Resolving the growth of the ICM at $z > 1.2$ with MUSTANG-2 and ALMA

ReCESS: the Resolved Cluster Evolution Sunyaev-Zeldovich Survey

Joshiwa van Marrewijk,
Allegro postdoc, This work is done in collaboration with ACT, Luca Di Mascolo & Tony Mroczkowski

How does really hot, low-density gas form?

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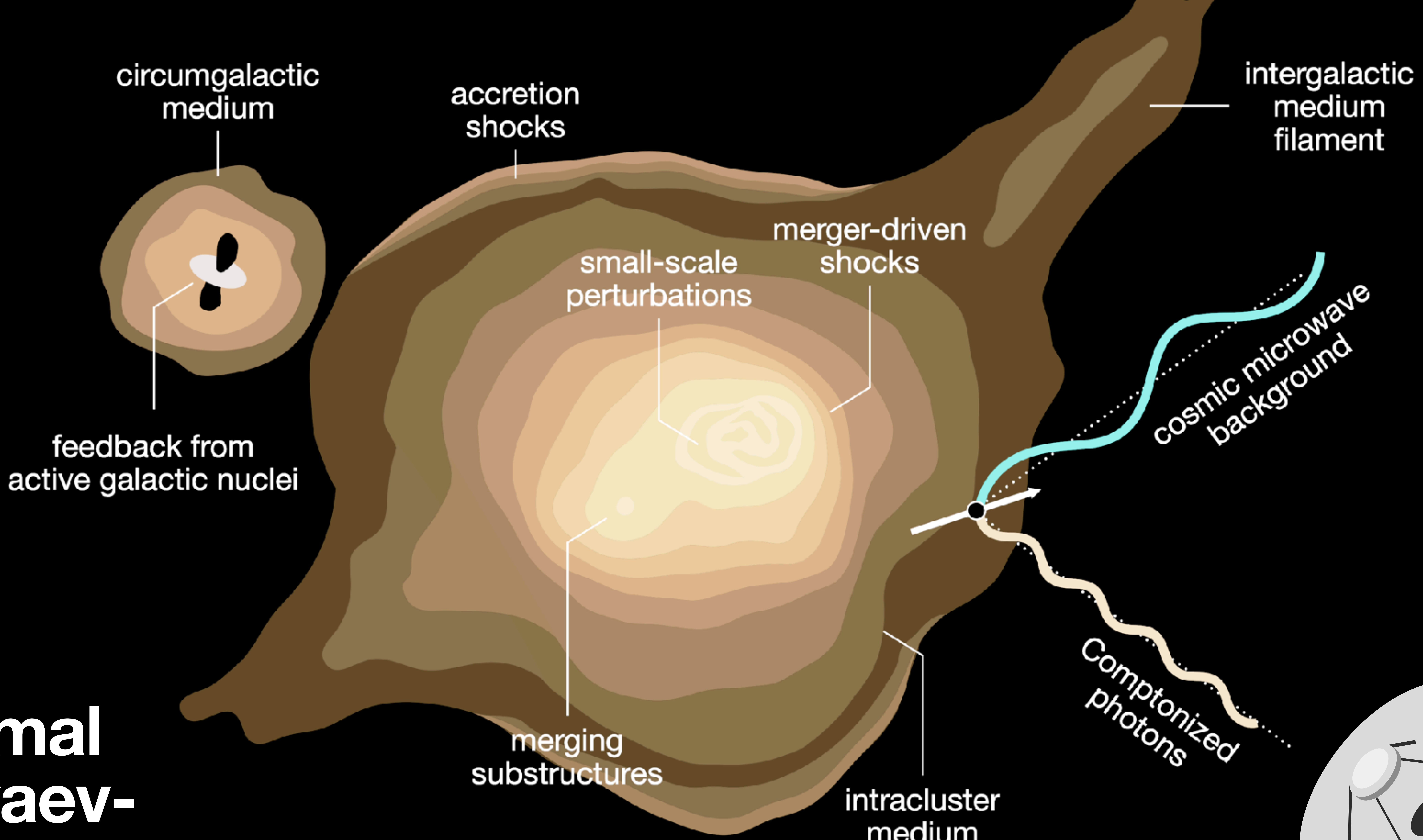
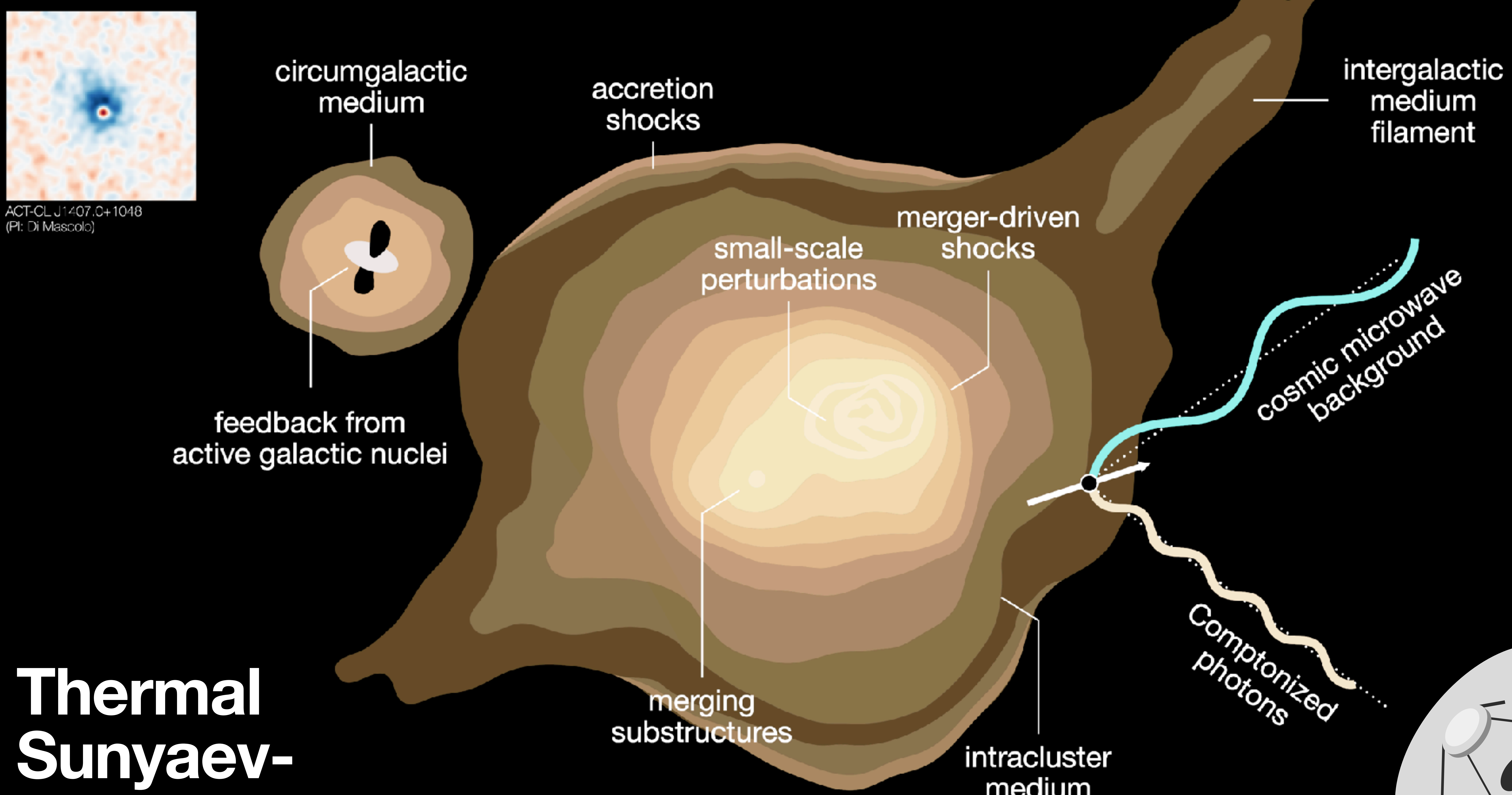


Thermal Sunyaev-Zeldovich effect (tSZ effect)



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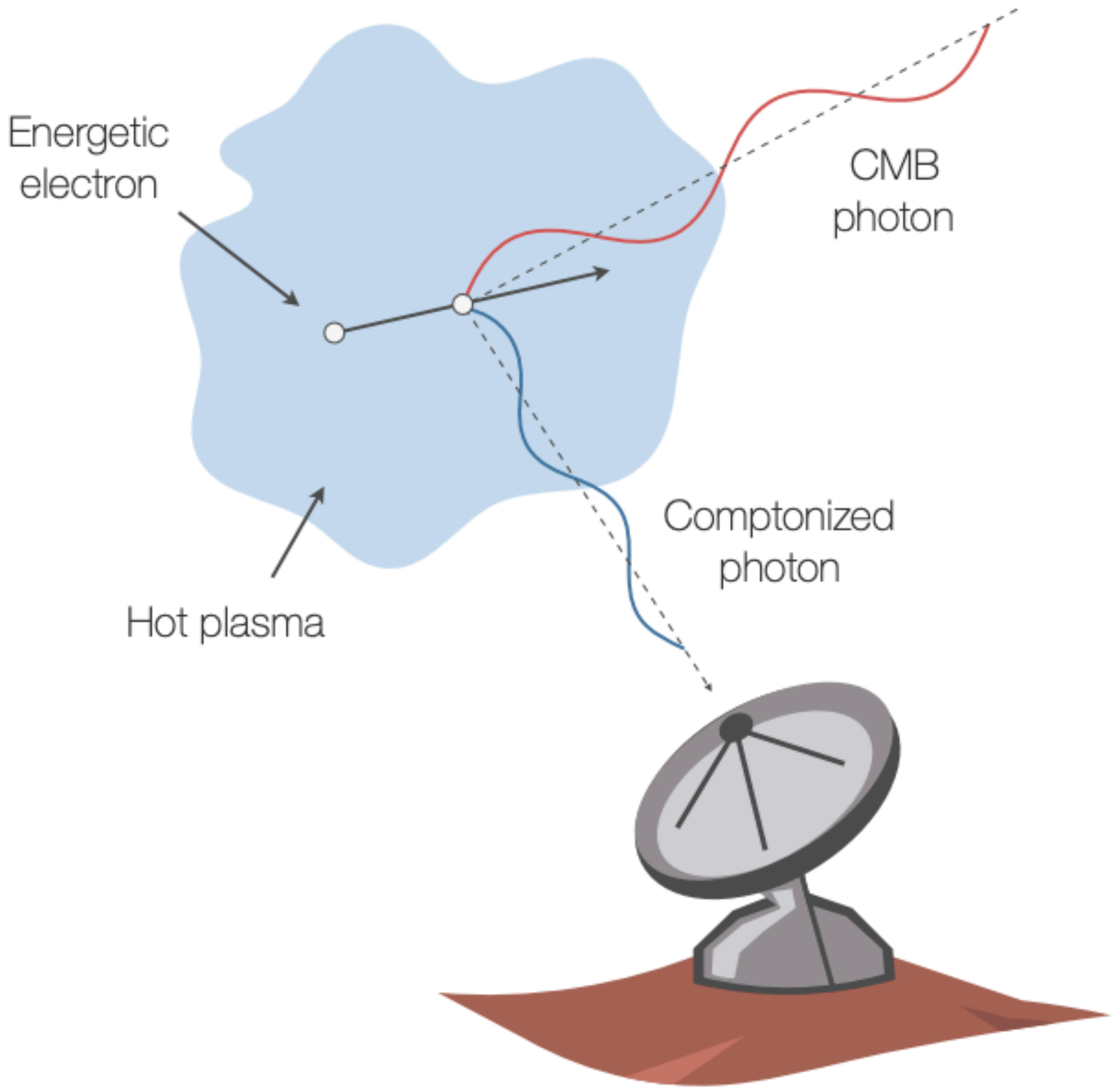
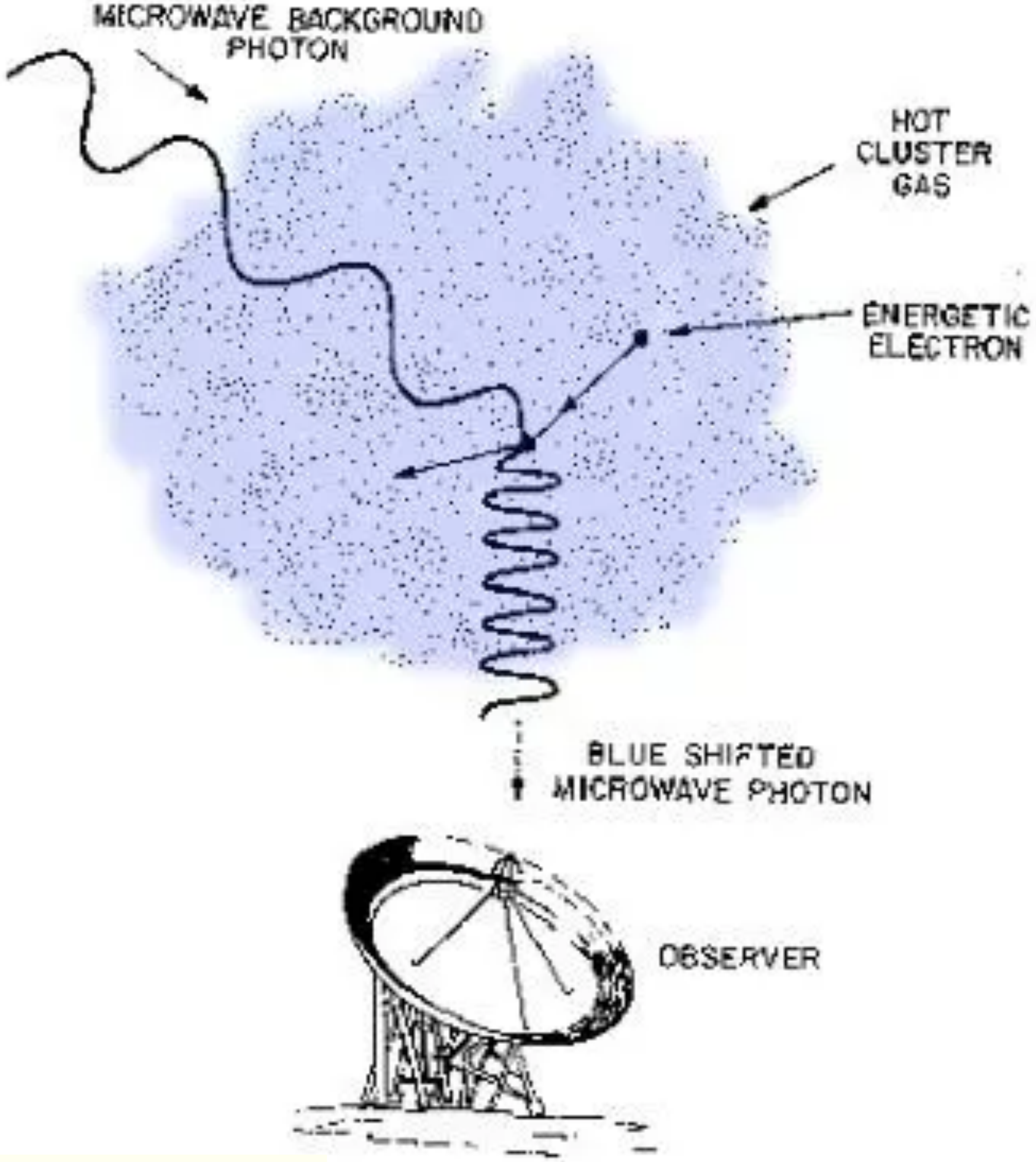


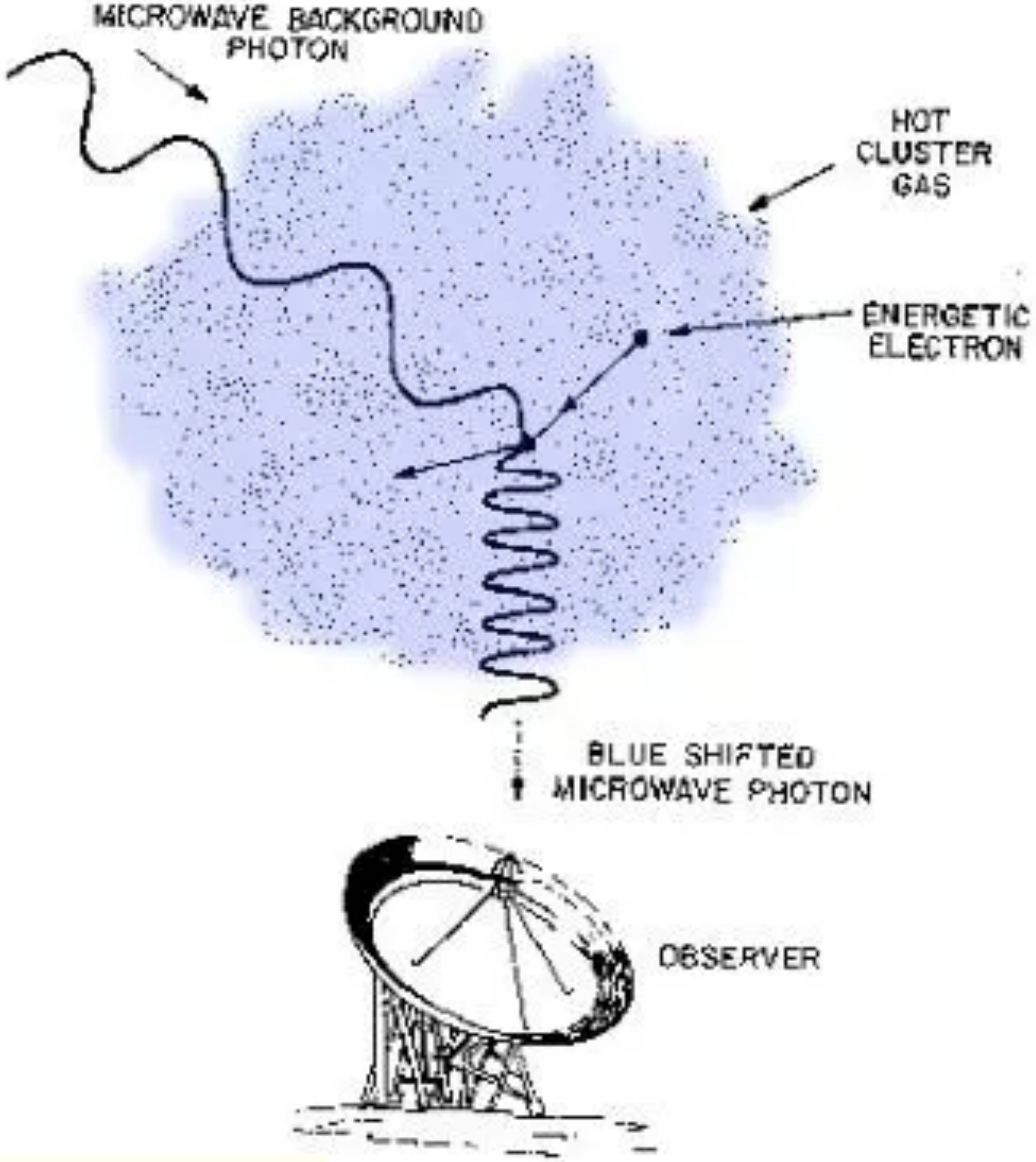
T. Mroczkowski+2019

SUNYAEV-ZELDOVICH EFFECT



L. Van Speybroeck (1999)

SUNYAEV-ZELDOVICH EFFECT



L. Van Speybroeck (1999)

Sunyaev-Zeldovich (1972)

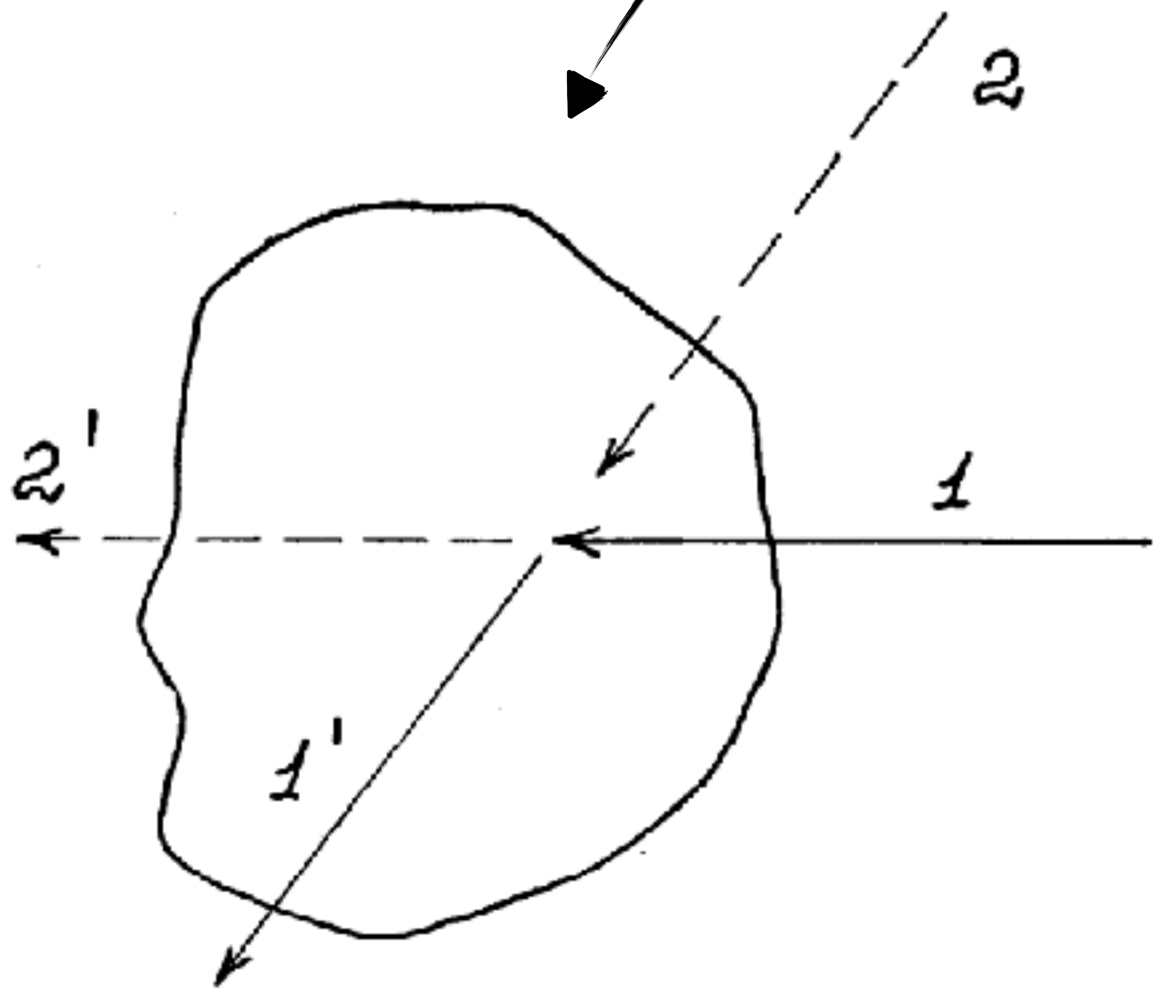
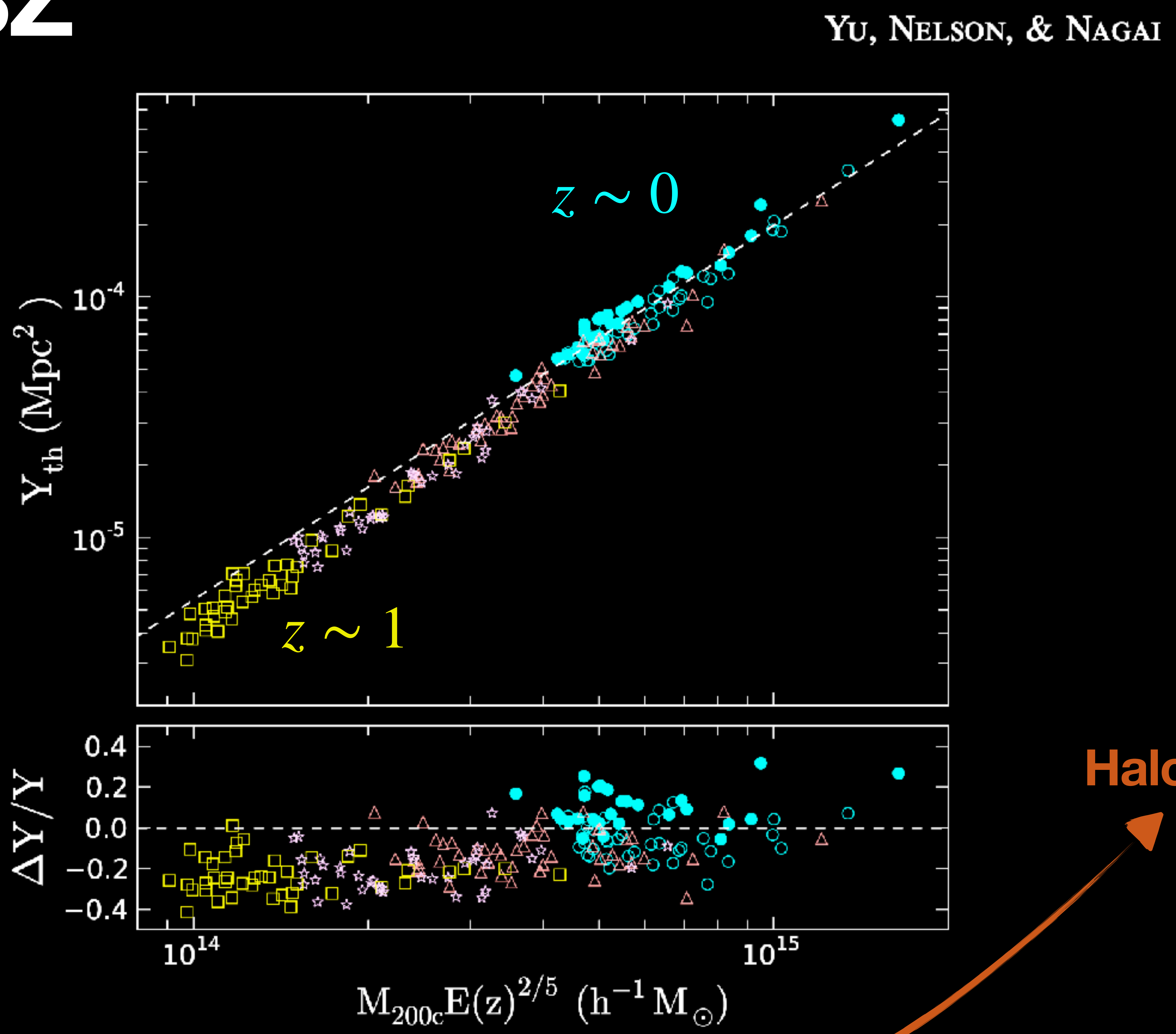


FIG. 2. The scattering of isotropic radiation field by the cloud of electrons.

How to use the SZ effect for Cosmology:



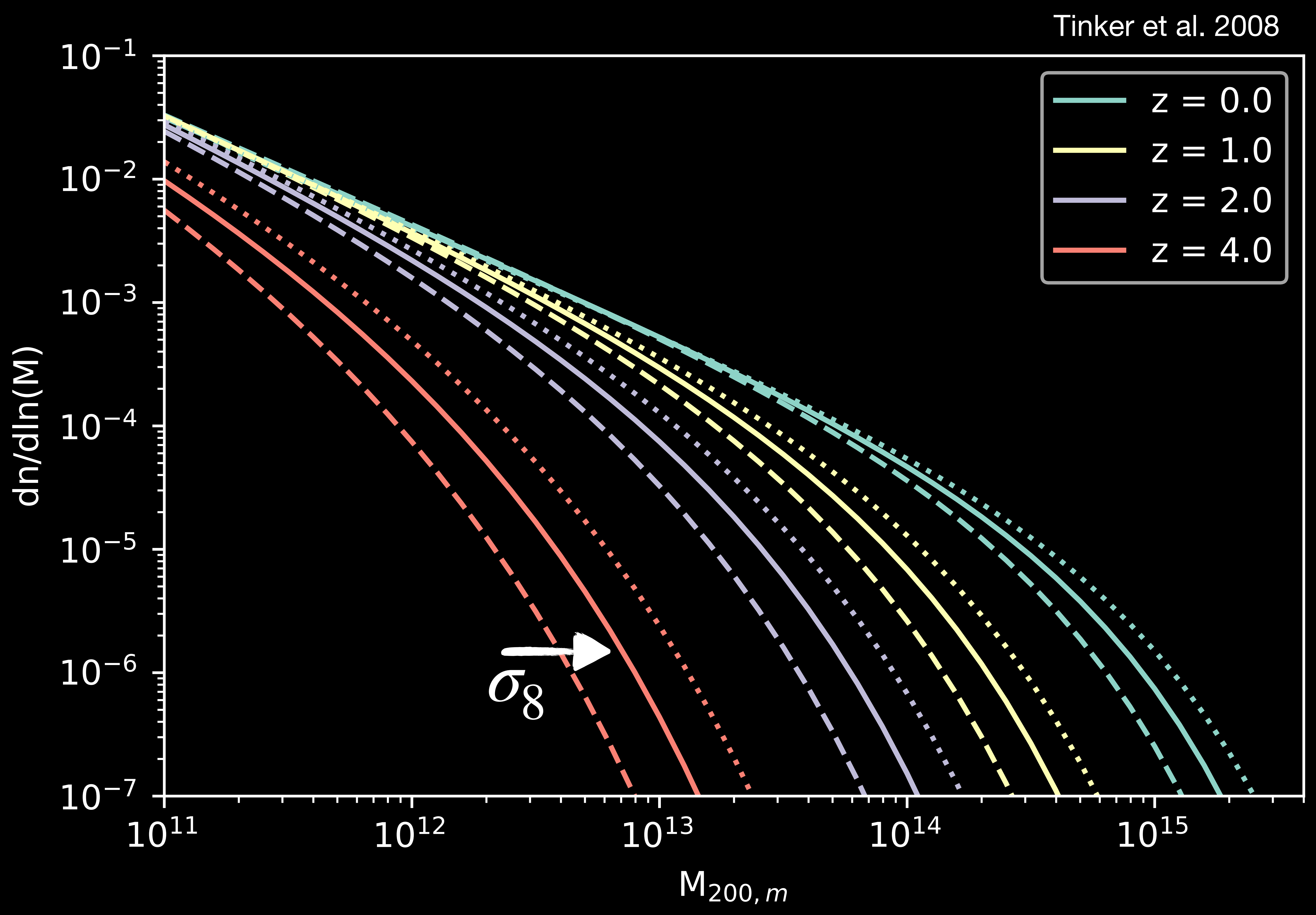
Total integrated flux

Halo Mass

$$M_{200,c} = 200\ \rho_c \times \frac{4}{3}\pi r_{200,c}$$

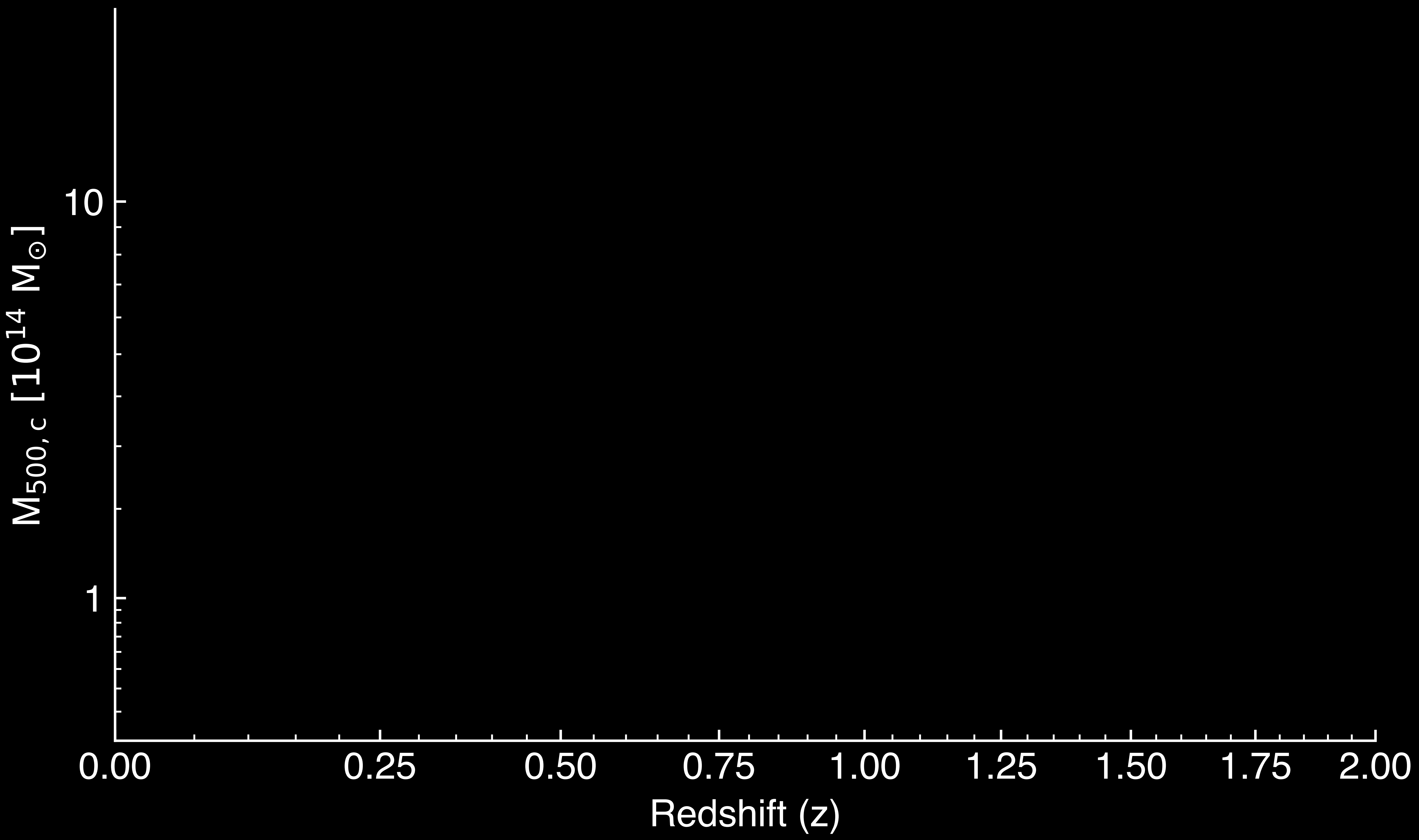
How many haloes are there per halo mass?

Halo mass function

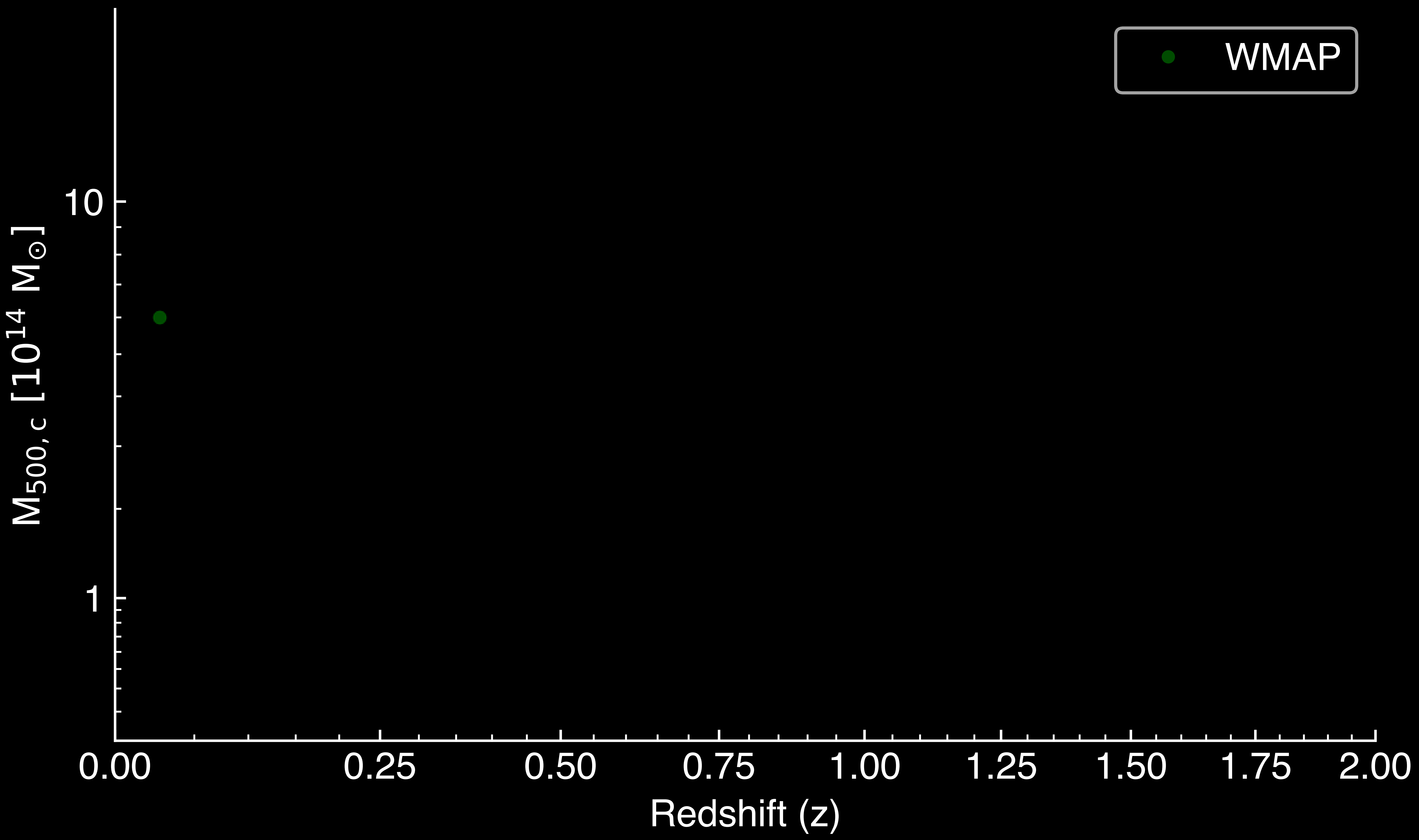


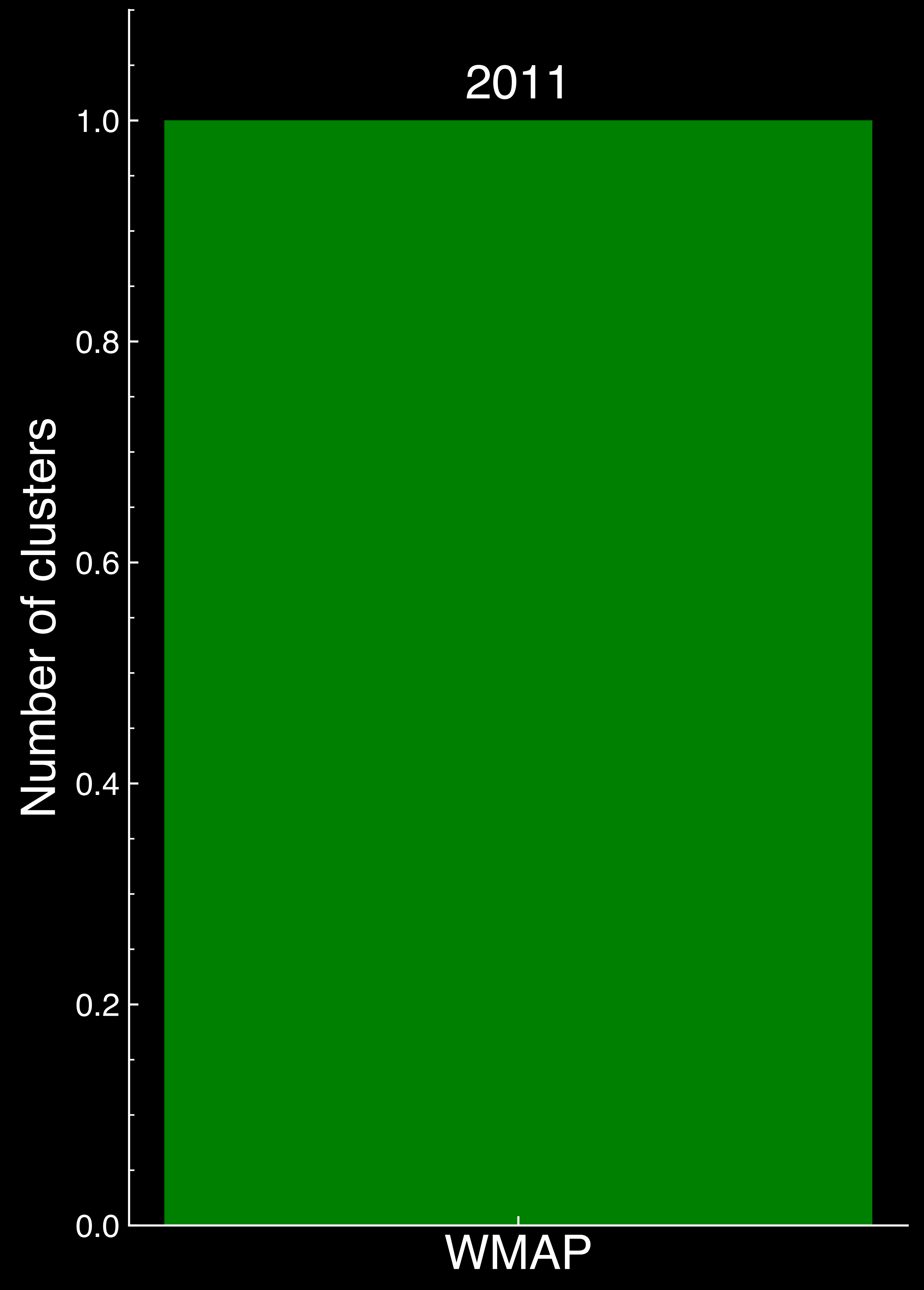
$\sigma_8 = [0.7, 0.8, 0.9]$

Wide field SZ surveys

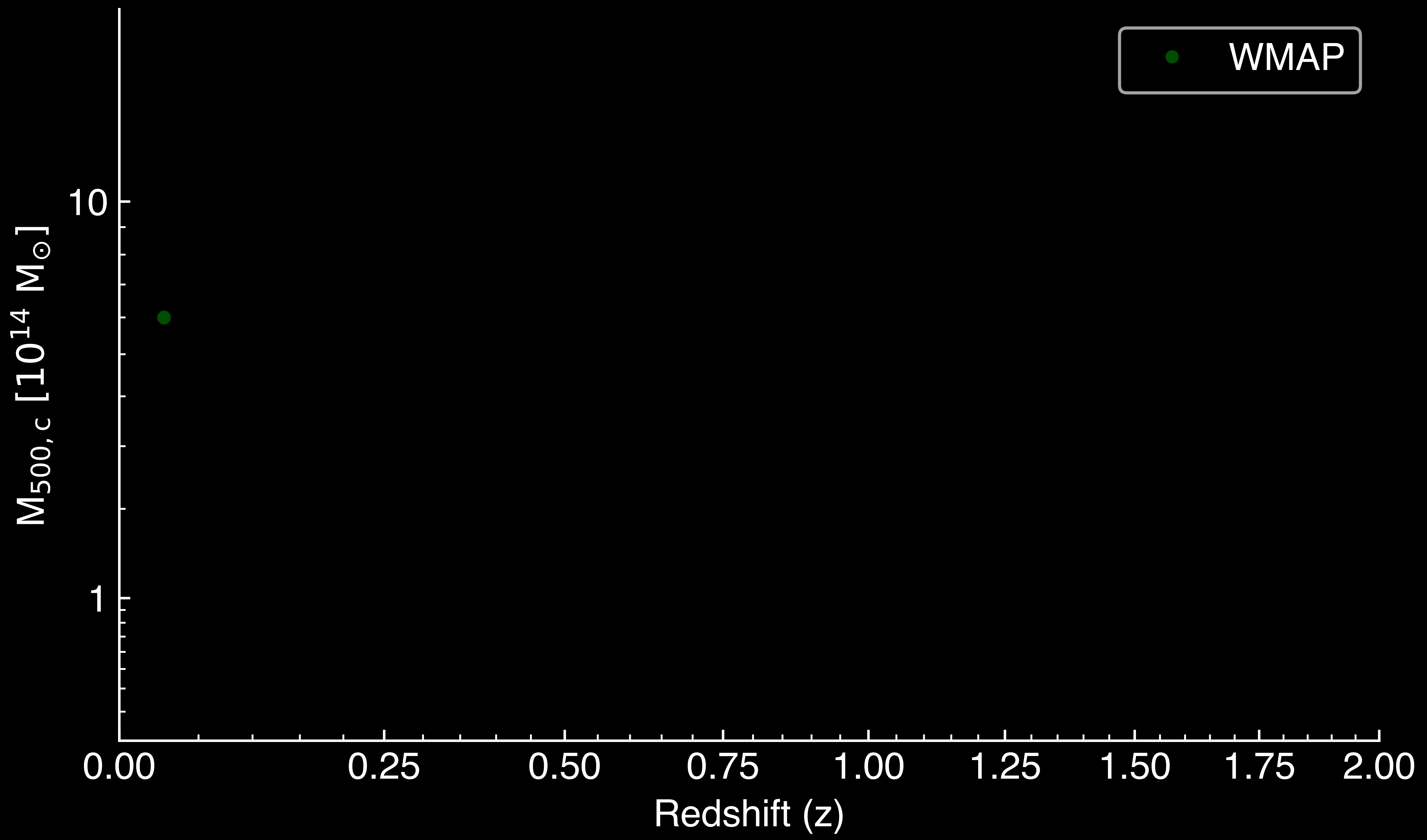


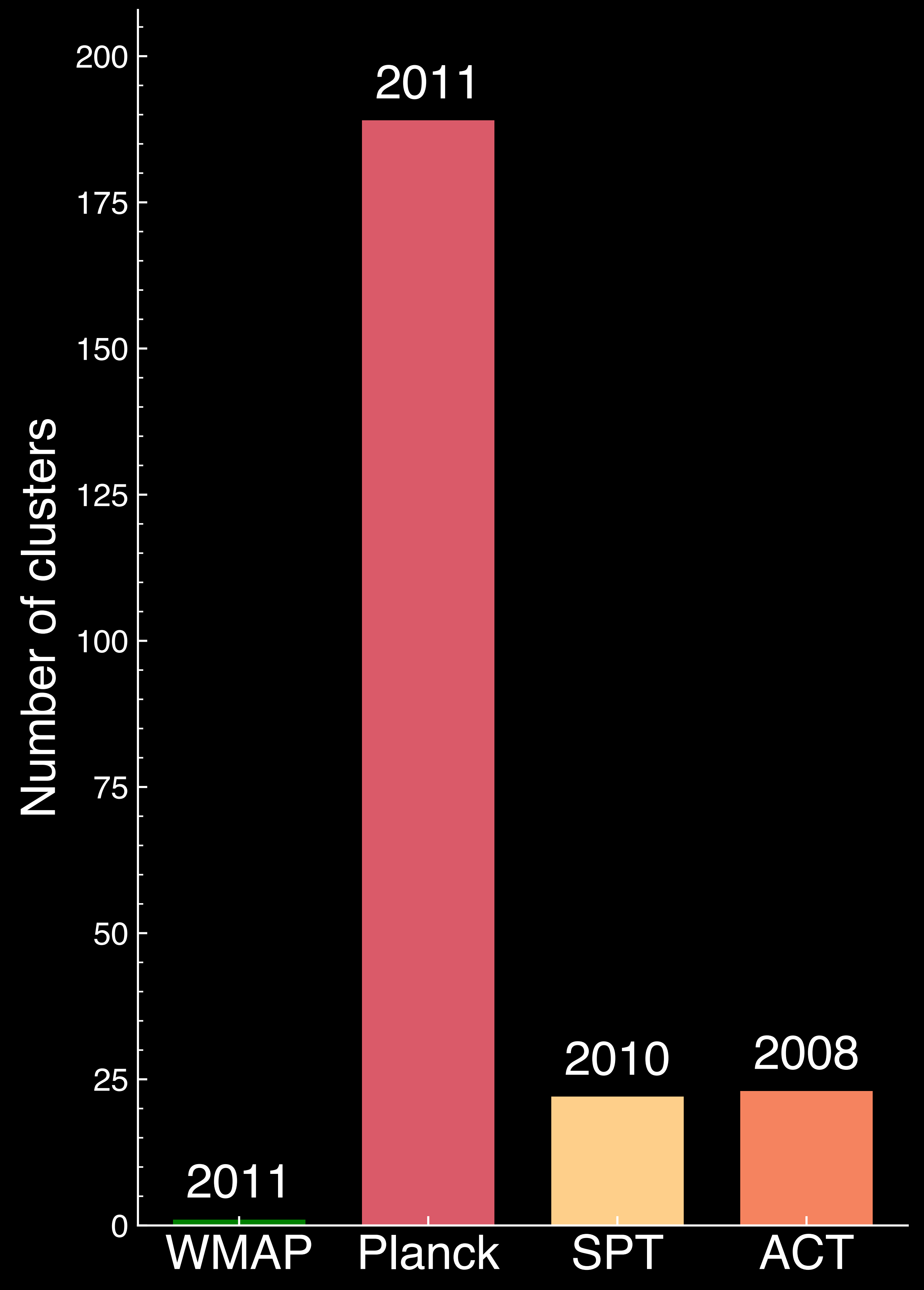
Wide field SZ surveys



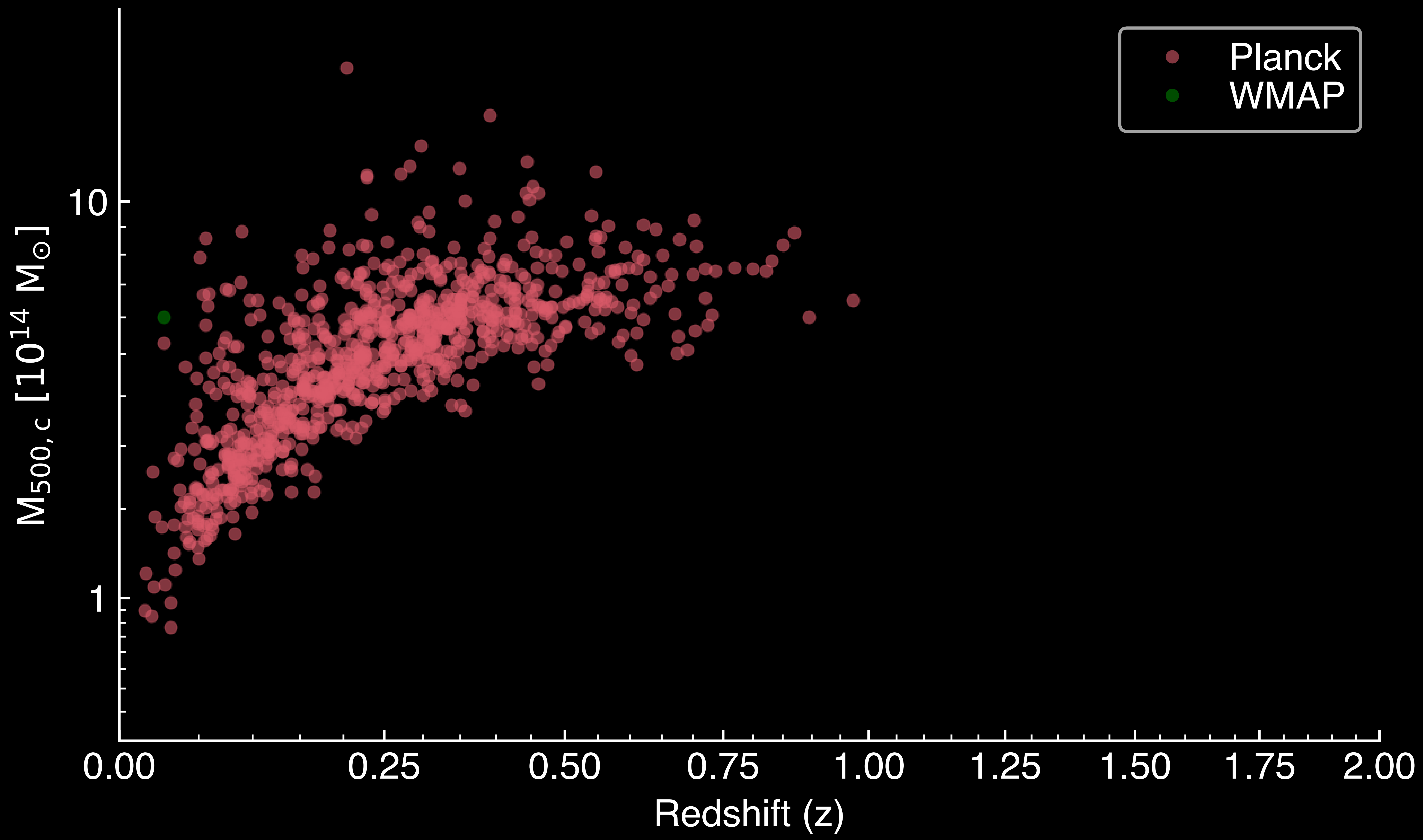


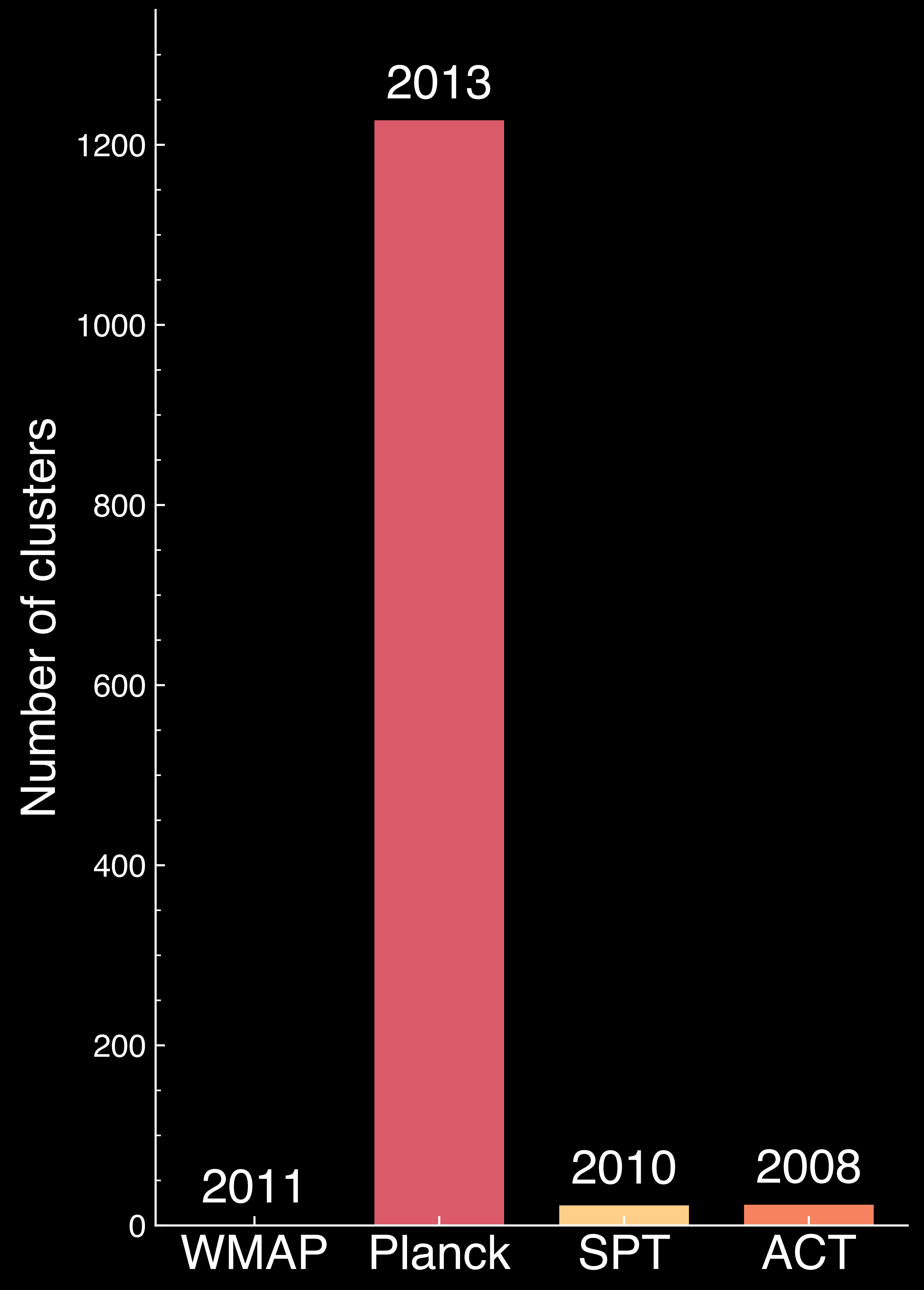
Wide field SZ surveys



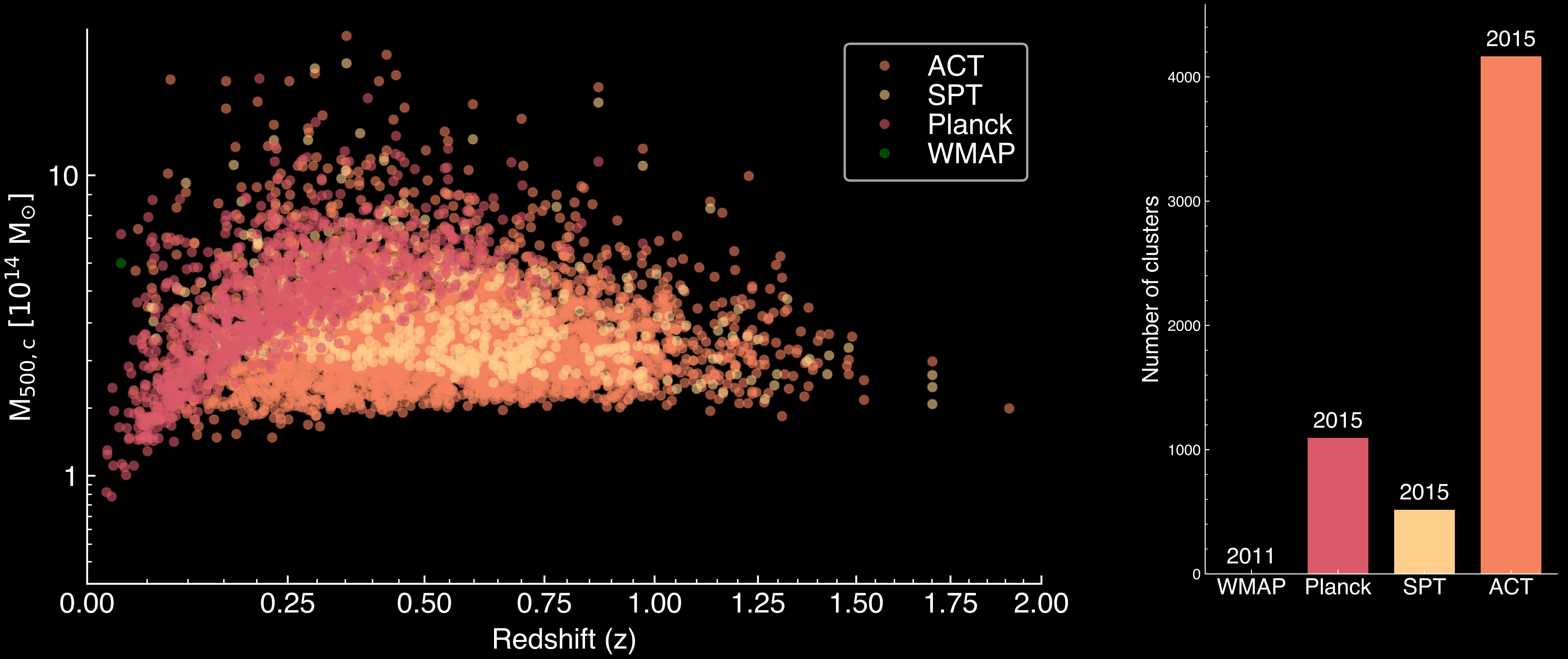


Wide field SZ surveys

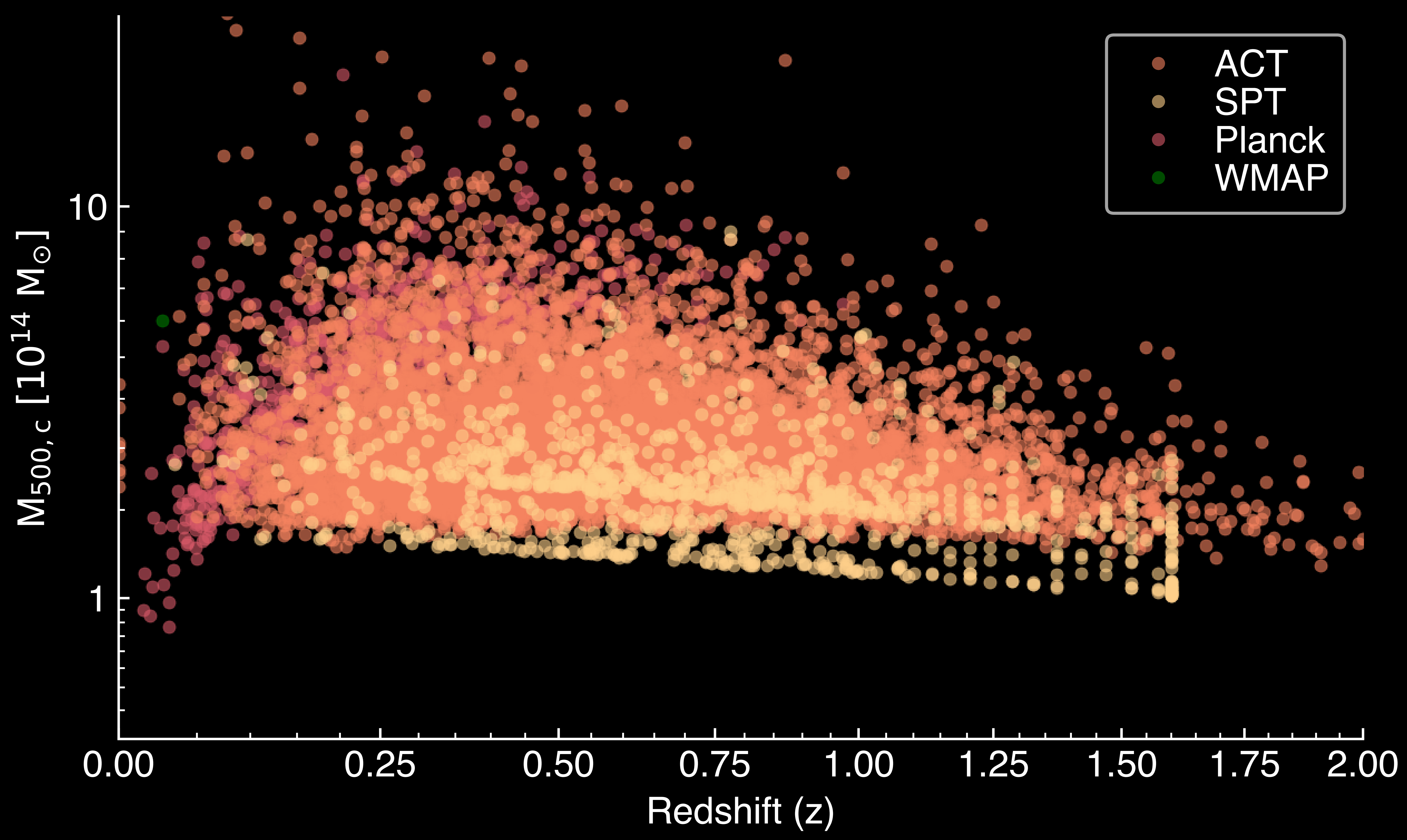


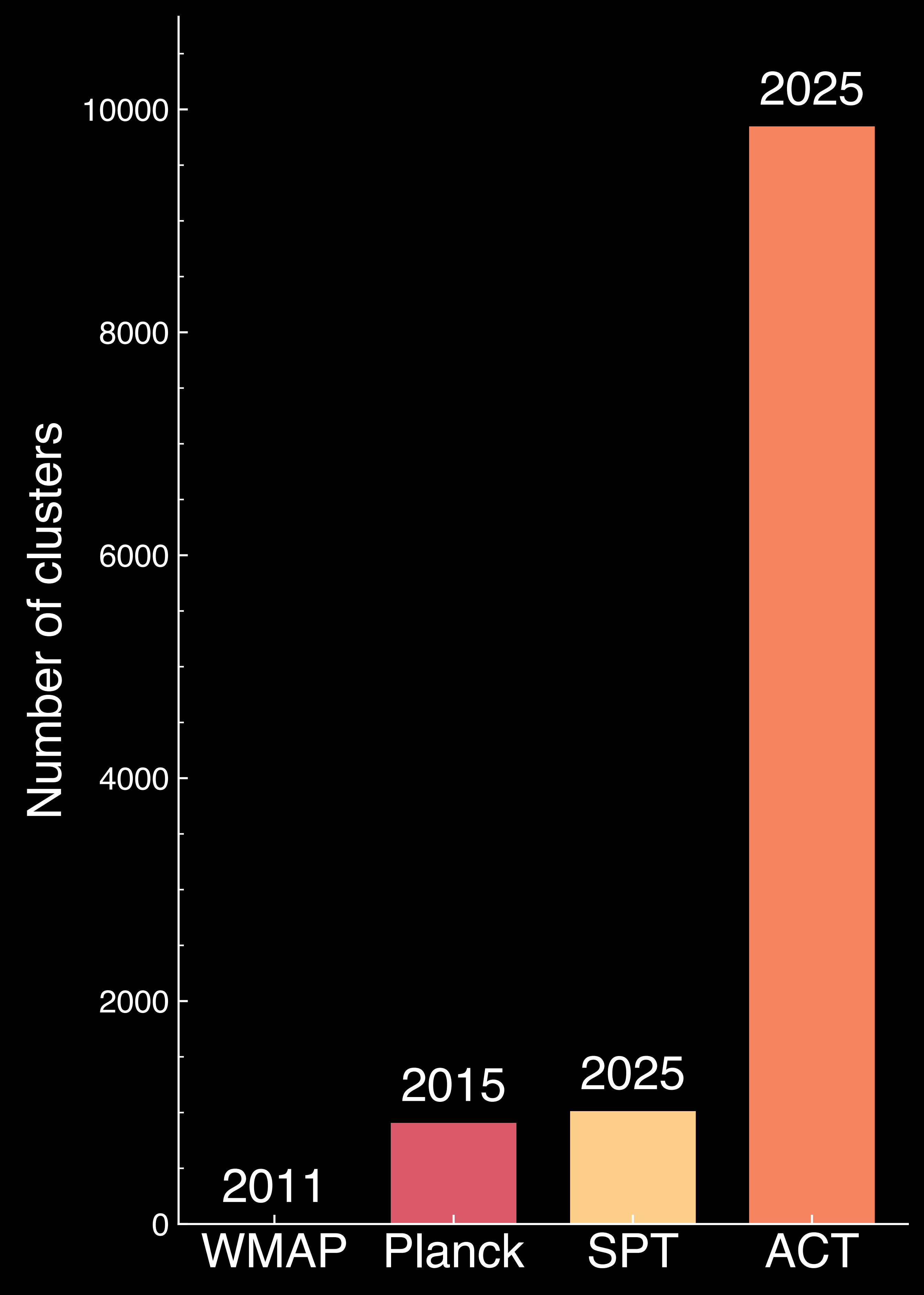


Wide field SZ surveys

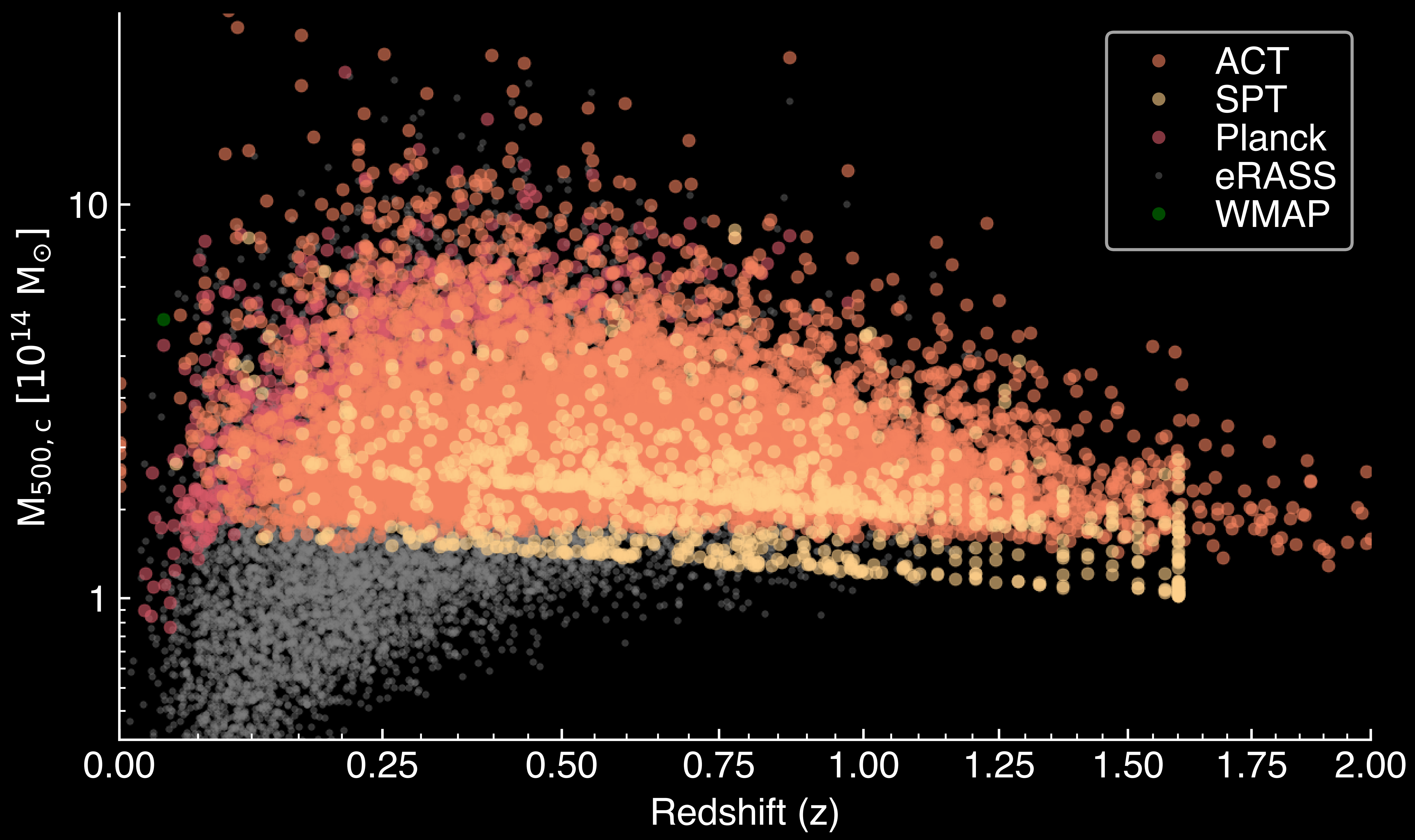


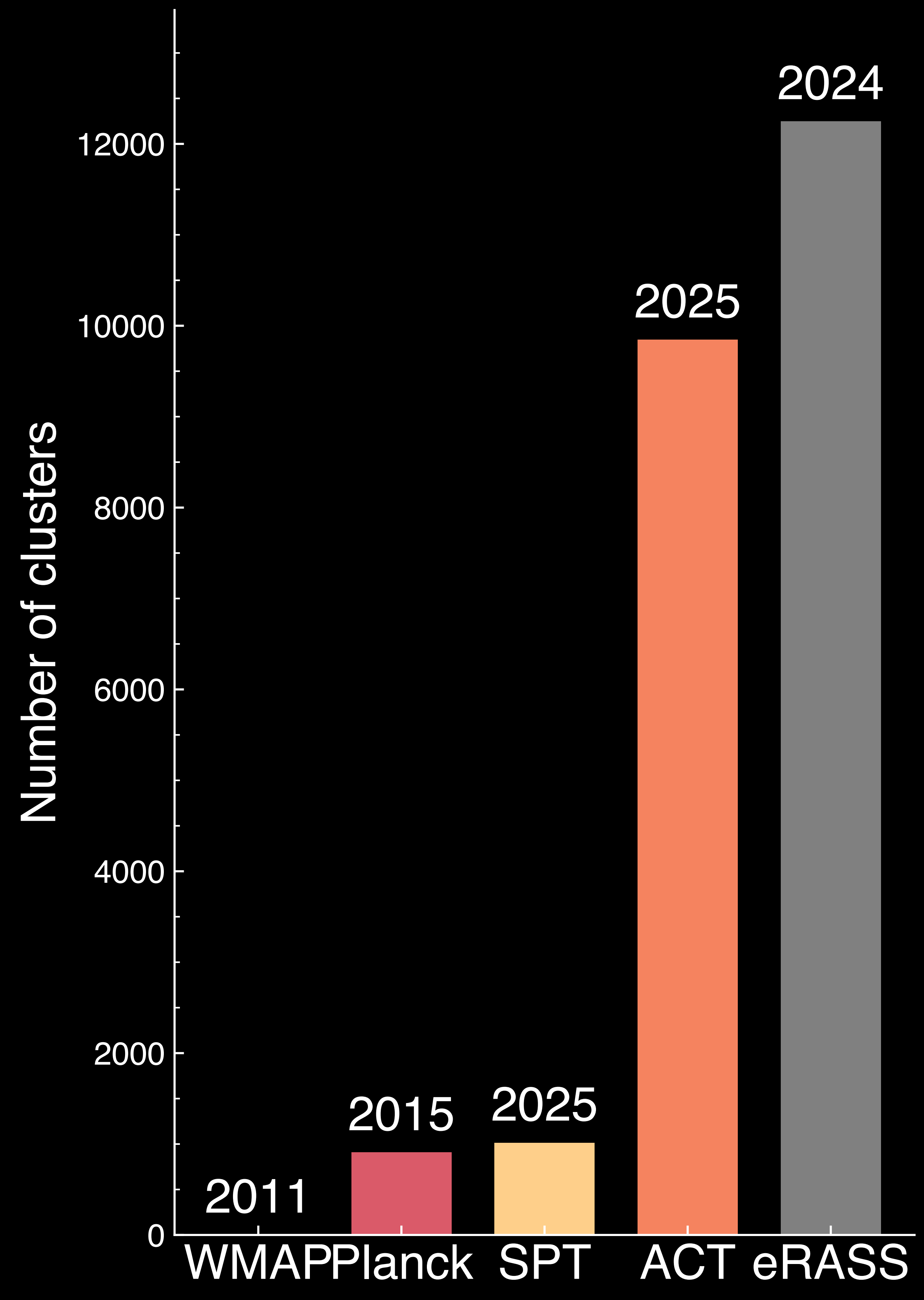
Wide field SZ surveys



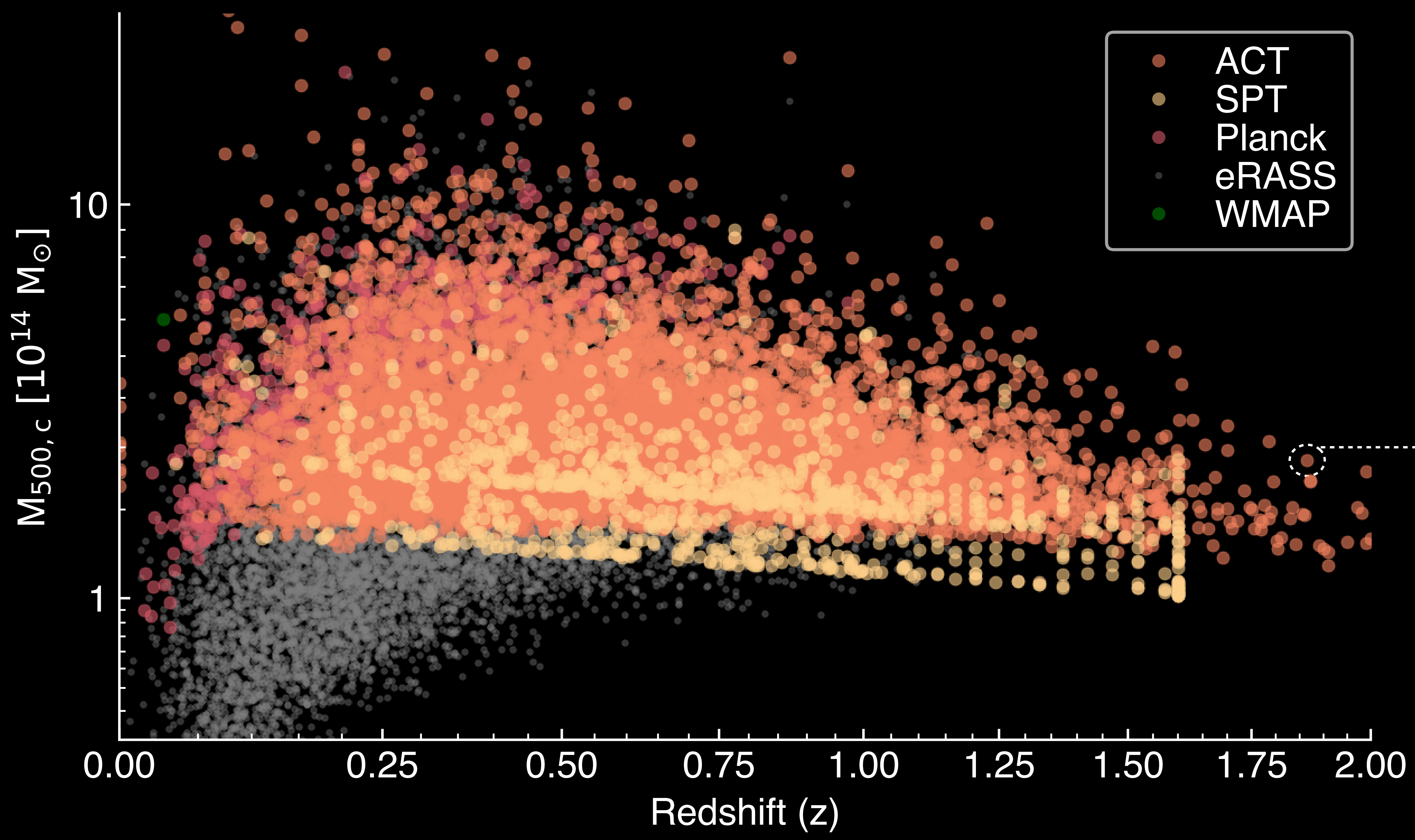


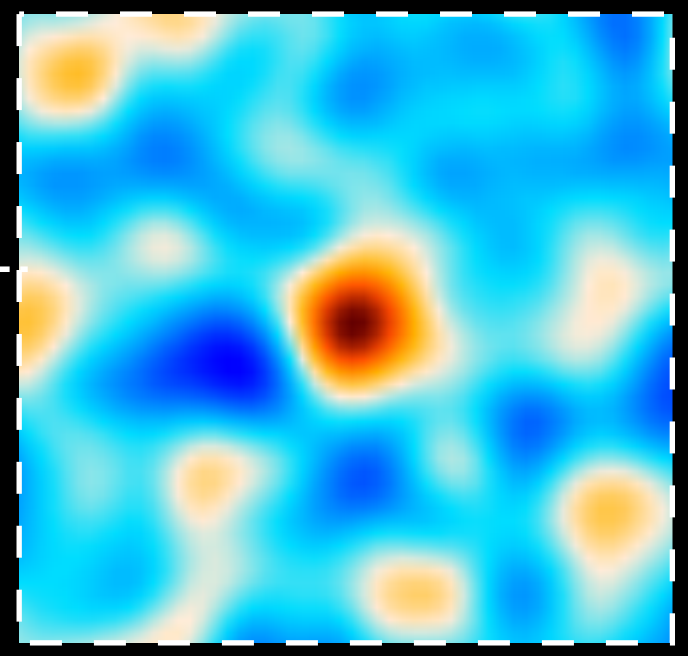
Wide field SZ surveys



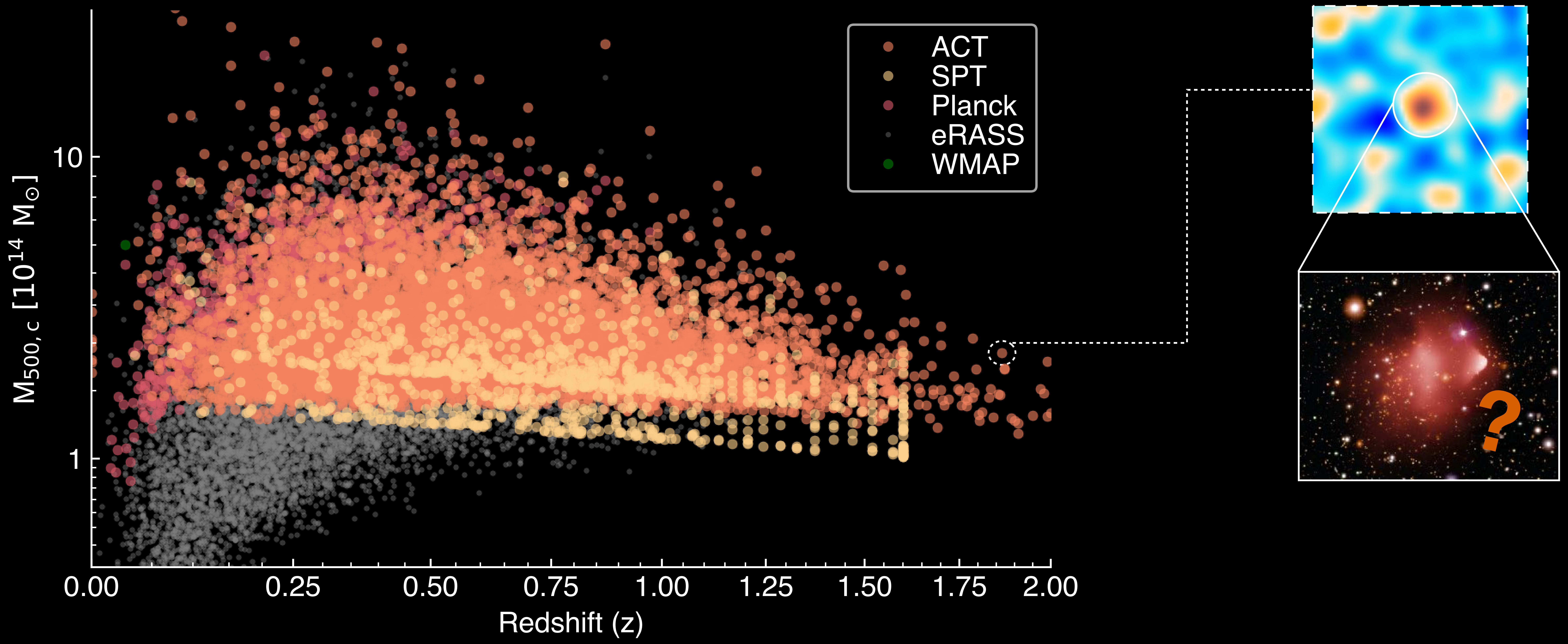


Wide field SZ surveys

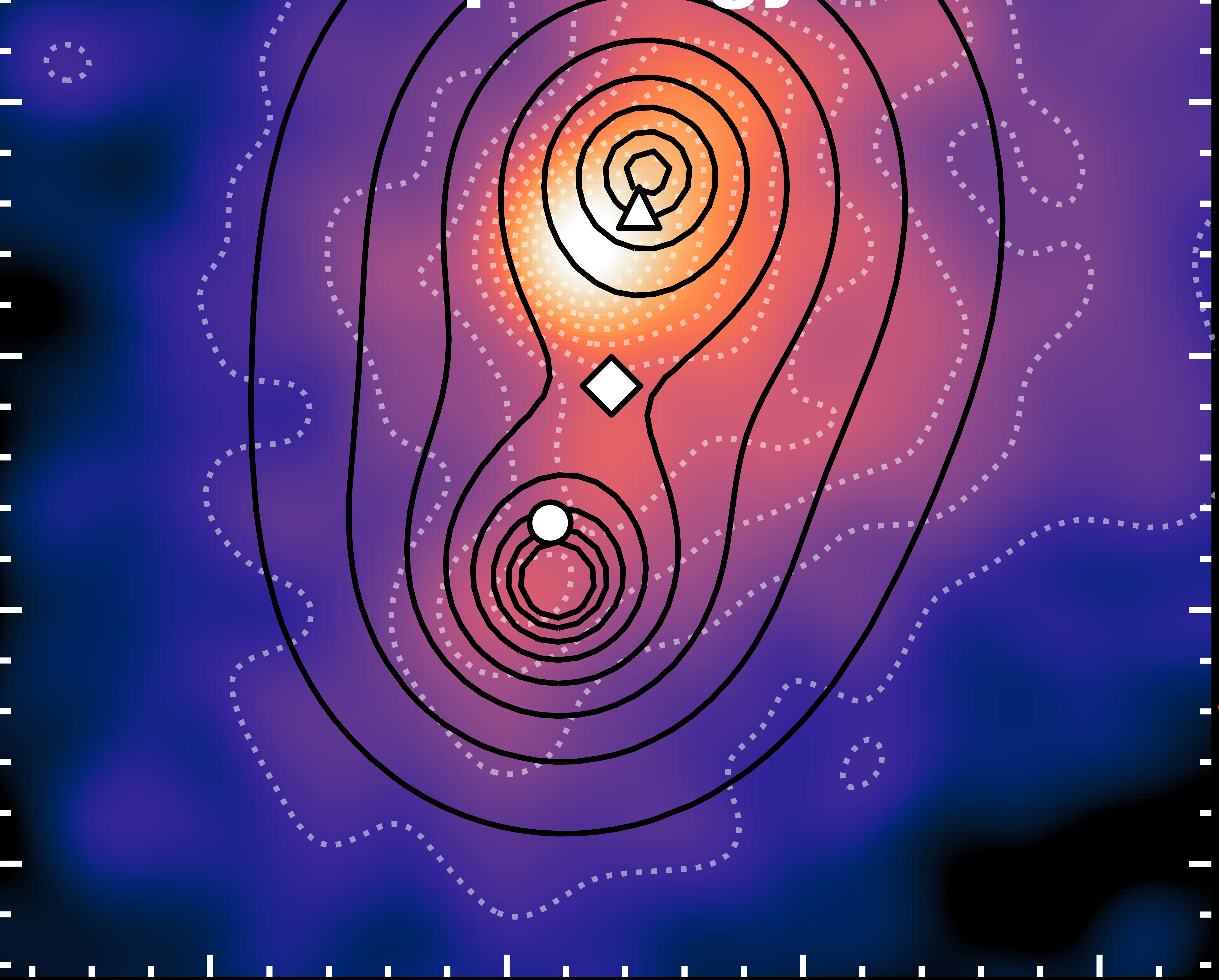


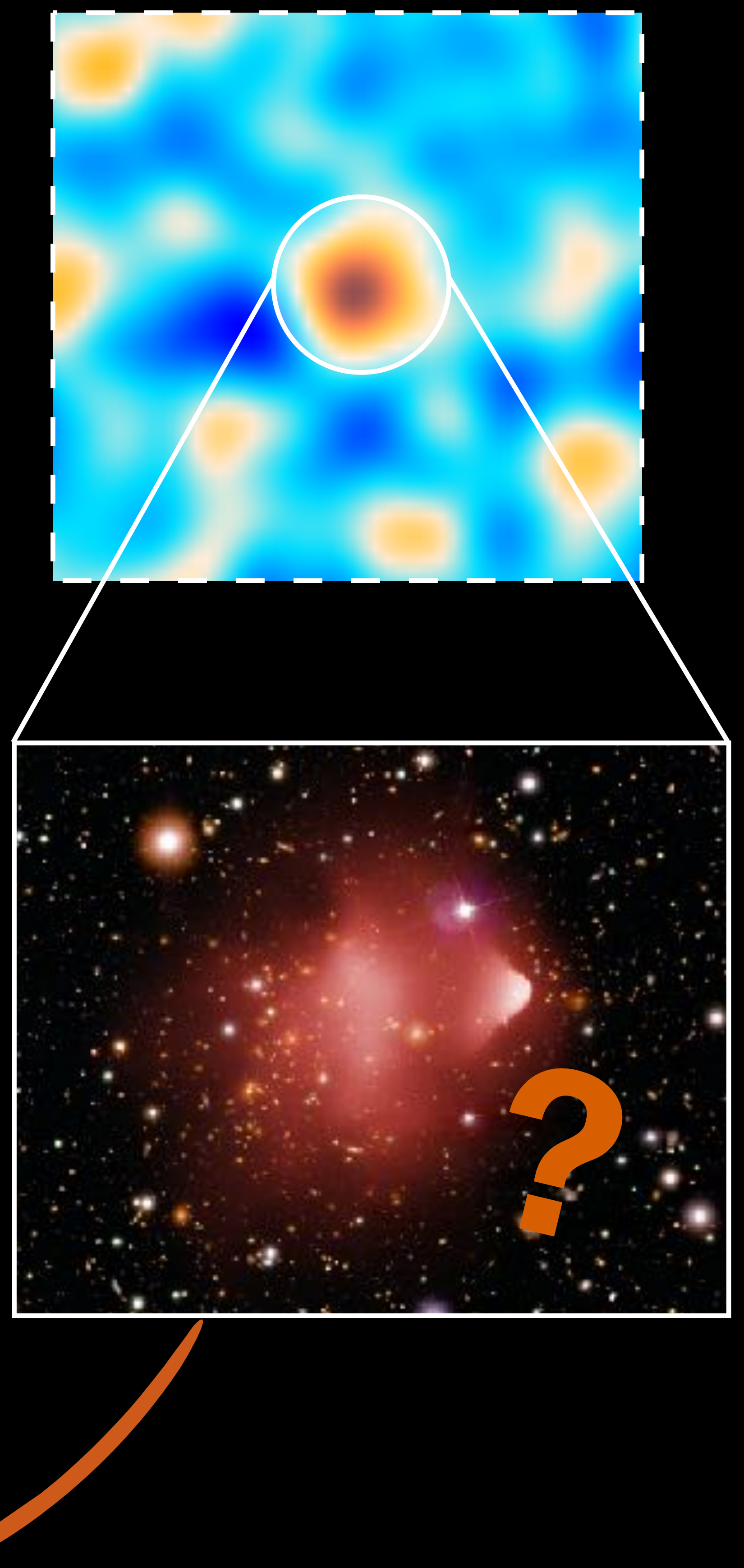


Wide field SZ surveys

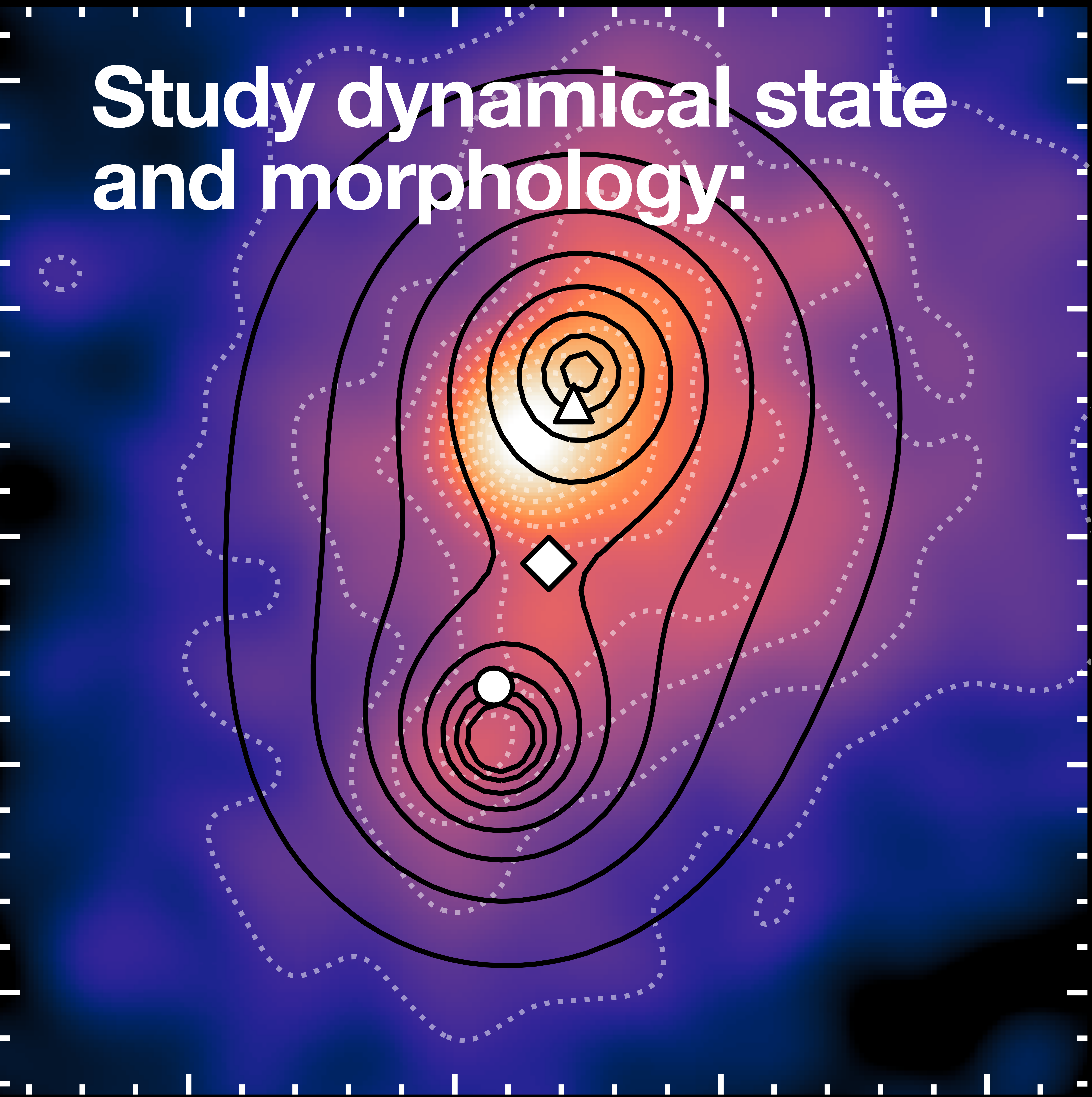


Study dynamical state and morphology:

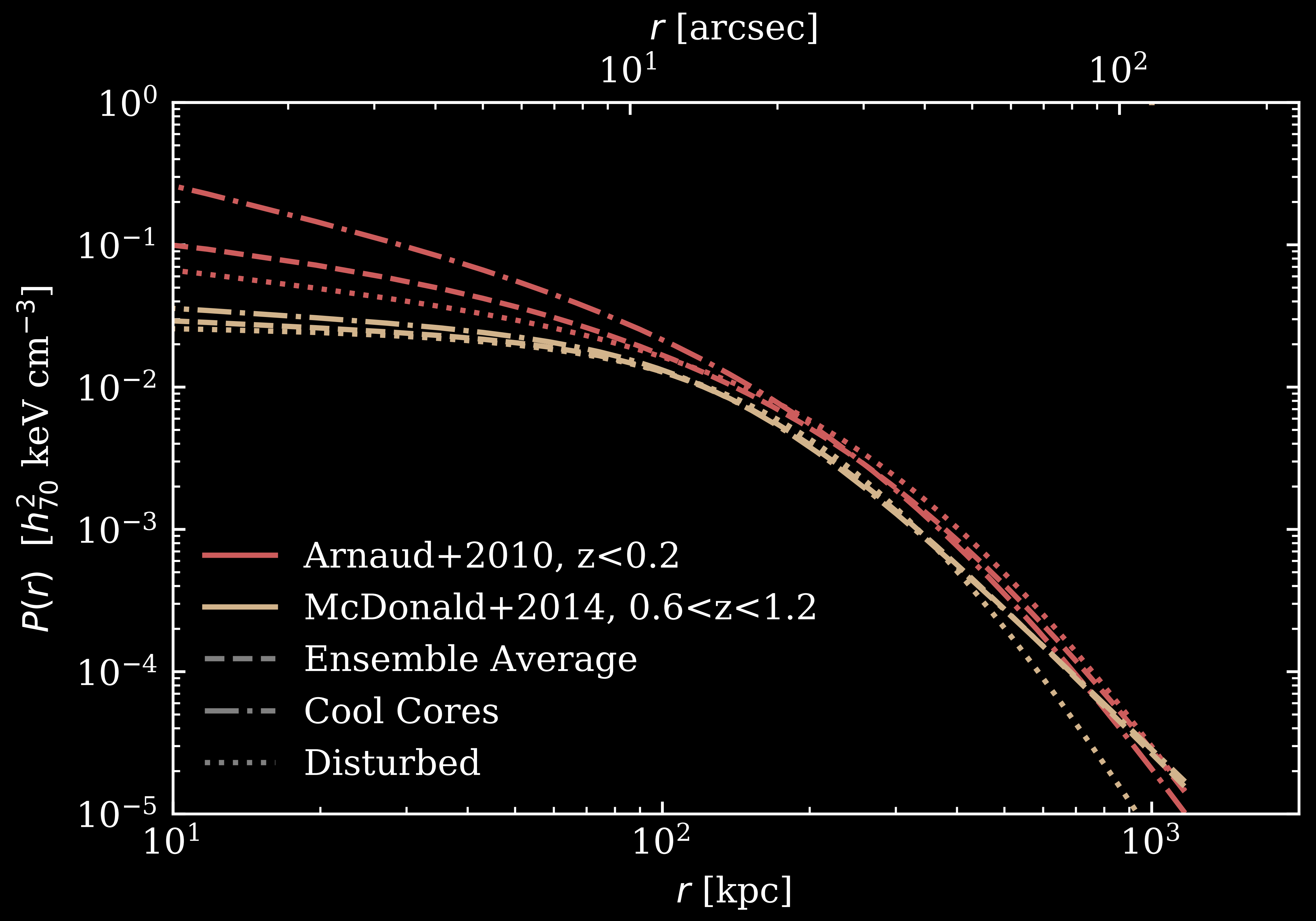




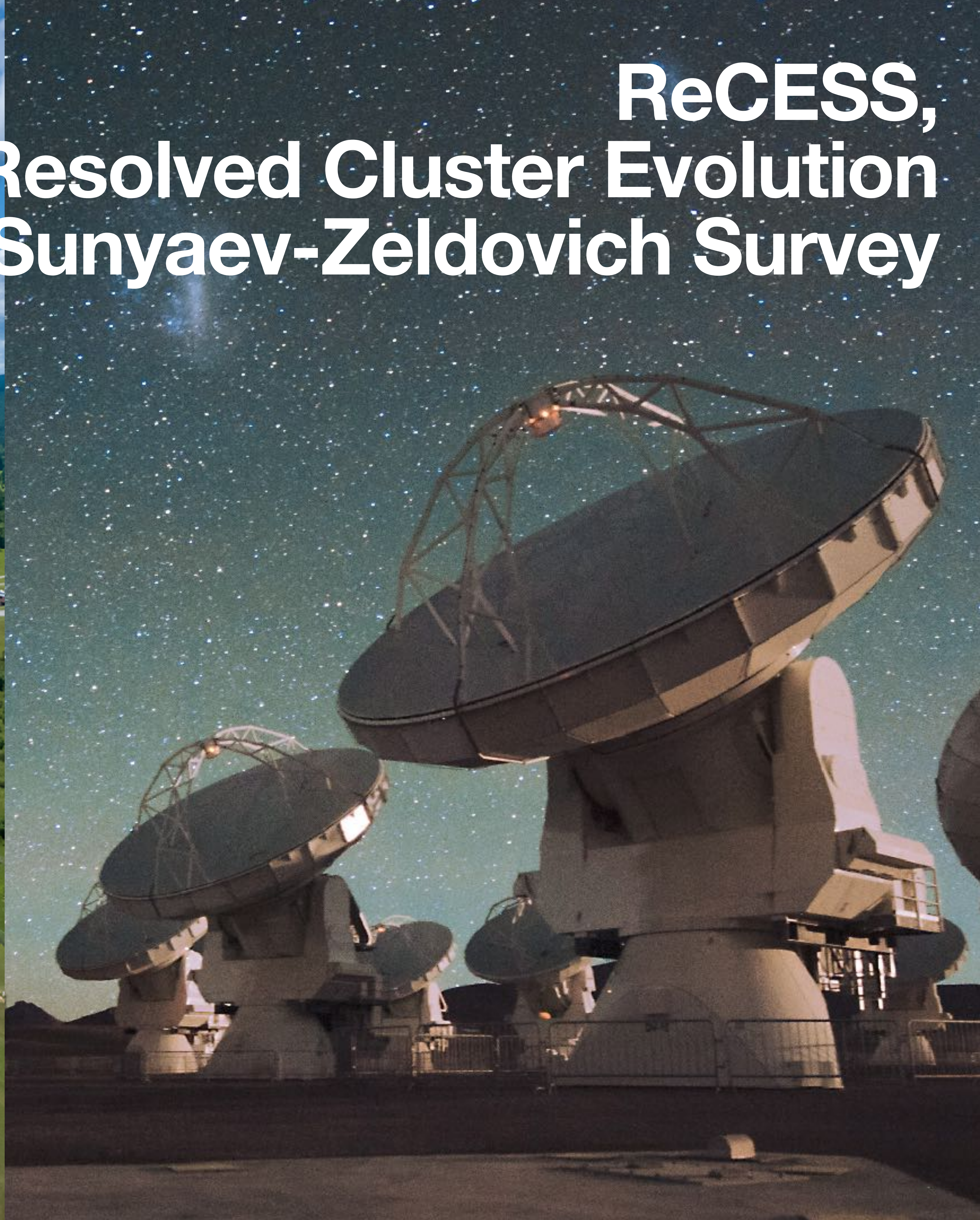
Study dynamical state and morphology:



Or take a radial average

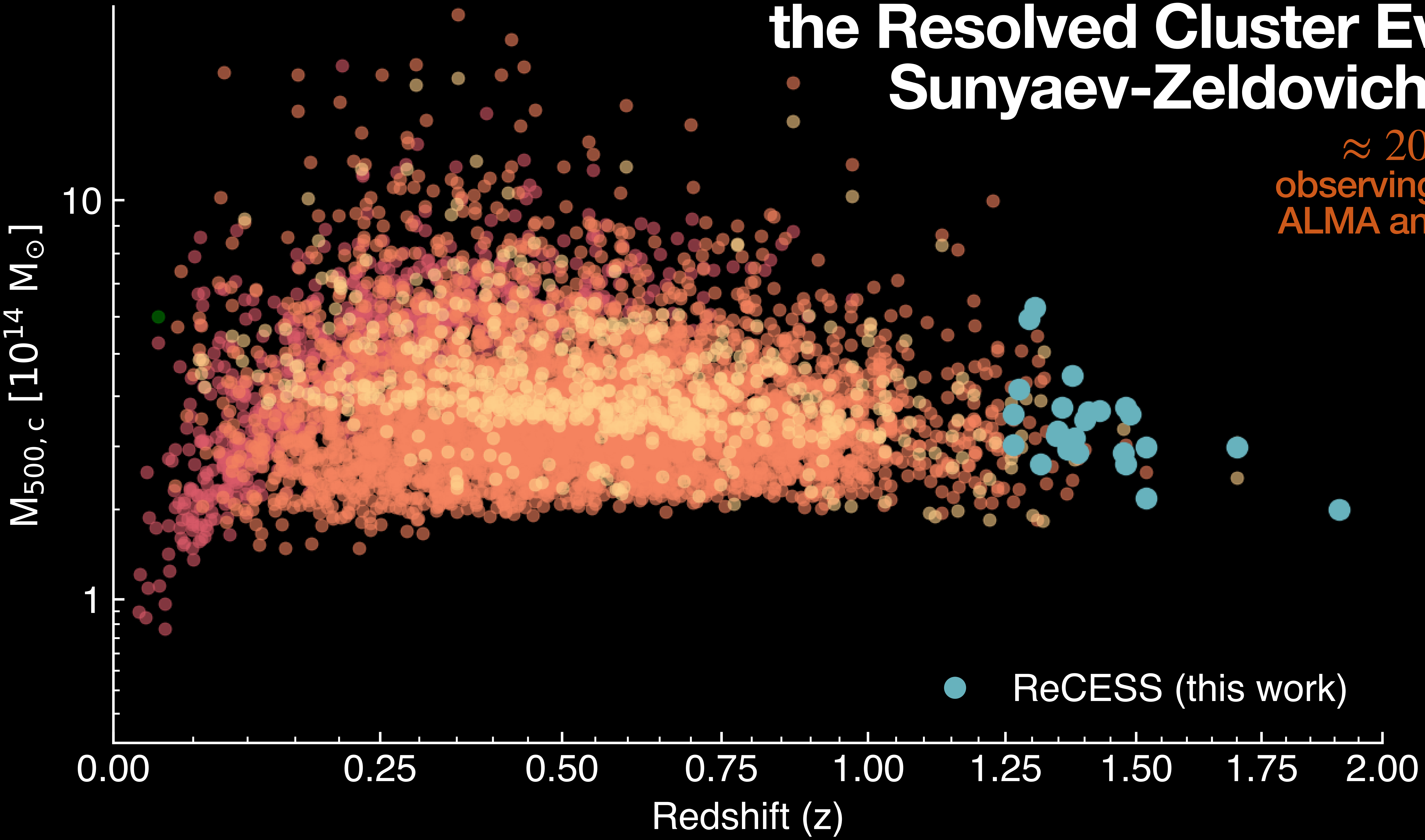


ReCESS,
the Resolved Cluster Evolution Sunyaev-Zeldovich Survey

ReCESS, the Resolved Cluster Evolution Sunyaev-Zeldovich Survey

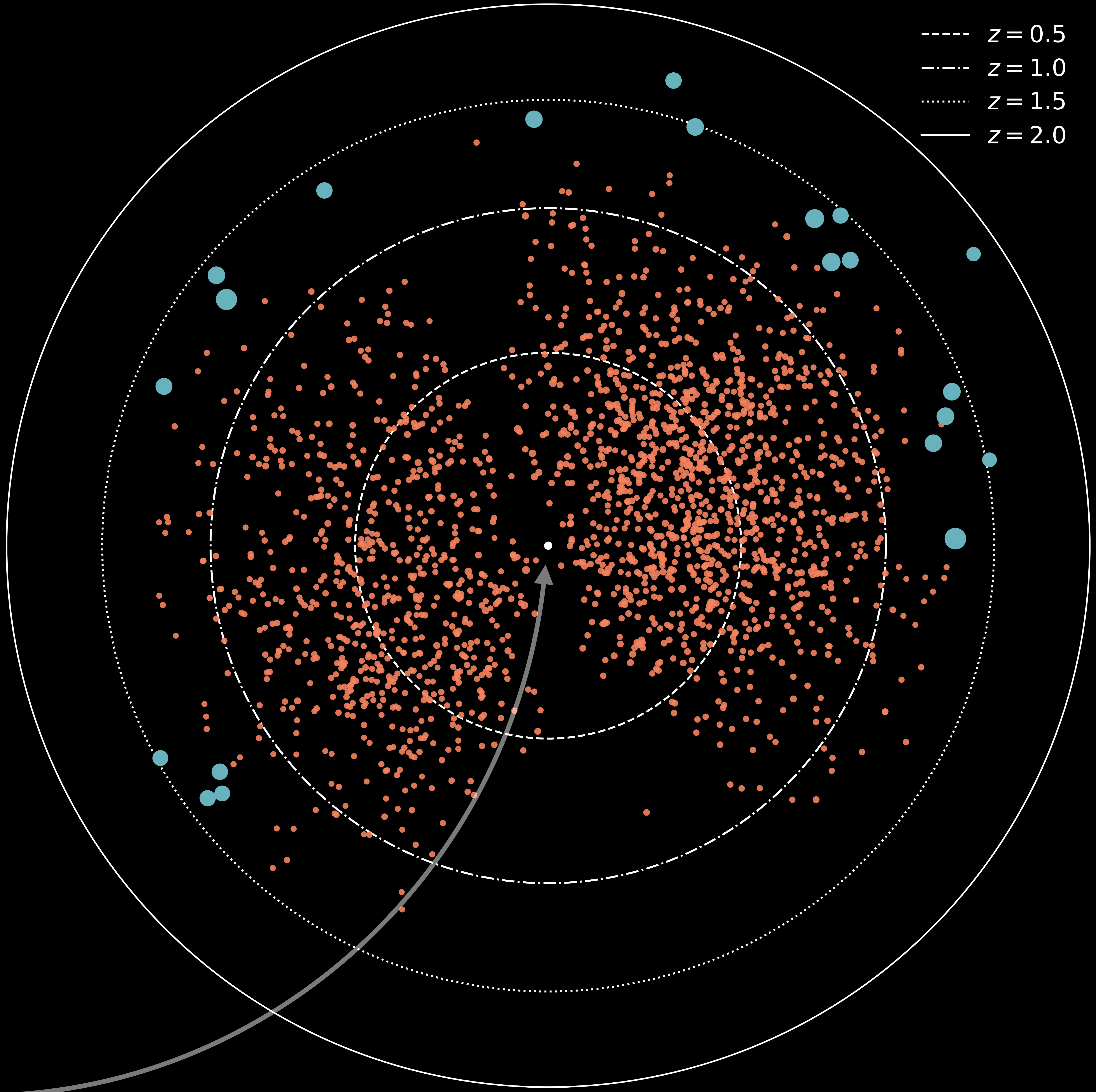
≈ 200 hours of observing time with ALMA and the GBT



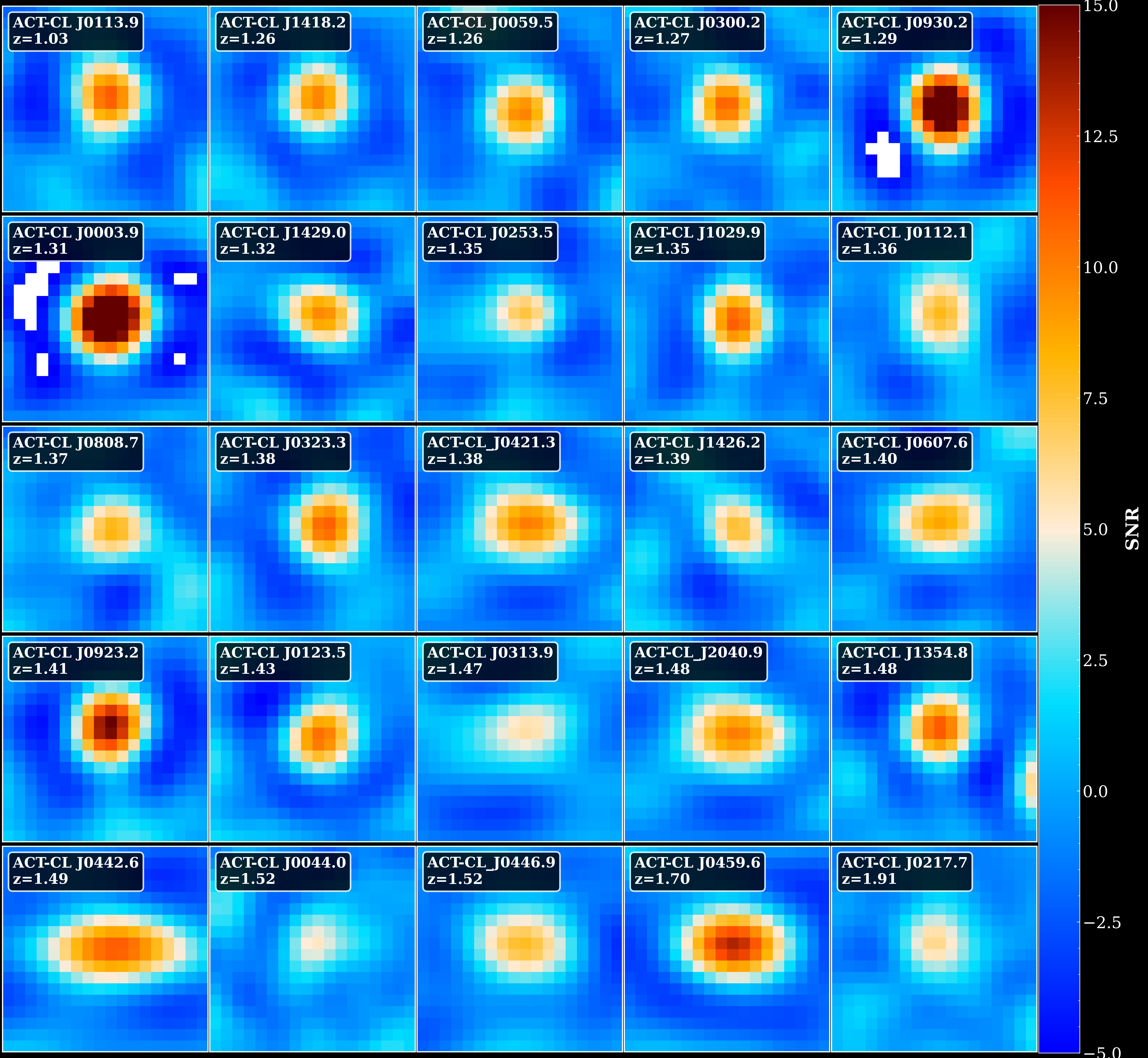

ReCESS,
the Resolved Cluster Evolution
Sunyaev-Zeldovich Survey
≈ 200 hours of
observing time with
ALMA and the GBT
$M_{500,c}$ [10^{14} $M_\odot$]
10
1
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Redshift (z)
ReCESS (this work)
REXCESS+10
CHEX-MATE+21
McDonald+13

ReCESS

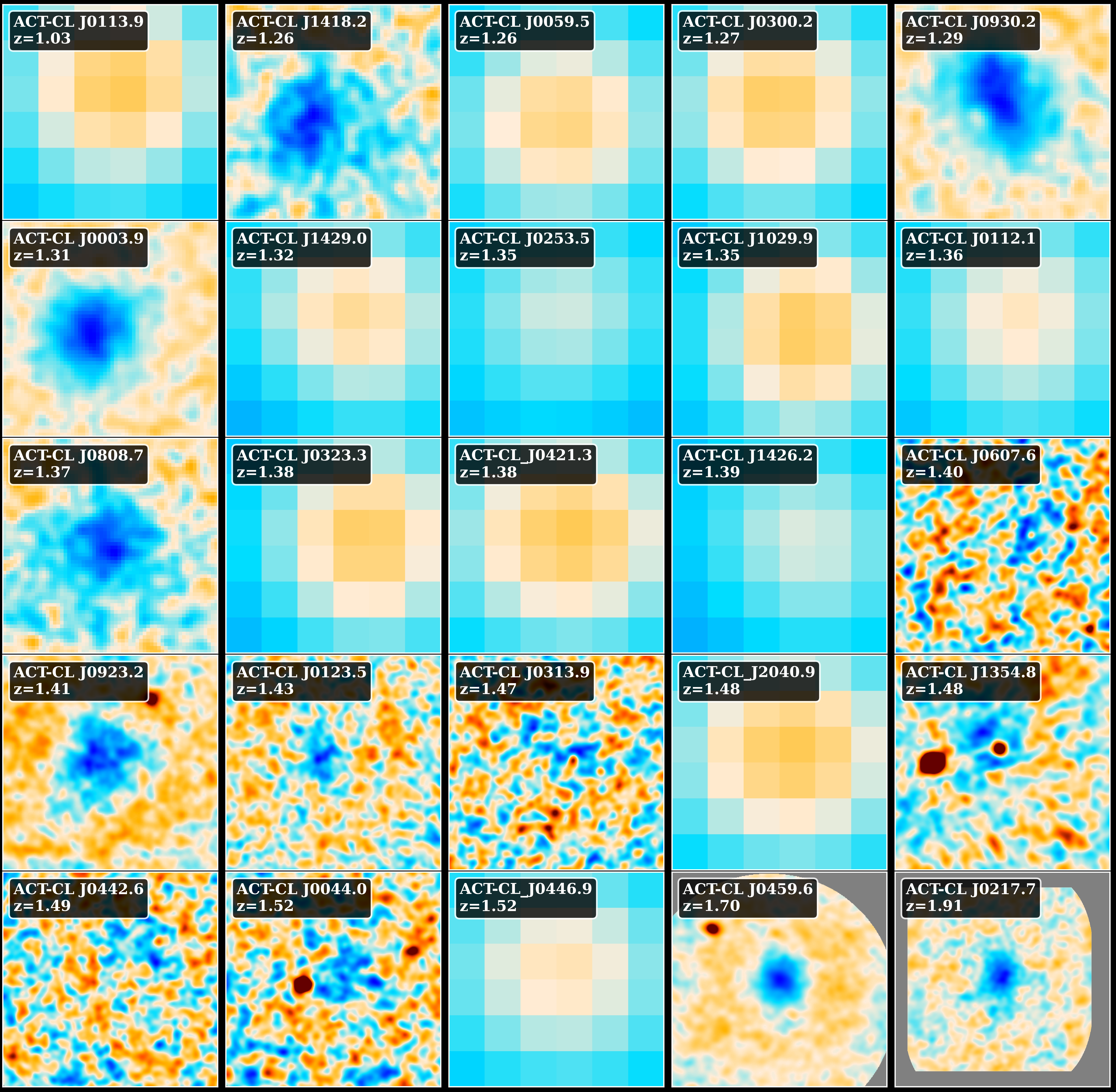
van Marrewijk et al. (in prep.)



We are here!

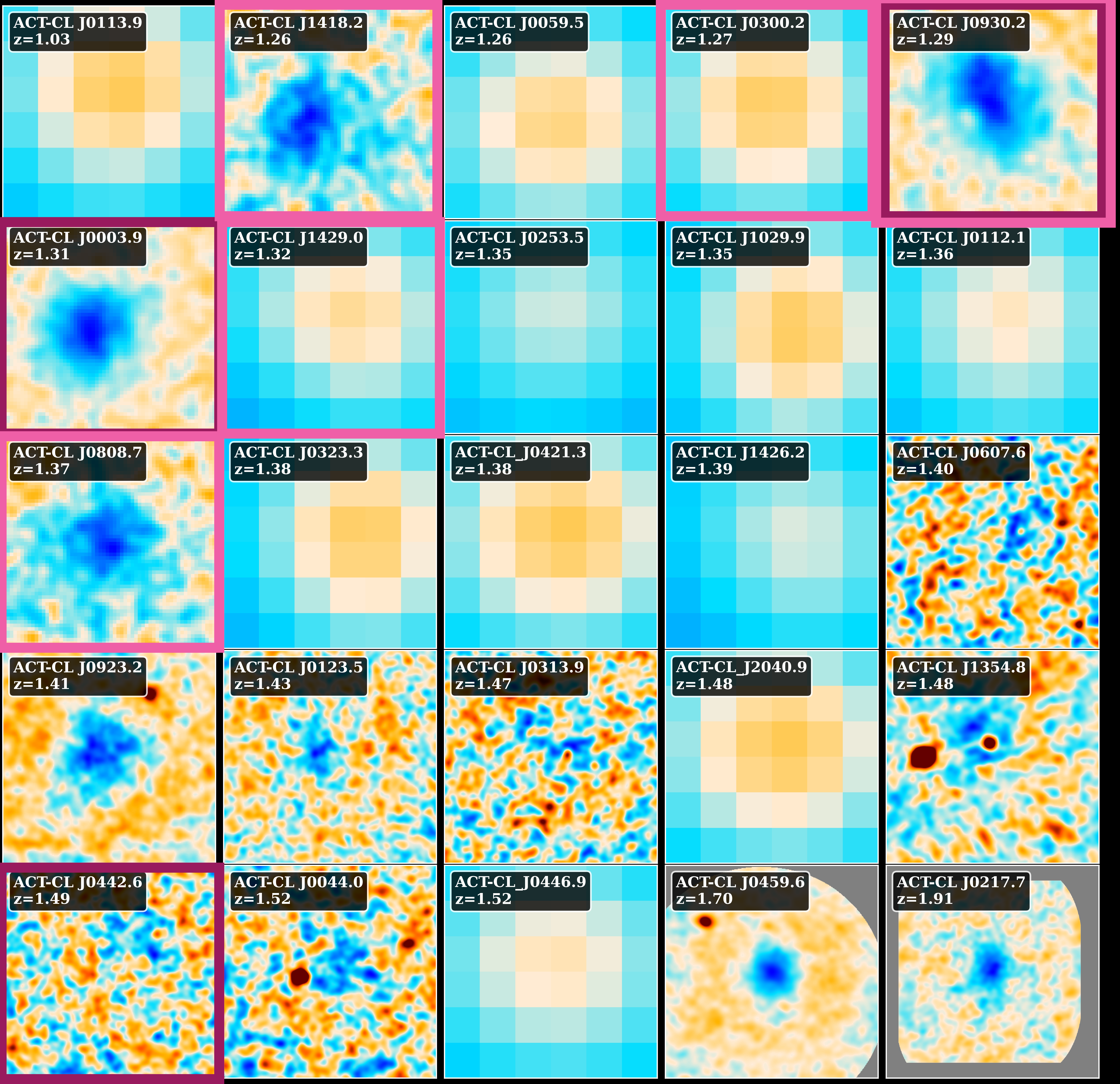


The selection of the full sample



The full sample

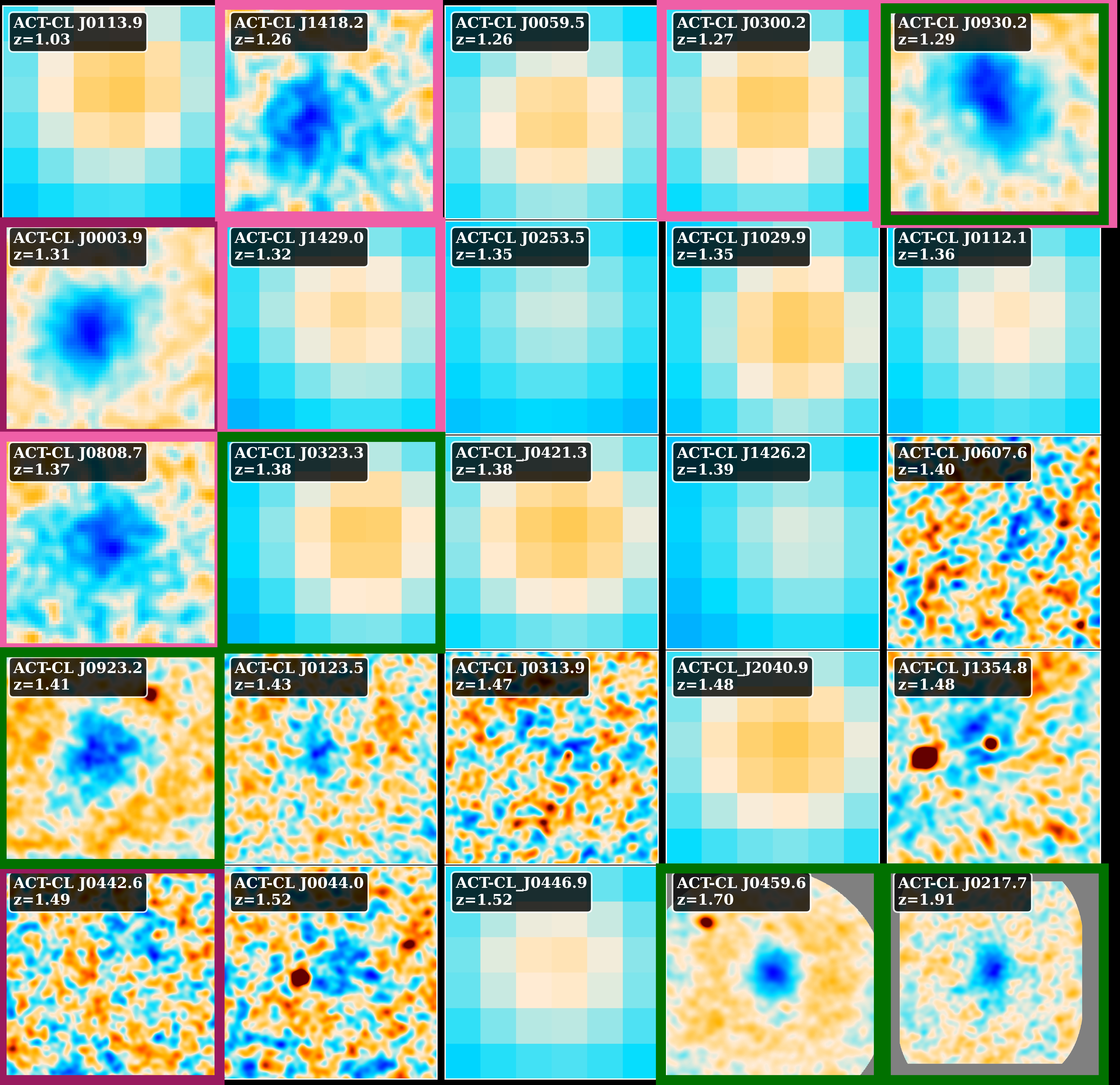
So far…



The full sample

So far…

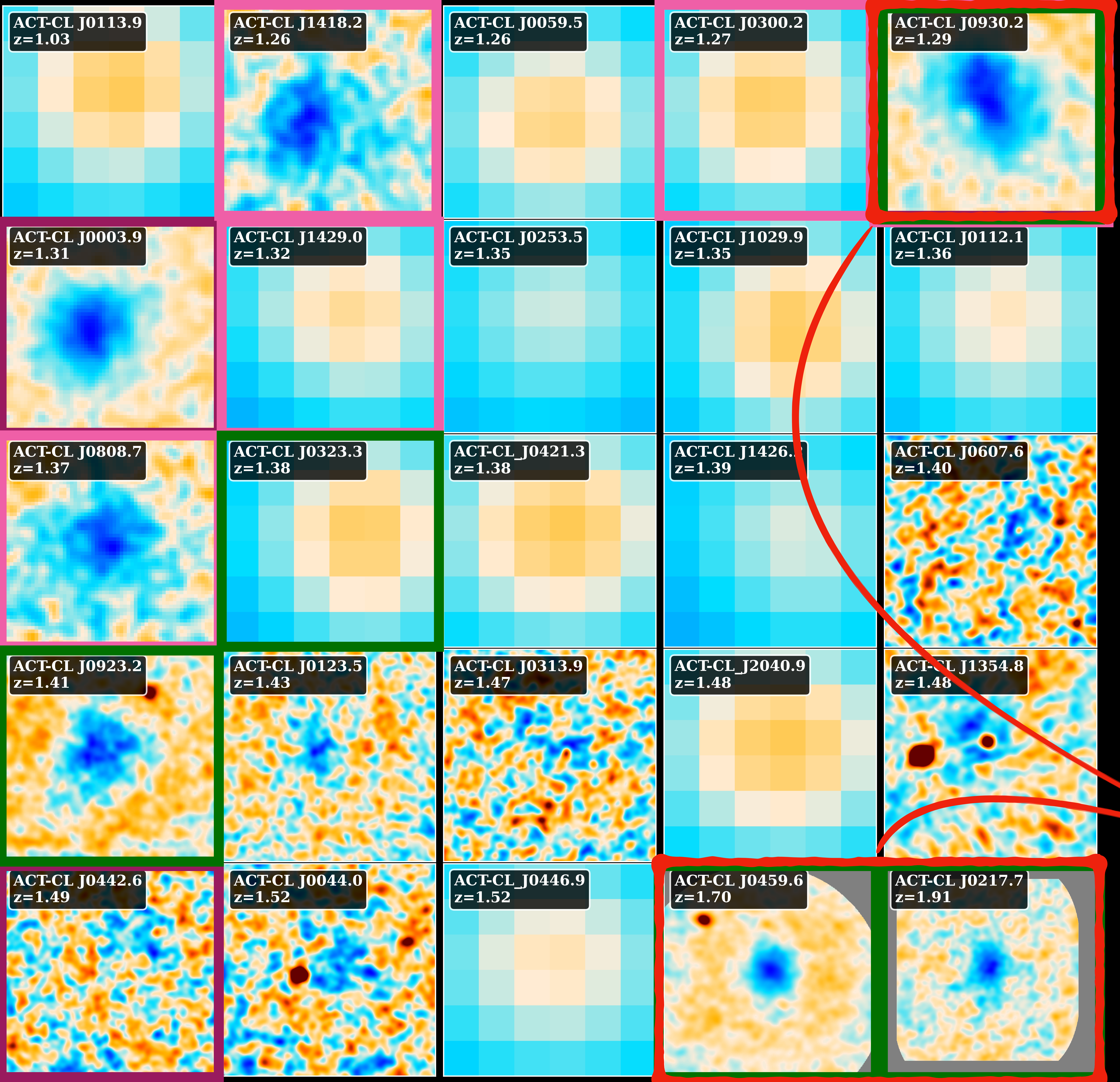
- Radio
  - MeerKAT
  - LoTSS DR3



The full sample

So far…

- Radio
  - MeerKAT
  - LoTSS DR3
- X-ray (Chandra/XMM-Newton)



The full sample

So far…

- Radio
  - MeerKAT
  - LoTSS DR3
- X-ray (Chandra/XMM-Newton)

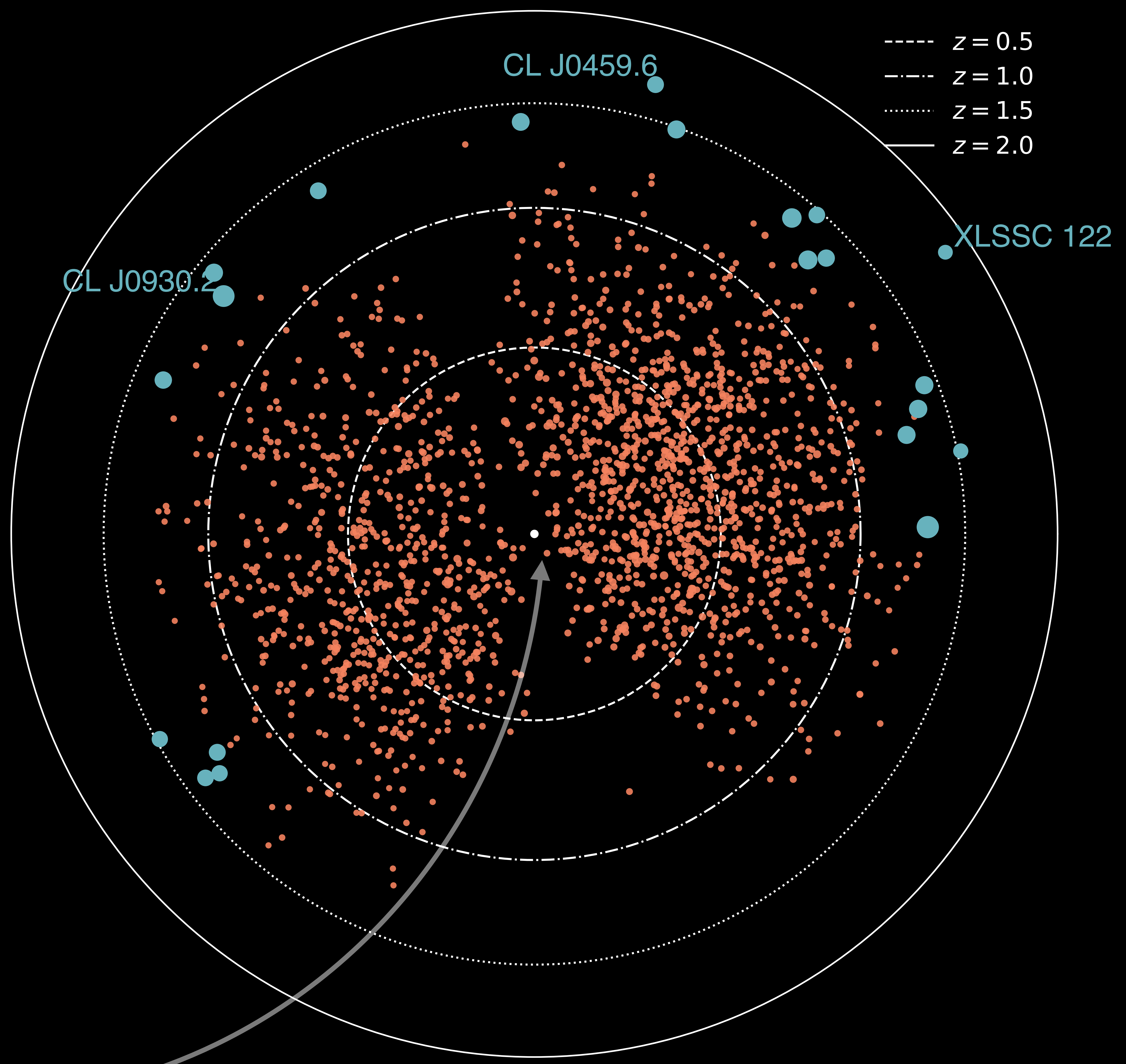
What I will focus on for the remainder of this talk

ReCESS

van Marrewijk et al. (in prep.)

How does really hot gas form in the Universe?

- Gravitationally
- Mechanical Feedback

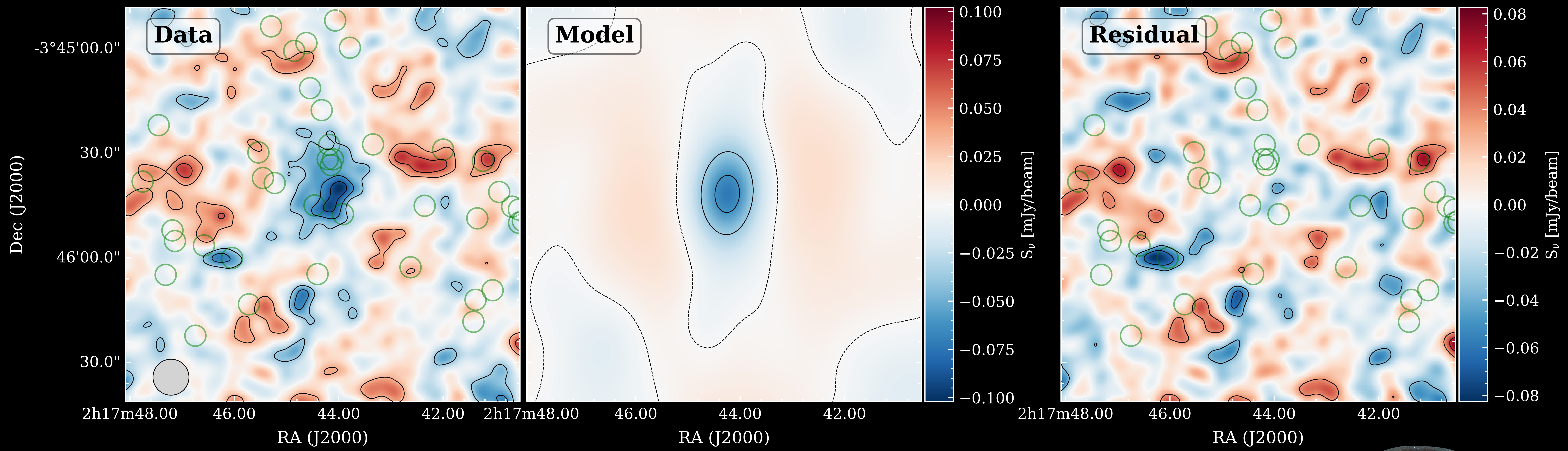


We are here!

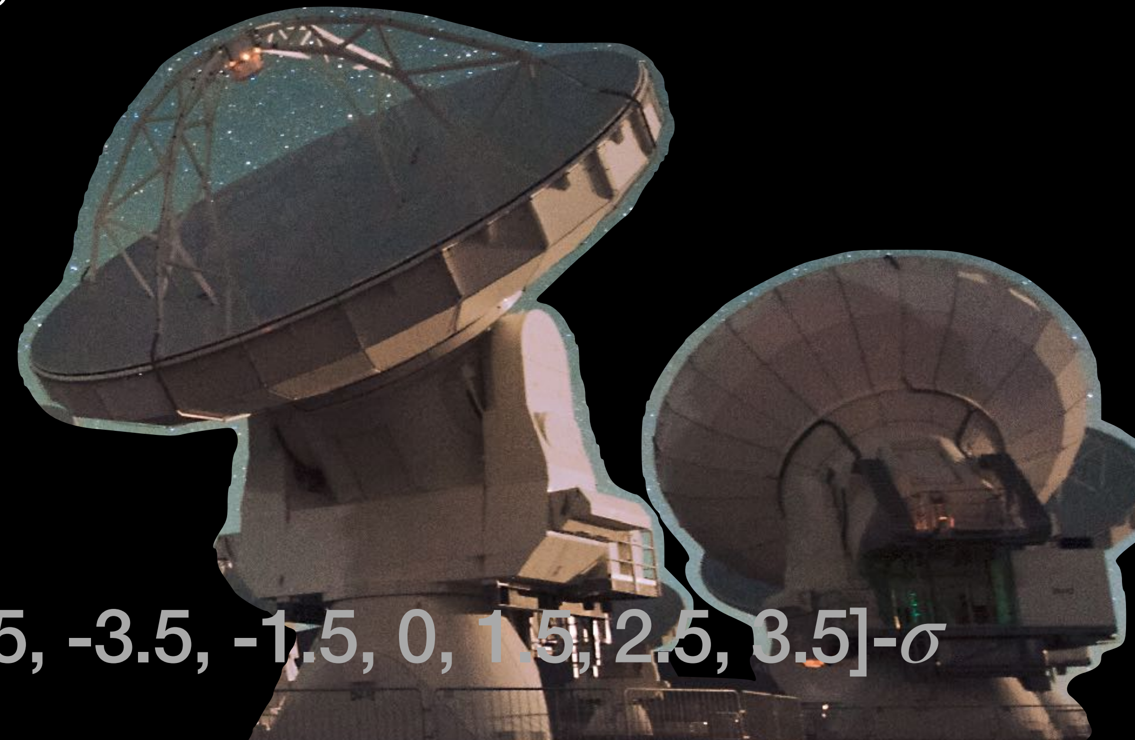
XLSSC 122, the highest−z cluster out there

Dirty Image

Imaged Residuals



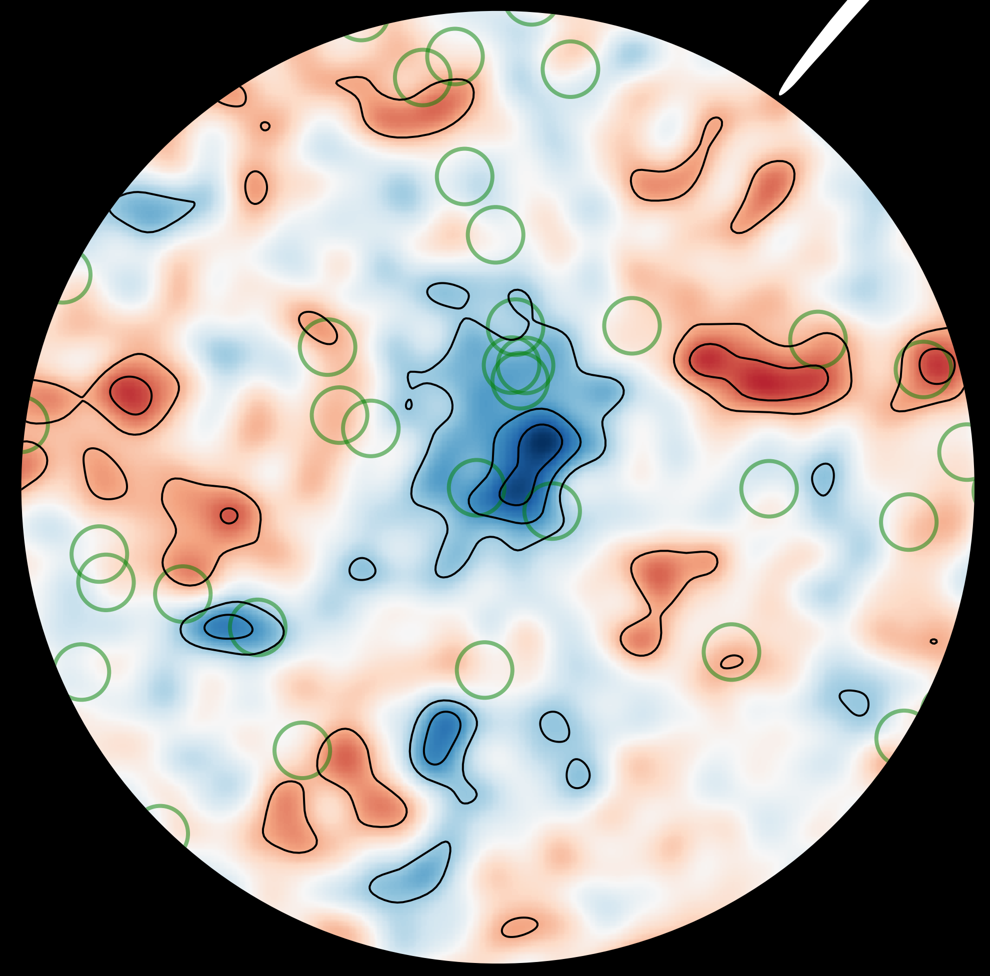
A model reconstruction Corrected for the uv-coverage



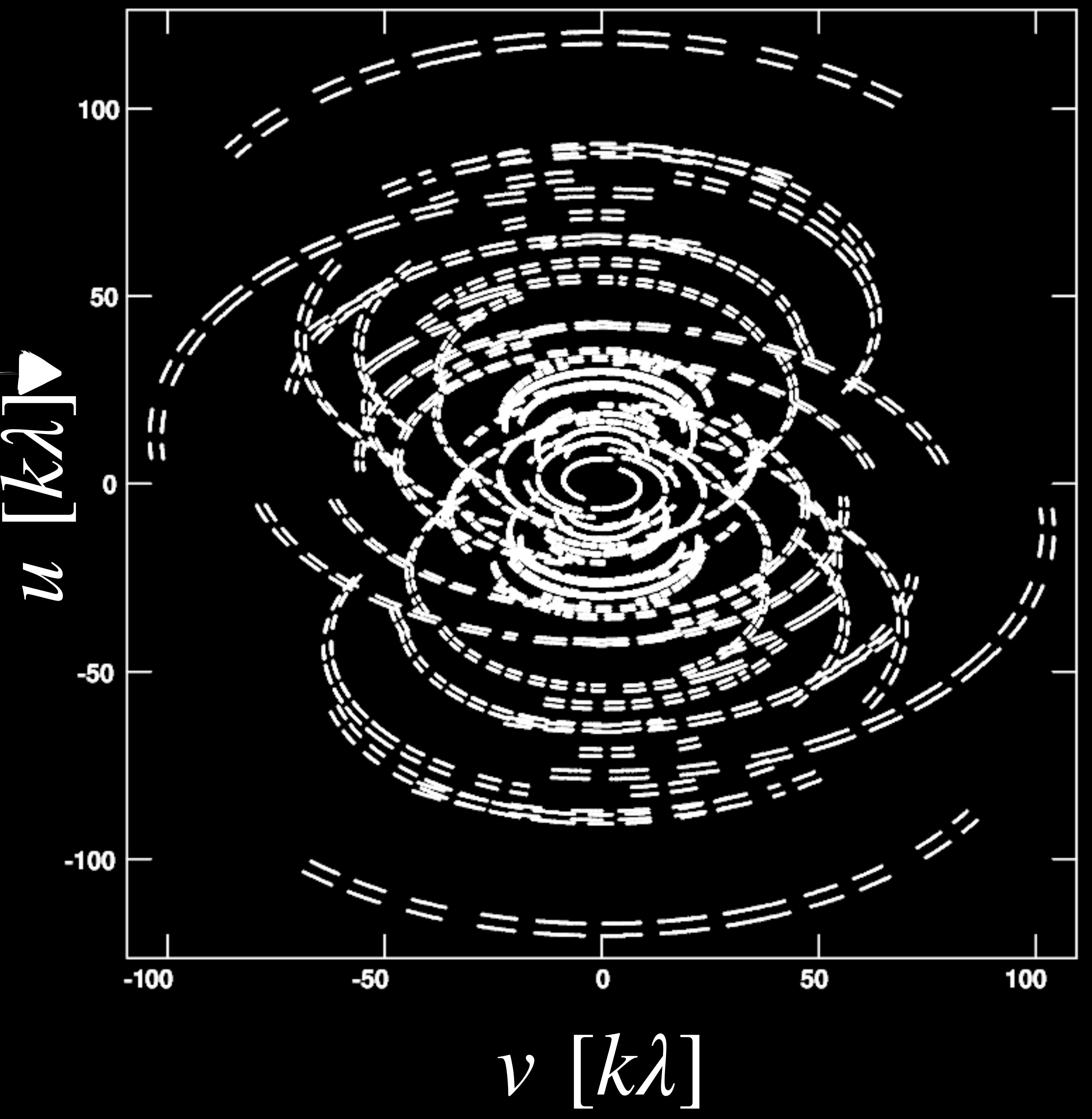
Cluster Members

Contours are drawn at [-4.5, -3.5, -3.5, -1.5, 0, 1.5, 2.5, 3.5]-σ

The visibility plane

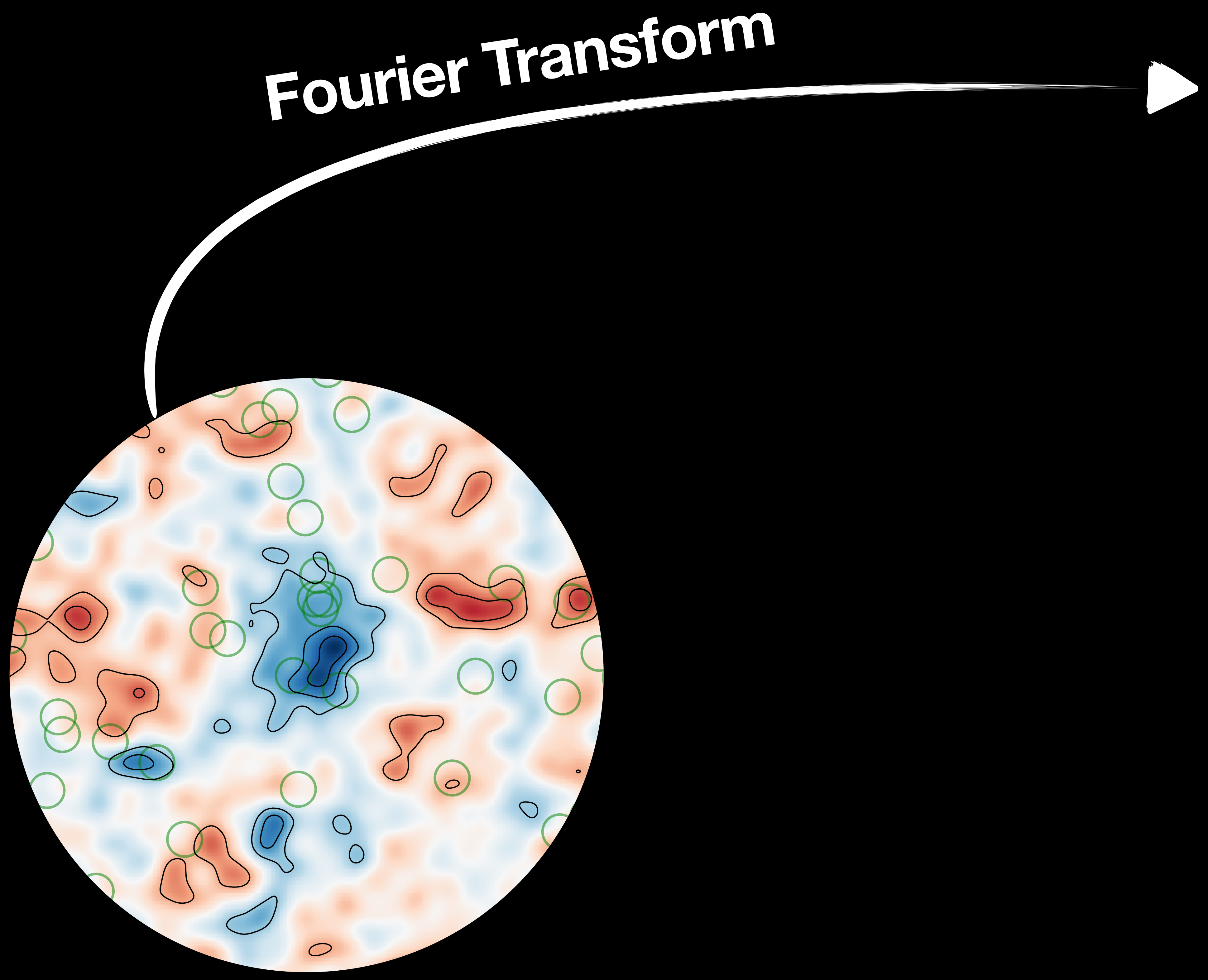


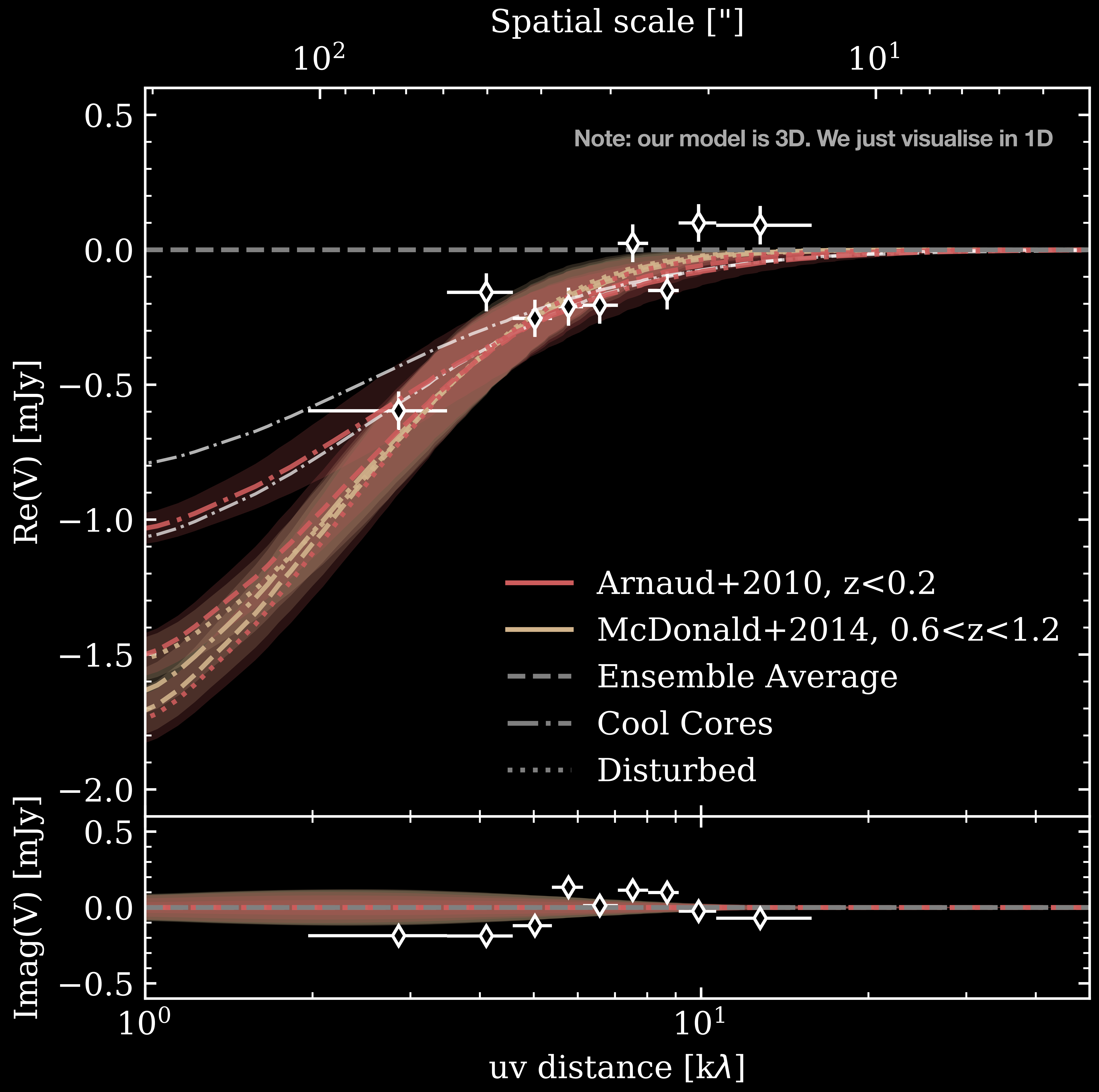
Fourier Transform



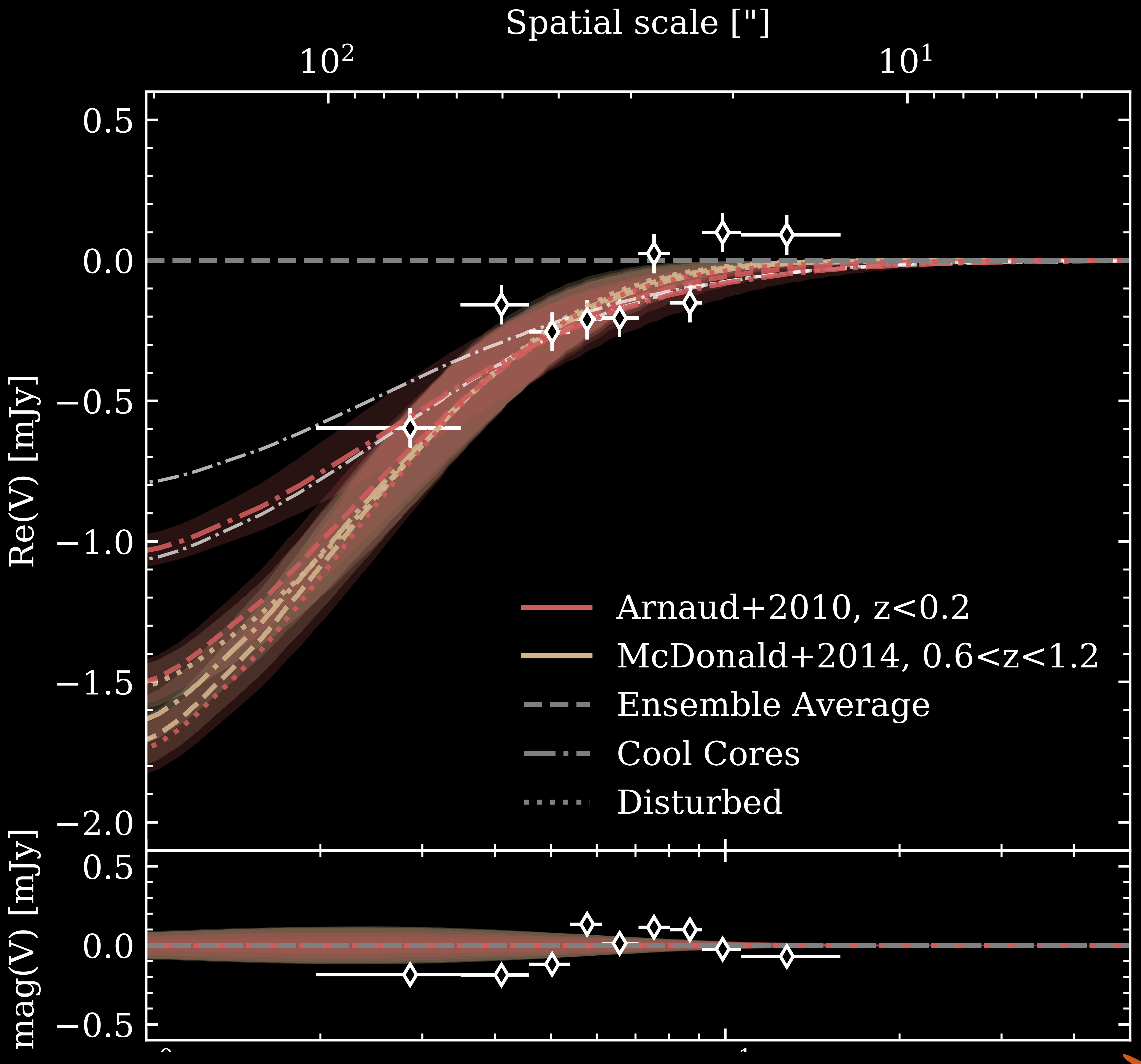
XLSSC 122

A classification based on pressure profiles is hard!





XLSSC 122: Pressure profiles



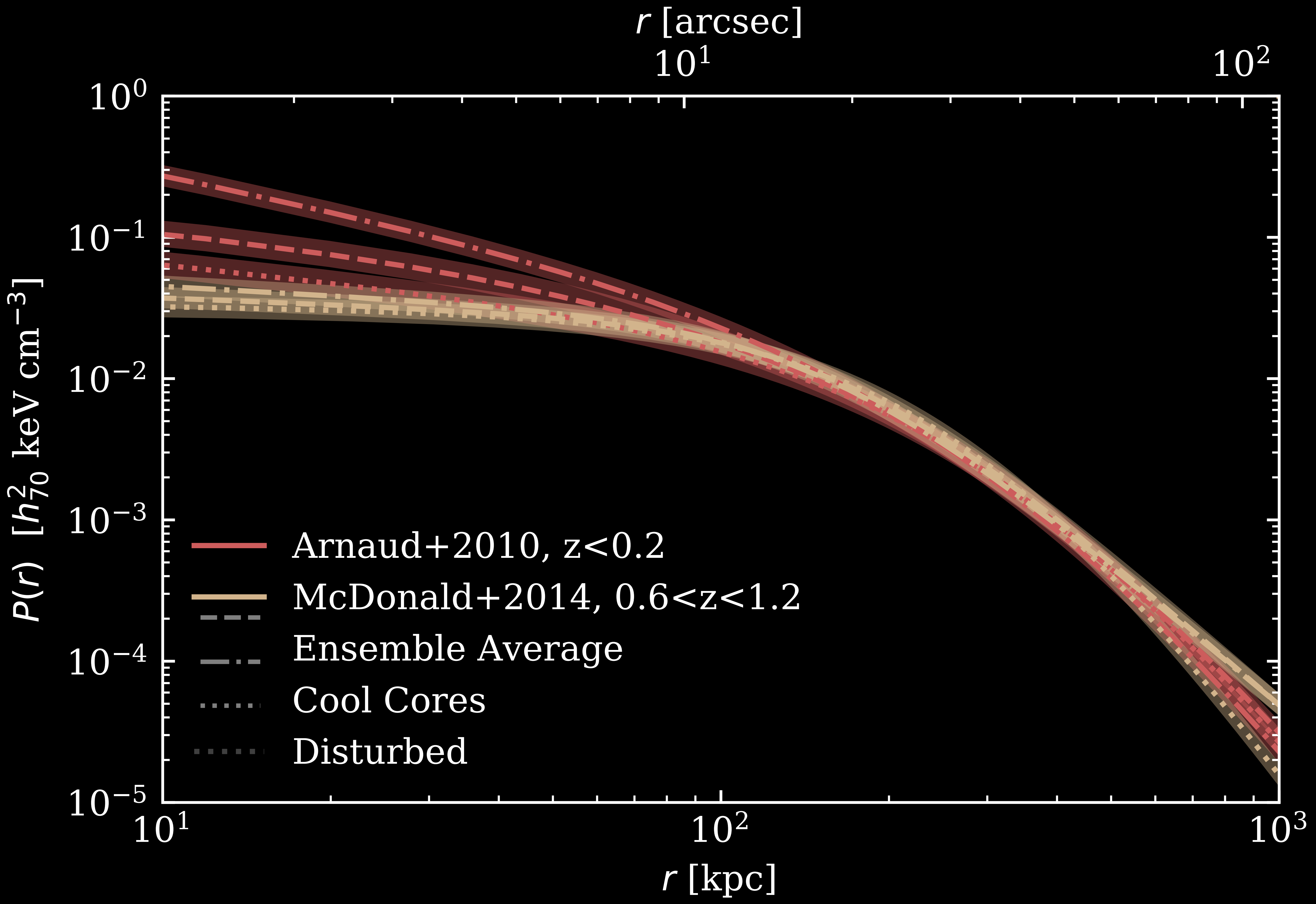
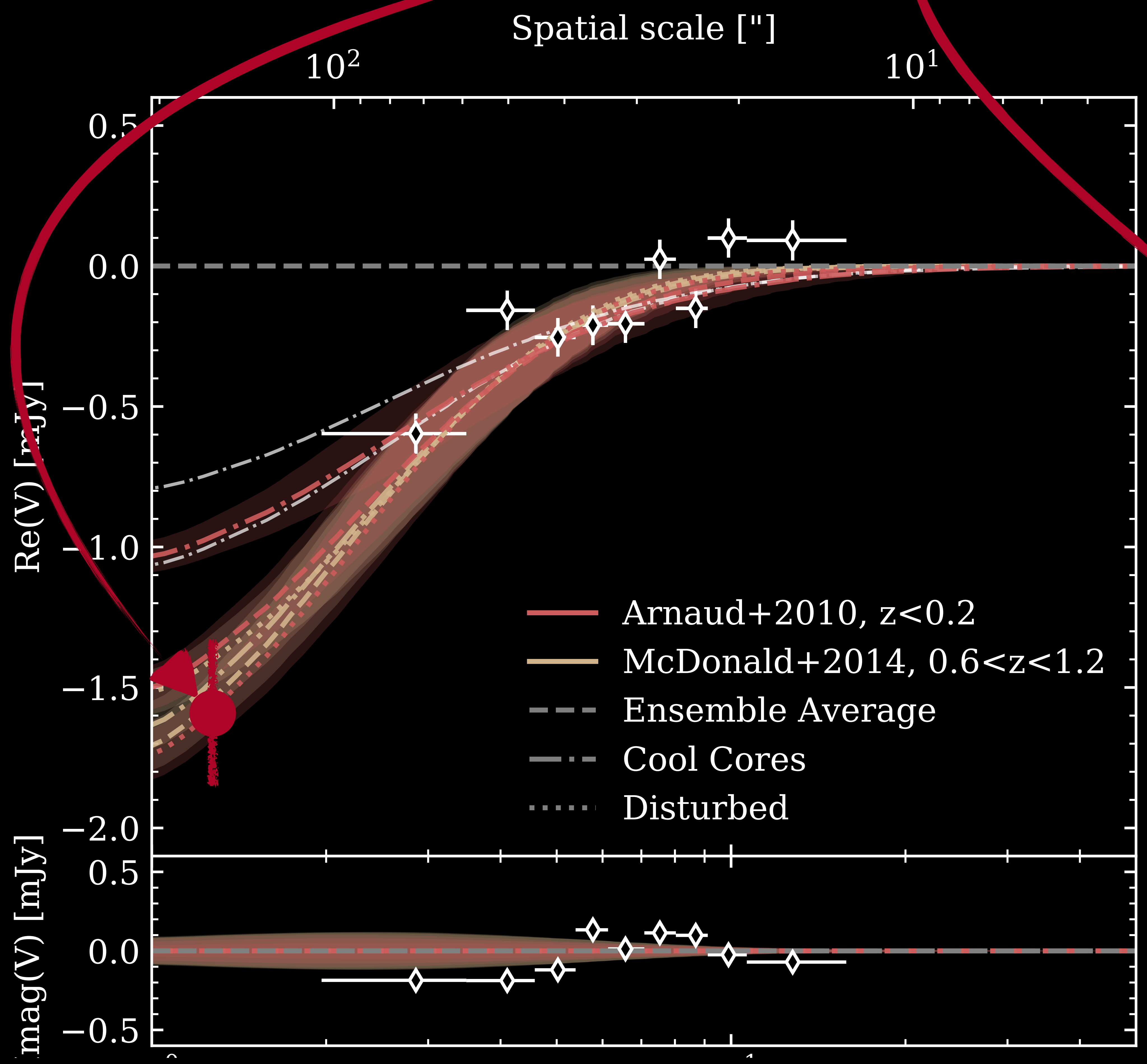
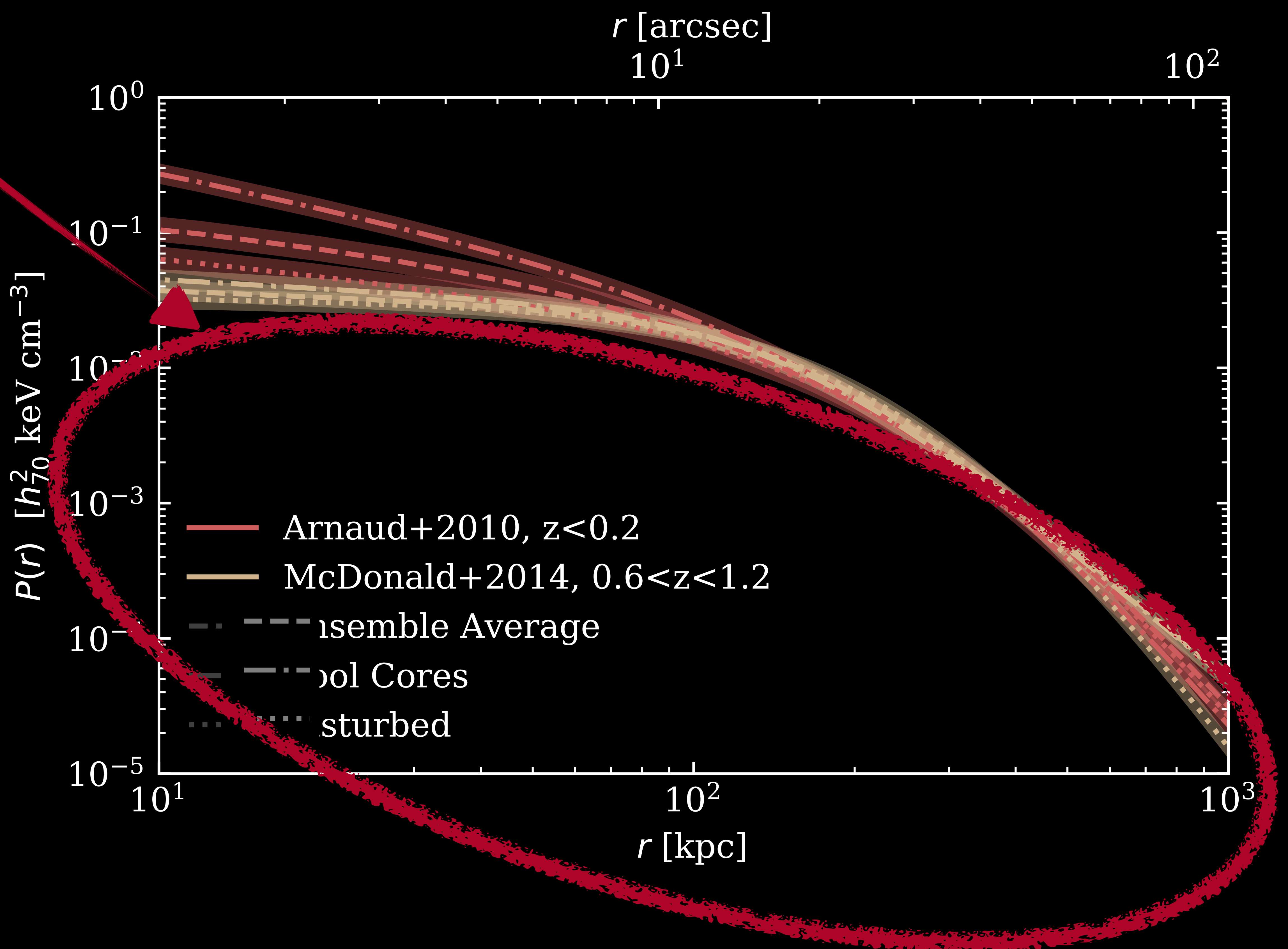


Image plane variant

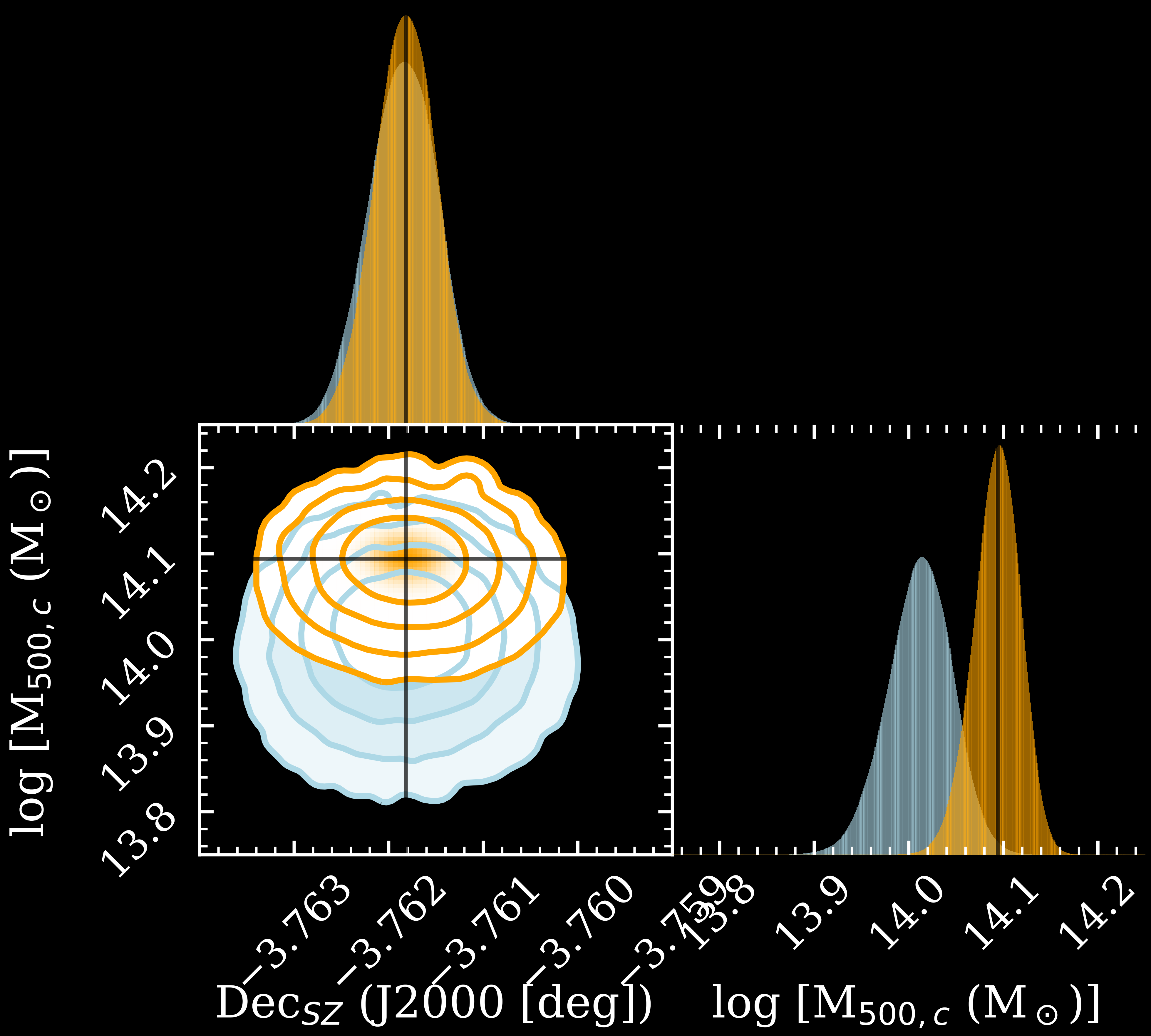
Joint modelling of interferometric & single dish observations

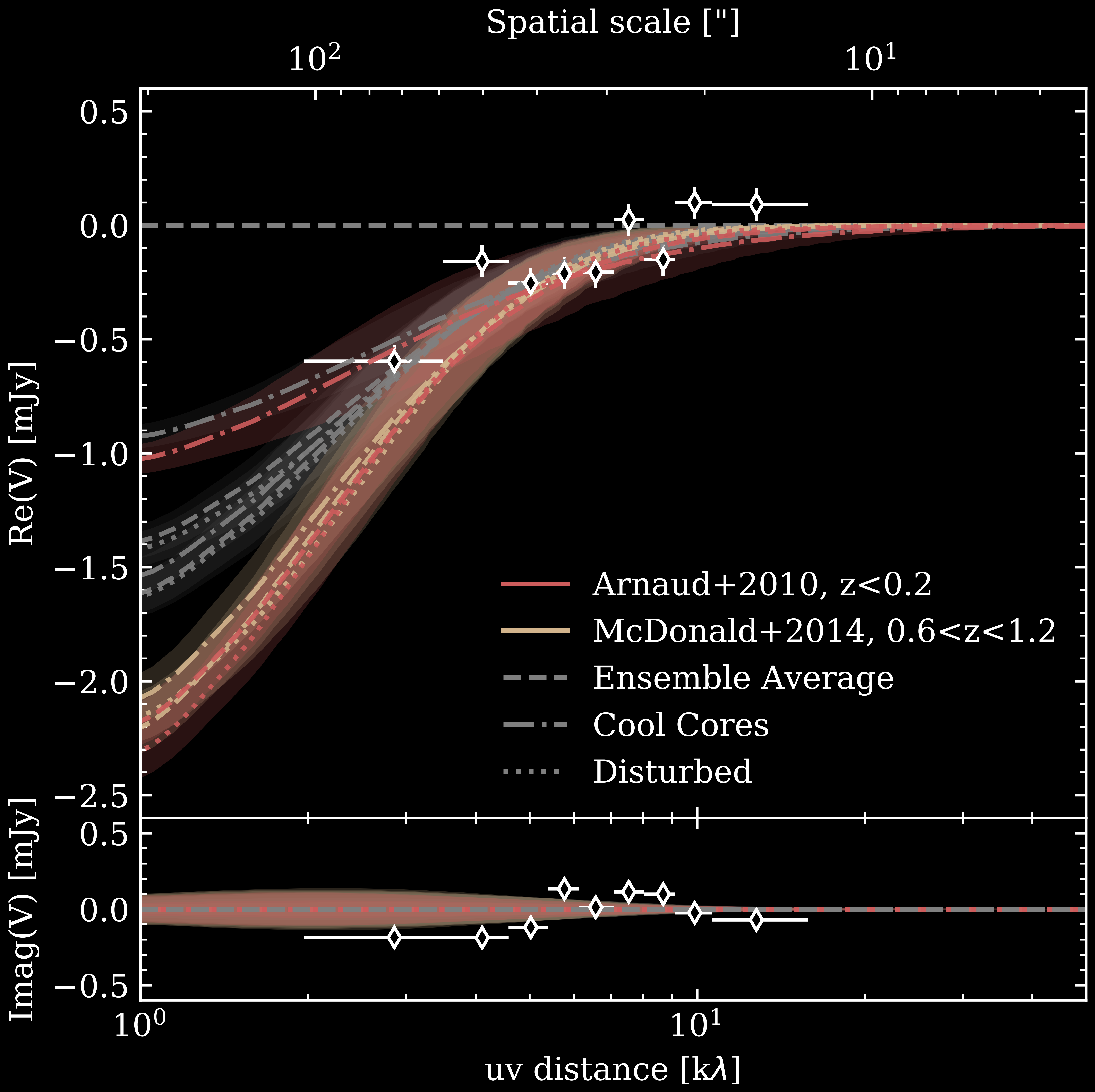
Adding additional constraining power



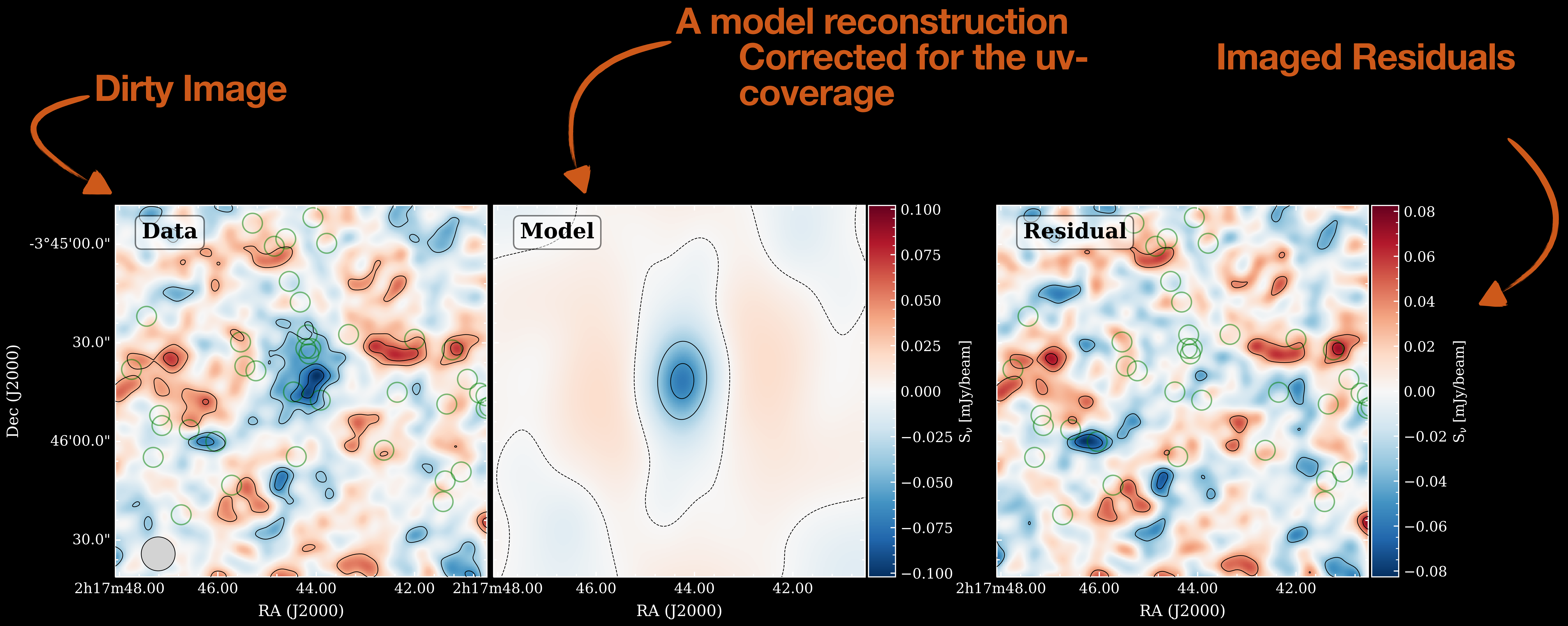


Adding additional constraining power





What does the cluster look like?

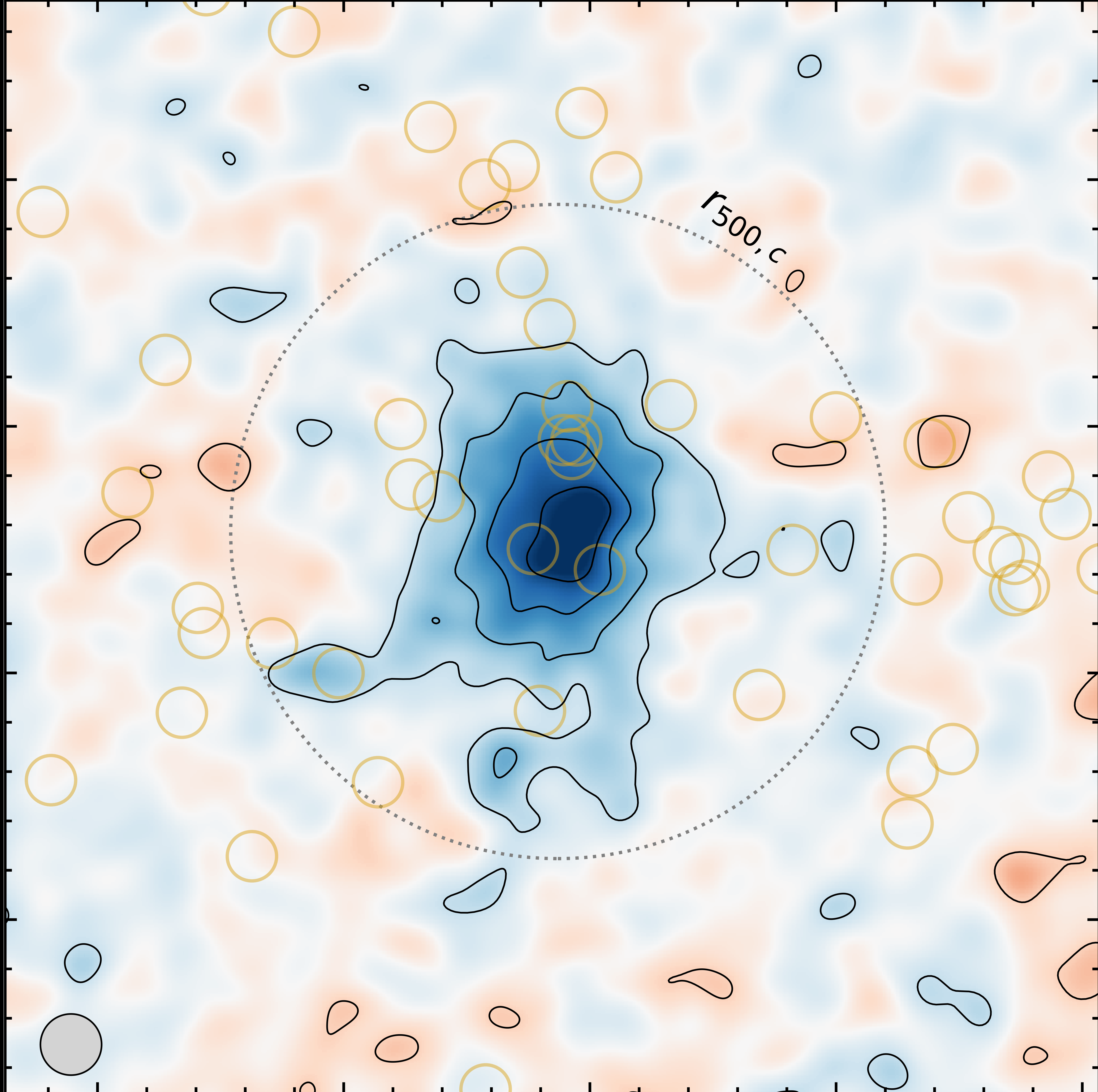


Cluster Members

Contours are drawn at [-4.5, -3.5, -3.5, -1.5, 0, 1.5, 2.5, 3.5]-σ

Searching for asymmetries:

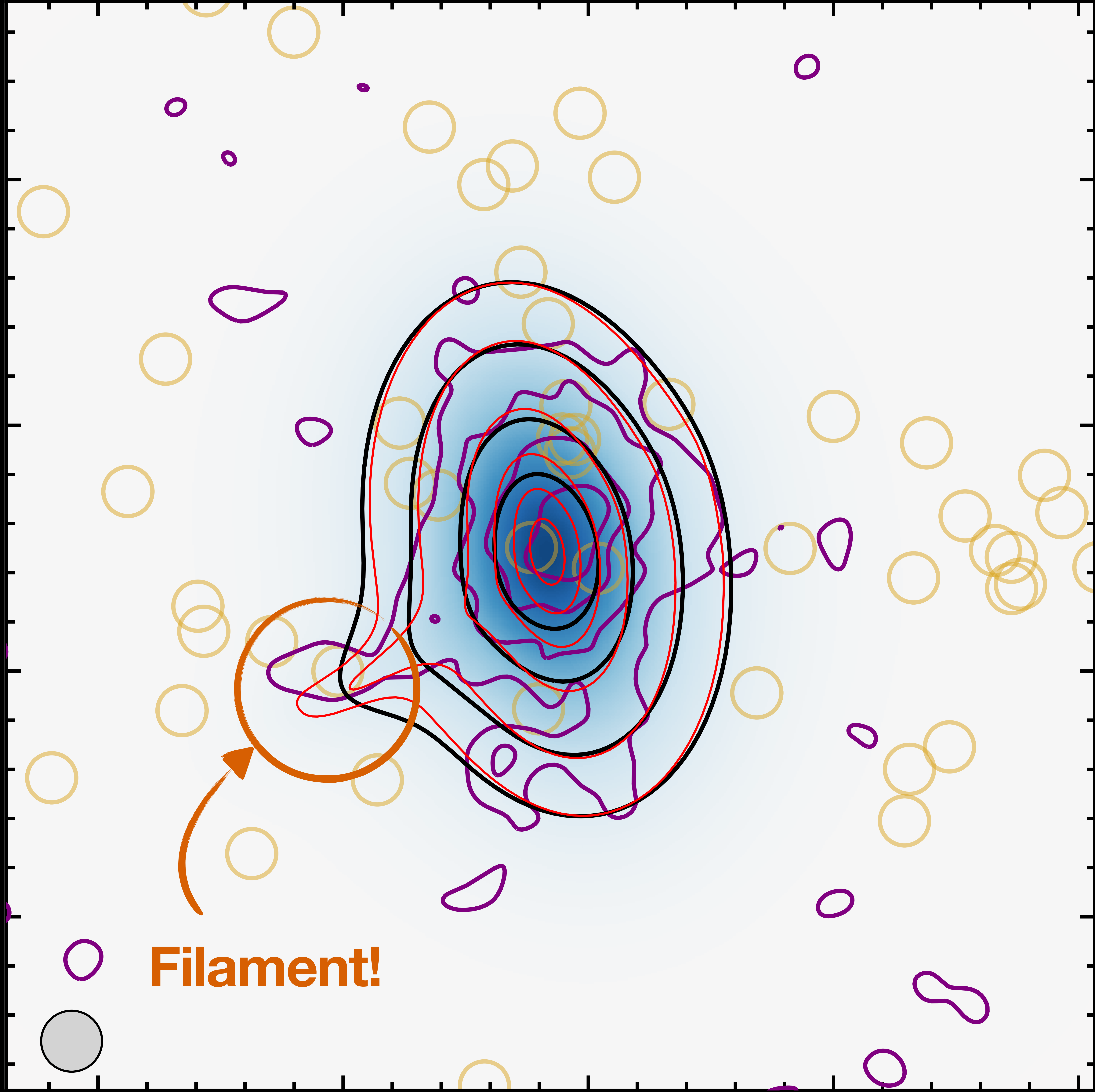
Likelihood-weighted model
⊛
Synthesised beam
+
Residuals
=
Cleaned image reconstruction



Contours are drawn at [-10, -8, -6, -4, -2, 2, 4]-σ

A 2-component likelihood-weighted model reconstruction

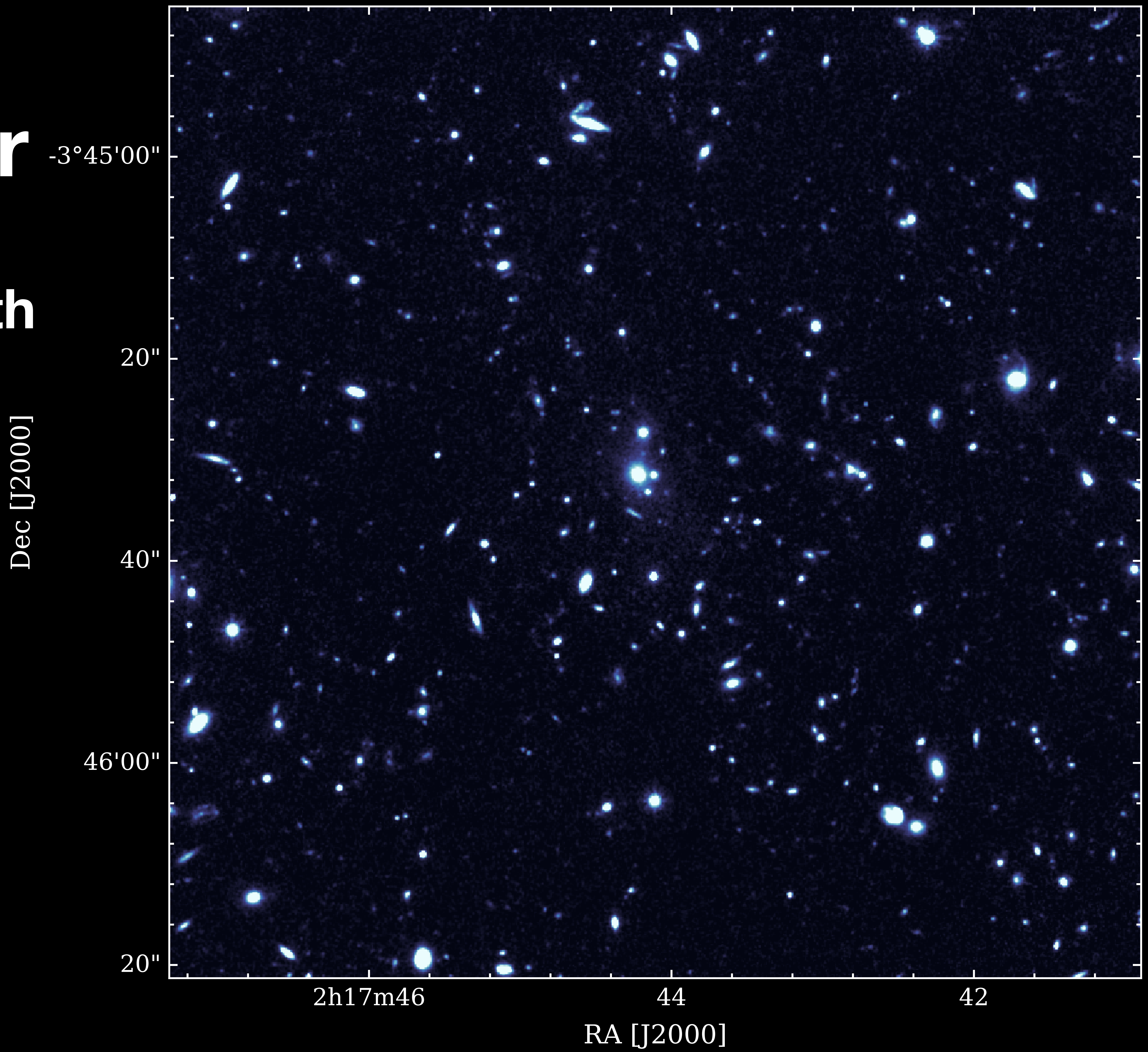
- Equivalent to a $2.1\sigma - 3.6\sigma$ detection!
- A flux ratio 1:2



Contours are drawn at [-10, -8, -6, -4, -2, 2, 4]-σ

Let us bring everything together

- **We need multi-wavelength information**
  - Optical



Let us bring everything together

- **We need multi-wavelength information**
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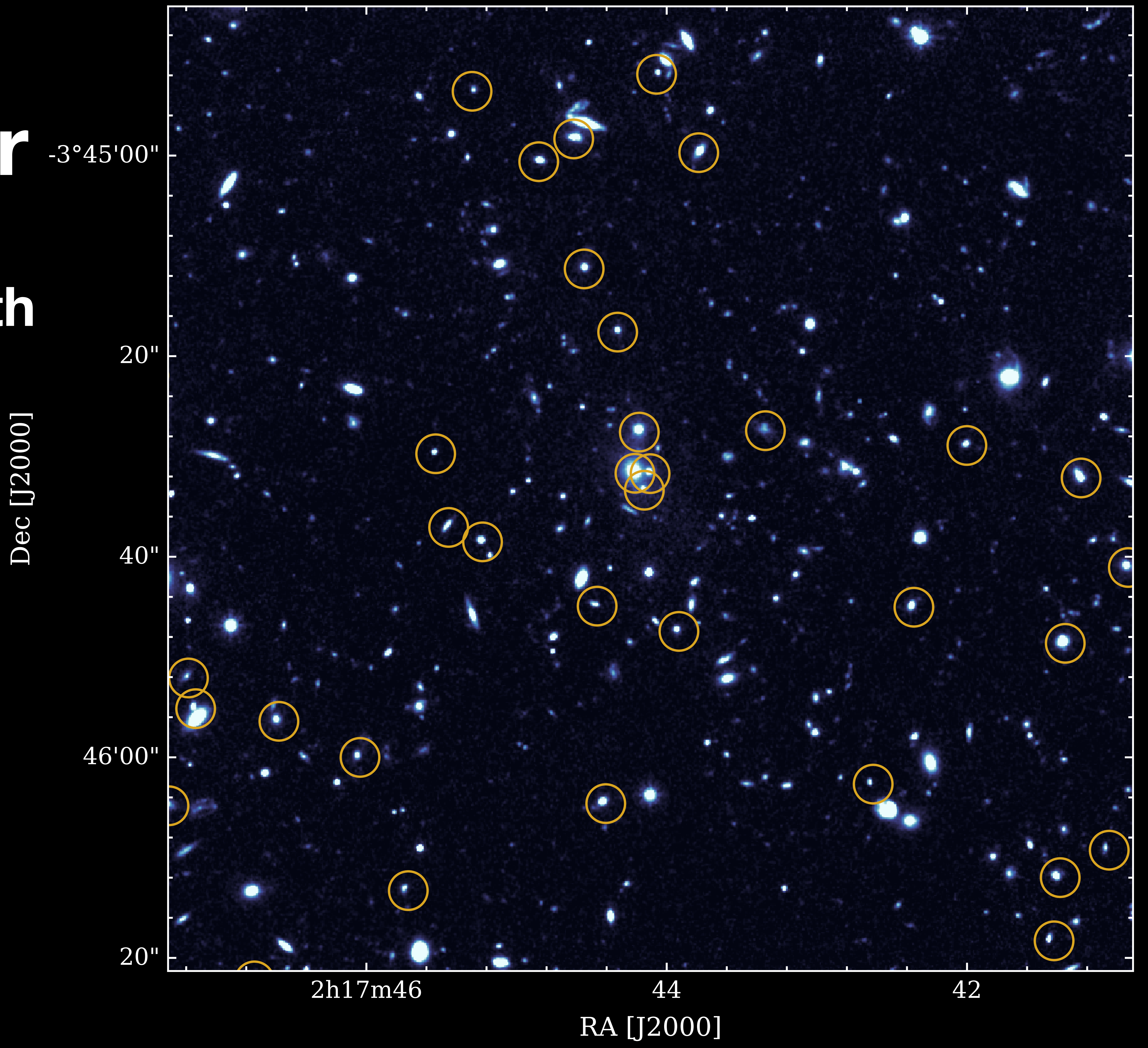
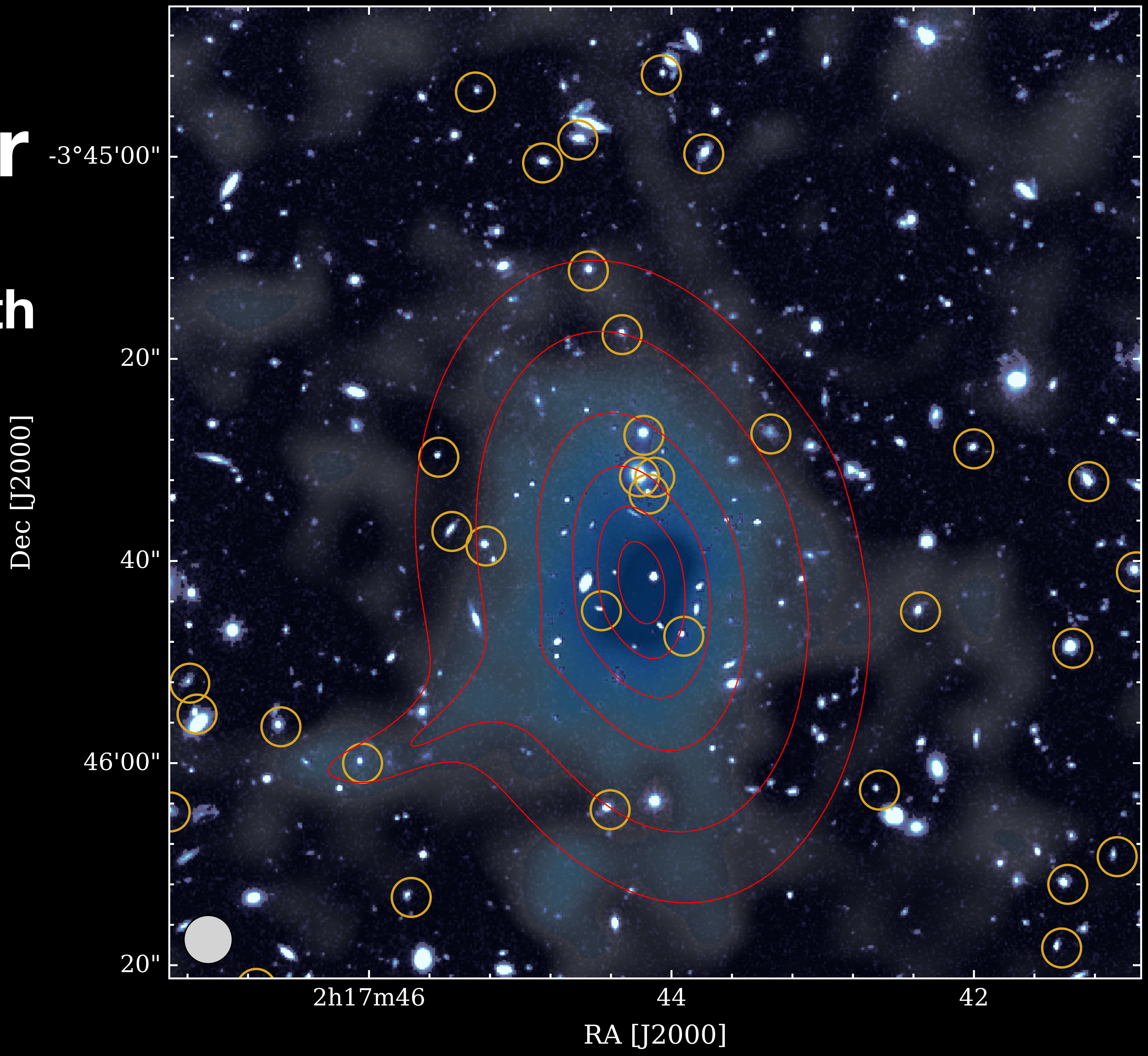
  - $H\alpha$



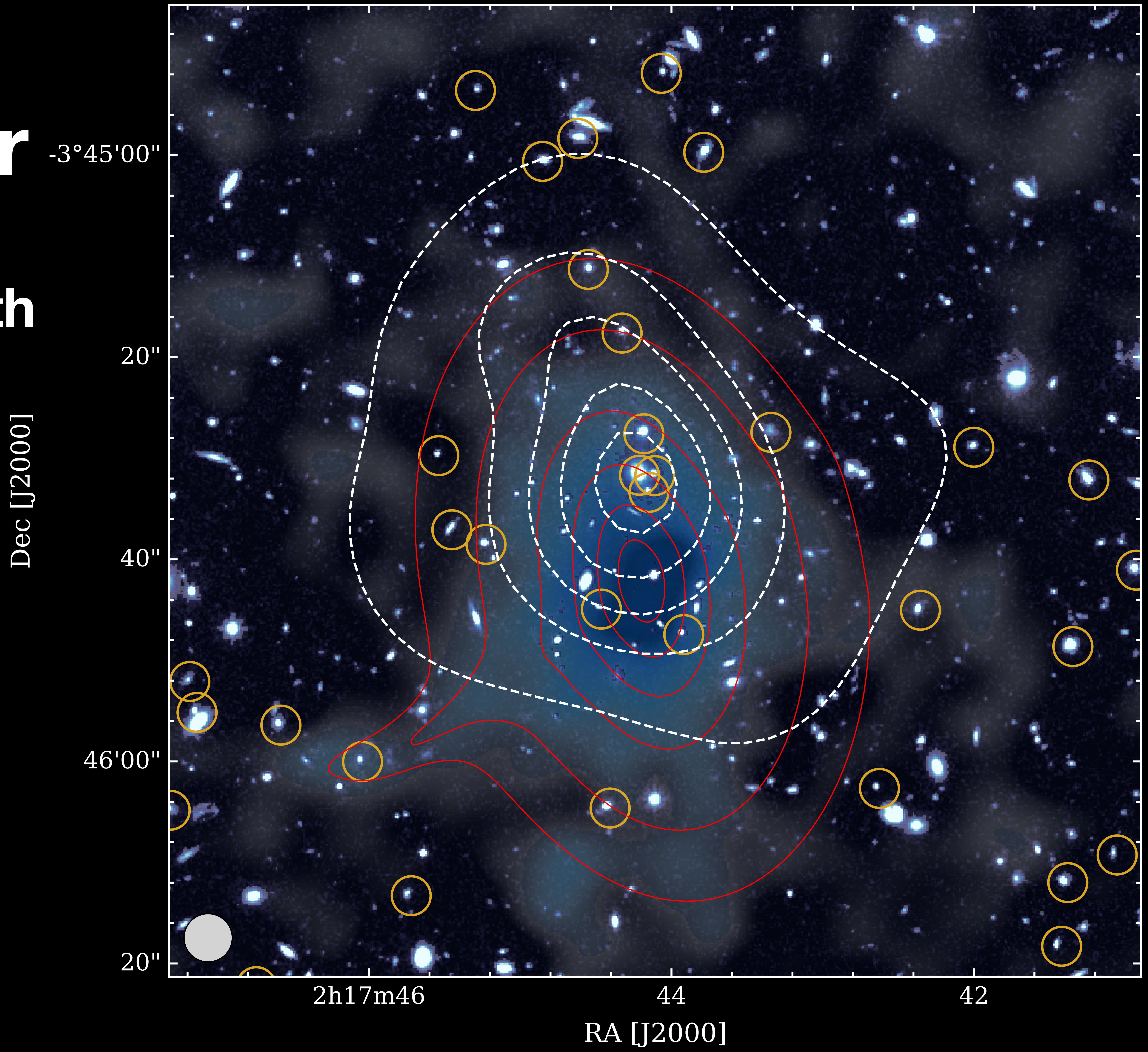
Let us bring everything together

- **We need multi-wavelength information**
  - Optical
  - $H\alpha$
  - SZ



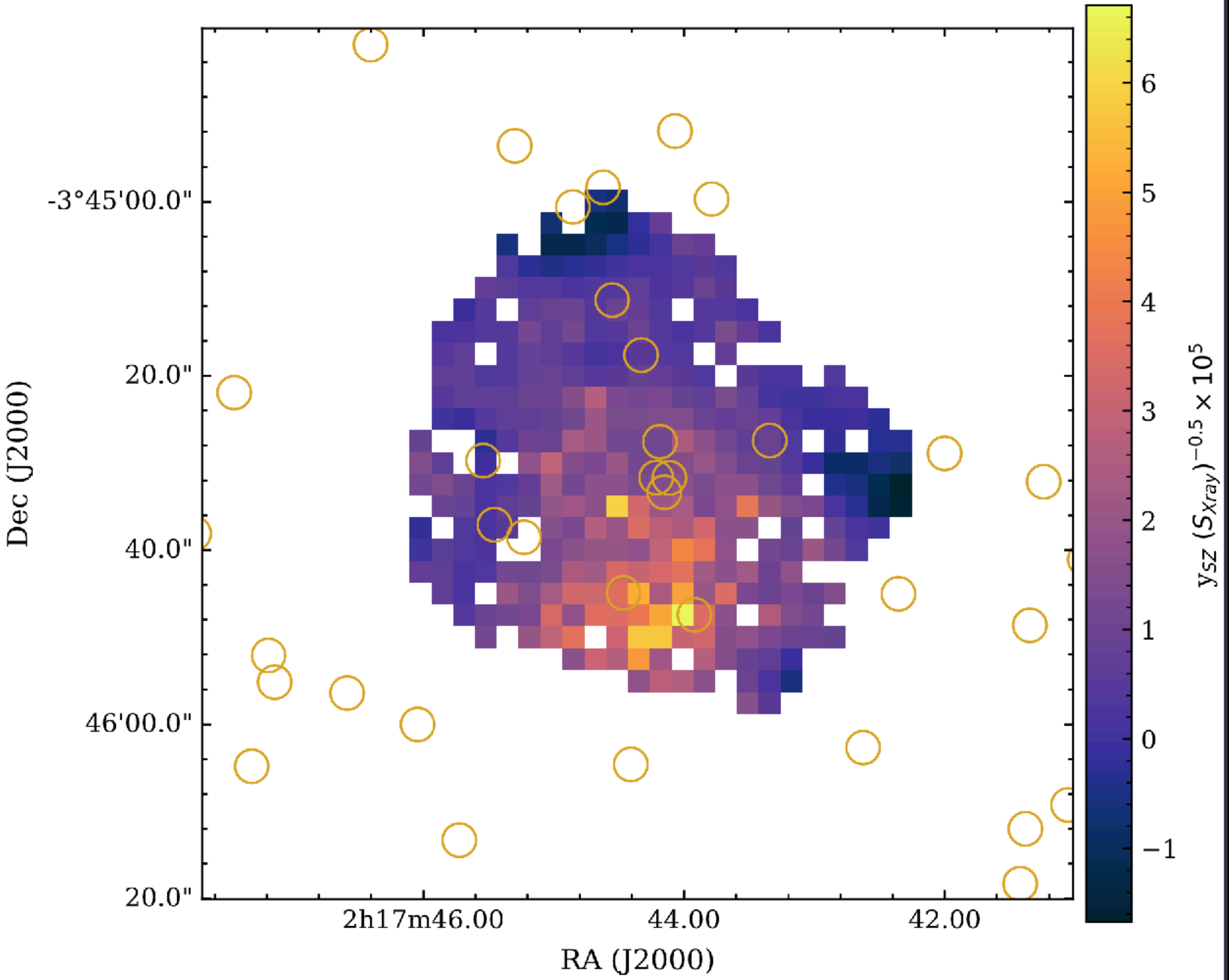
Let us bring everything together

- **We need multi-wavelength information**
  - Optical
  - $H\alpha$
  - SZ
  - X-ray



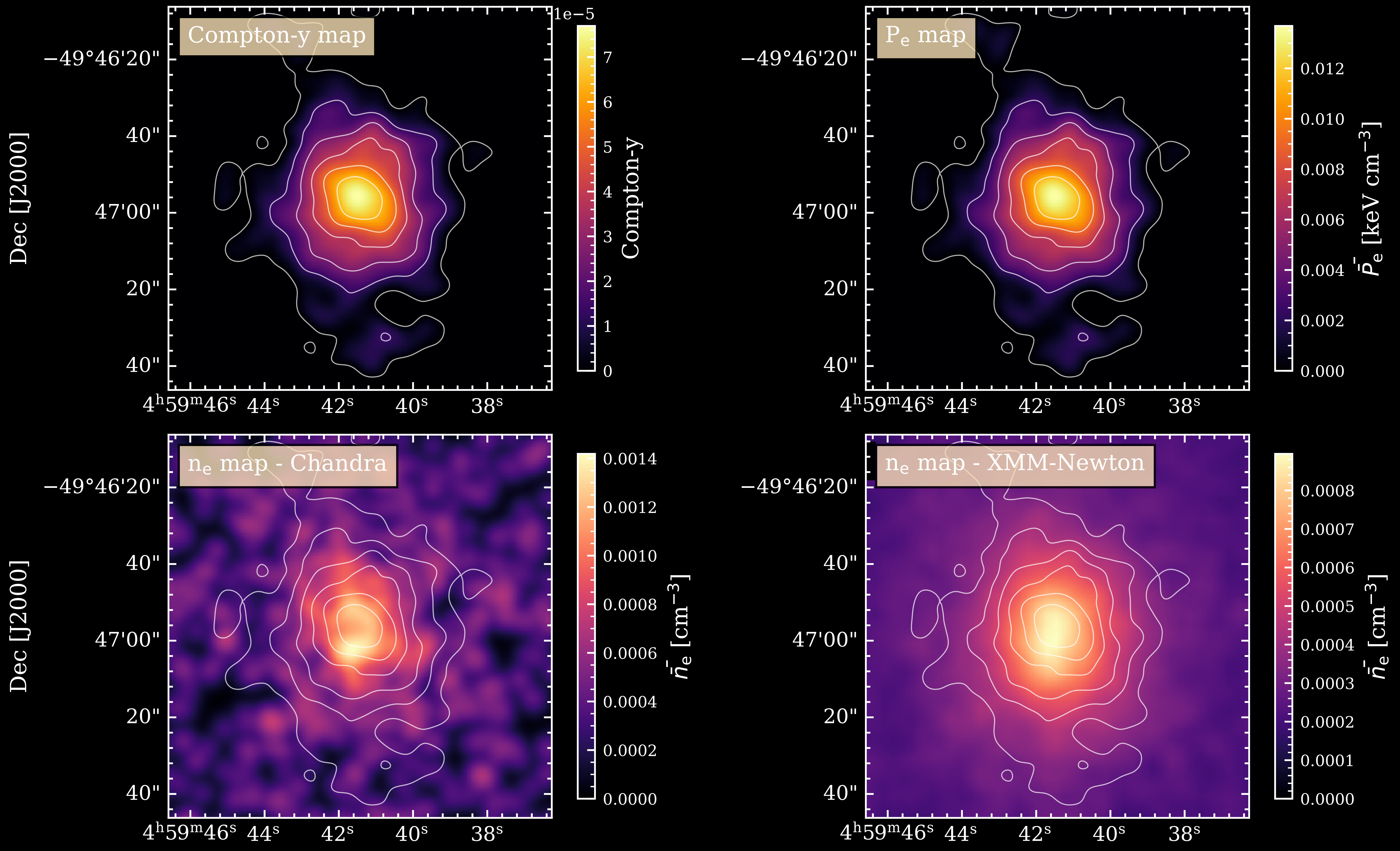
An
X-ray + SZ view

- $\propto SZ_{\mathrm{flux}}/\sqrt{SZ_{\mathrm{X-ray}}} \propto k_b T$



CL-J0459, the highest−z in SPT

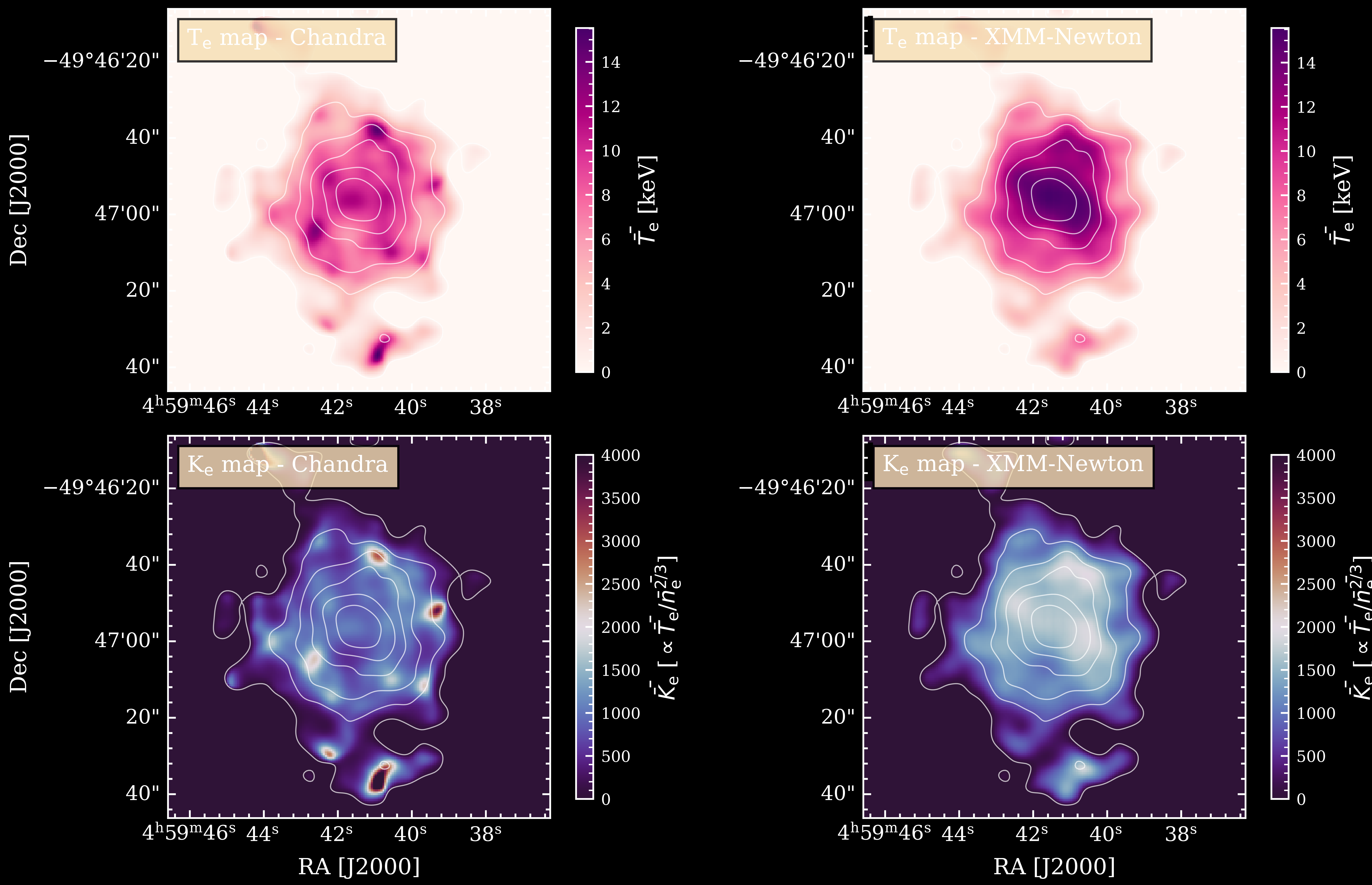
$$\propto SZ_{\mathrm{flux}}/\sqrt{SZ_{\mathrm{X-ray}}} \propto k_b T$$



Contours are drawn at [-10, -8, -6, -4, -2, 2, 4]-σ

CL-J0459, the highest$-z$ in SPT

$$\propto \mathrm{SZ_{flux}}/\sqrt{\mathrm{SZ_{X-ray}}} \propto \mathrm{k_b T}$$

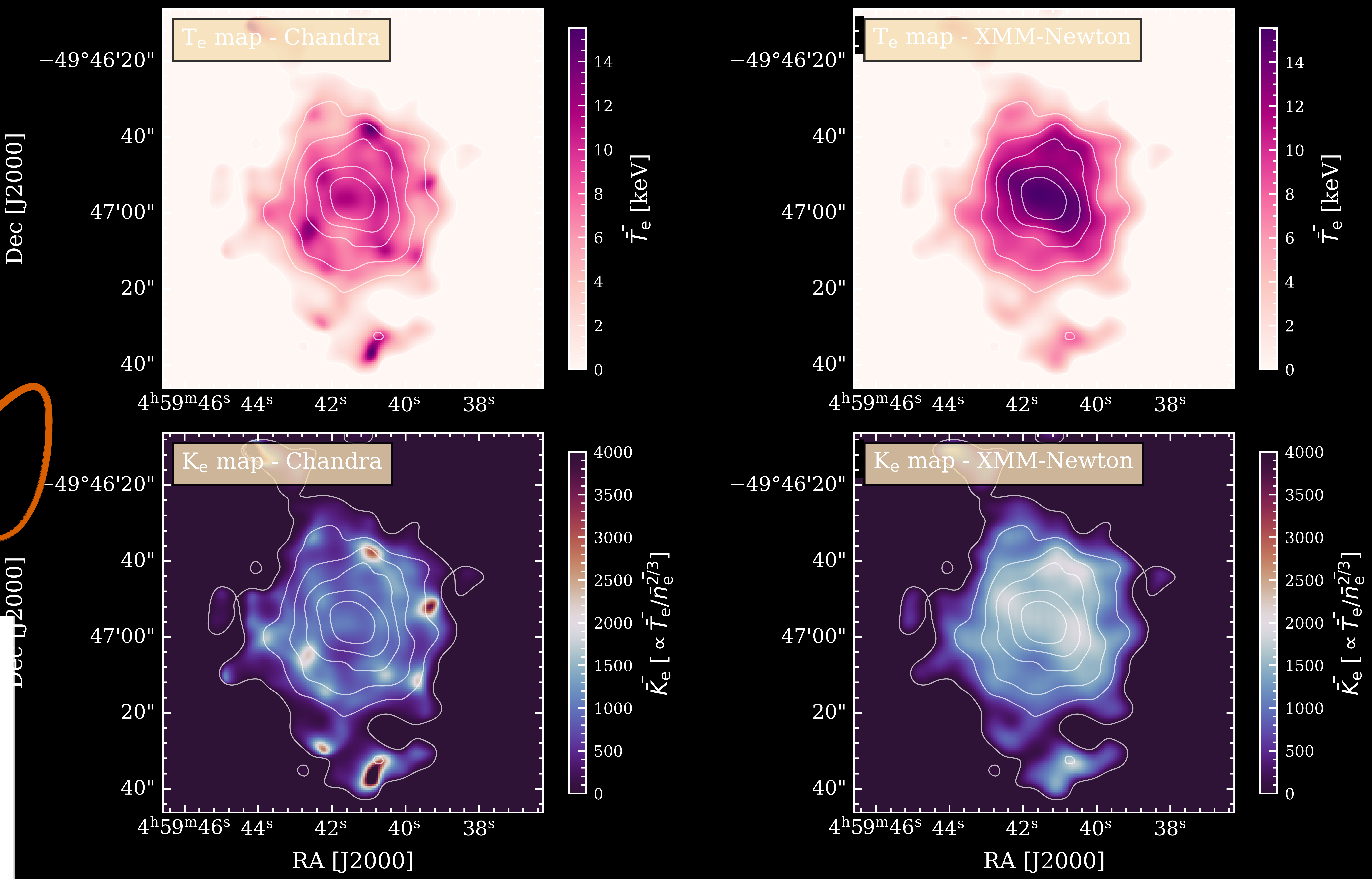


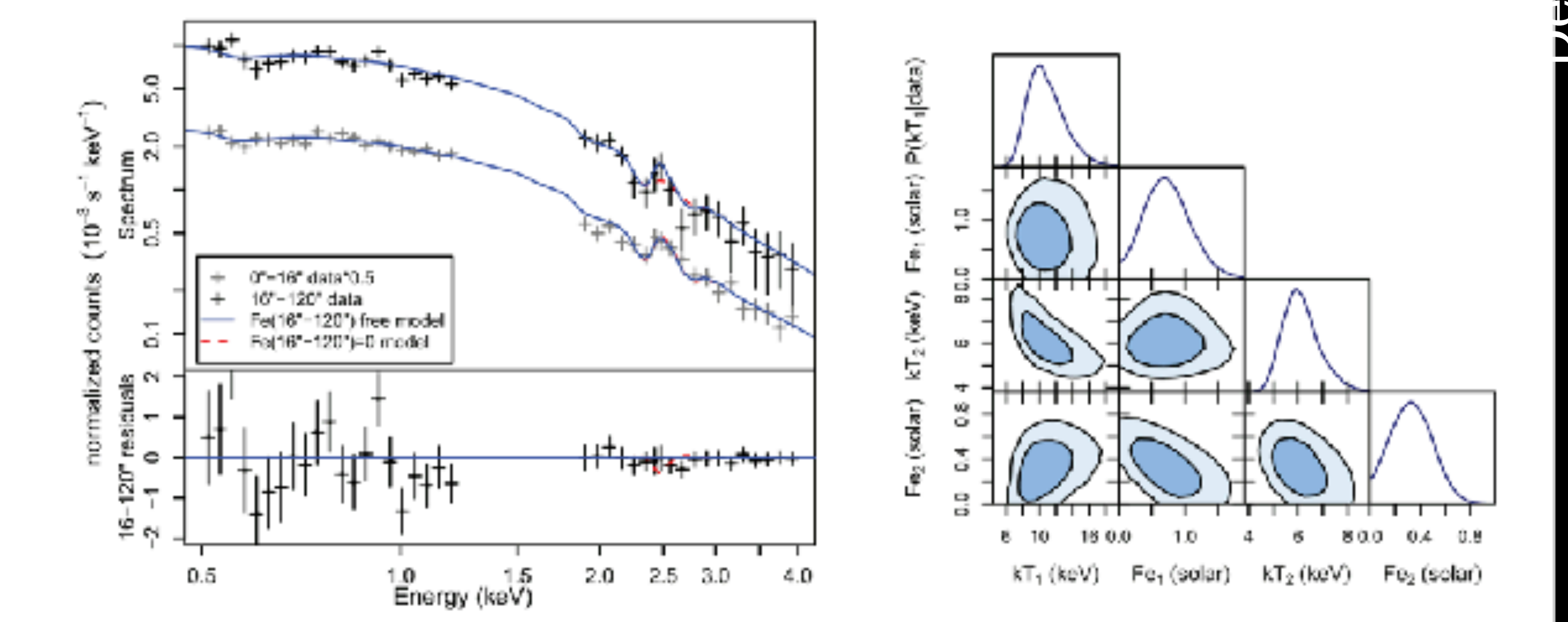
Contours are drawn at [-10, -8, -6, -4, -2, 2, 4]-σ

CL-J0459, the highest$-z$ in SPT

$$\propto \mathrm{SZ_{flux}}/\sqrt{\mathrm{SZ_{X-ray}}} \propto \mathrm{k_b T}$$

Compare with Mantz+2020





1560 A. B. Mantz et al.

Figure 5. As Fig. 3, but for the deprojection analysis in Section 4.3, showing the posteriors for the temperature and metallicity of two spherical shells. The cluster redshift is marginalized over, although we do not include it in the right-hand panel; constraints are similar to those in Fig. 3. The 'Fe = 0' and 'Fe free' models in the left-hand panel refer to the metallicity in the outer shell. The metallicity of the inner shell is free in both cases, and PSF mixing thus produces an emission line feature in the outer annulus even for the 'Fe = 0' case. The data and models for the inner annulus are scaled by a factor of 0.5 in the left-hand panel for clarity.

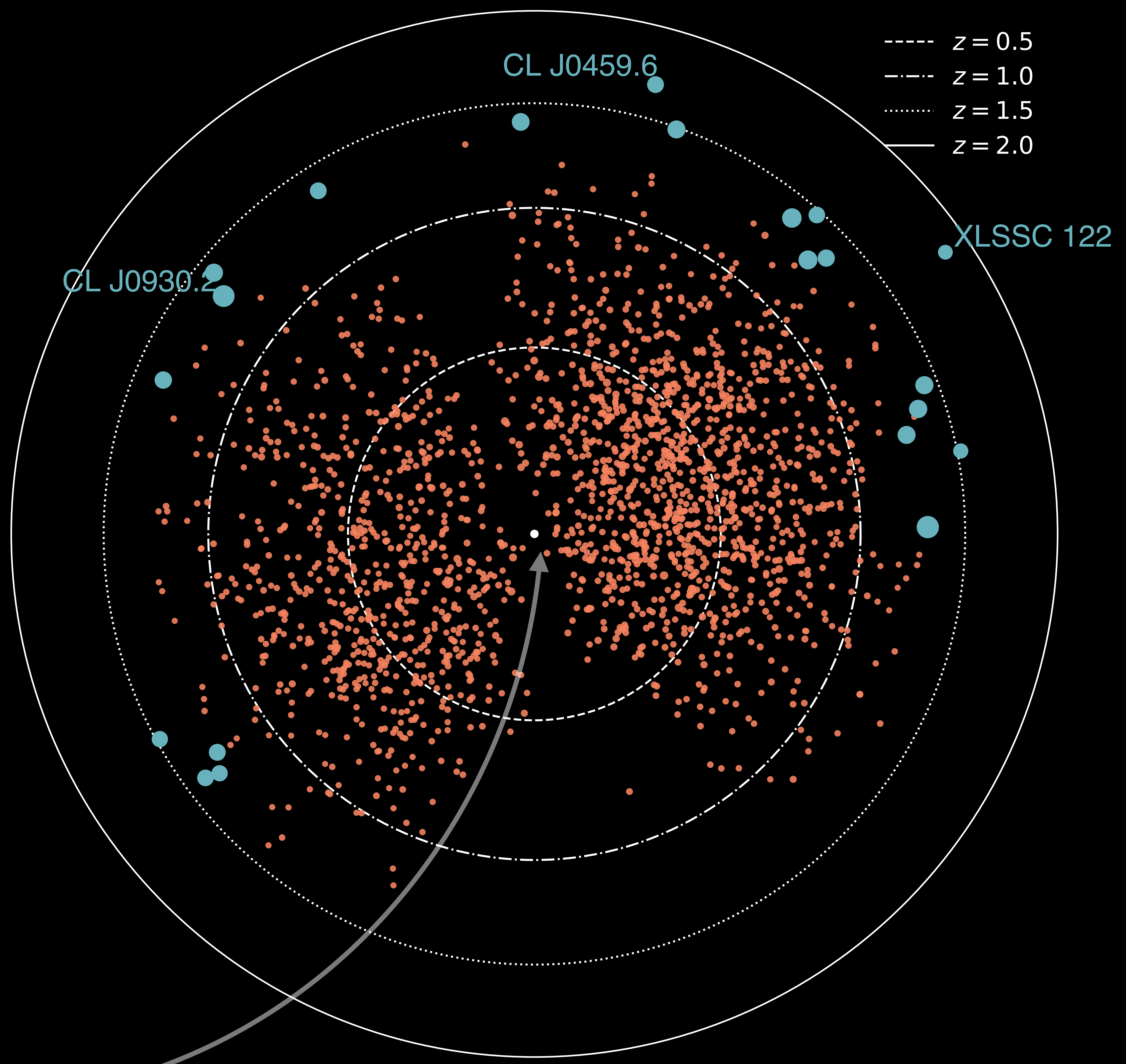
Contours are drawn at [-10, -8, -6, -4, -2, 2, 4]-σ

ReCESS

van Marrewijk et al. (in prep.)

How does really hot gas form in the Universe?

- Gravitationally
- Mechanical Feedback



We are here!

Mechanical feedback at $z = 1.3$

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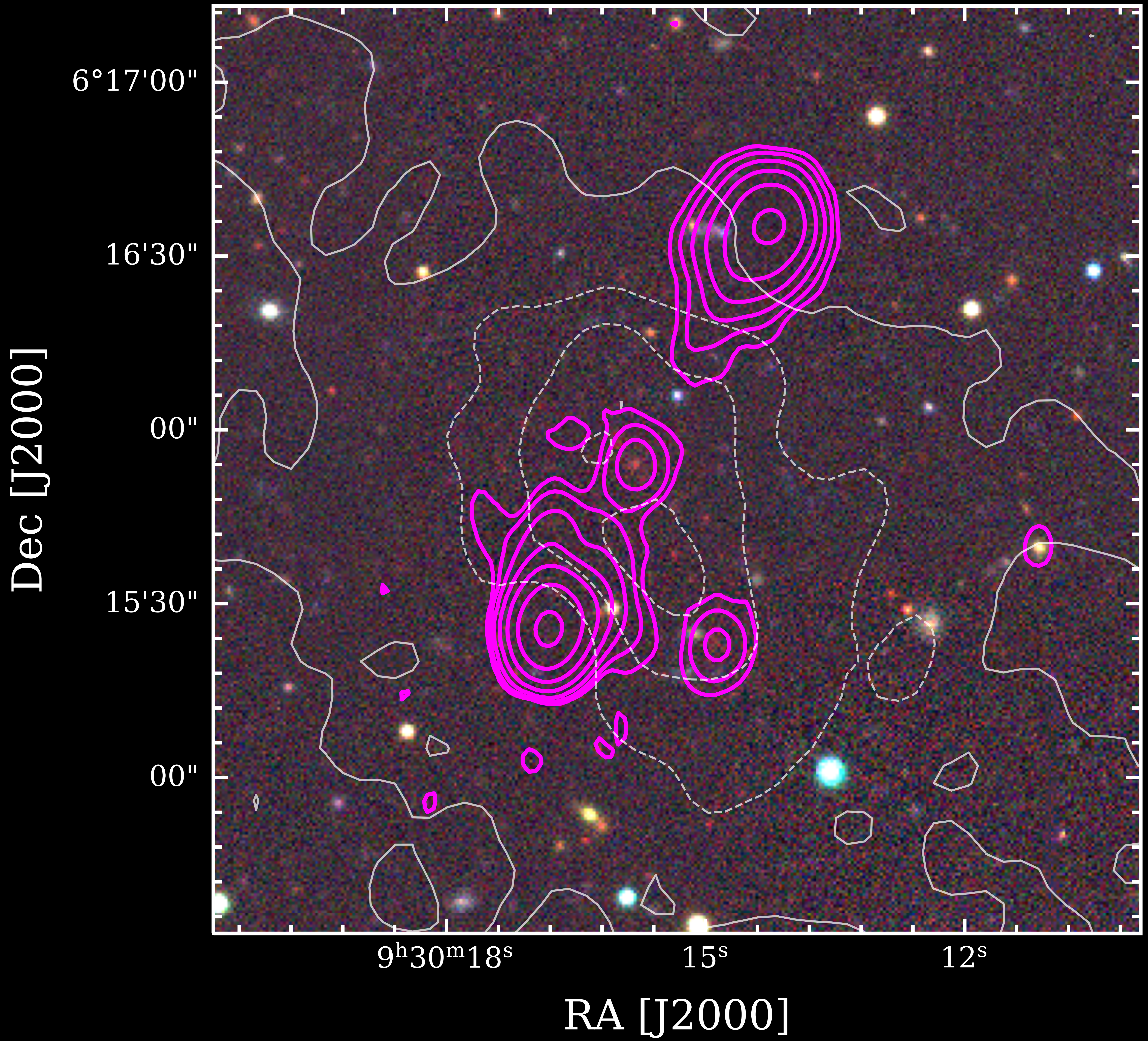
- MeerKAT & LoTSS DR3
- Legacy Survey DR10
- Mustang-2 contours



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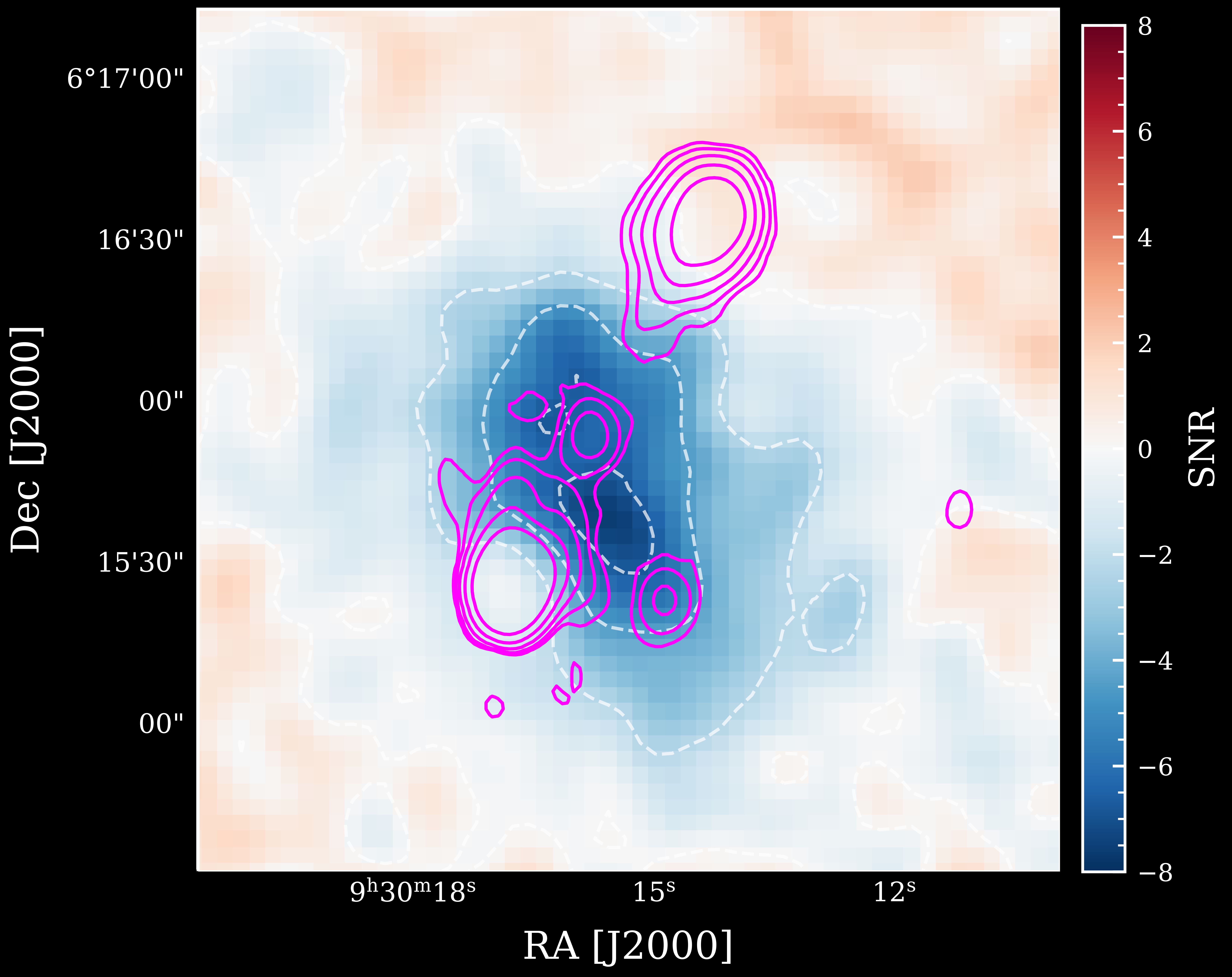
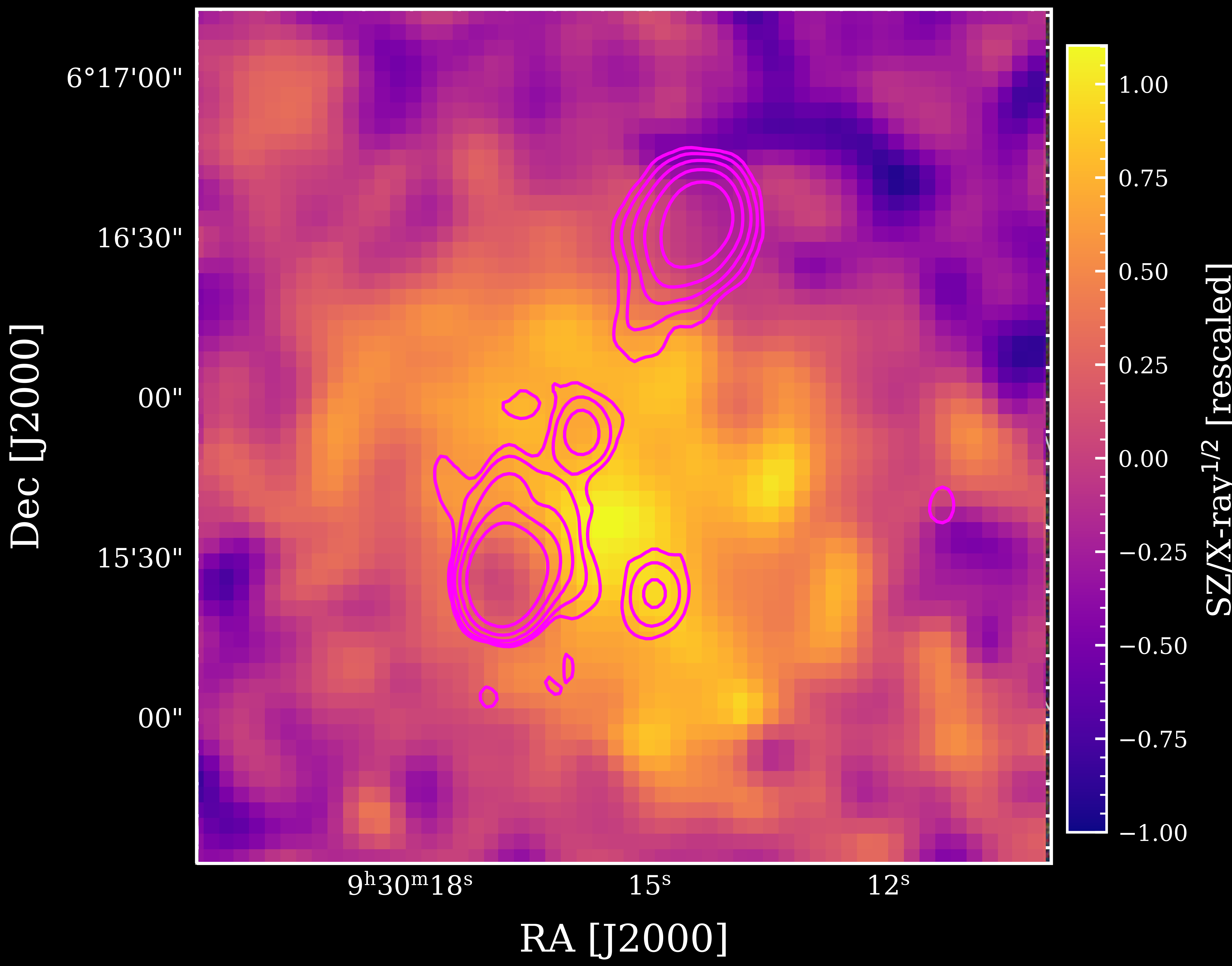


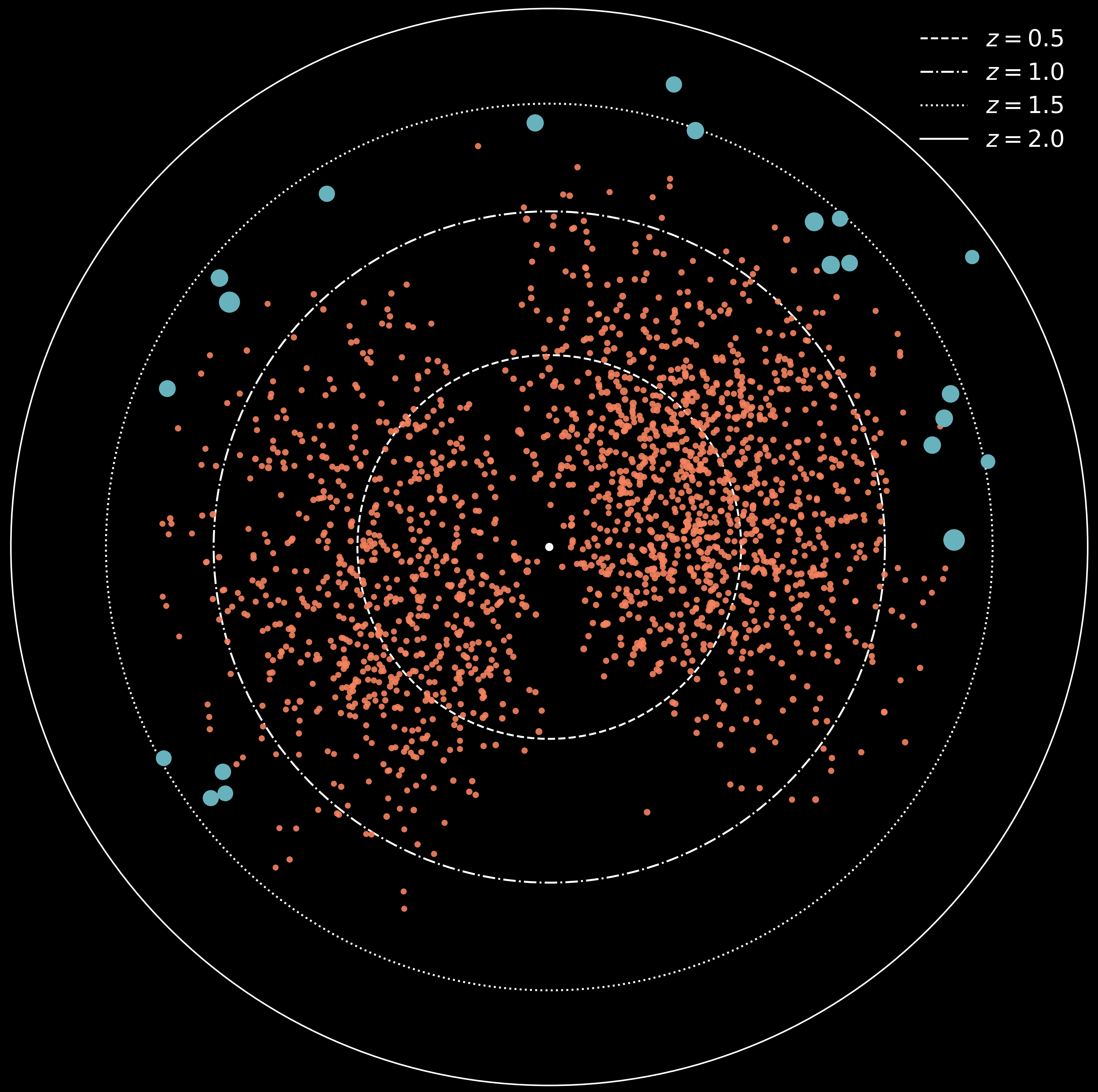
Mechanical feedback at $z = 1.3$

$\propto SZ_{flux}/\sqrt{SZ_{X-ray}} \propto k_b T$



To recap,

Three takeaways



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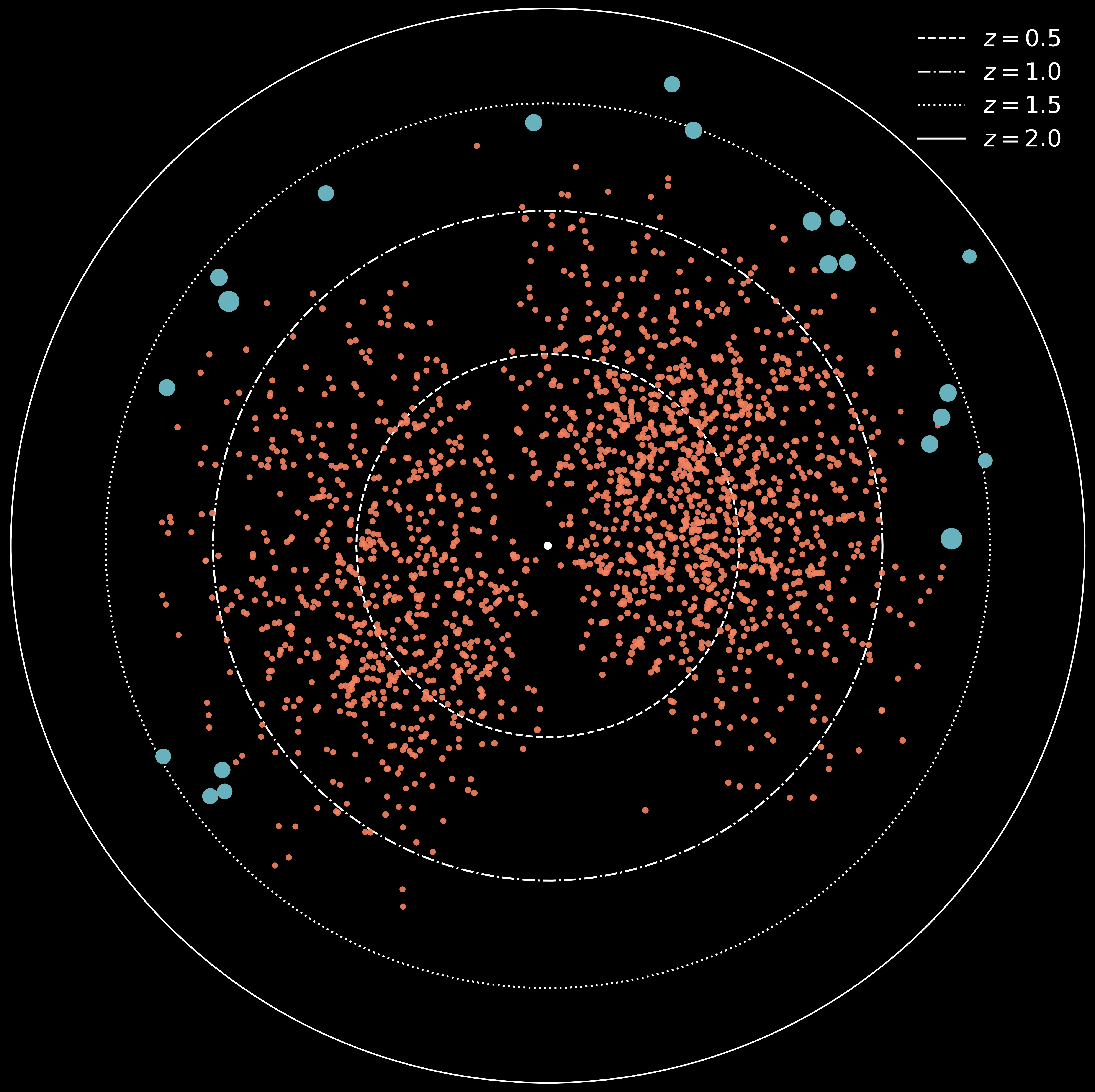
1. CMB surveys are perfect for selecting high-z clusters.



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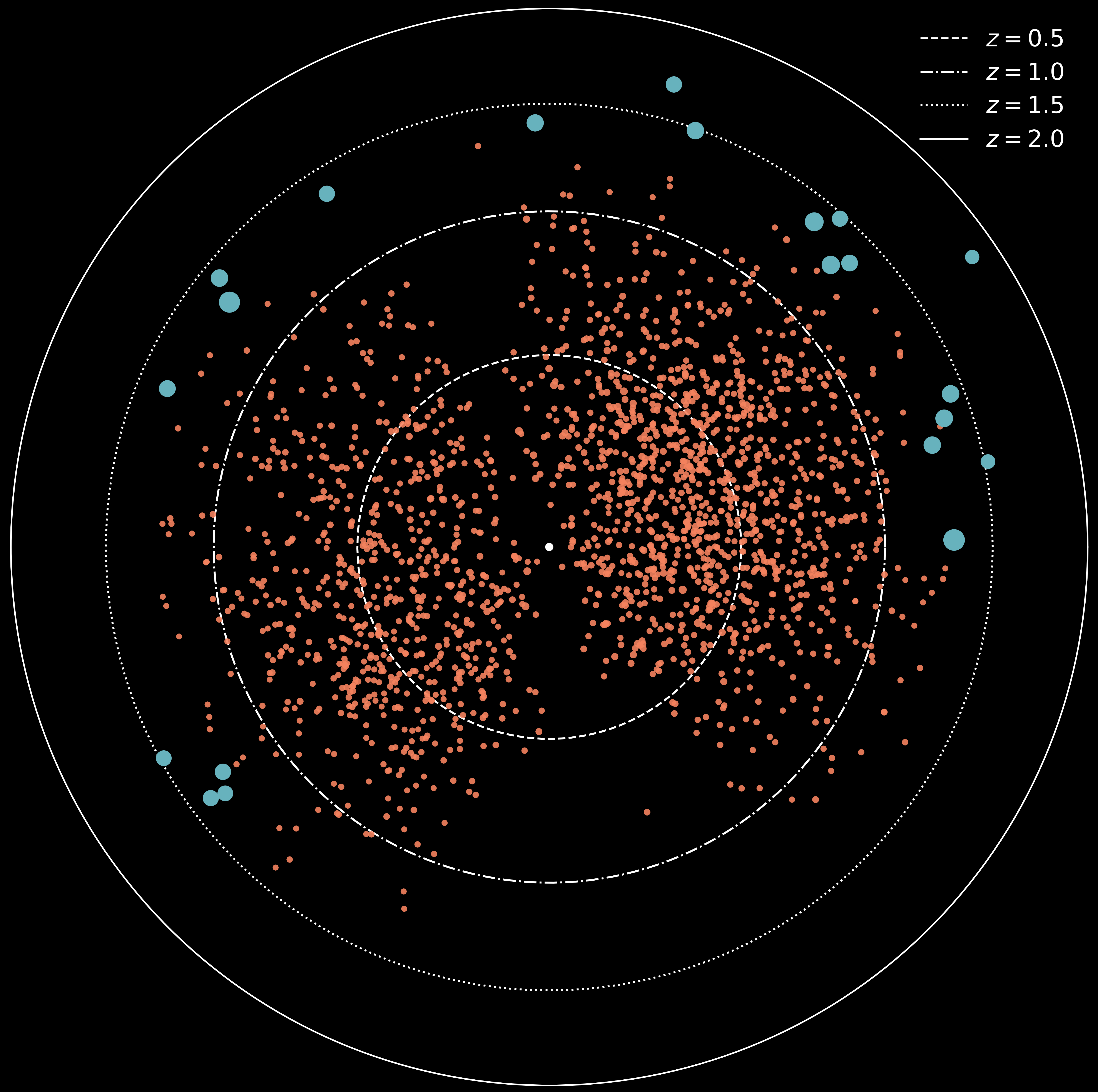
2. Example cases illustrate large halo-to-halo variance in the thermodynamic properties of forming clusters (I haven't gotten to study population averages yet).



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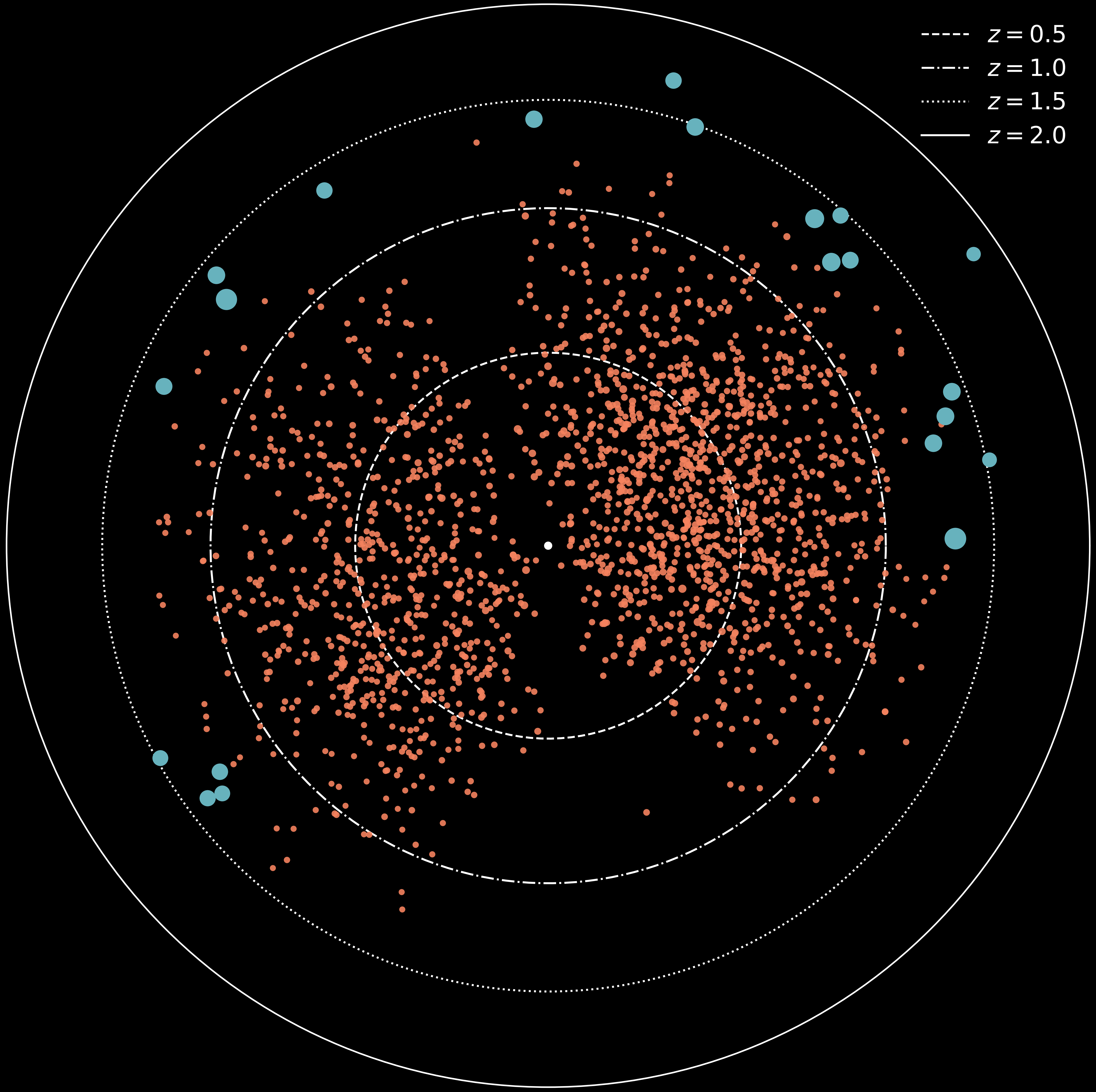
    1. Try to think in terms of 2 or 3D distributions instead of the classical 1D radial profile variant.

    2. Be careful of missing flux when using interferometers



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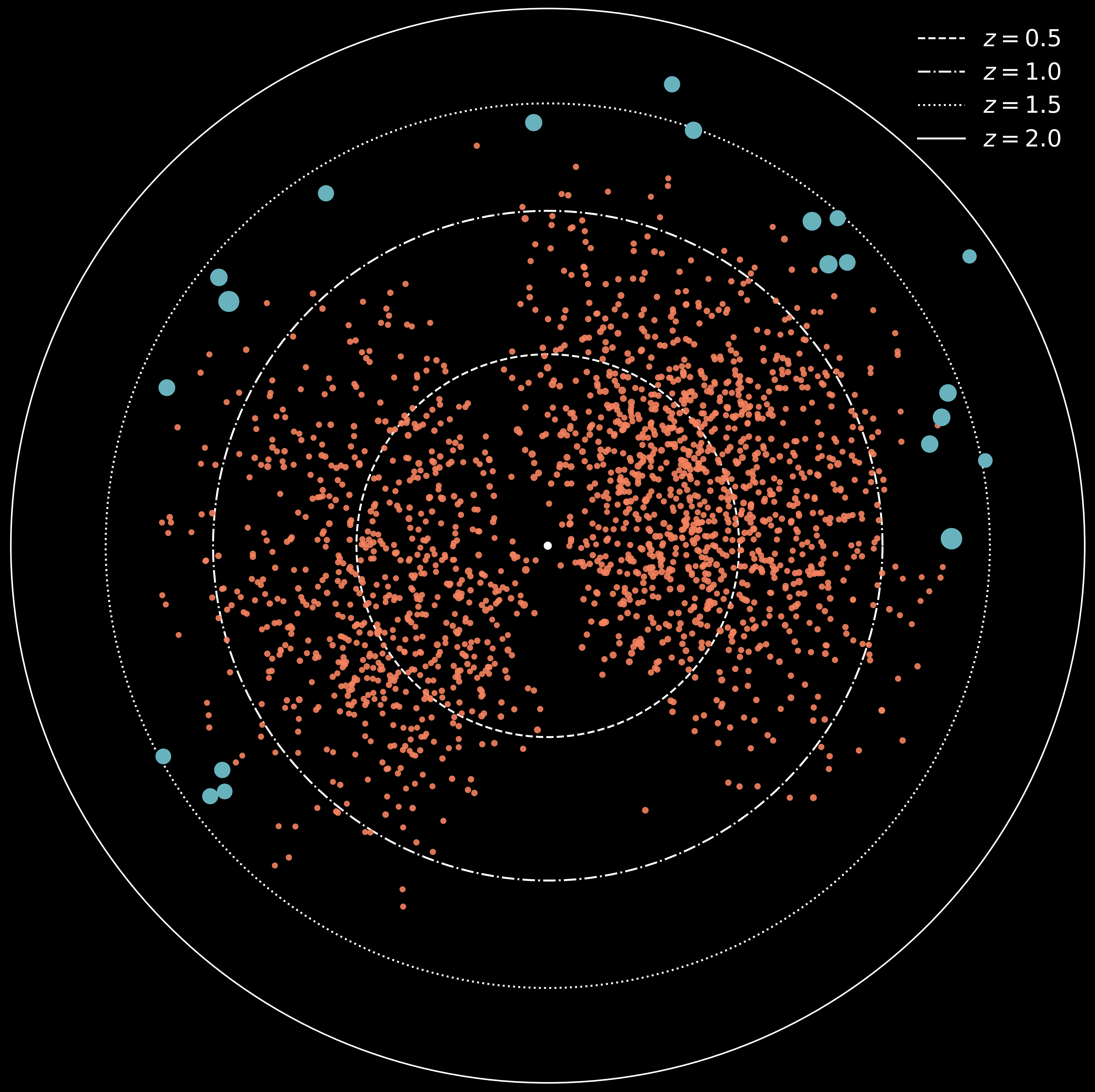
4. There is much much more to come…



Future surveys will go much much deeper!