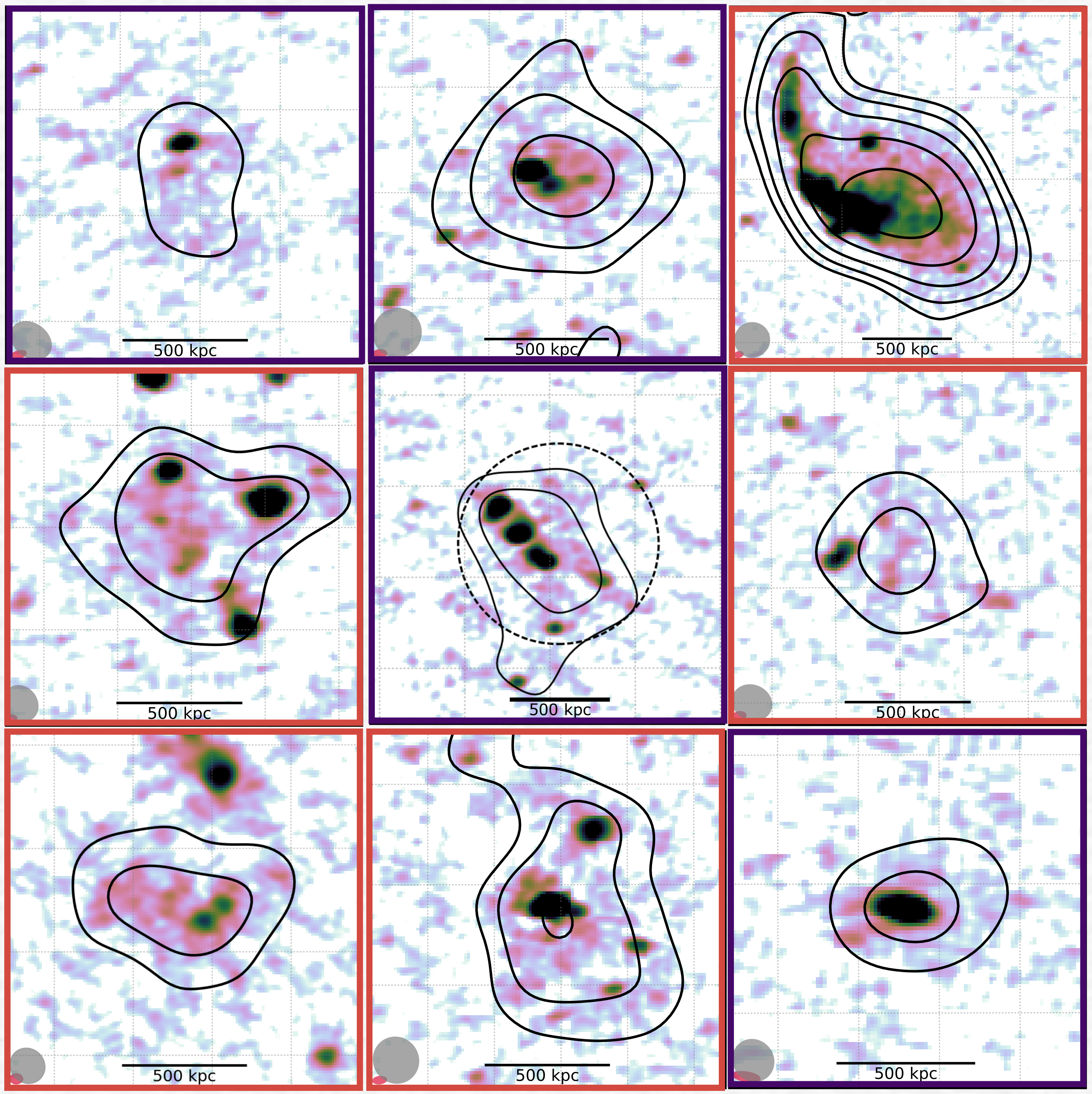
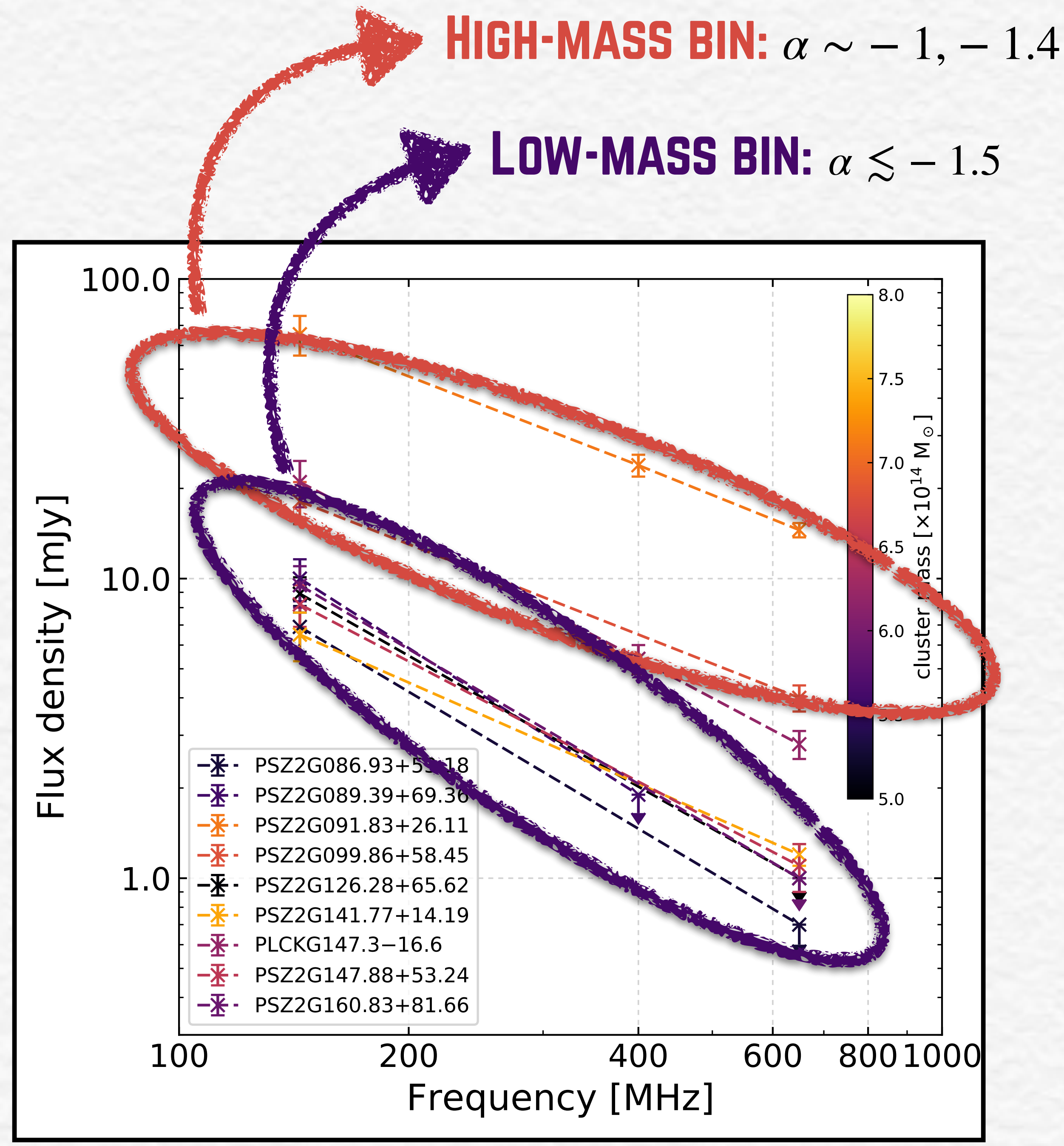


WHAT ABOUT PARTICLE RE-ACCELERATION ?

Di Gennaro+2021a, Nat. Astron., 5, 268



Di Gennaro+2021b, A&A, 654, A166



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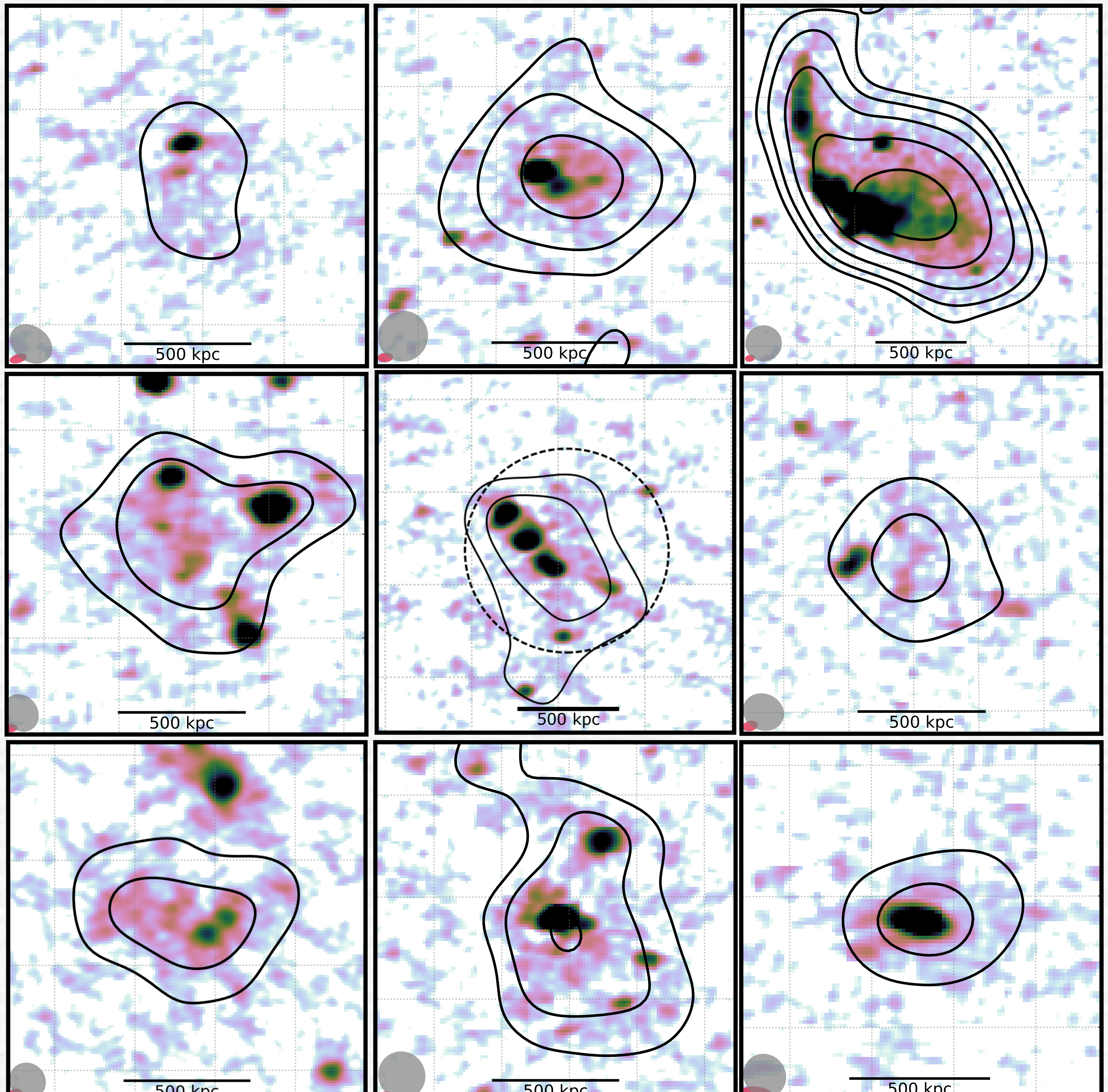

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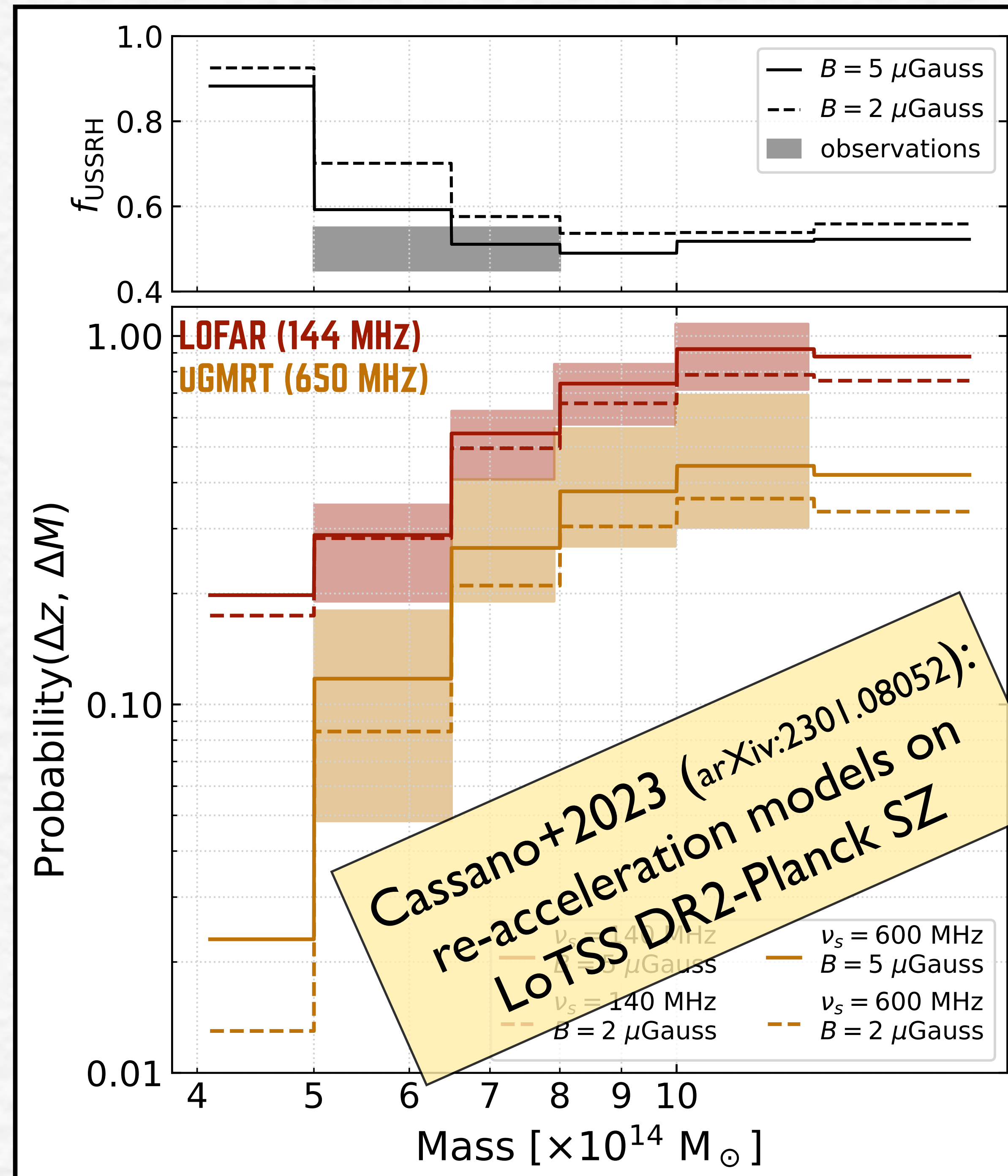
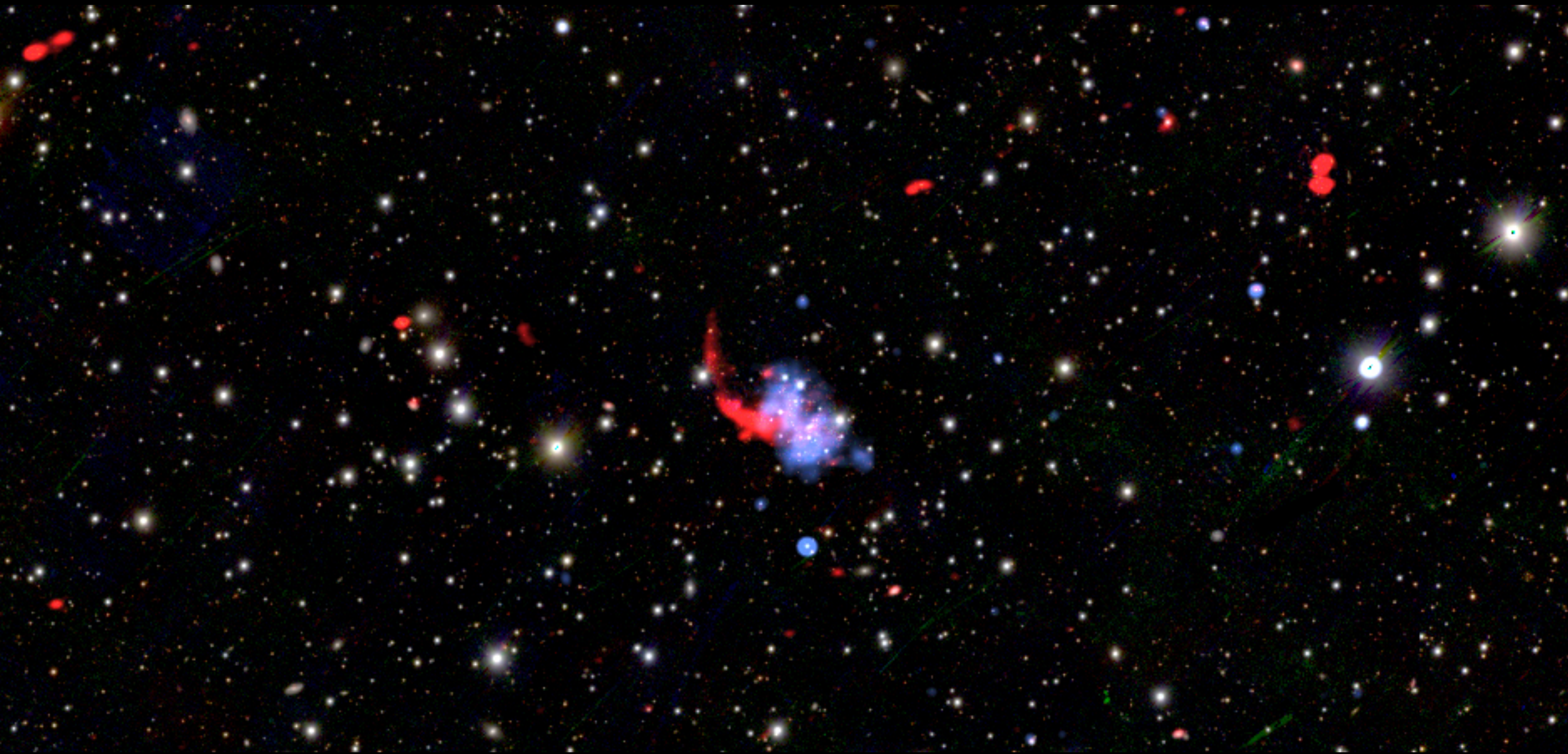
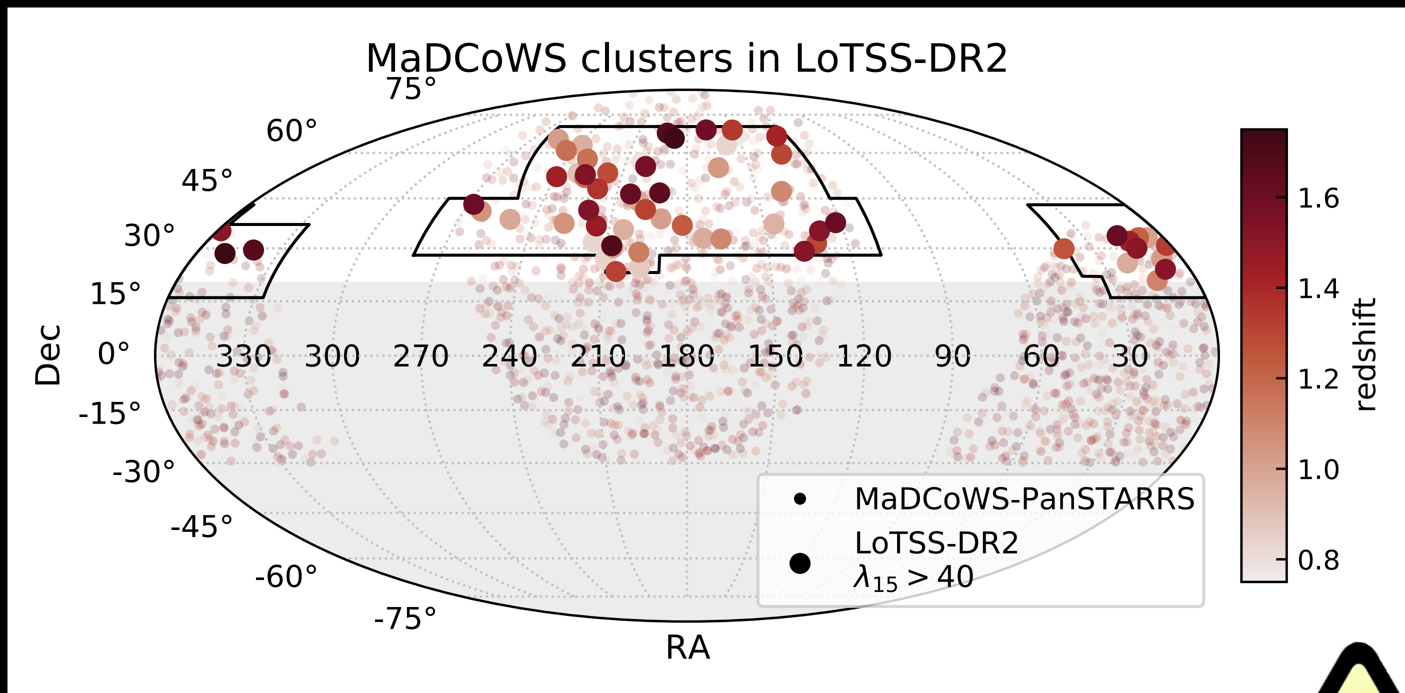


WHAT'S NEXT ?

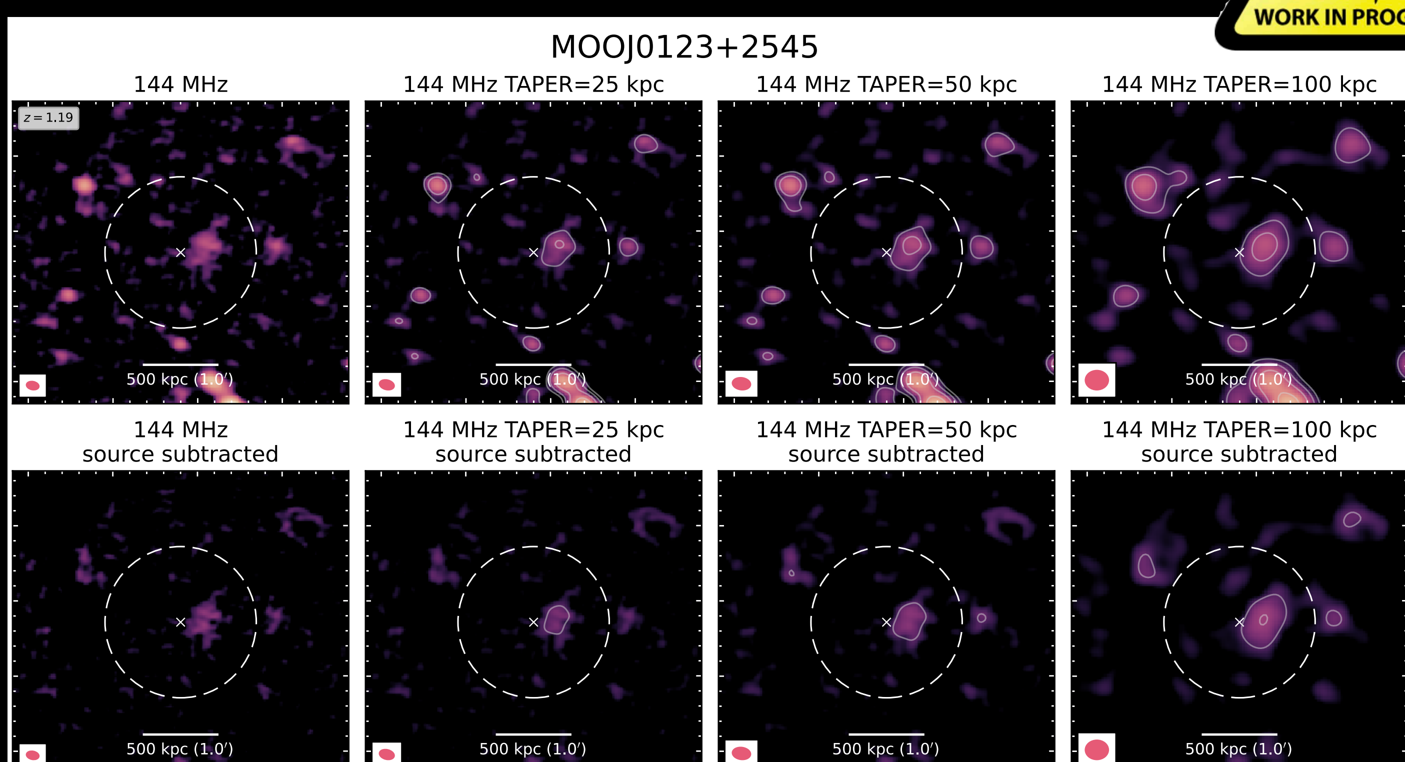


LARGER SAMPLE OF DISTANT HALOS



THE MASSIVE AND DISTANT CLUSTERS OF WISE SURVEY (MADCOWS Gonzales+2019):

IR-SELECTED CLUSTERS AT REDSHIFT~1



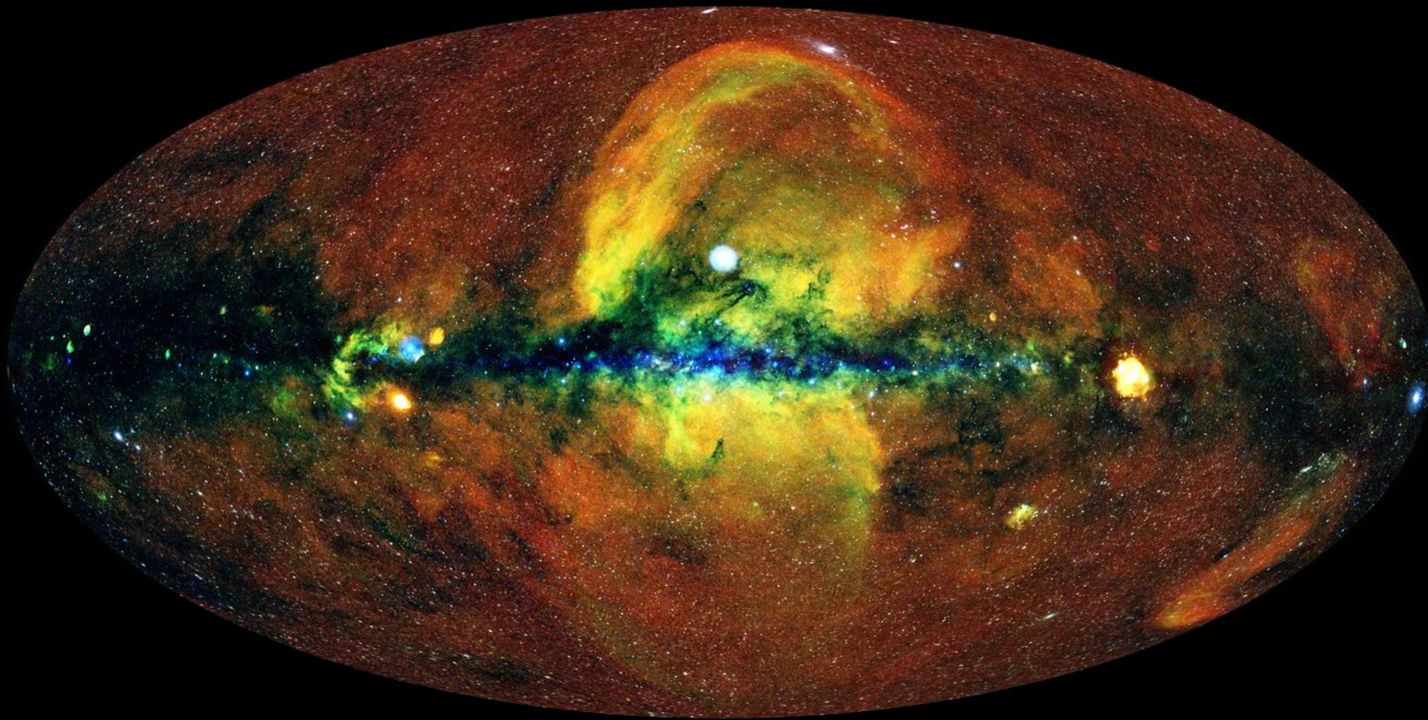
PROs:

- Large sample (~500 clusters in LOFAR DR2)
- Large (photometric) redshift coverage (0.7 < z < 1.75)

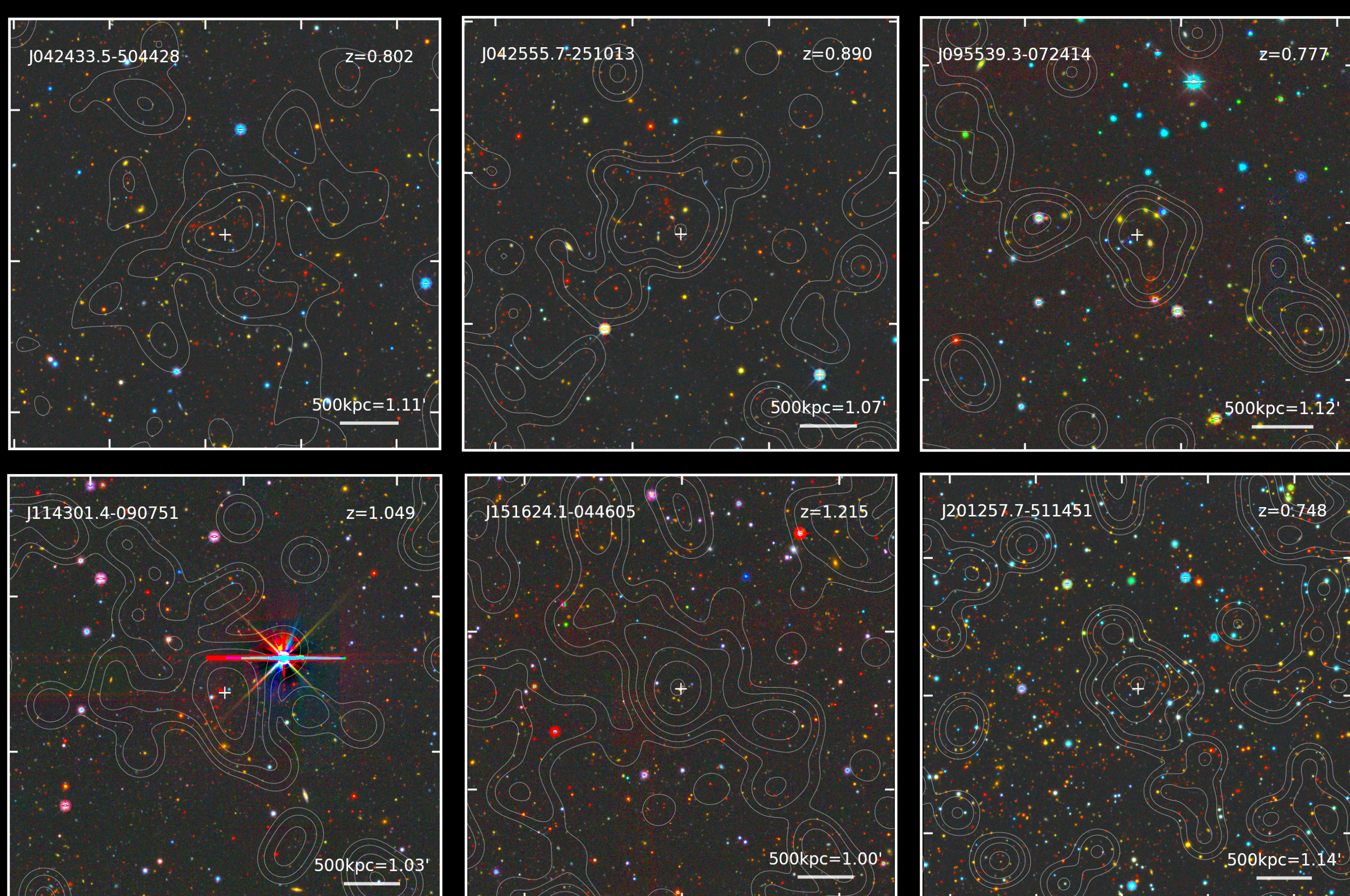
CONs:

- No clear conversion from richness (λ) to cluster mass ($M_{SZ,500}$)
- No X-ray available (so far) ⟶ SZ !

LARGER SAMPLE OF DISTANT HALOS



eROSITA ALL-SKY SURVEY (eRASS Merloni+2012, Predehl+2021): Xray-selected clusters



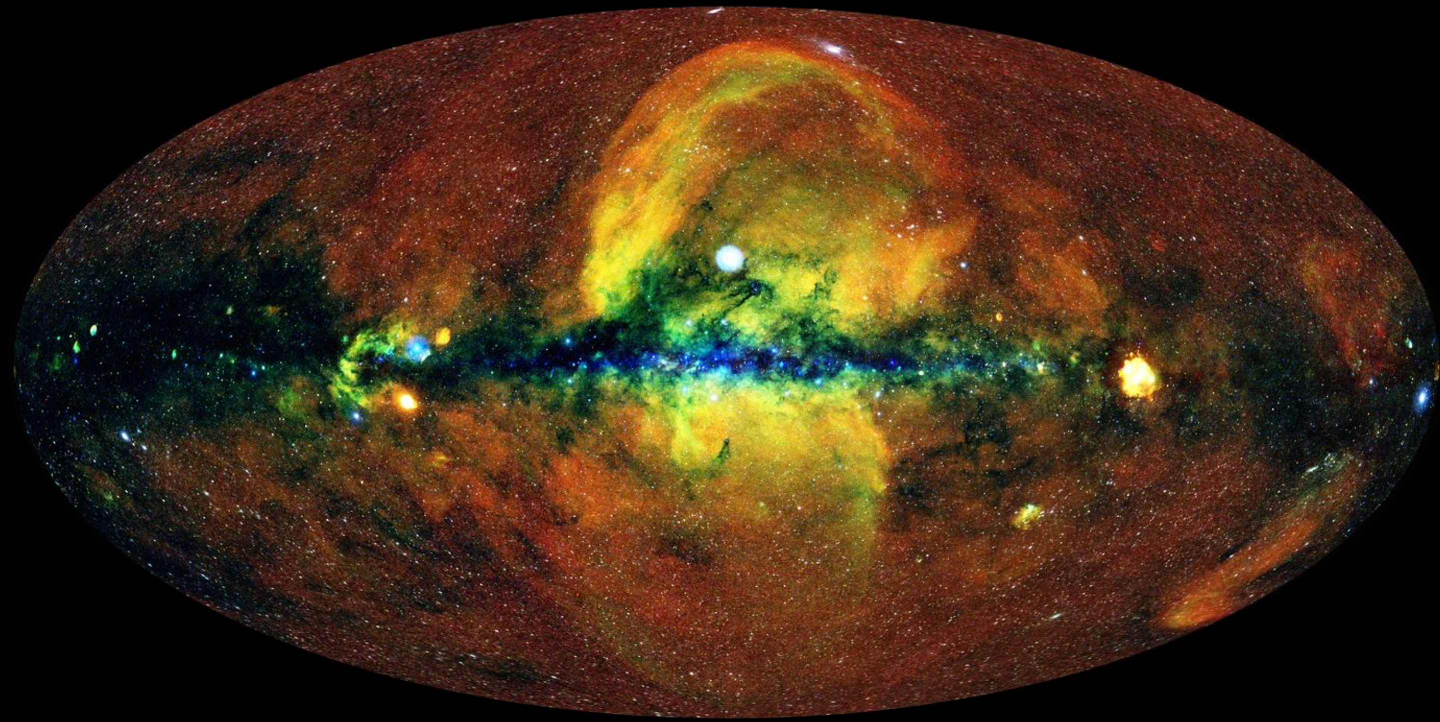
PROs:

- X-ray available
- Good mass estimation ($M_{\mathrm{SZ,500}}$) from scale relations (Lovisari & Maughan 2022)

CONs:

- German side covers the southern hemisphere
- No high-resolution high-sensitivity radio surveys below 100 MHz (but good feelings by MeerKAT, Knowles+2022)

LARGER SAMPLE OF DISTANT HALOS



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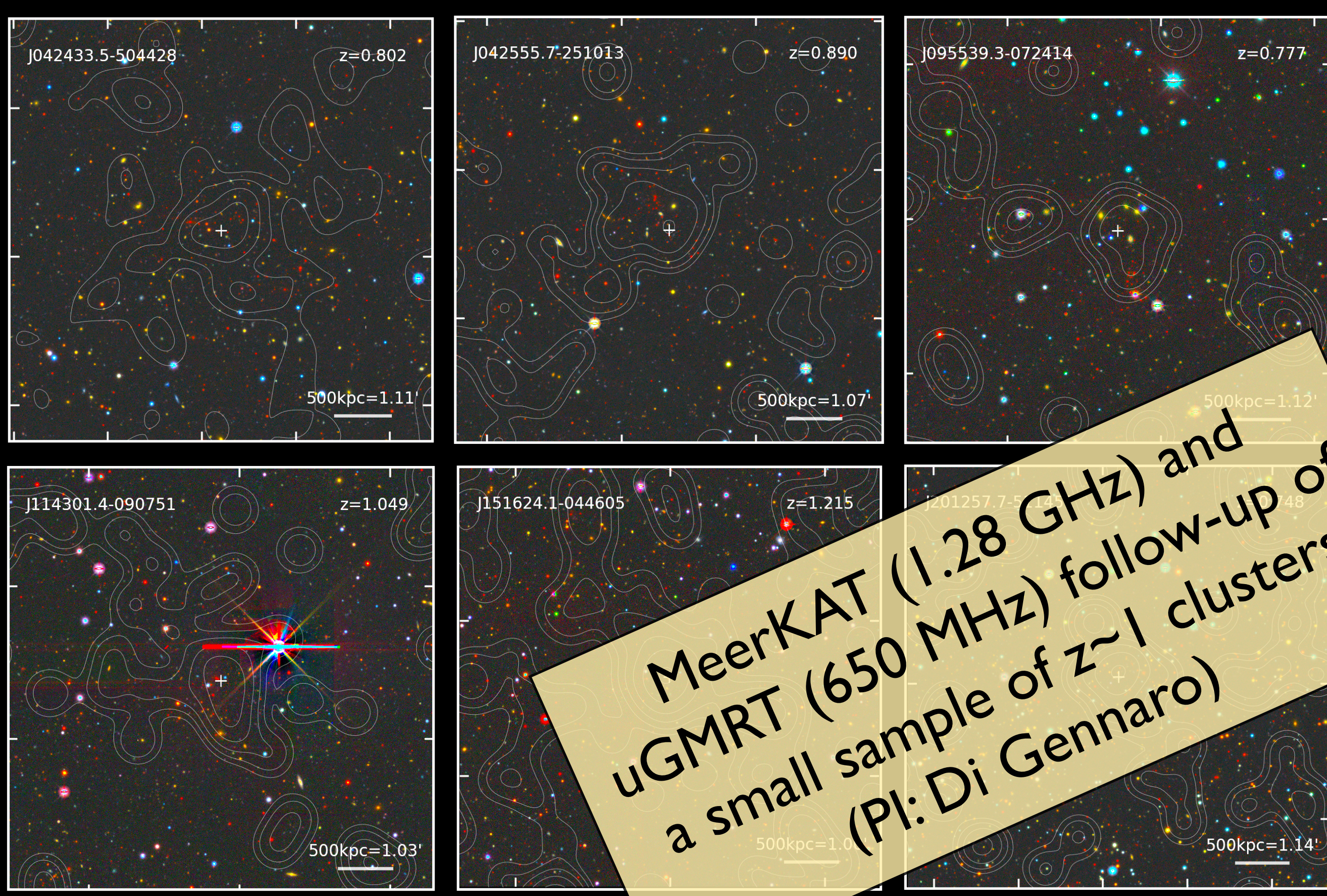

MeerKAT (1.28 GHz) and uGMRT (650 MHz) follow-up of a small sample of z~1 clusters (PI: Di Gennaro)

PROs:

- X-ray available
- Good mass estimation ($M_{\rm SZ,500}$) from scale relations (Lovisari & Maughan 2022)

CONs:

- German side covers the southern hemisphere
- No high-resolution high-sensitivity radio surveys below 100 MHz (but good feelings by MeerKAT, Knowles+2022)

SUMMARY

- LOFAR observations of a sample of Planck-selected galaxy clusters at z≥0.6 (Universe half of its current age)
  - occurrence rate of diffuse radio emission is high in our PlanckSZ sample
  - magnetic field strength at high-z is similar to that at low-z
  - Reynolds number should be surprisingly high (>10^4) in the ICM

- uGMRT follow-up for spectral index studies, i.e.test for the re-acceleration model
  - Low-mass ($M_{\rm SZ,500} < 5 \times 10^{14}\ {\rm M}_\odot$) clusters have ultra-steep spectral indices (in agreement with theoretical expectations, see Cassano+2023)

- Increasing the high-z radio halo sample:
  - MaDCoWS + LOFAR-DR2
  - eRASS + MeerKAT/uGMRT
  - SZ follow-ups to investigate ICM dynamical state

Thank you