EVOLUTION OF THE LARGE-SCALE MAGNETISM THROUGH RADIO OBSERVATIONS

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THE FIFTH NATIONAL WORKSHOP ON THE SKA PROJECT
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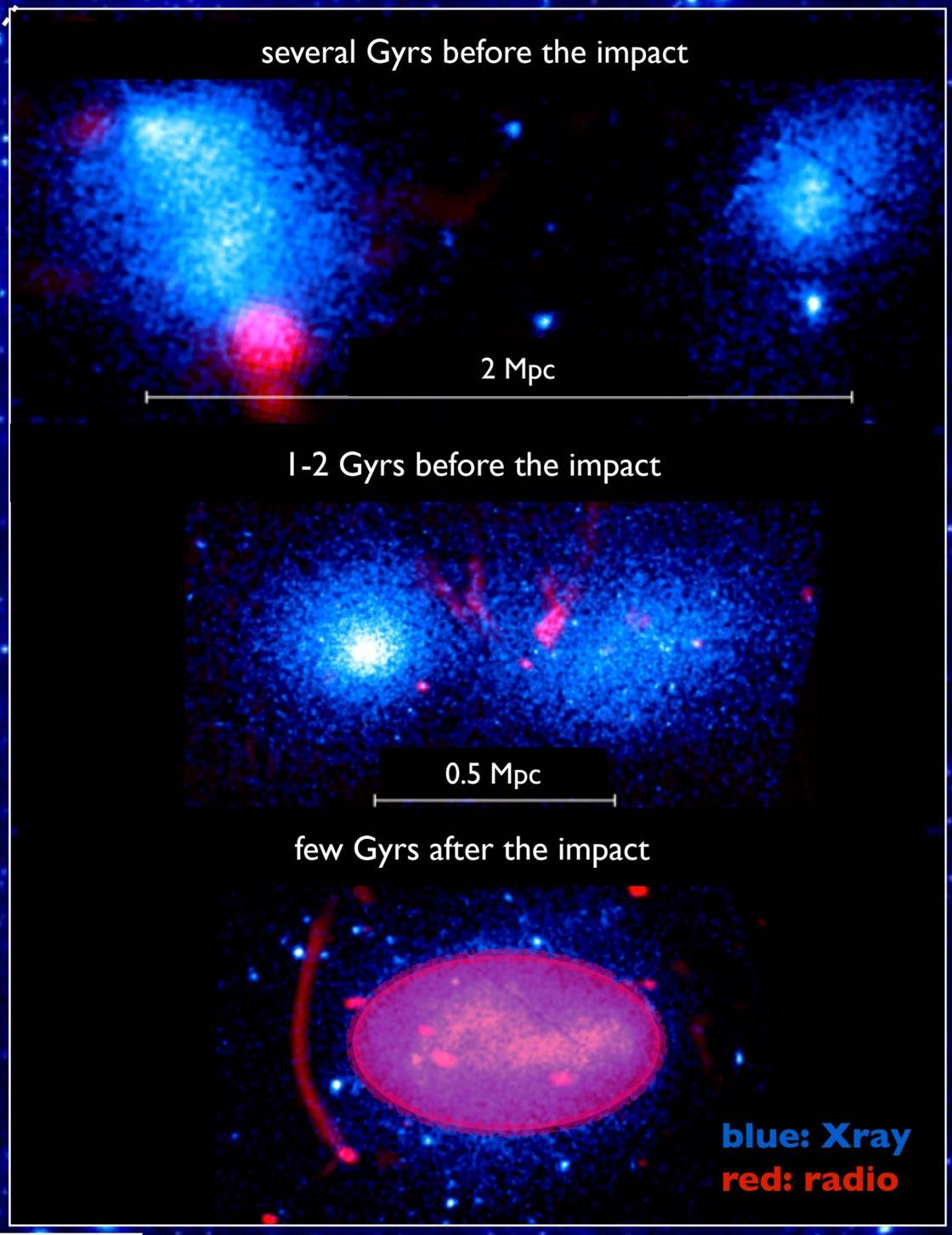
European Research Council
Established by the European Commission

INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

COSMIC WEB

~50 Mpc

CLUSTER EVOLUTION AND FORMATION



Pearce+ 2017

RADIO: MAGNETIC FIELD + COSMIC RAYS (CRs)

HALOS

- Centrally located
- Roundish (~Mpc size)
- Roughly smooth
- Particle acceleration from merger turbulence
- Unpolarised → Magnetic fields ~ few μG

RELICS

- Cluster outskirts
- Elongated (~Mpc size)
- Filamentary morphologies
- Particle acceleration from merger shock
- Polarised → Magnetic fields ~ few μG

1 Mpc

Pearce+ 2017

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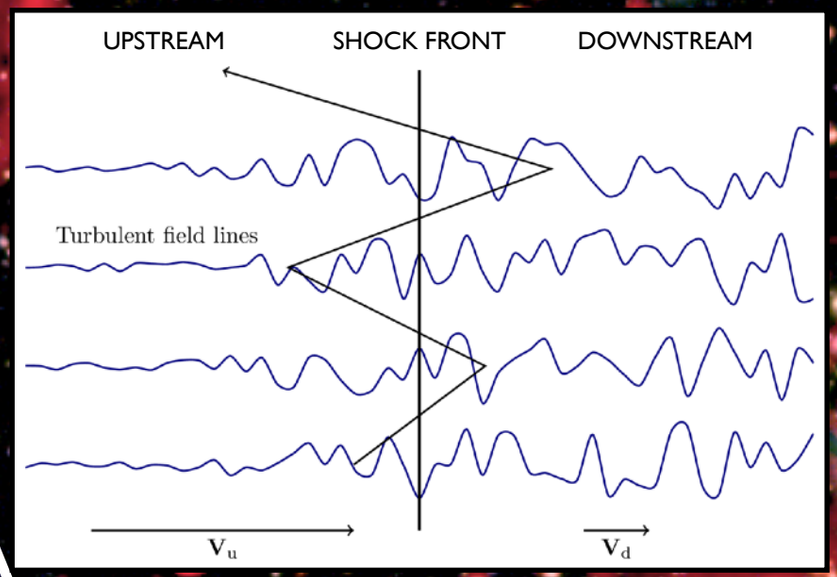

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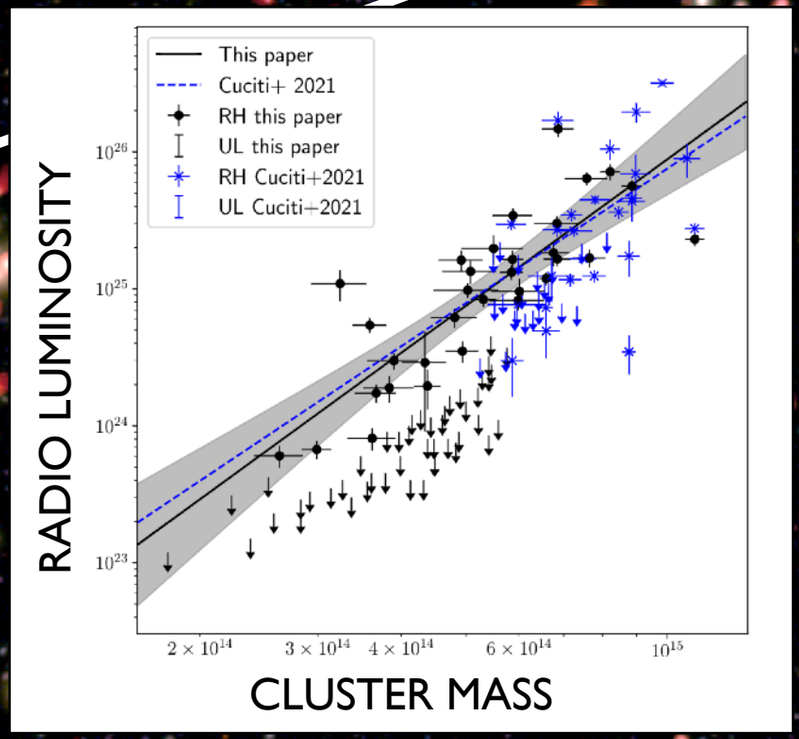

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Osinga+2022

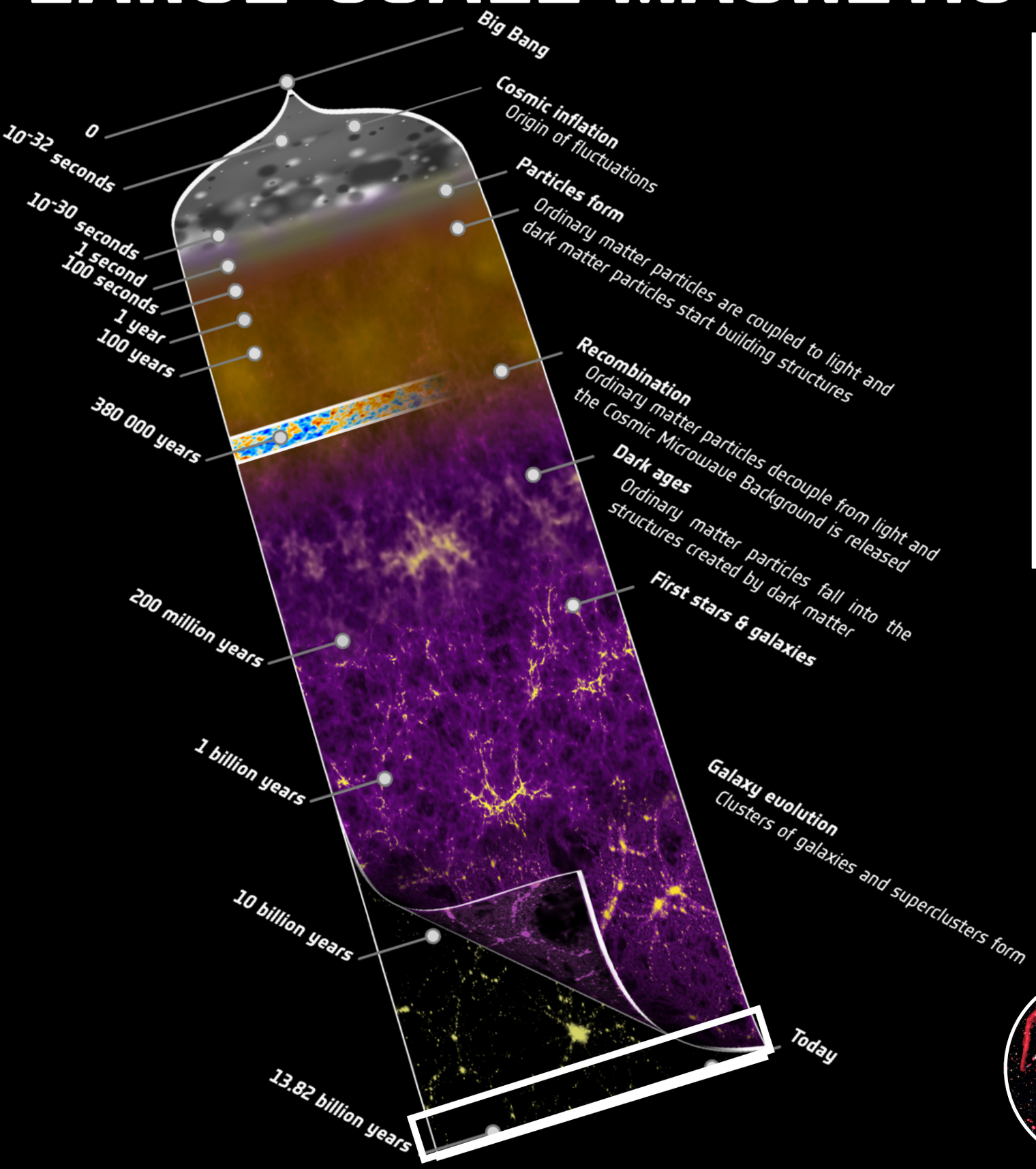
FARADAY ROTATION

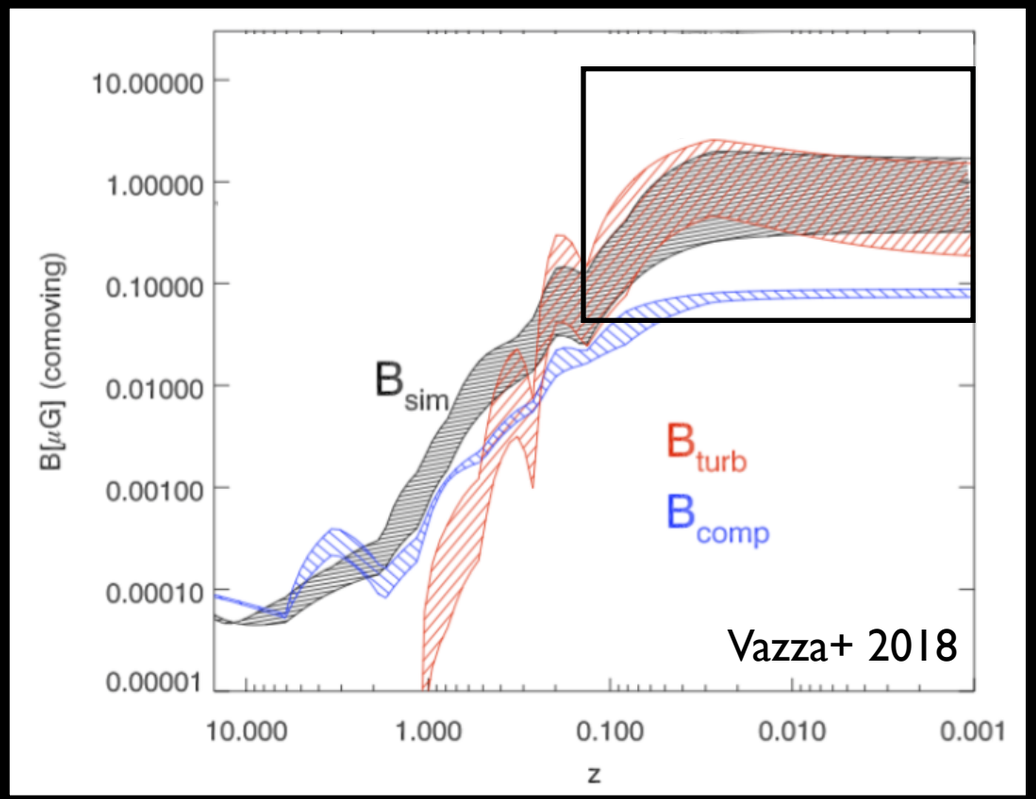
$$\Delta\Theta = \lambda^2 \times \phi(\boldsymbol{r})$$

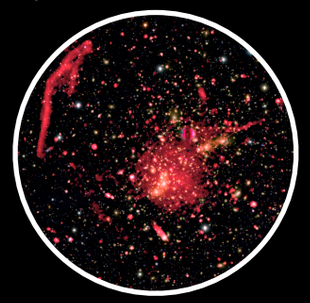
$$\phi(\boldsymbol{r}) = 0.81 \int_{\text{there}}^{\text{here}} n_e \boldsymbol{B} \cdot \mathrm{d}\boldsymbol{r} \quad [\text{rad m}^{-2}]$$

1 Mpc

LARGE-SCALE MAGNETIC FIELD EVOLUTION





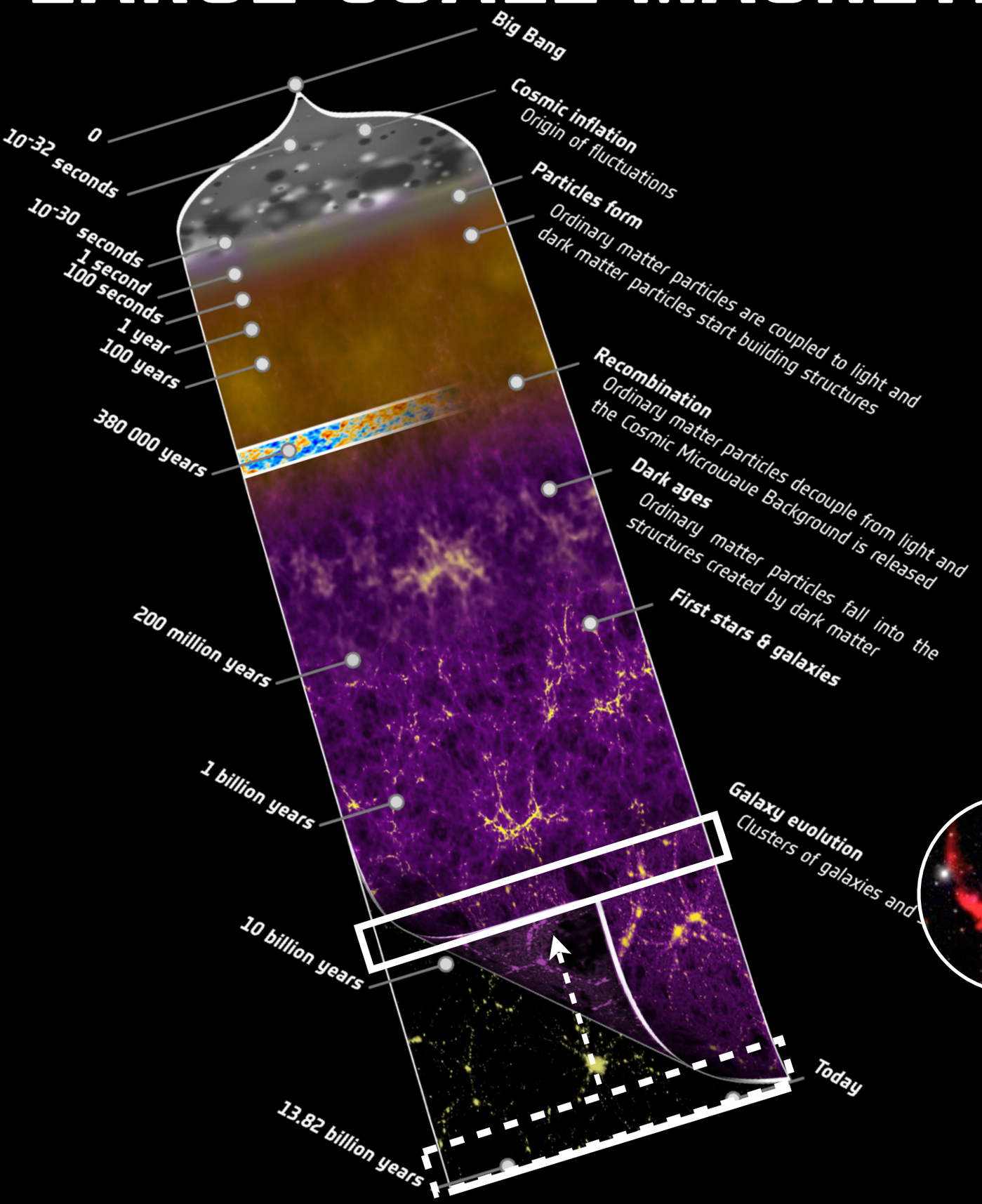


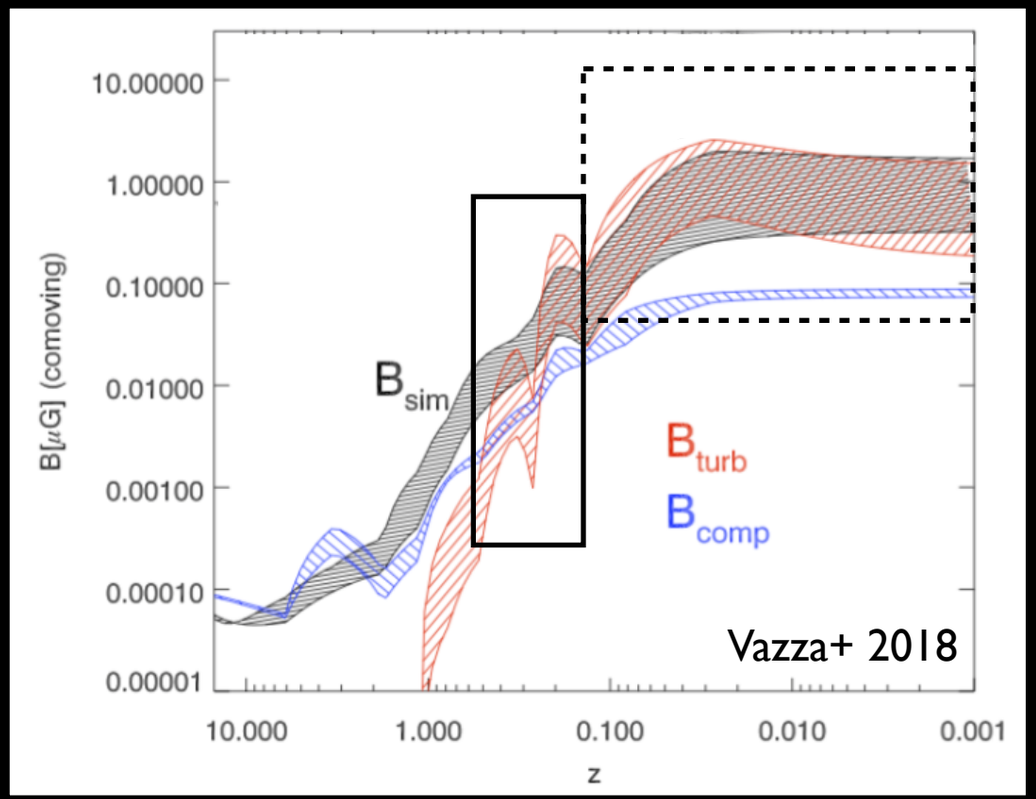
Universe age: ~14 billion years

- Fermi (re-)acceleration
- Magnetic field level: few μG

➡ Magnetic field amplification takes over several billion yrs

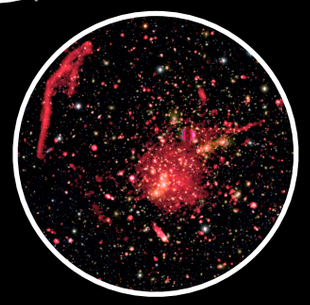
LARGE-SCALE MAGNETIC FIELD EVOLUTION





Universe age: ~7 billion years

- Fermi (re-)acceleration: ?
- Magnetic field level: ?



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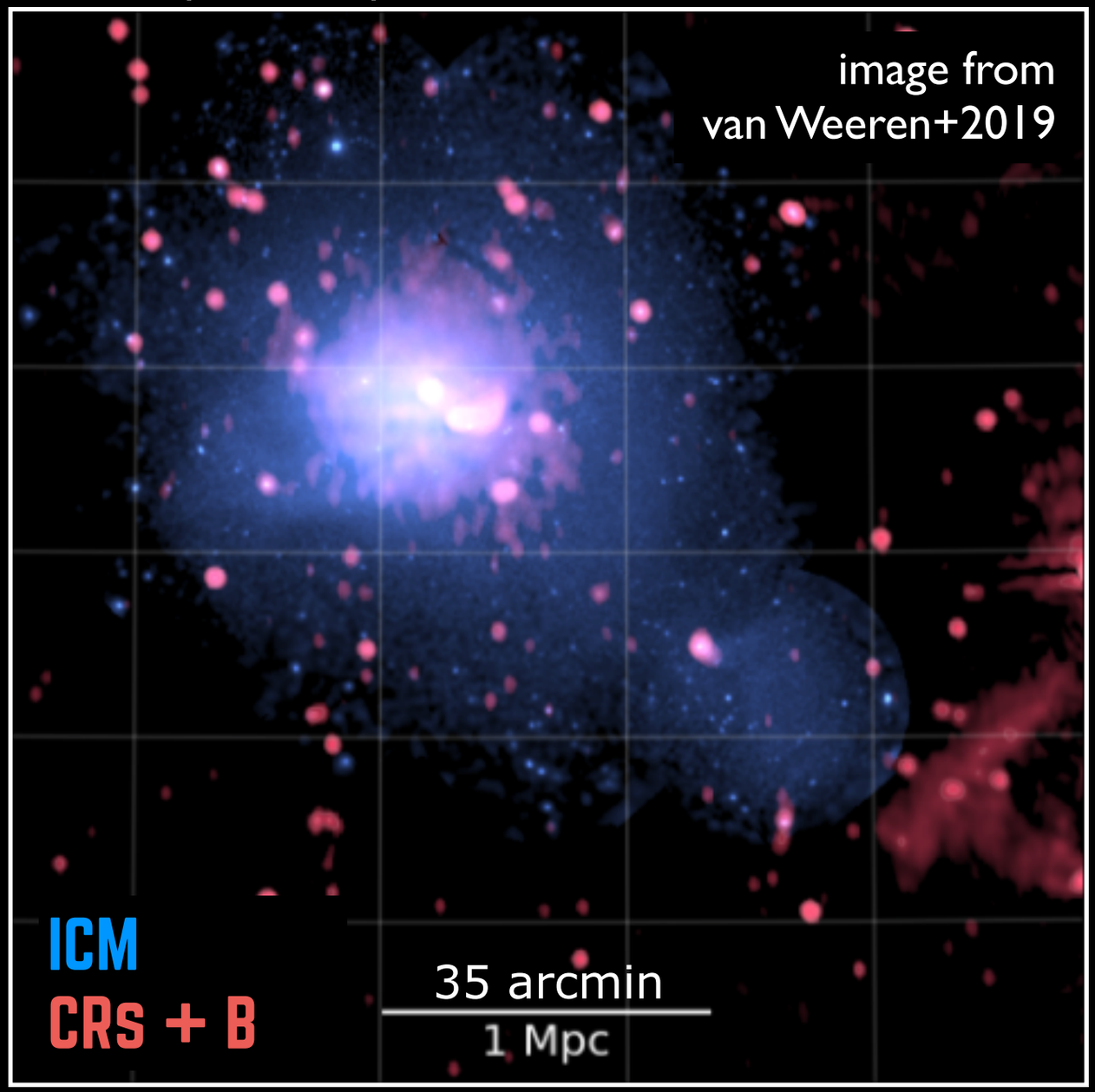
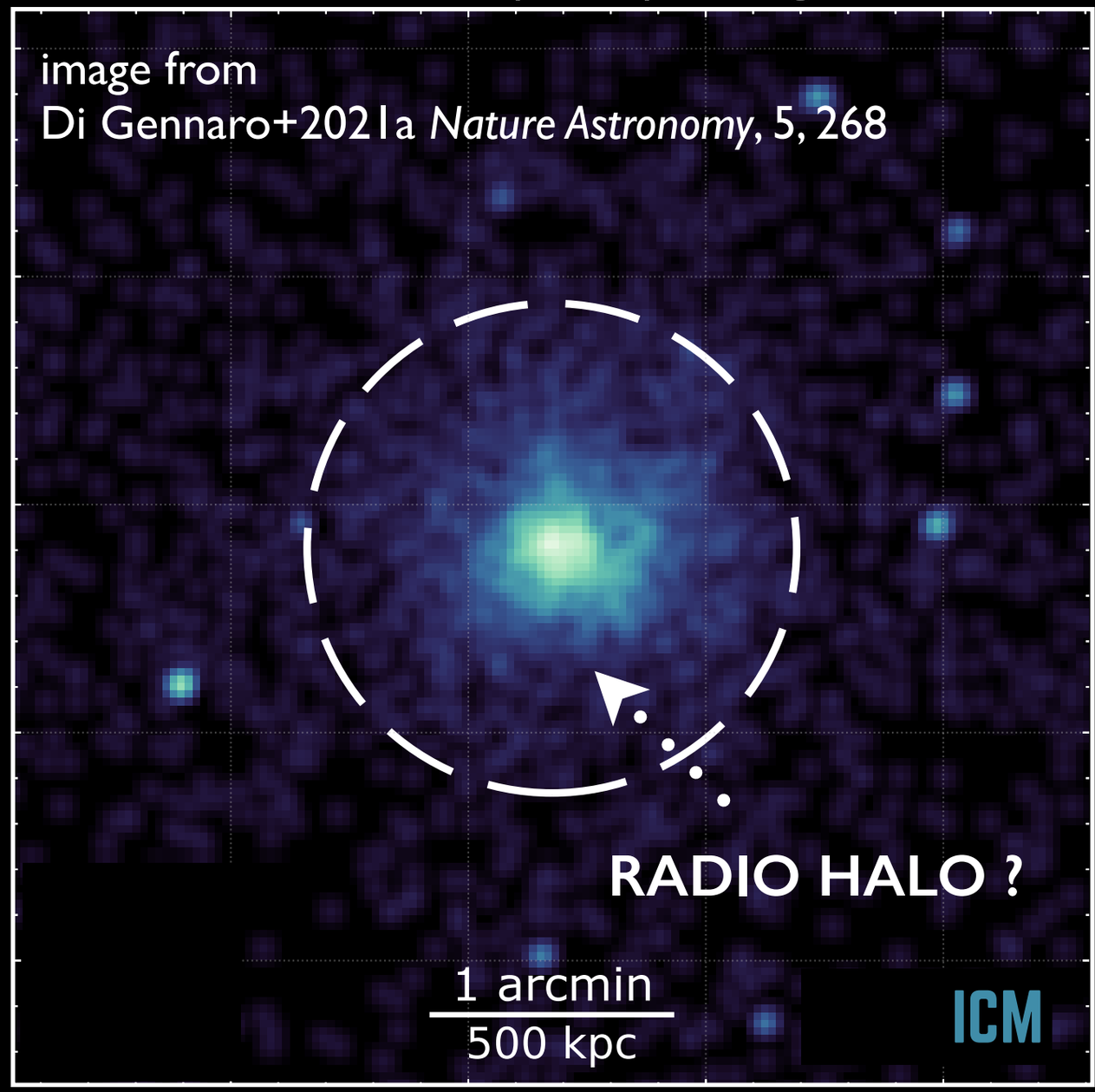
CAN WE DETERMINE MAGNETIC FIELDS IN HIGH REDSHIFT CLUSTERS ?

Coma (z=0.023); Bonafede+2010, 2020

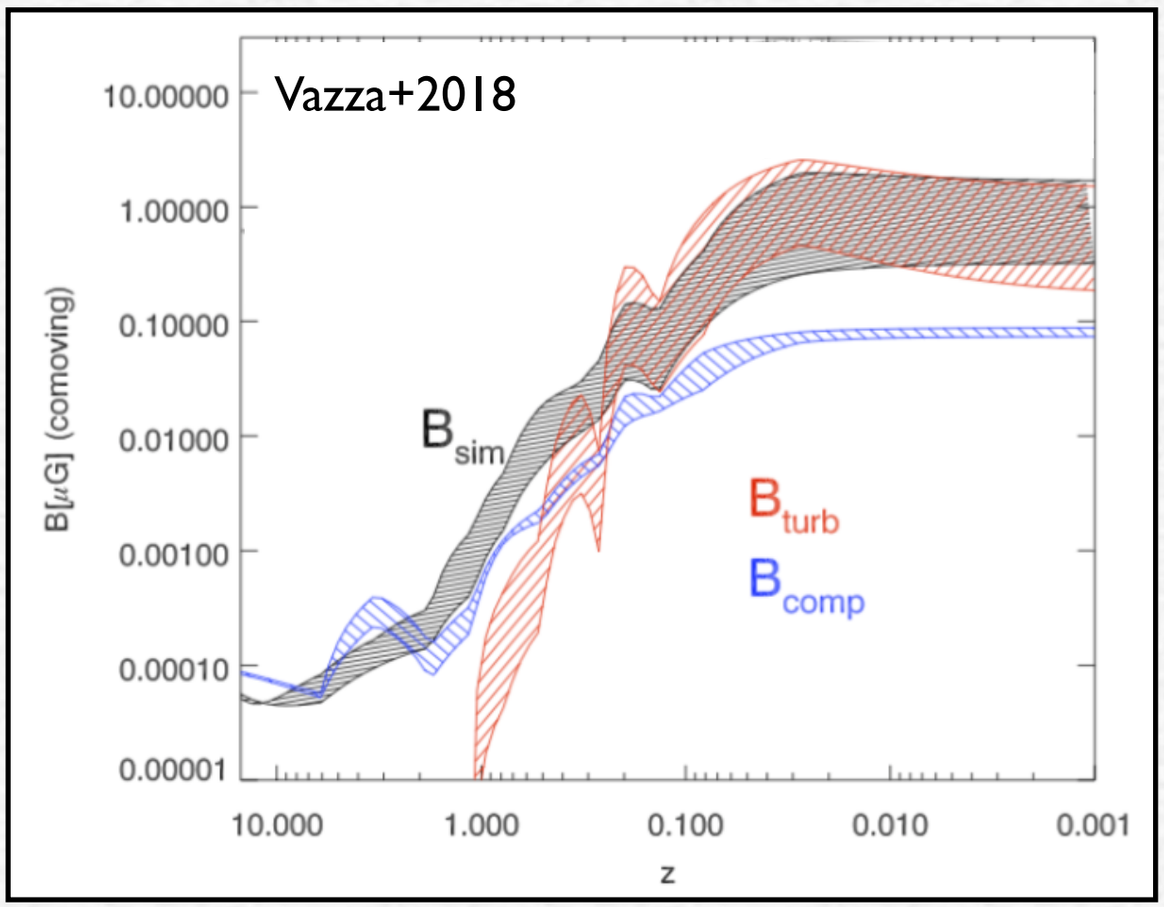


PSZ2G160.83+81.66 (z~0.9); Maughan+2007

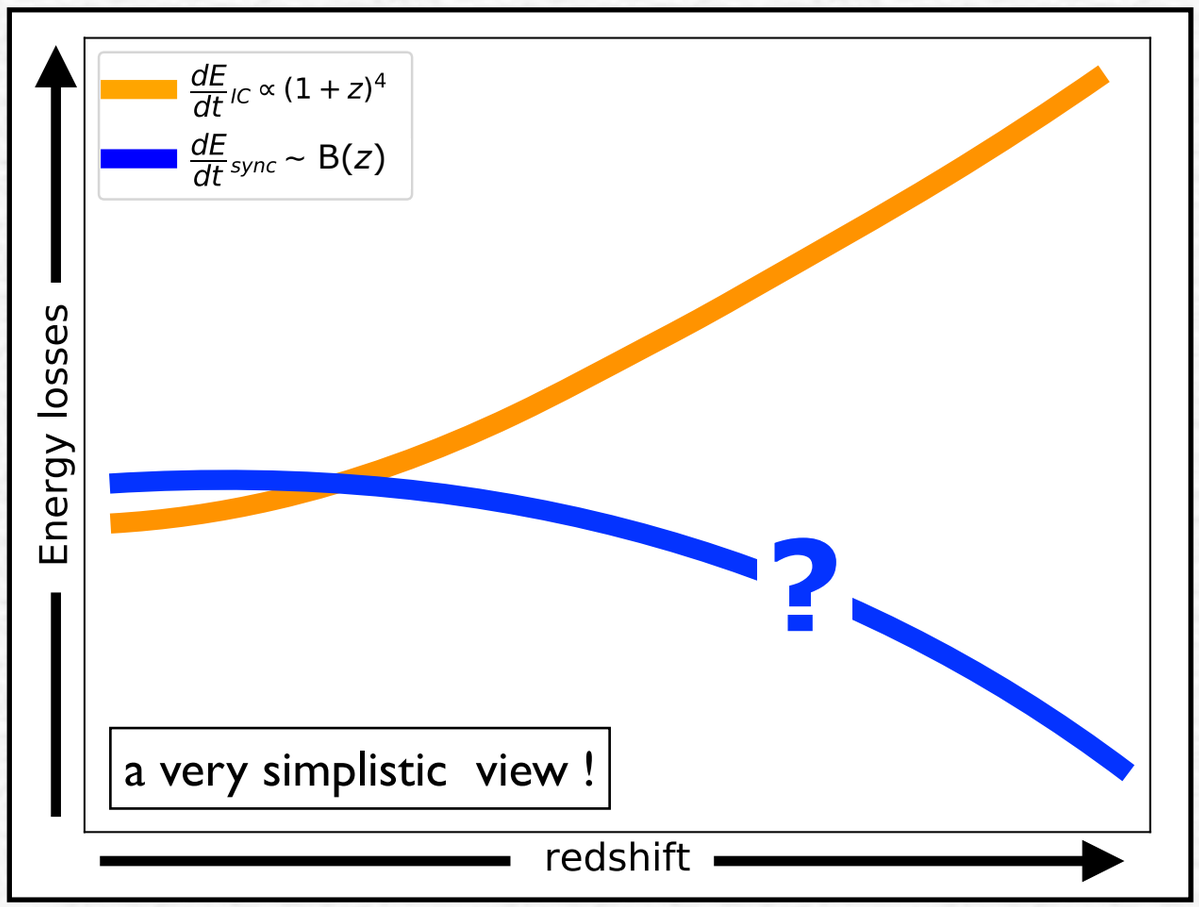


DETECTION OF RADIO HALOS AT HIGH z

MAGNETIC FIELD EVOLUTION



ENERGY LOSSES (SYNCHROTRON + IC) EVOLUTION



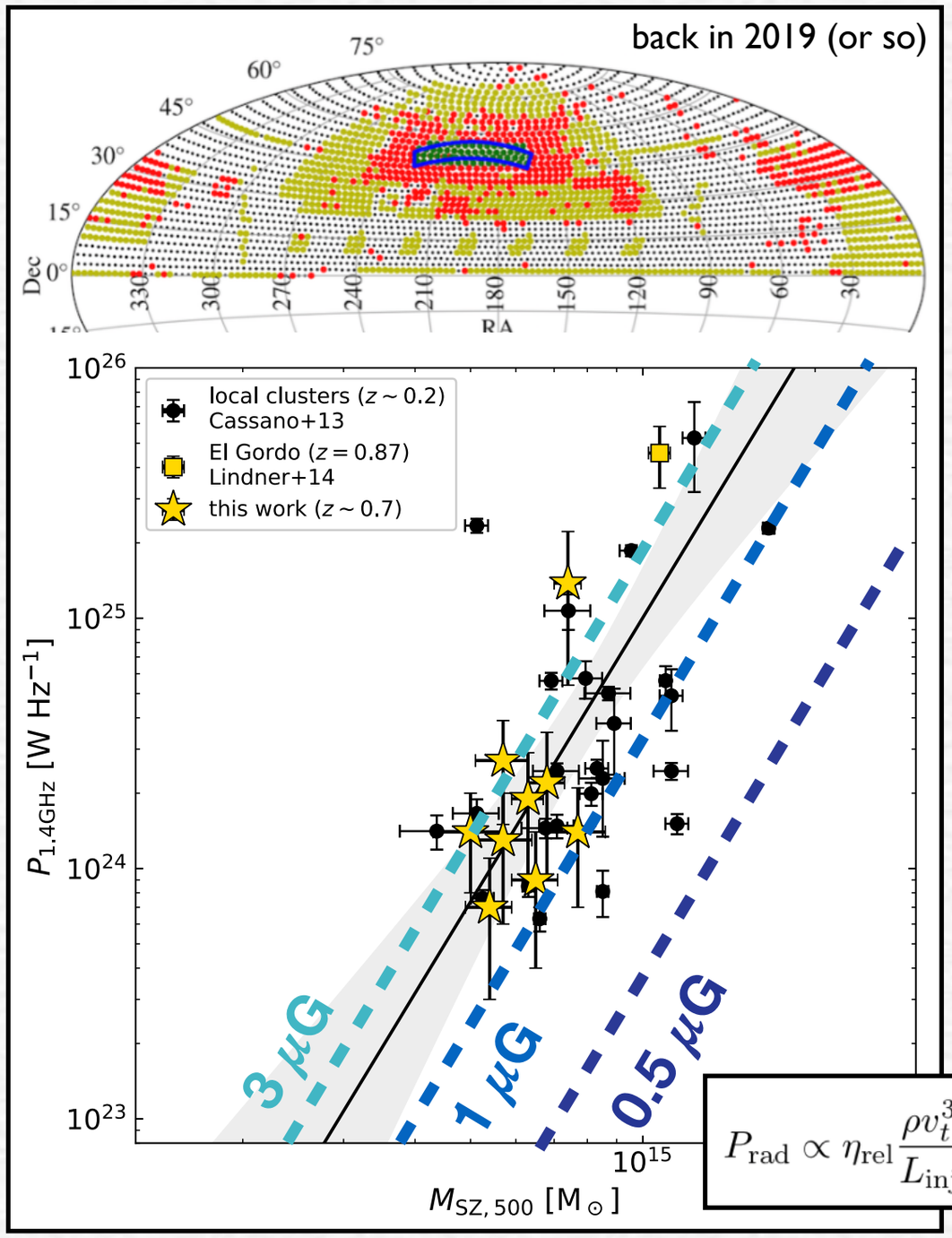
- **Prediction:** occurrence rate at *is lower* than in low-z clusters due to IC losses and they should have steeper spectra, $\alpha \lesssim -1.5$ (Cassano & Brunetti 2005, Cassano+2010)
- **Observations:** difficult, because such an emission is very faint (k-correction) and the resolution blurs radio sources

DETECTION OF RADIO HALOS AT HIGH z

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

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

FIRST ATTEMPT FOR A STATISTICAL STUDY

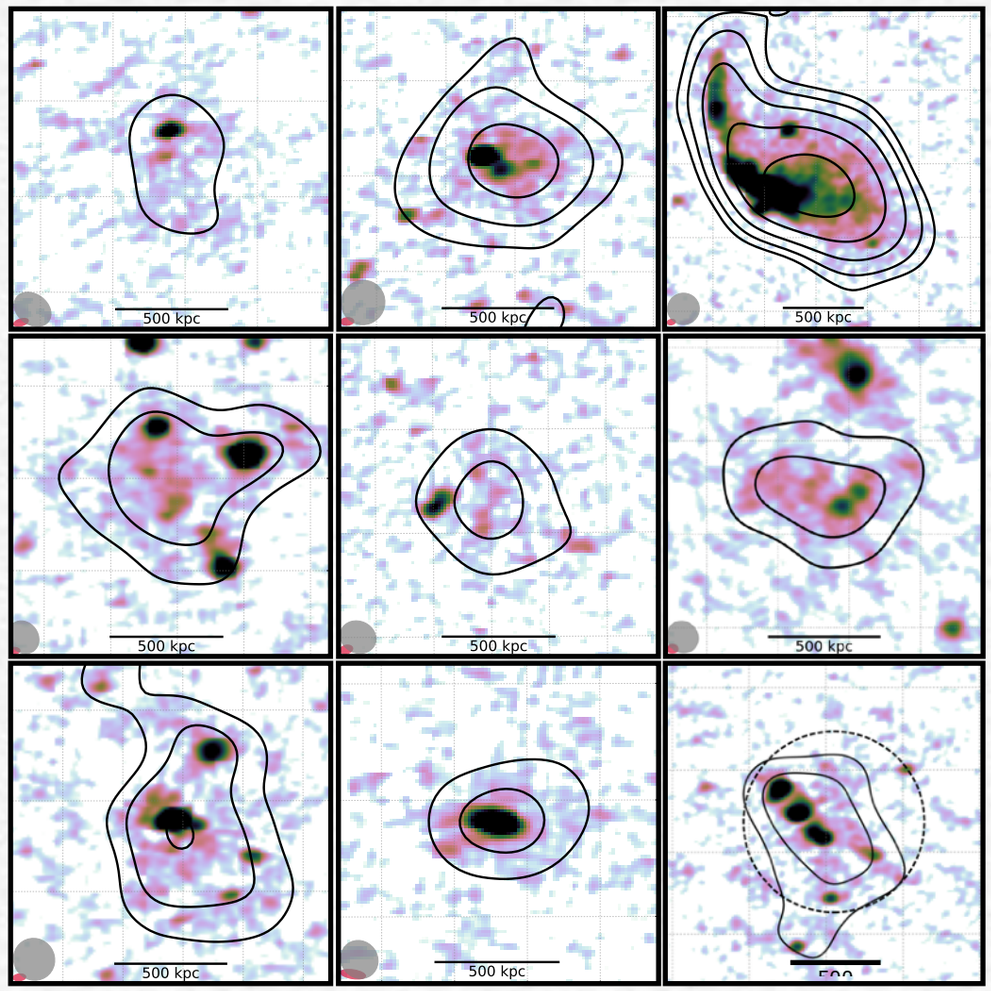


$$P_{\rm rad} \propto \eta_{\rm rel} \frac{\rho v_t^3}{L_{\rm inj}} \frac{B^2}{B^2 + B^2_{\rm CMB}}$$

What we did:

- All PSZ clusters in the available LoTSS pointings *and* new spectroscopically-confirmed systems
- $z > 0.6$, no cut in mass
- Dec > 20 deg (best LoTSS sensitivity)

➡19 clusters, 9 of which with diffuse radio emission



DETECTION OF RADIO HALOS AT HIGH z

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Di Gennaro+2021a, Nat. Astron., 5, 268 + Di Gennaro+2021b, A&A, 654, A166

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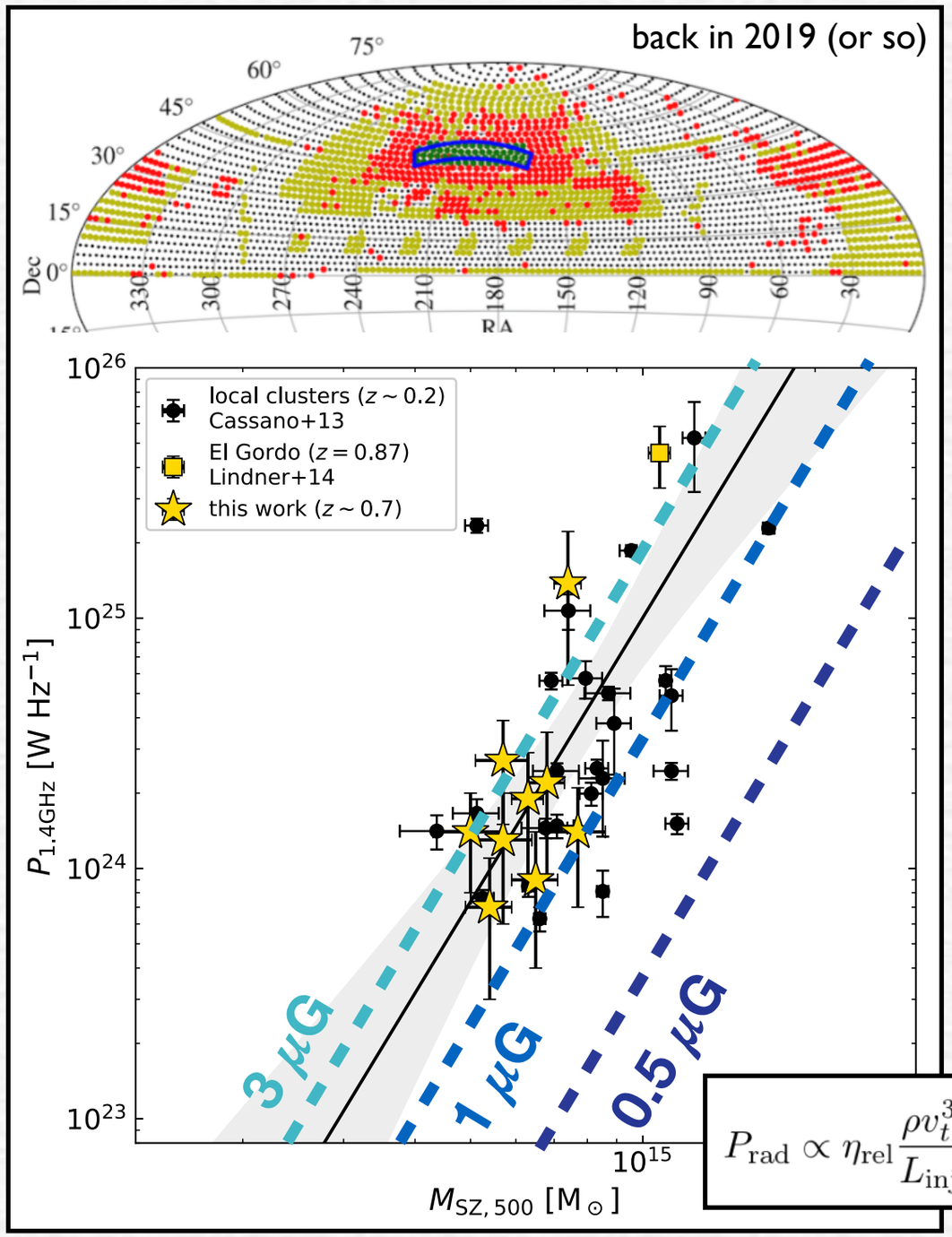

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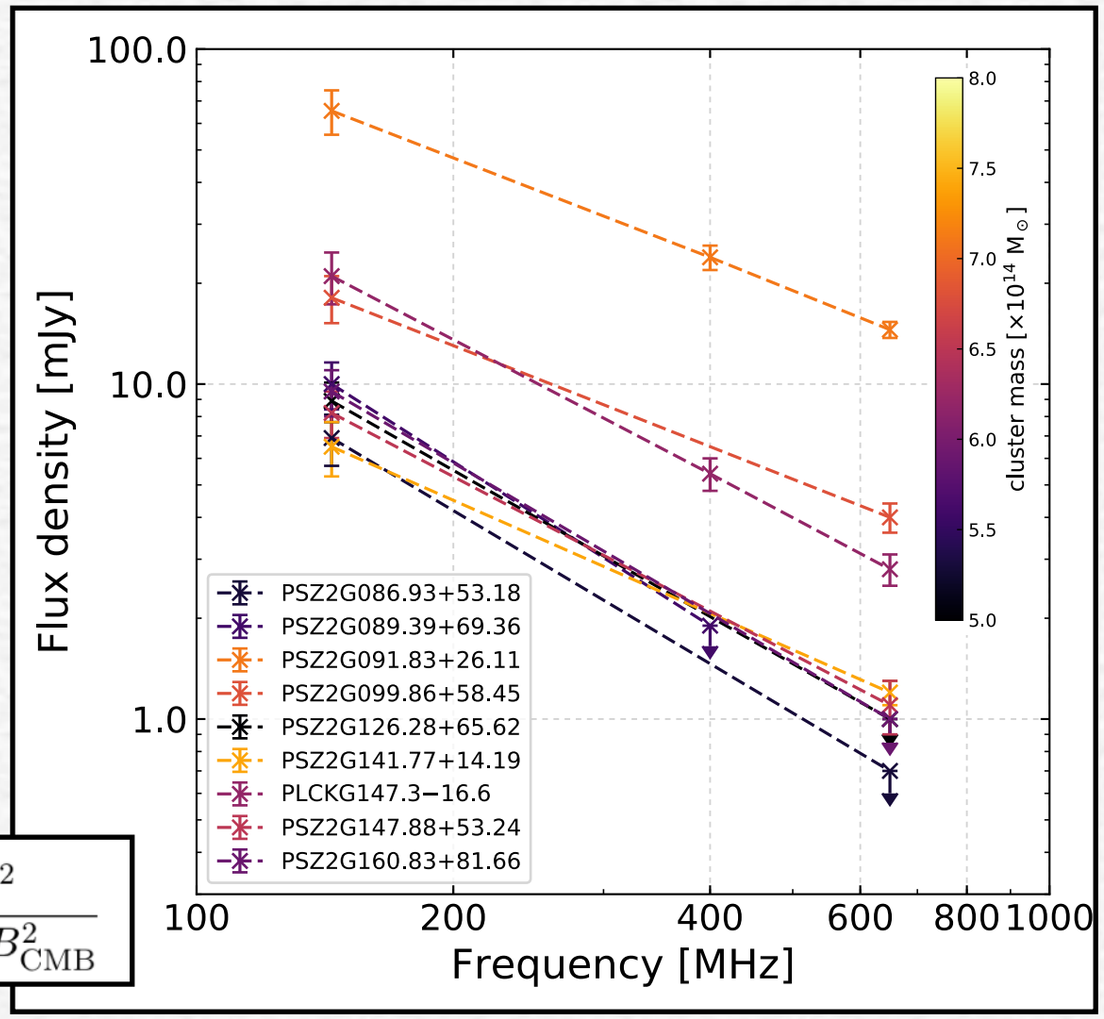

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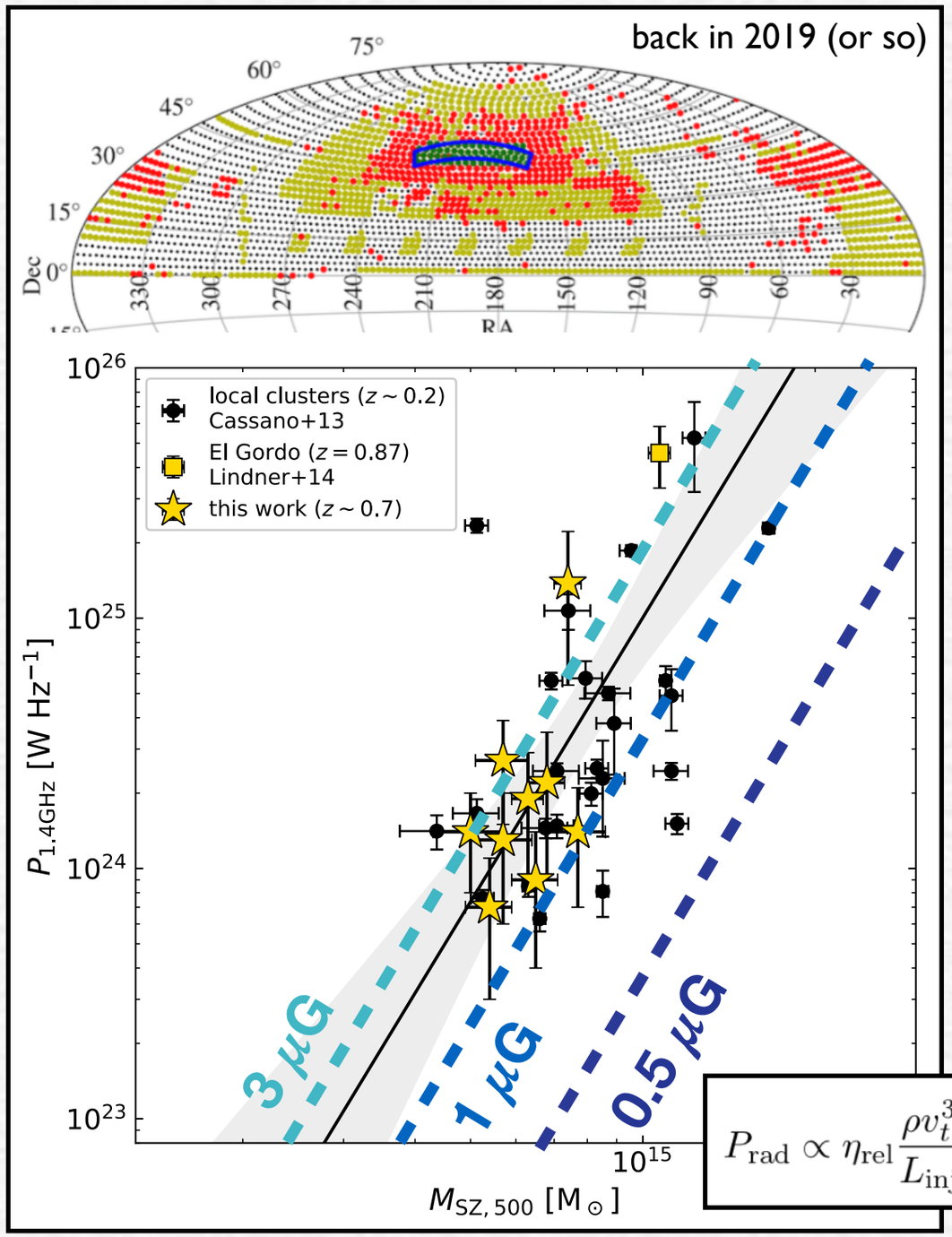

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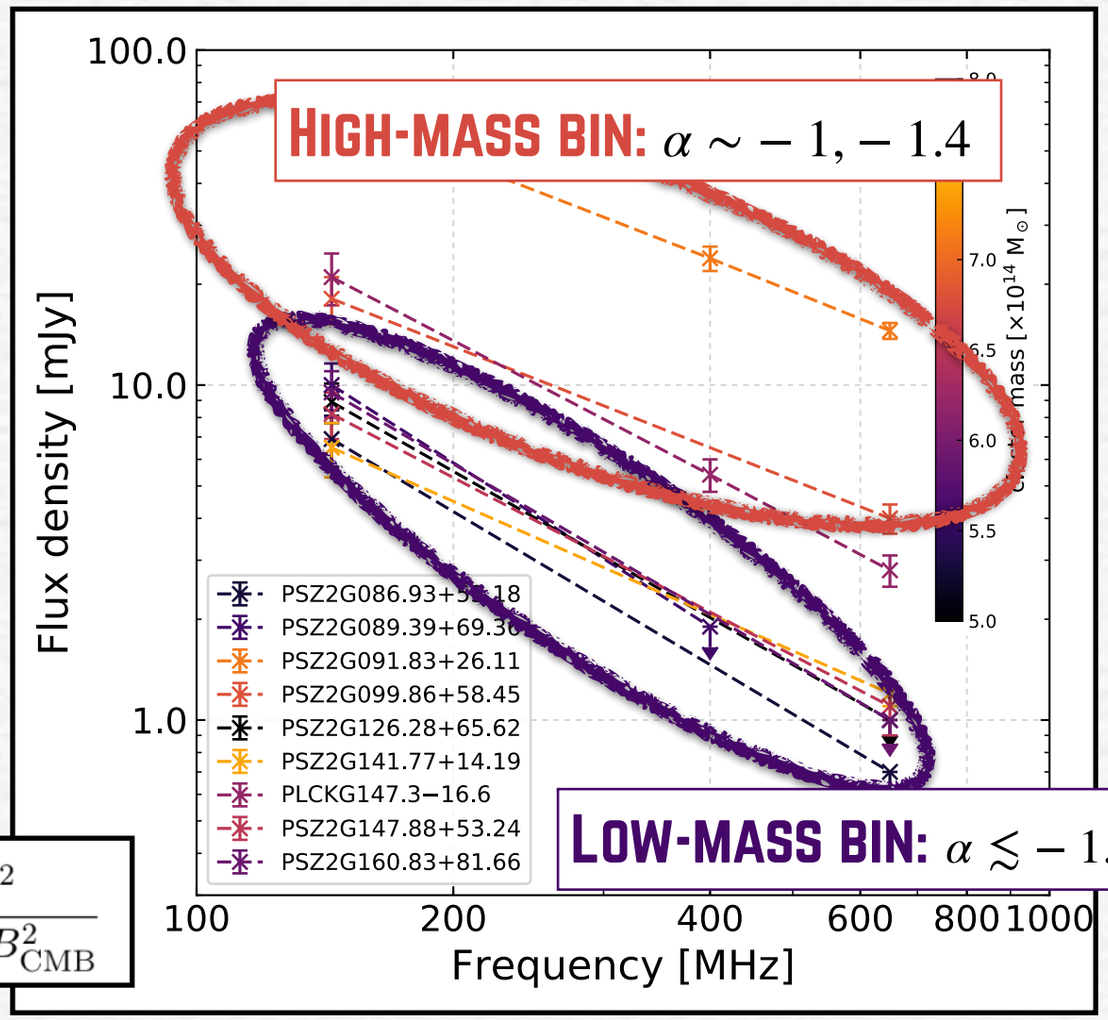

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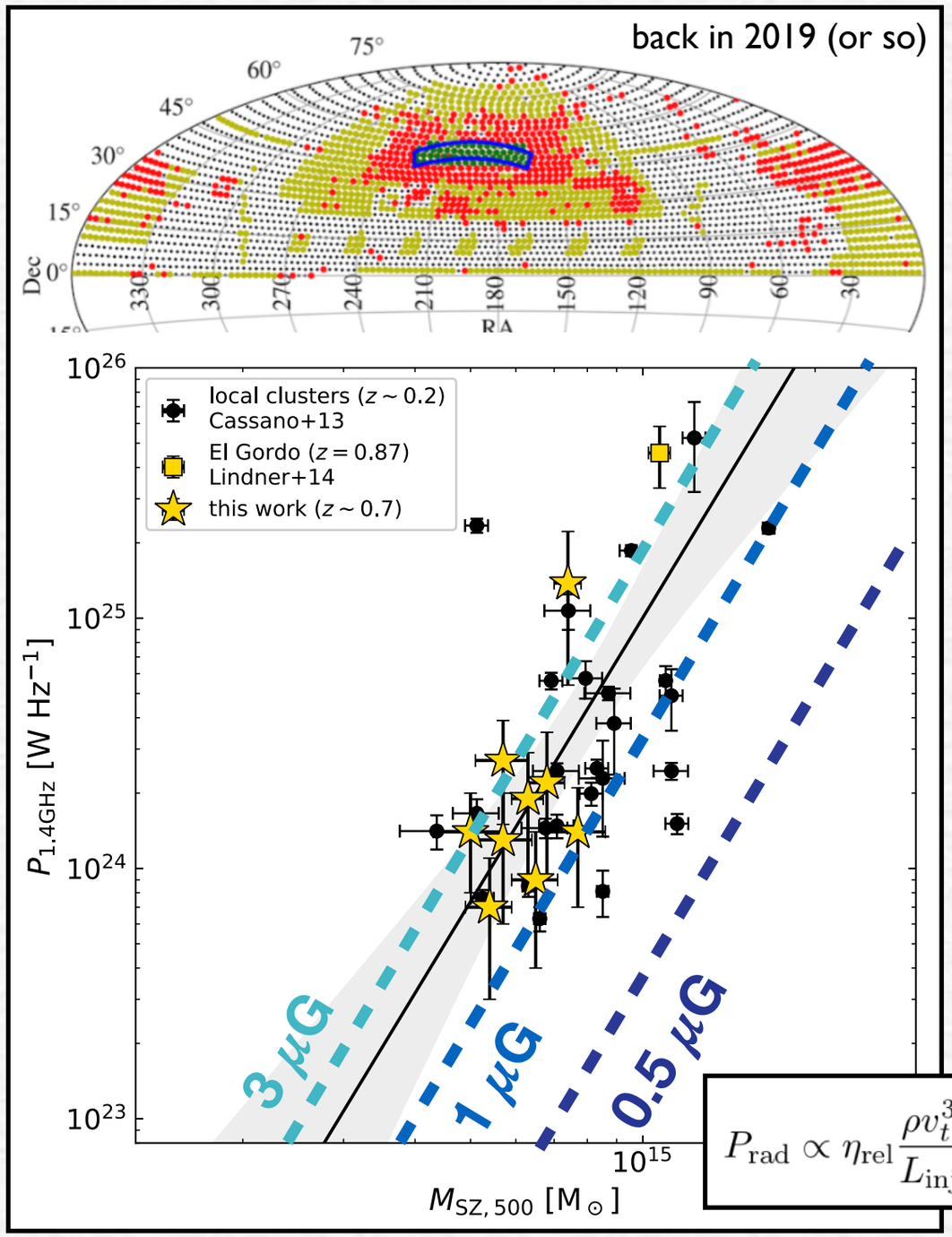

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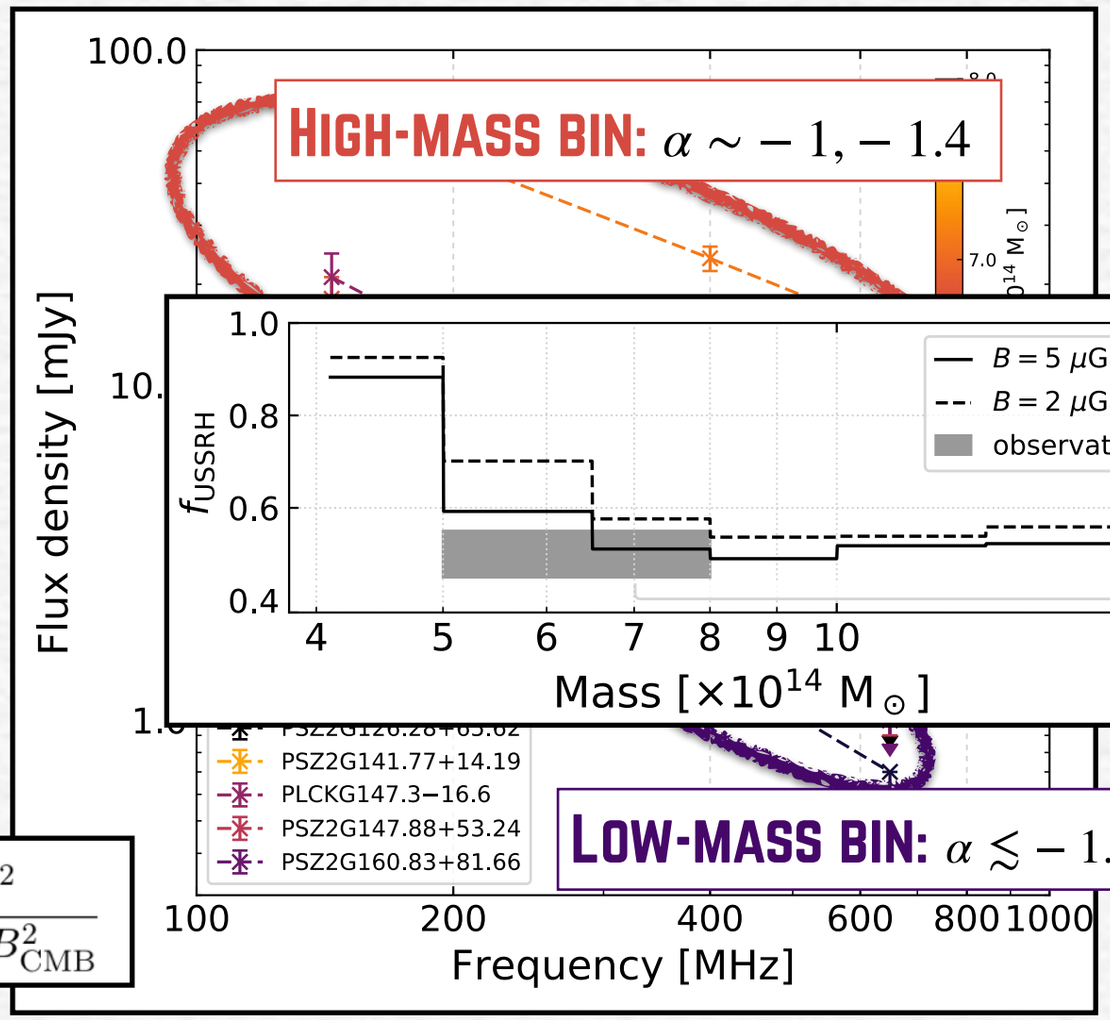
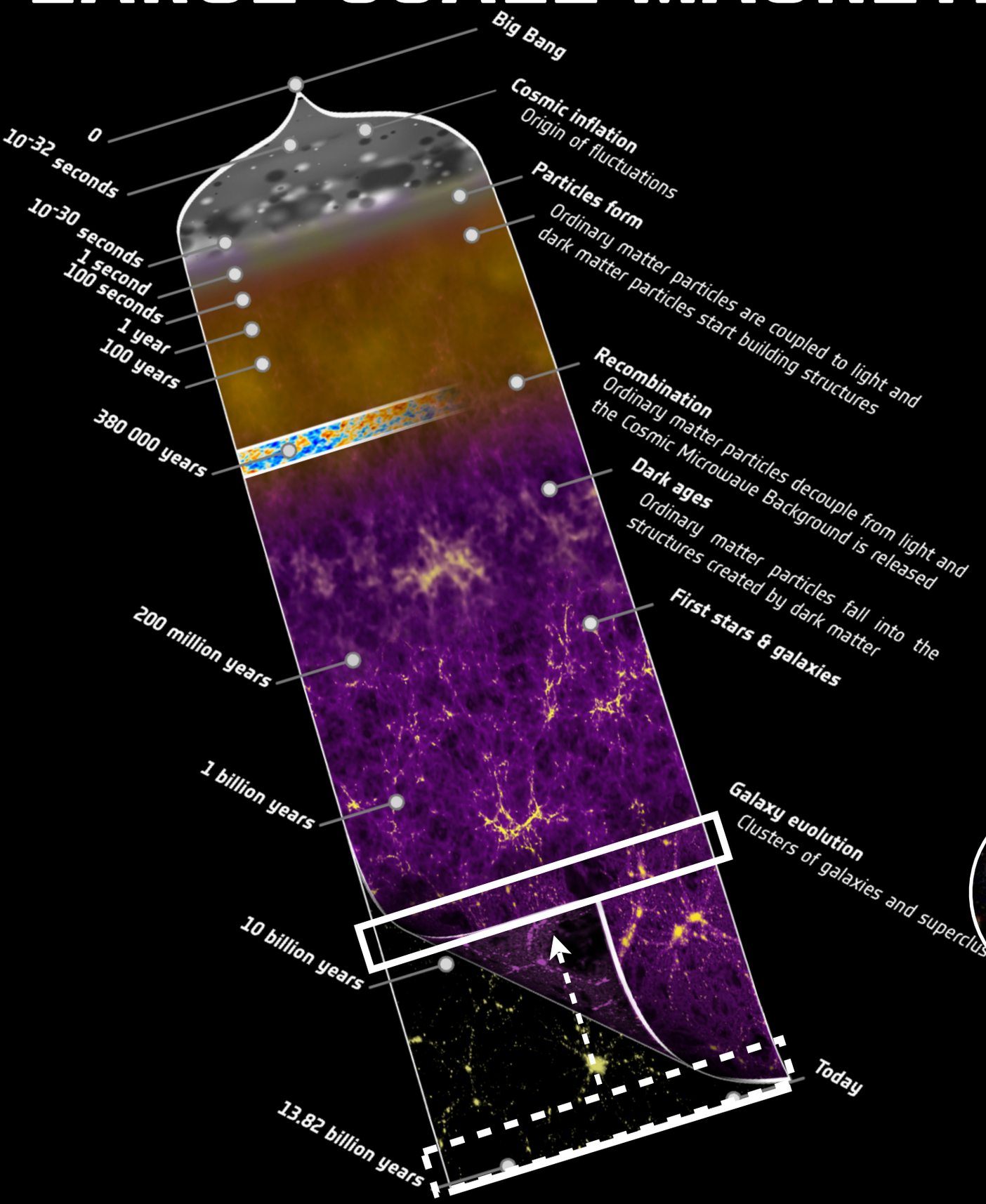
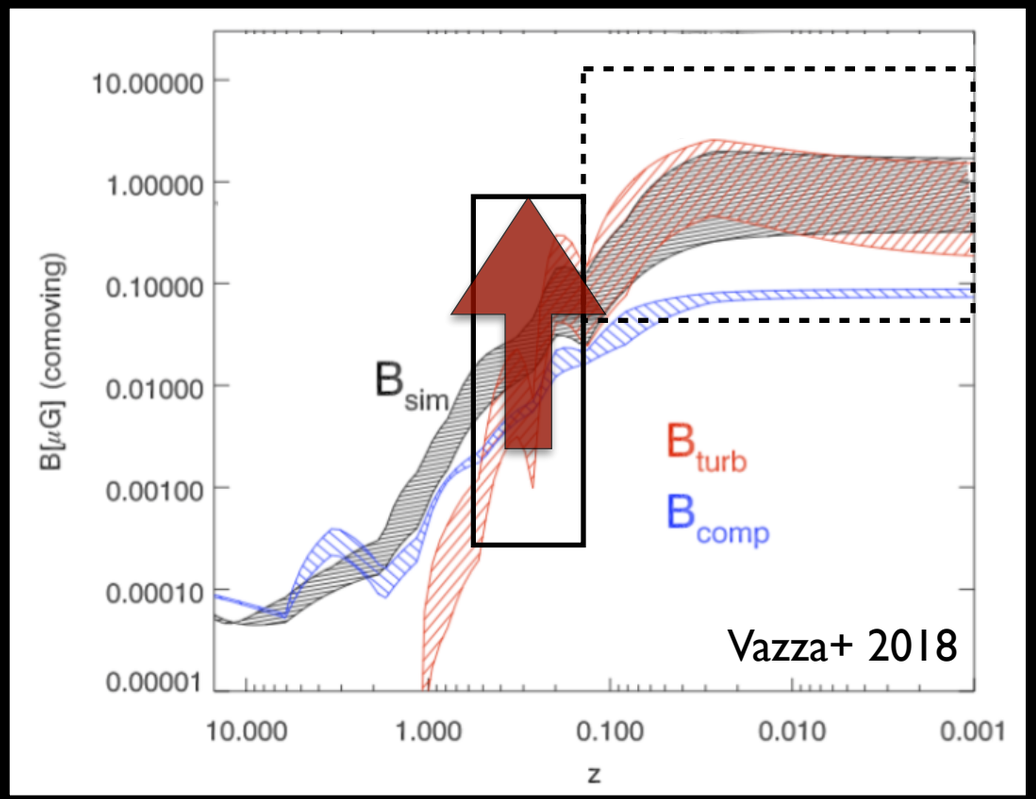


LARGE-SCALE MAGNETIC FIELD EVOLUTION



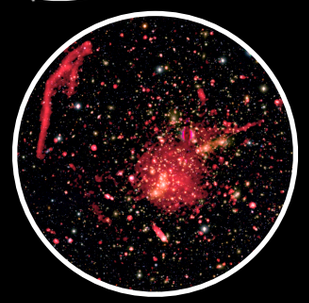


Universe age: ~7 billion years

- Fermi (re-)acceleration
- Magnetic field level: few μG

➡ Fast amplification

Additional findings: van Weeren+14, Cassano+19, Knowels+21, Botteon+22



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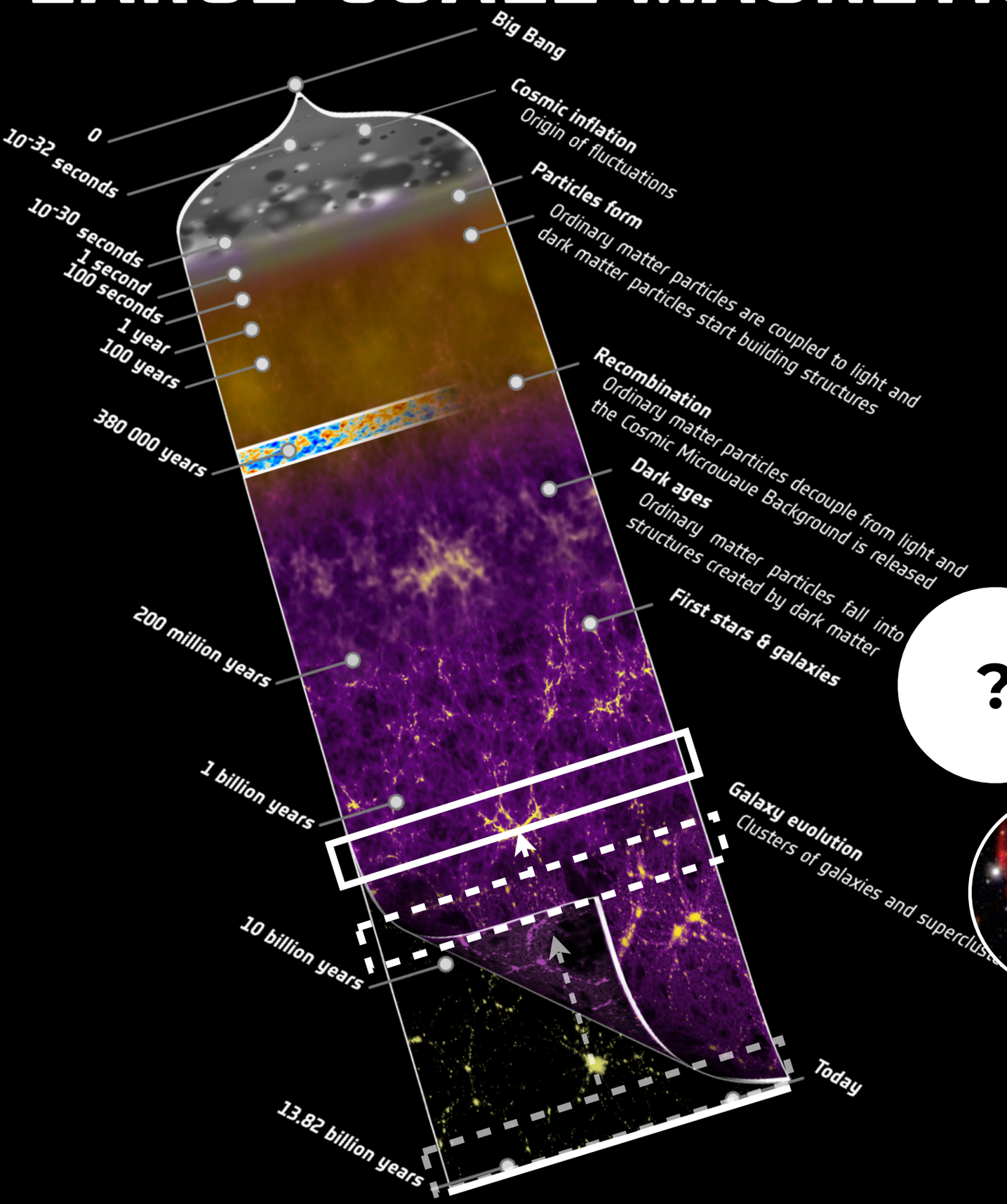

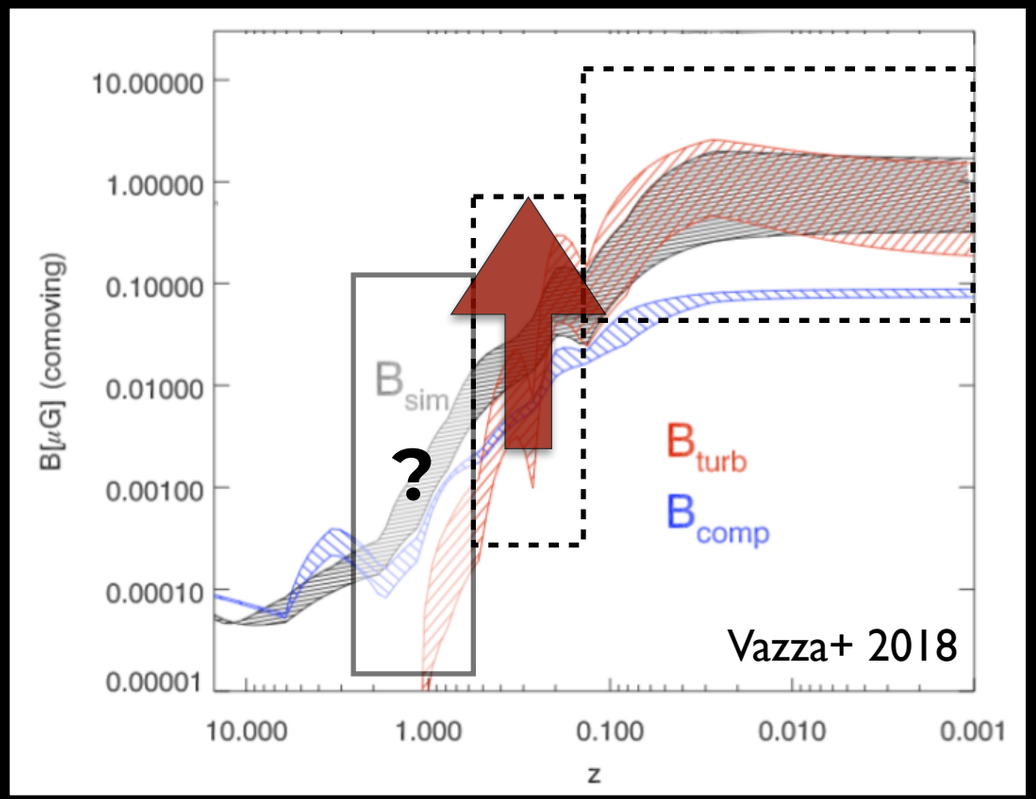

?

Universe age: ≪7 billion years

- Fermi (re-)acceleration: ?
- Magnetic field level: ?

Additional findings: Lindner+14, Di Mascolo+21, Sikhosana+24, Magolego+25, Phuravhathu+25, Hlavacek-Larrondo+25

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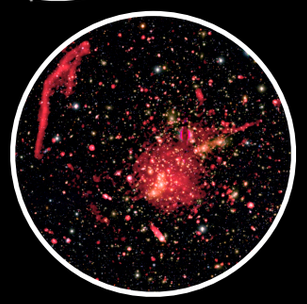
LOADING...



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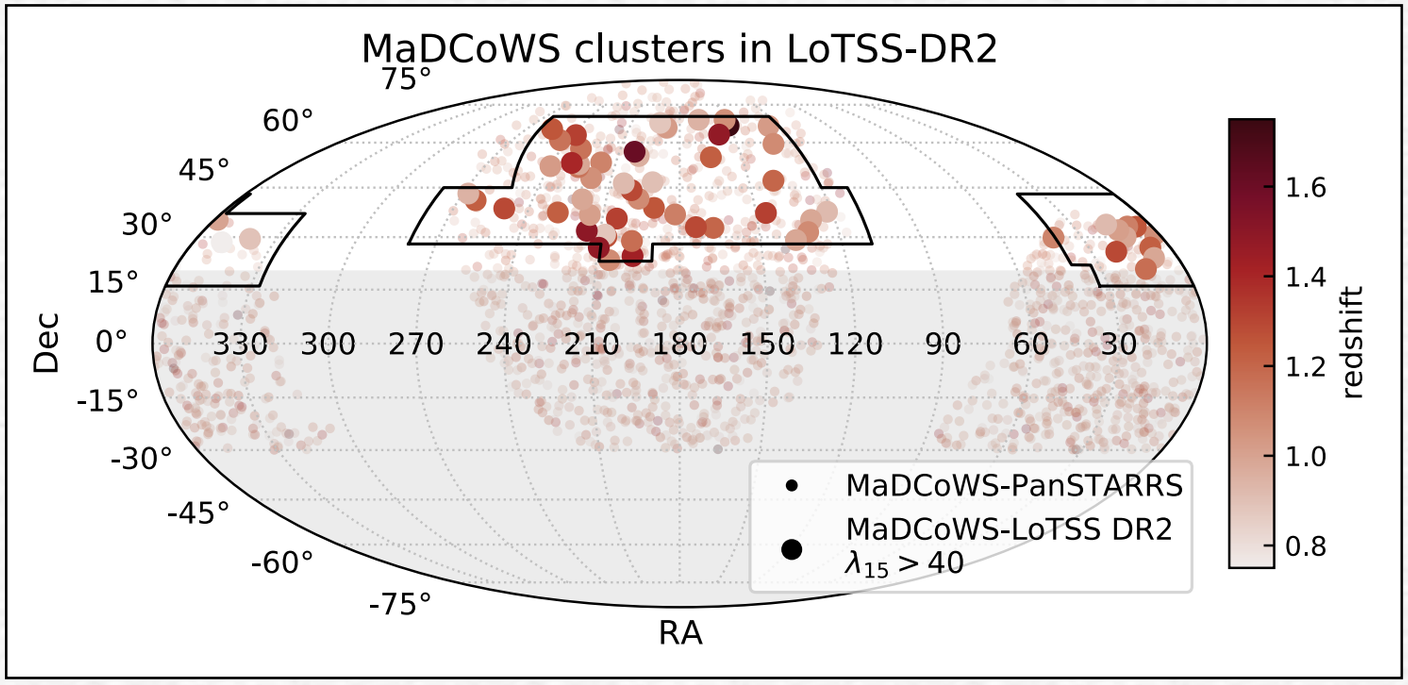
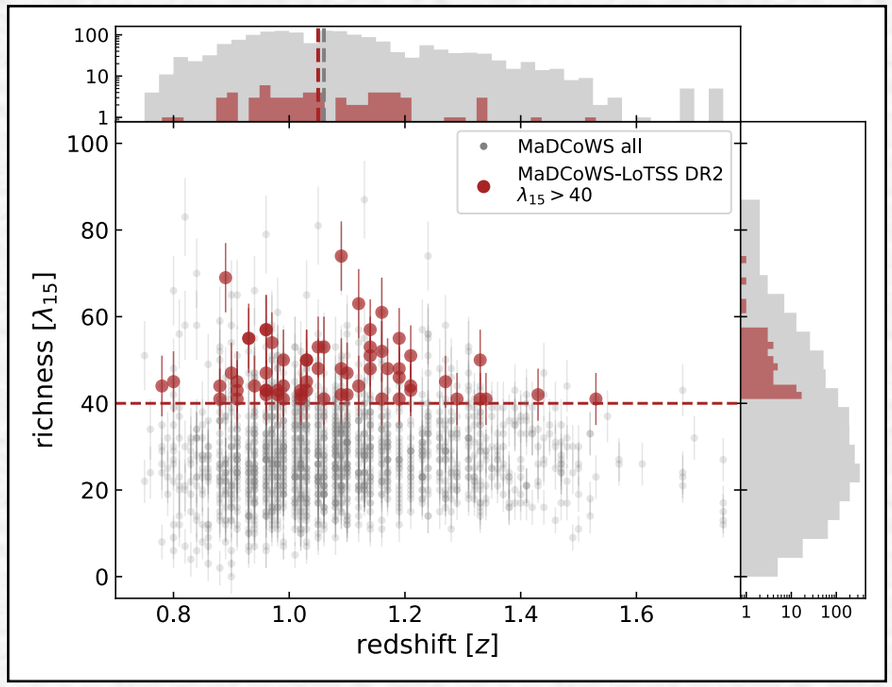
LARGER SAMPLE OF DISTANT RADIO HALOS

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

Di Gennaro+2025, A&A, 695, A215





PROs:

- Large sample (~500 clusters in LOFAR DR2; ~60 with $\lambda > 40$)
- Large (photometric) redshift coverage ($0.7 < z < 1.75$)

CONs:

- Large scatter in the conversion from richness (λ) to cluster mass ($M_{\mathrm{SZ},500}$)
- No X-ray available (so far) ⟶ SZ (!)

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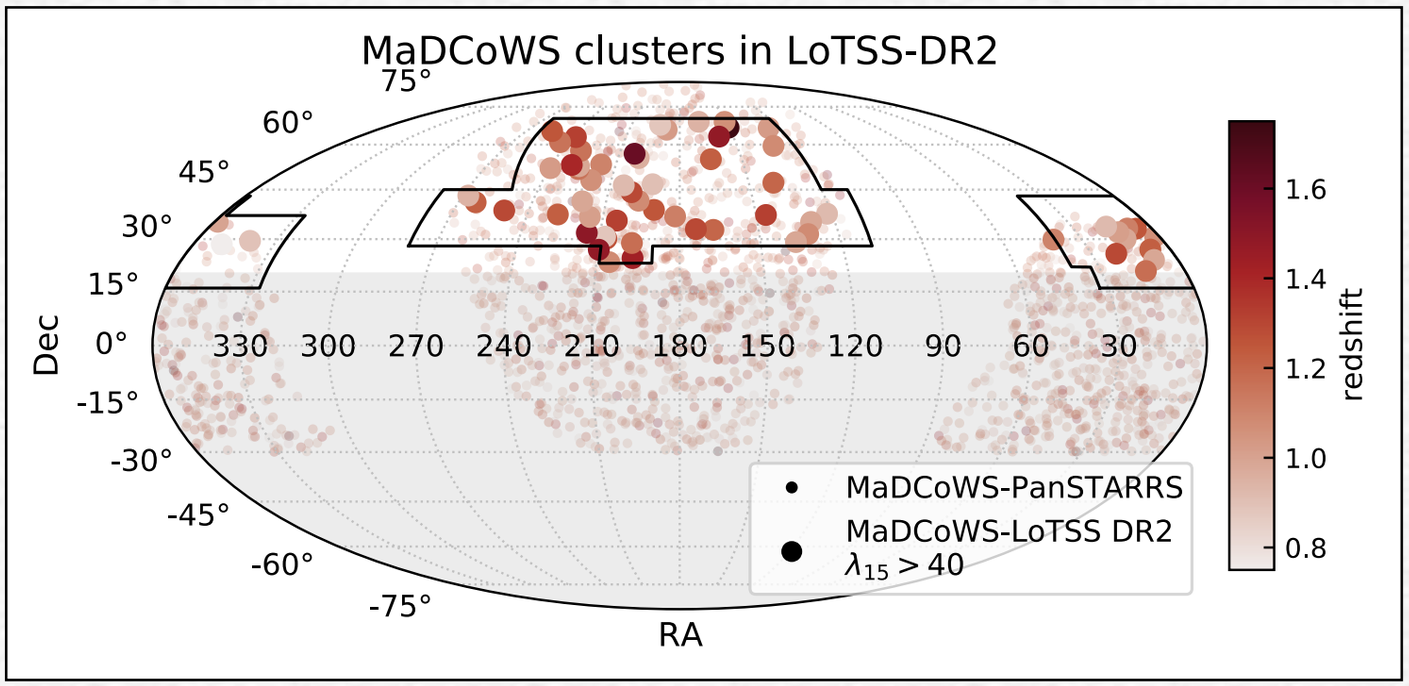

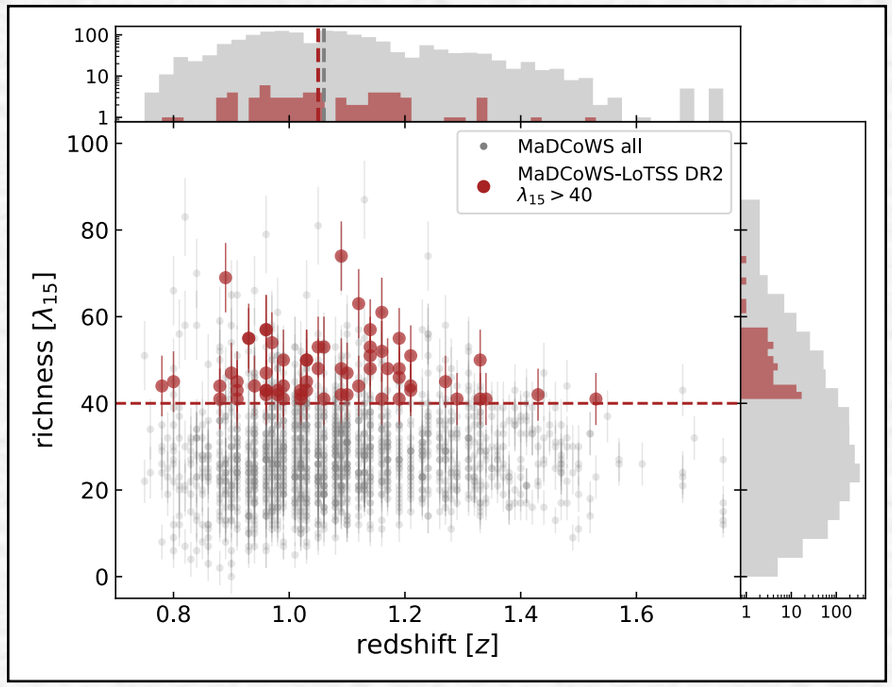

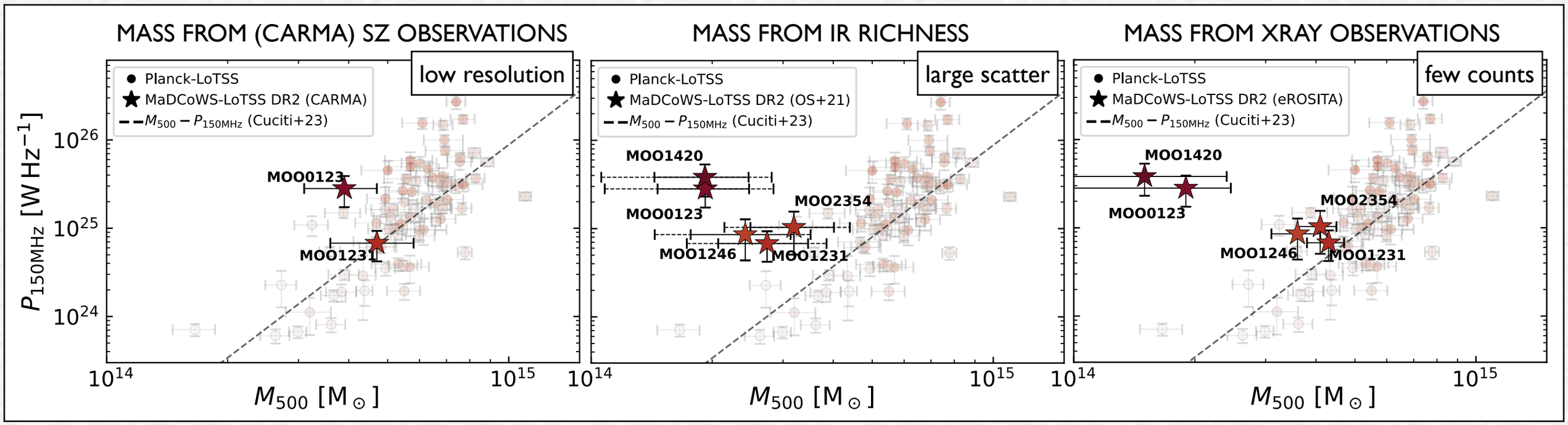

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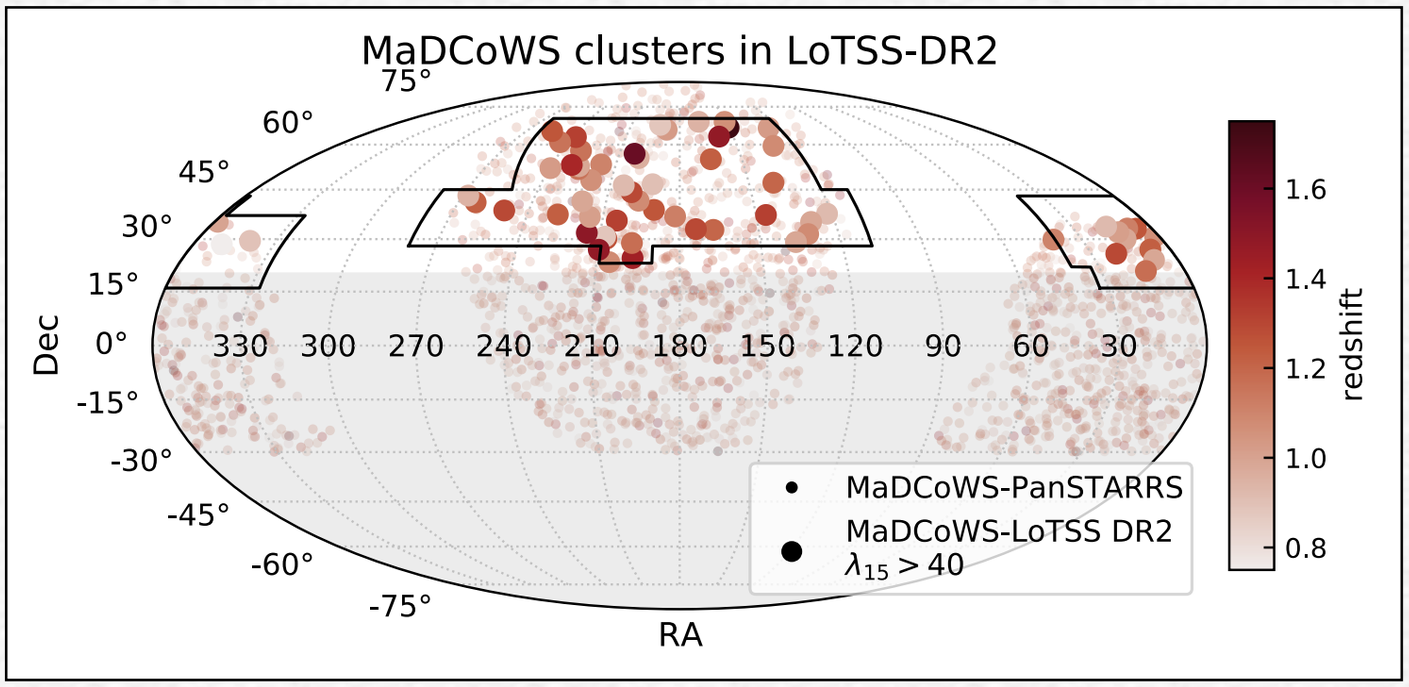
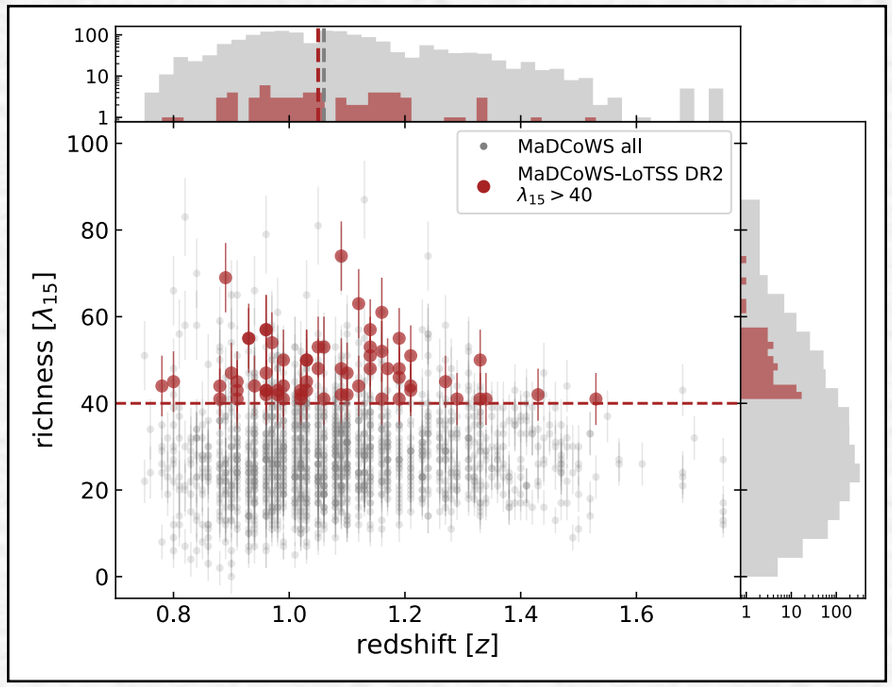
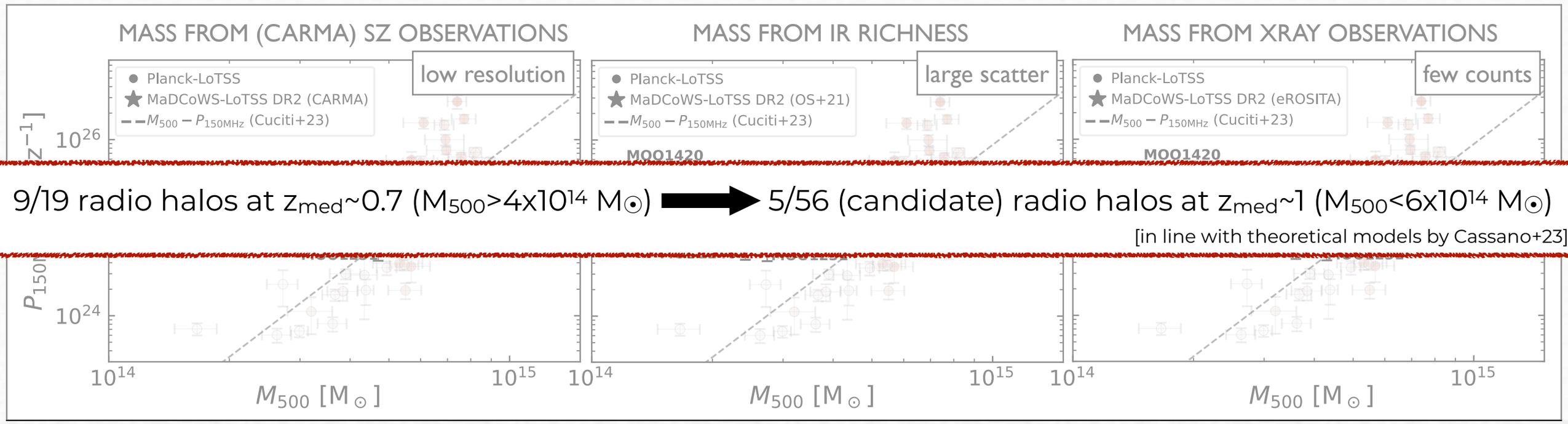


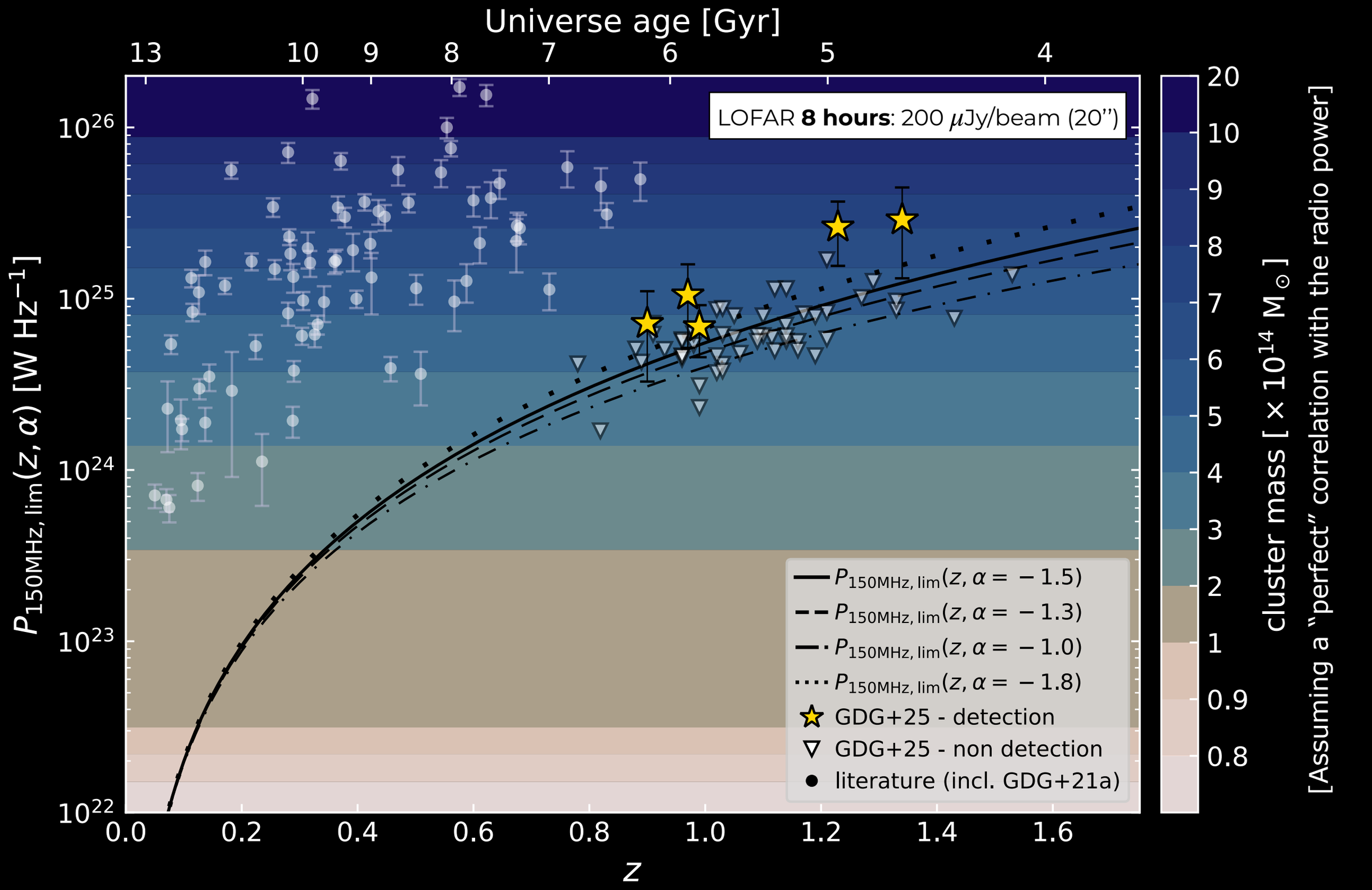




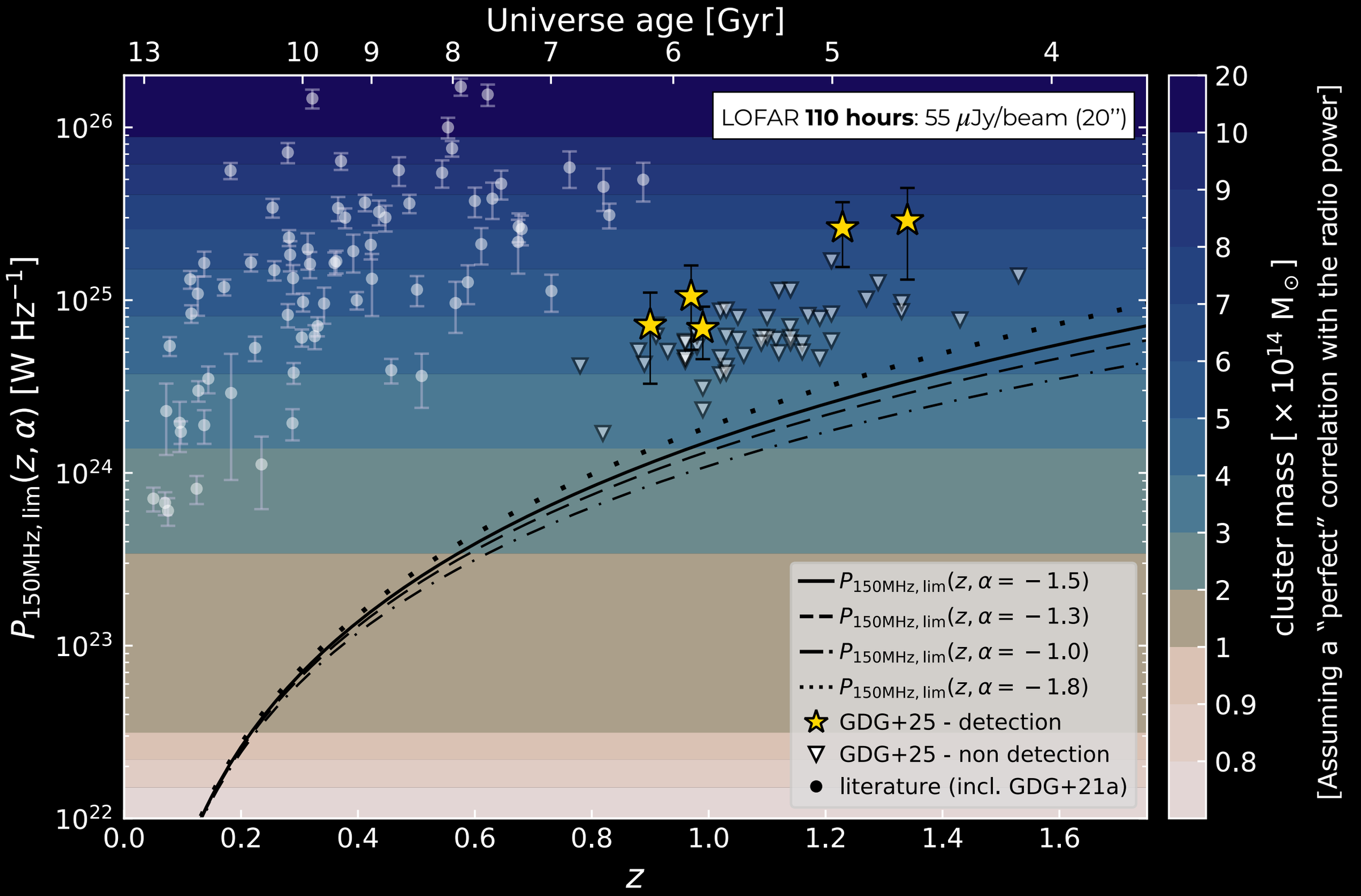
9/19 radio halos at z_{med}~0.7 (M_{500}>4x10^{14} $M_\odot$) → 5/56 (candidate) radio halos at z_{med}~1 (M_{500}<6x10^{14} $M_\odot$)

[in line with theoretical models by Cassano+23]

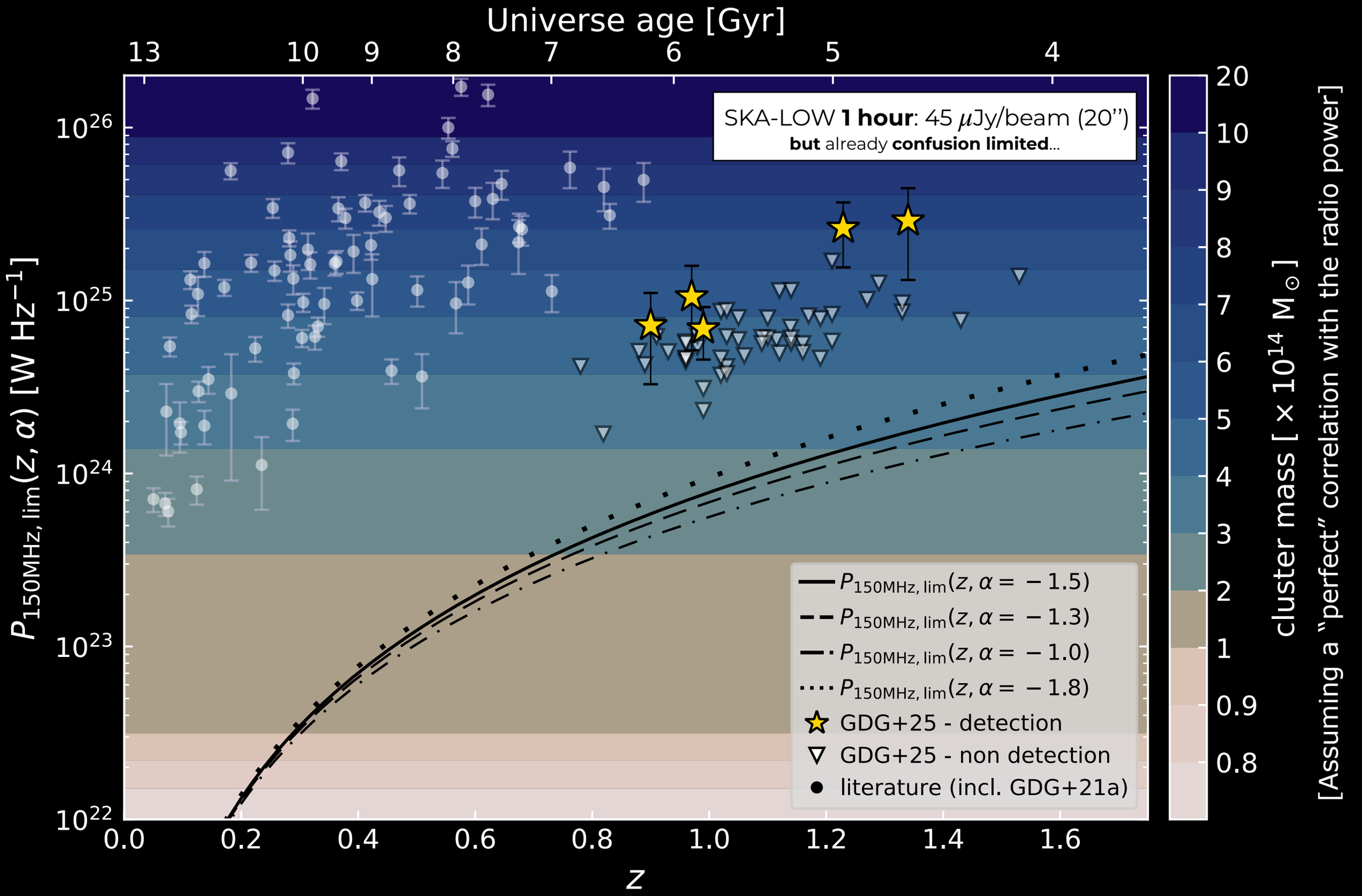
FROM LOFAR TO SKA-LOW



FROM LOFAR TO SKA-LOW

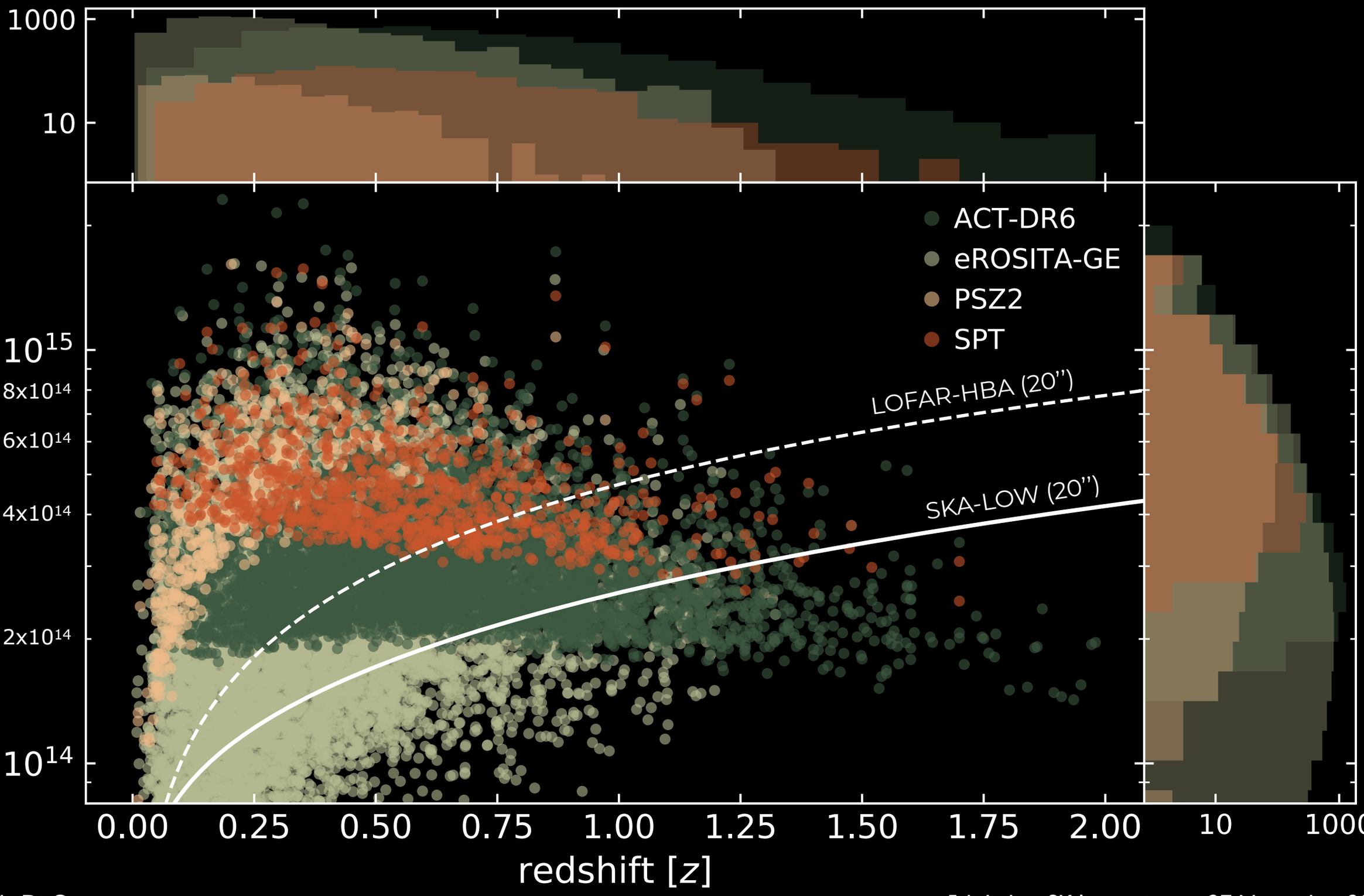


FROM LOFAR TO SKA-LOW



FROM LOFAR TO SKA-LOW

clusters in the SKA area



SUMMARY

- **LOFAR observations of a sample of galaxy clusters at z≥0.6**
  - Hints of decreasing occurrence rate of diffuse radio emission from z~0.7 (intermediate-high cluster masses) to z~1.0 (intermediate-low cluster masses)
  - magnetic field strength at high-z is similar to that at low-z

- **uGMRT follow-up for spectral index studies, i.e. test for the re-acceleration model**
  - Low-mass ($M_{500} < 6 \times 10^{14}$ $\mathrm{M}_{\odot}$) clusters have ultra-steep spectral indices (in agreement with theoretical expectations, see Cassano+23)

- **The impact of SKA on high-redshift studies of galaxy clusters**
  - Going down of a factor of 2 in the mass detection limit (about one order of magnitude in 150 MHz radio power)
  - Confusion limited already after 1 hr of observations ⟶ SKA-LOW + SKA-MID

Thank you