Constraining Cosmology with Galaxy Cluster History

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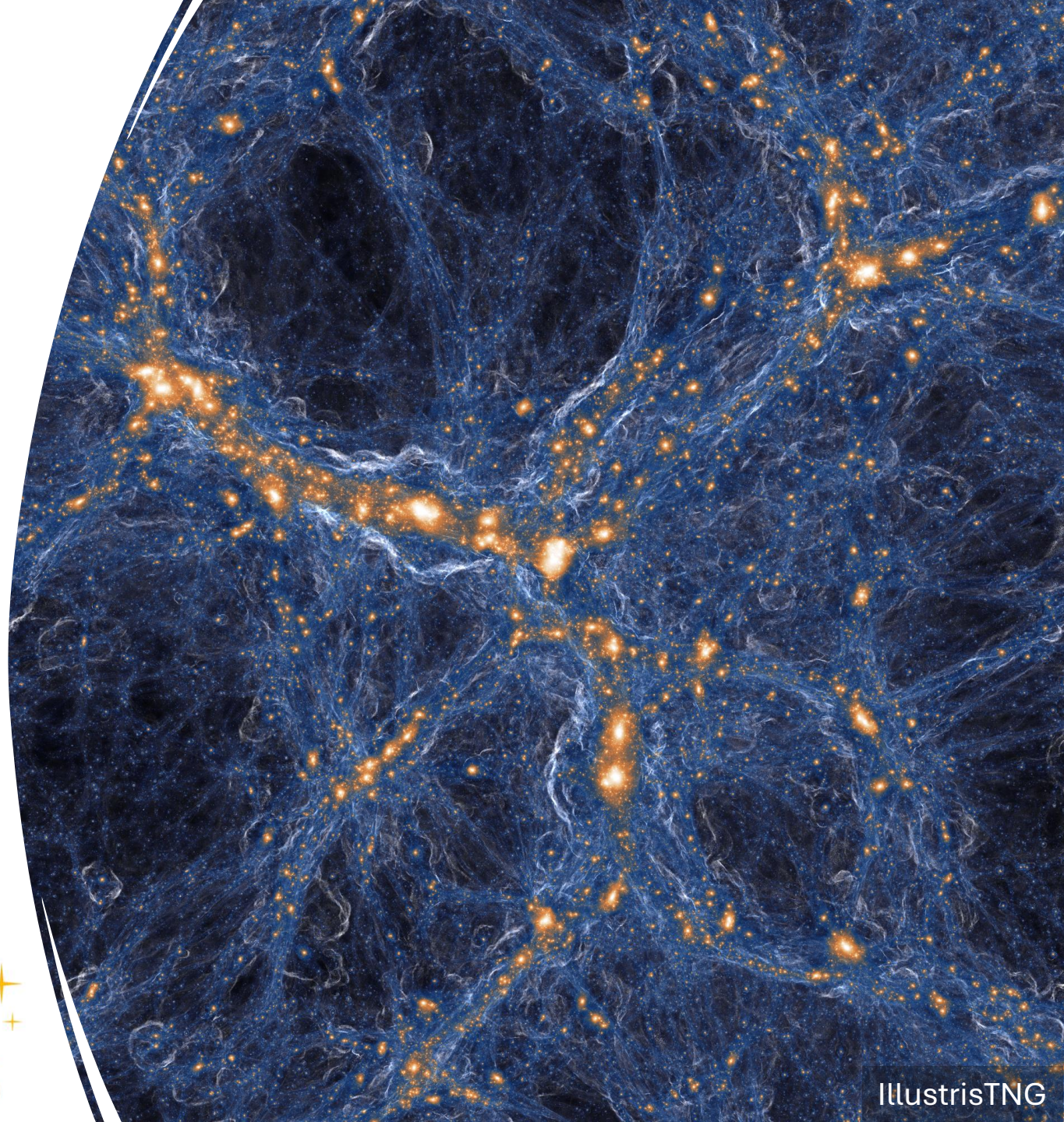

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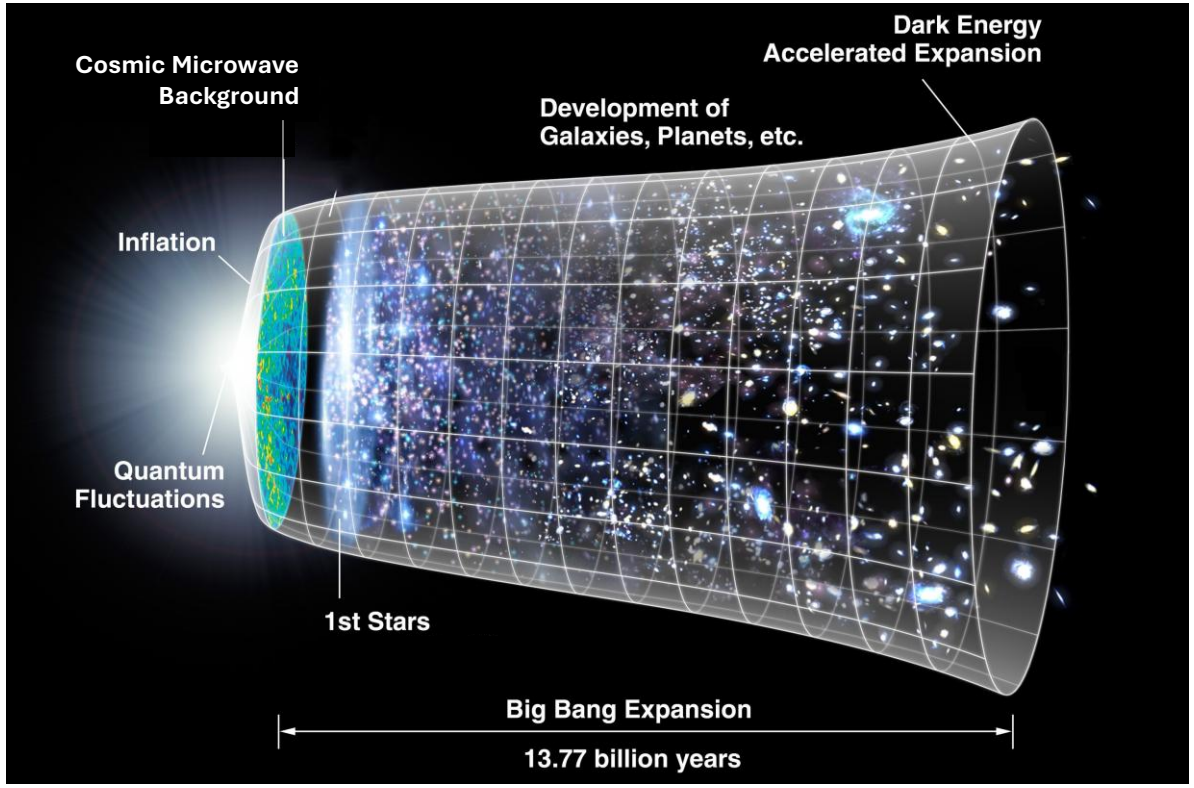
WATERLOO CENTRE FOR ASTROPHYSICS

Cosmological Parameters

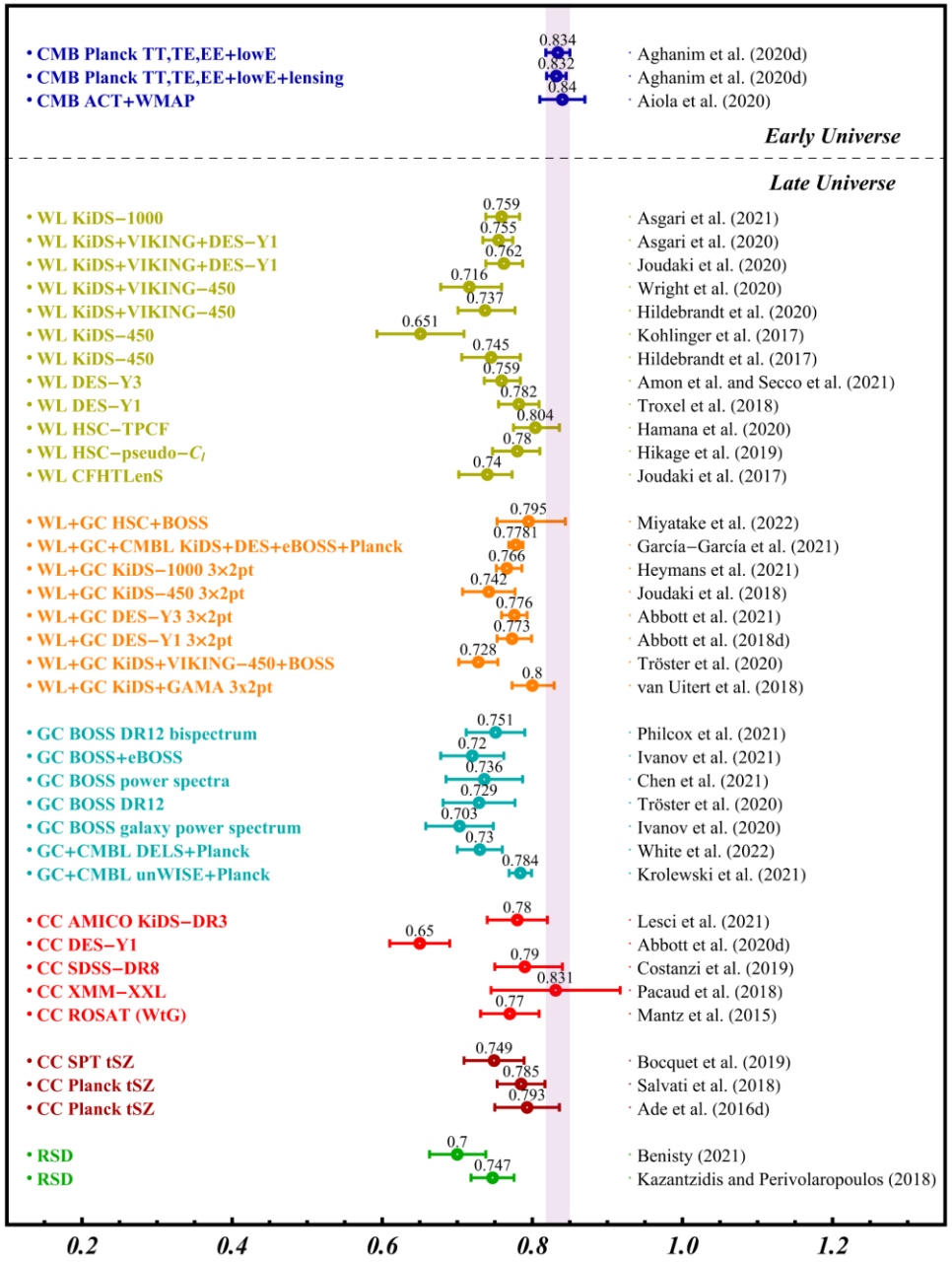
- Cosmology is the study of the origin and evolution of the universe on large scales
- We use a few parameters to quantify our universe's cosmology
  - $\boldsymbol{\Omega_m}$ *describes the fraction of the universe's energy represented by matter*
  - $\boldsymbol{\sigma_8}$ *describes how strongly matter clusters together*



NASA/WMAP

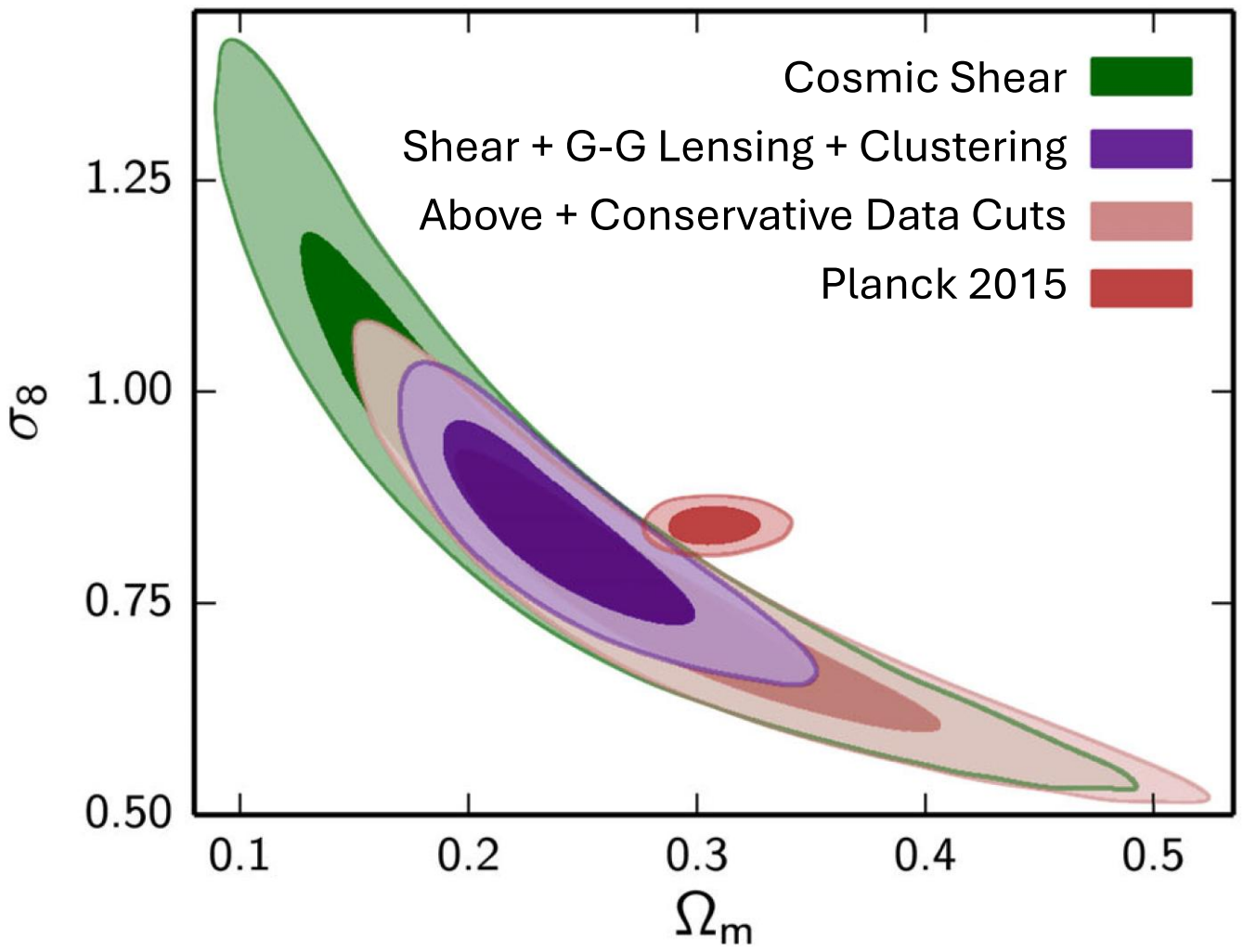
The S_8 Tension

- Measurements of $\boldsymbol{S_8}$ from nearby and distant sources are in tension
  - $\boldsymbol{S_8}$ *describes the amount of structure in the universe*
- The S_8 tension could highlight either systematic errors in measurements or a flaw in our model



$$S_8 = \sigma_8\sqrt{\Omega_m/0.3}$$

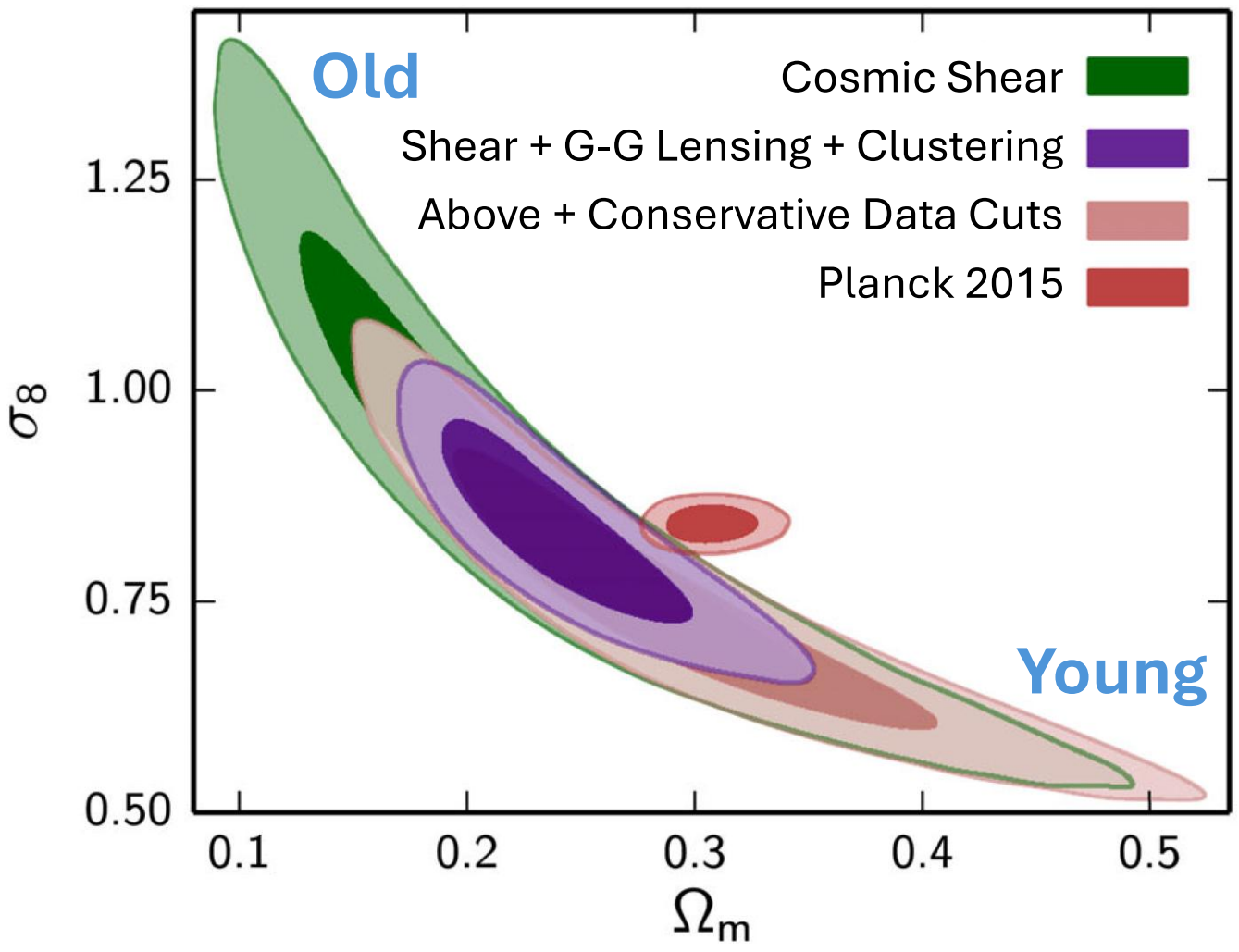
Abdalla et al. (2022)



Joudaki et al. (2017)

Breaking the Degeneracy

- Measurements of $\boldsymbol{\sigma_8}$ and $\boldsymbol{\Omega_m}$ from nearby structure are degenerate
- "Splitting the banana" would better constrain both parameters
  - *This would also allow us to better understand the S_8 tension*



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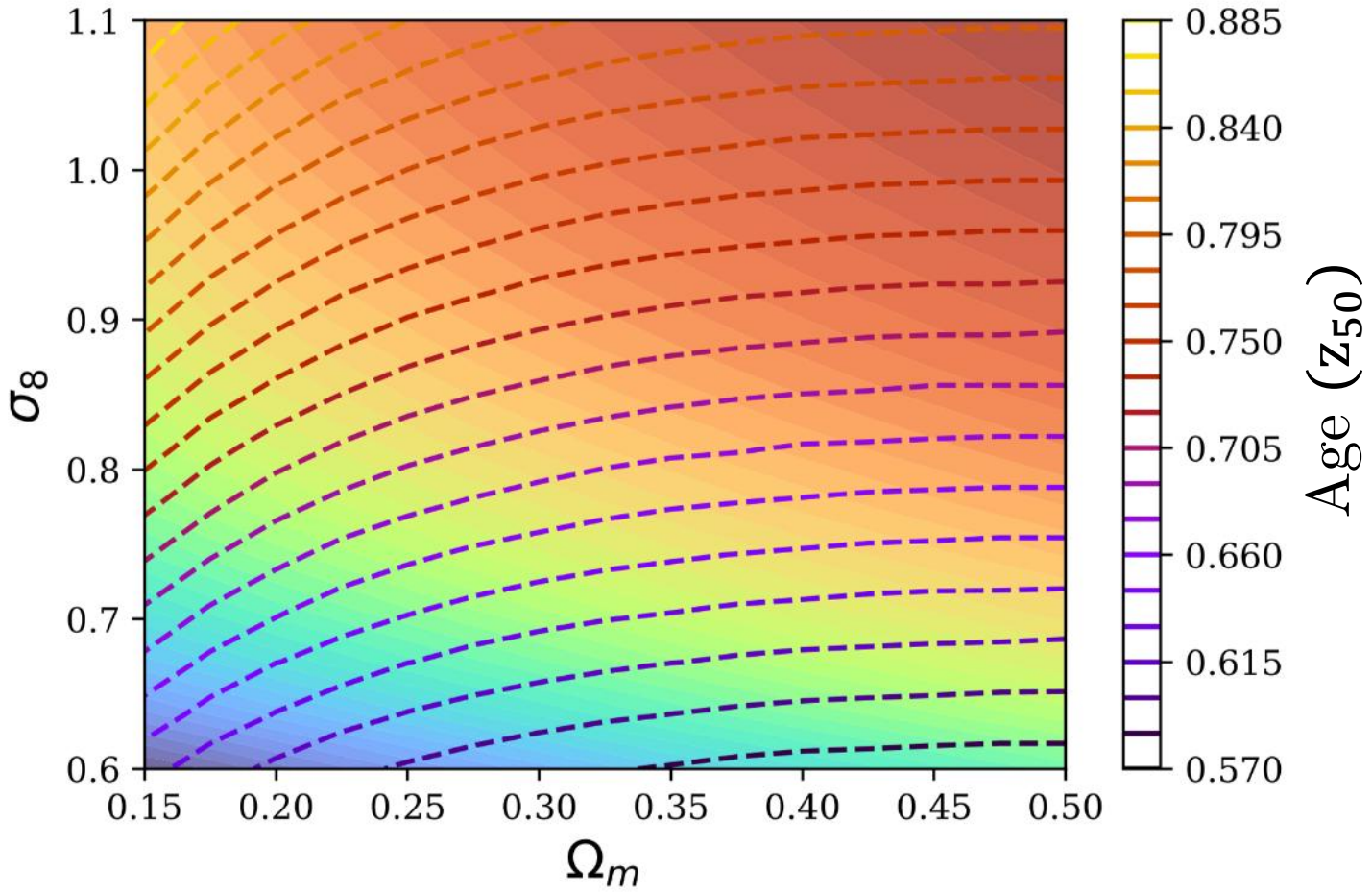


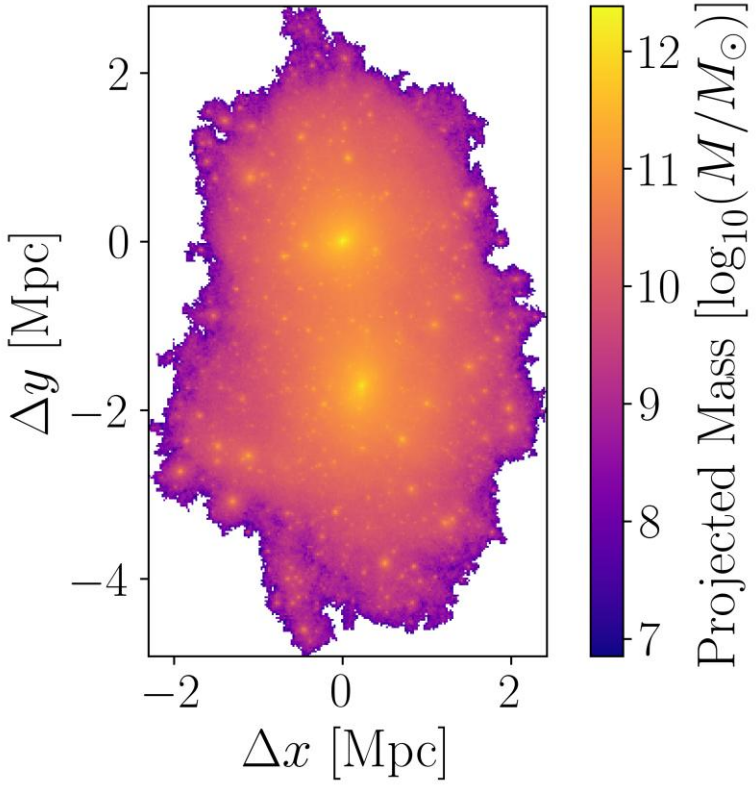
Amoura et al. (2021)

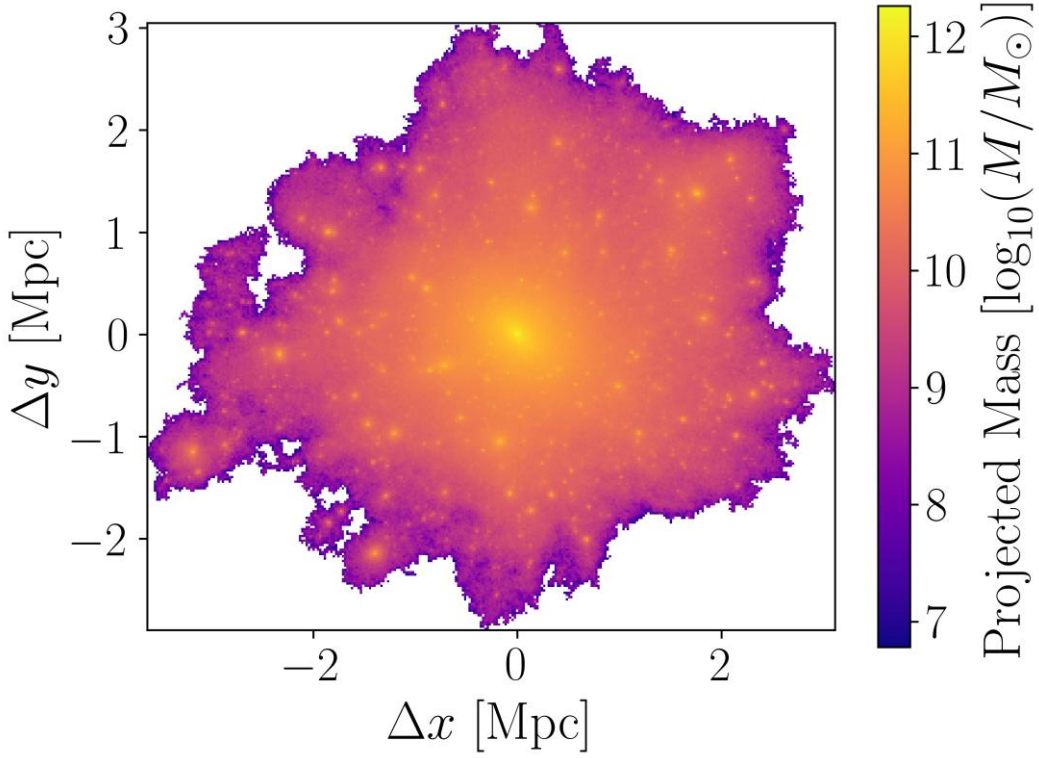
Breaking the Degeneracy

- Cluster age gives nearly perpendicular contours to cluster number counts
  - *High σ_8 produces old galaxy clusters*
  - *Low σ_8 produces young galaxy clusters*
- Measurements of galaxy cluster age can break the degeneracy between $\boldsymbol{\sigma_8}$ and $\boldsymbol{\Omega_m}$

Structural Indicators of Age

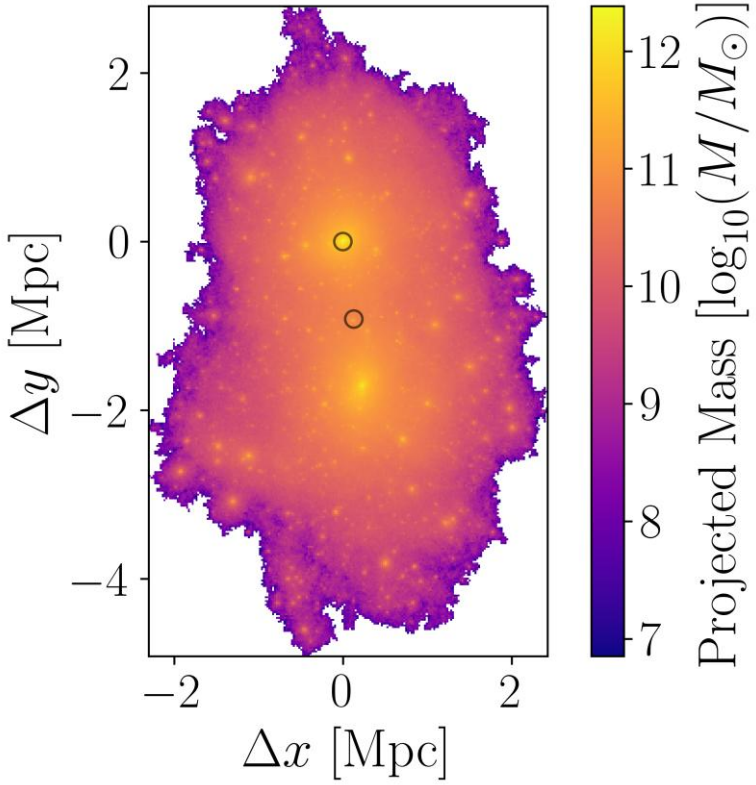
- Galaxy clusters grow hierarchically through mergers
  - *Young systems are dynamically disturbed due to recent mergers*
  - *Old systems are dynamically relaxed*
- Measurements of galaxy cluster relaxation indicate the age of large structures

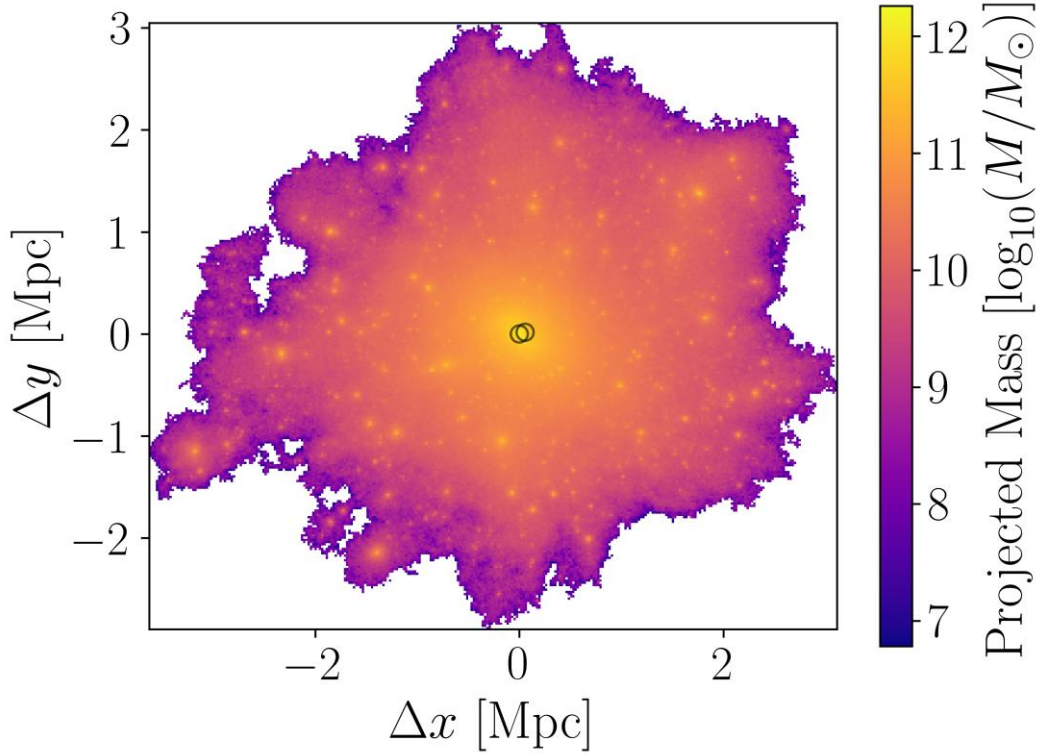




Structural Indicators of Age

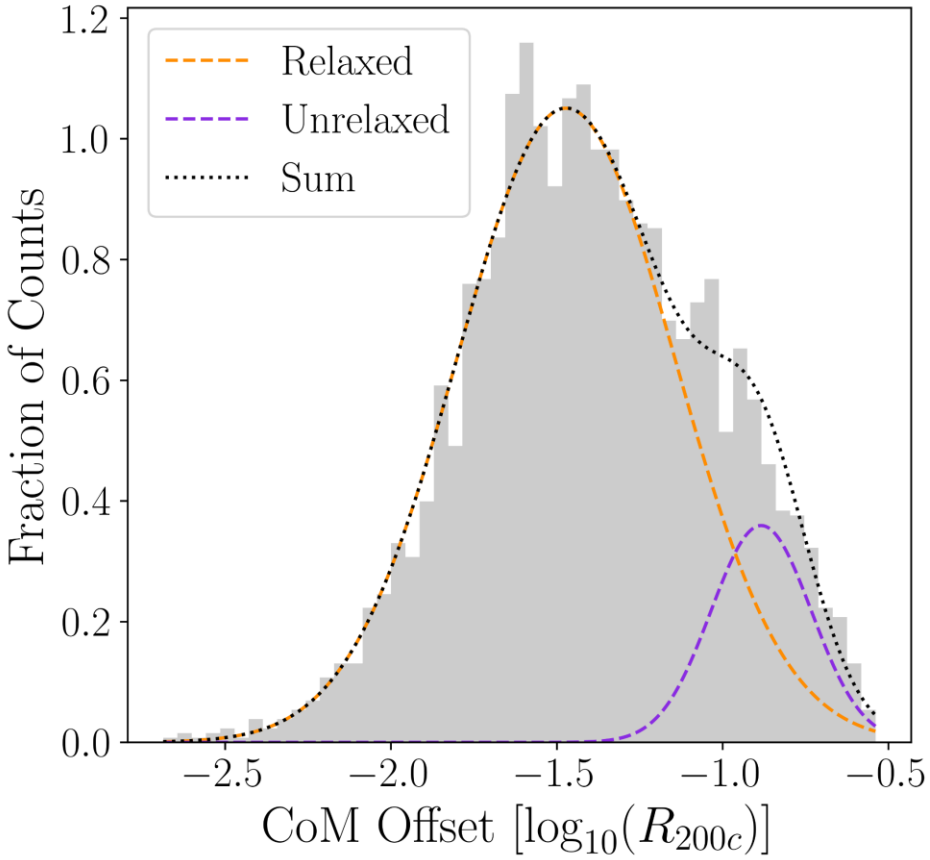
- There are several structural properties that indicate recent mergers of galaxy clusters:
  1. *Magnitude gap*
  2. *Centre-of-mass offset*
  3. *Asymmetry*

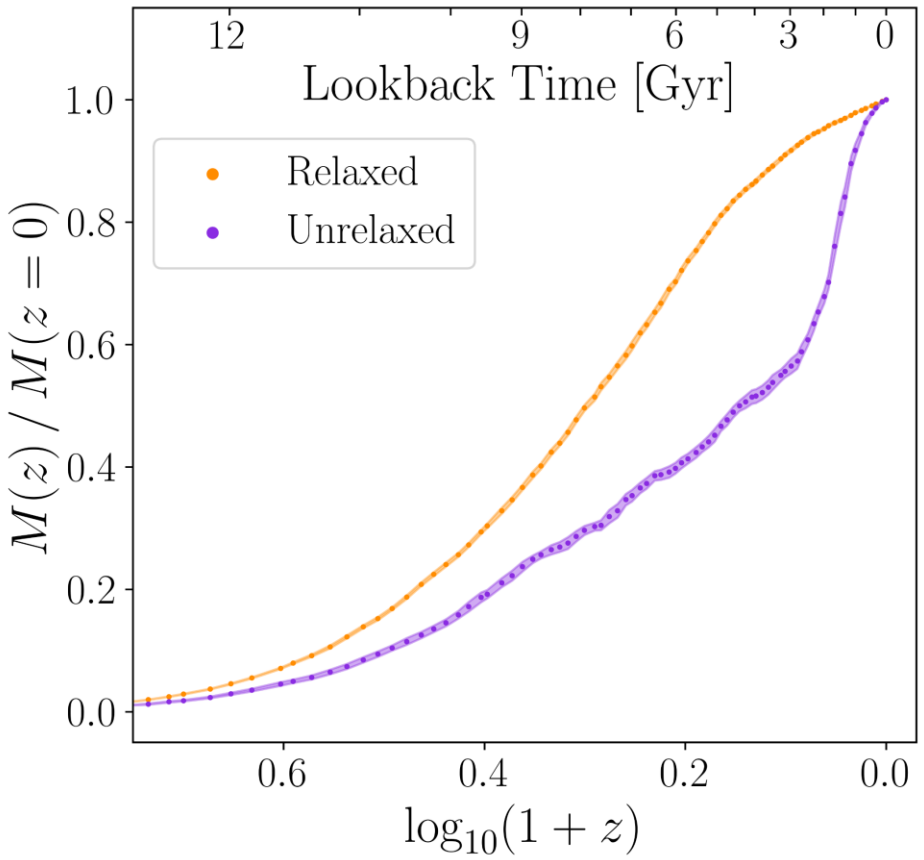


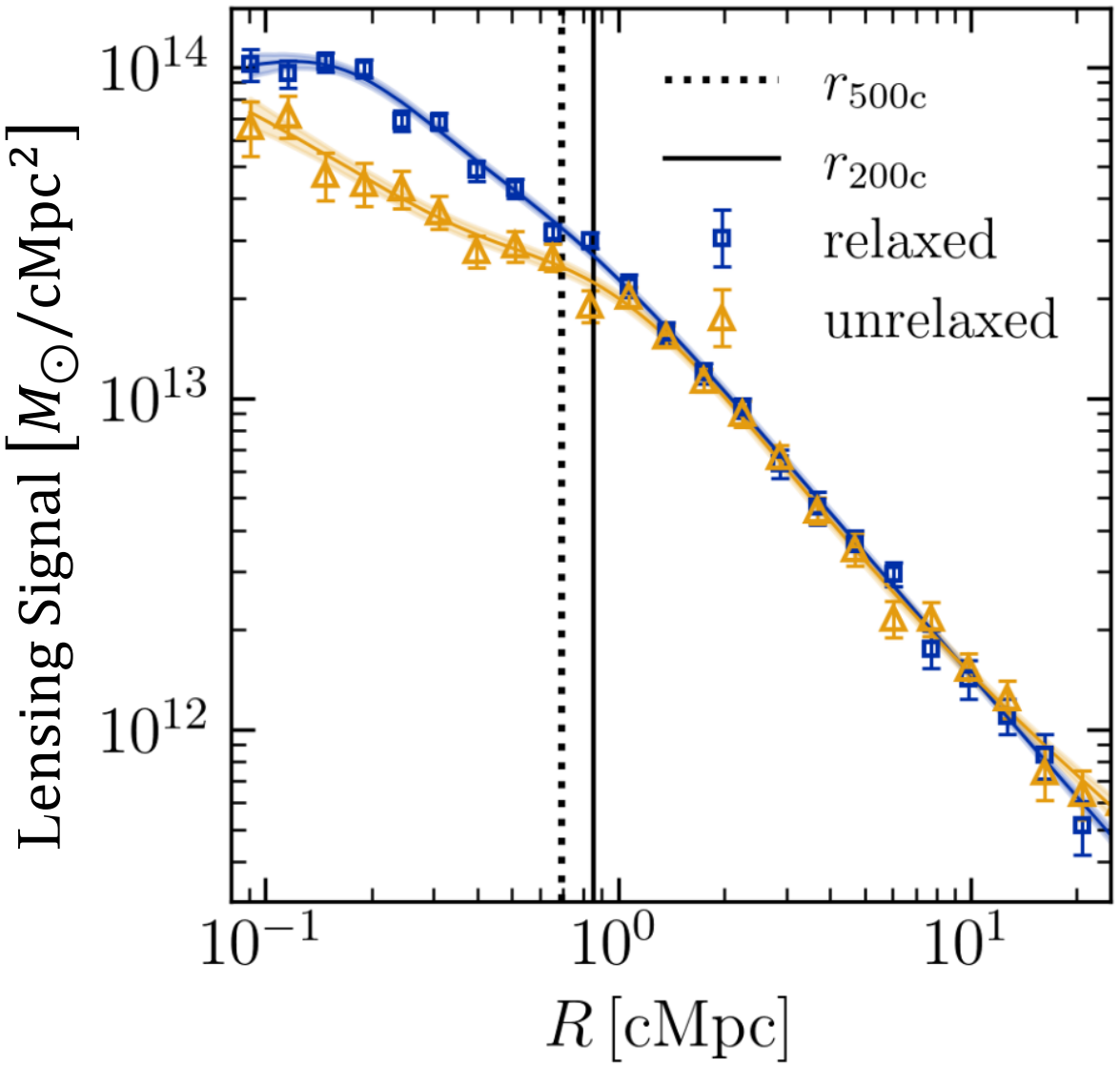


Group Mass Histories

- We can categorize clusters as relaxed and unrelaxed based on centre-of-mass offset
- These groups have different median mass histories
  - *The unrelaxed group experienced recent major mergers*







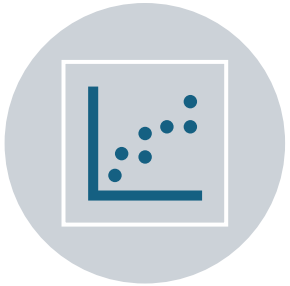
Mpetha+ (in prep)

Gravitational Lensing

- Gravitational lensing profiles from the UNIONS survey depend on dynamical state
  - *Relaxed galaxy clusters have stronger lensing signals in their cores*
- Novel ways to infer the ages of clusters from gravitational lensing may constrain our cosmology

Summary

More independent measurements of σ_8 and Ω_m are required to better understand the large scales of the universe



Understanding galaxy cluster age can break a measurement degeneracy and help clarify a tension in our model

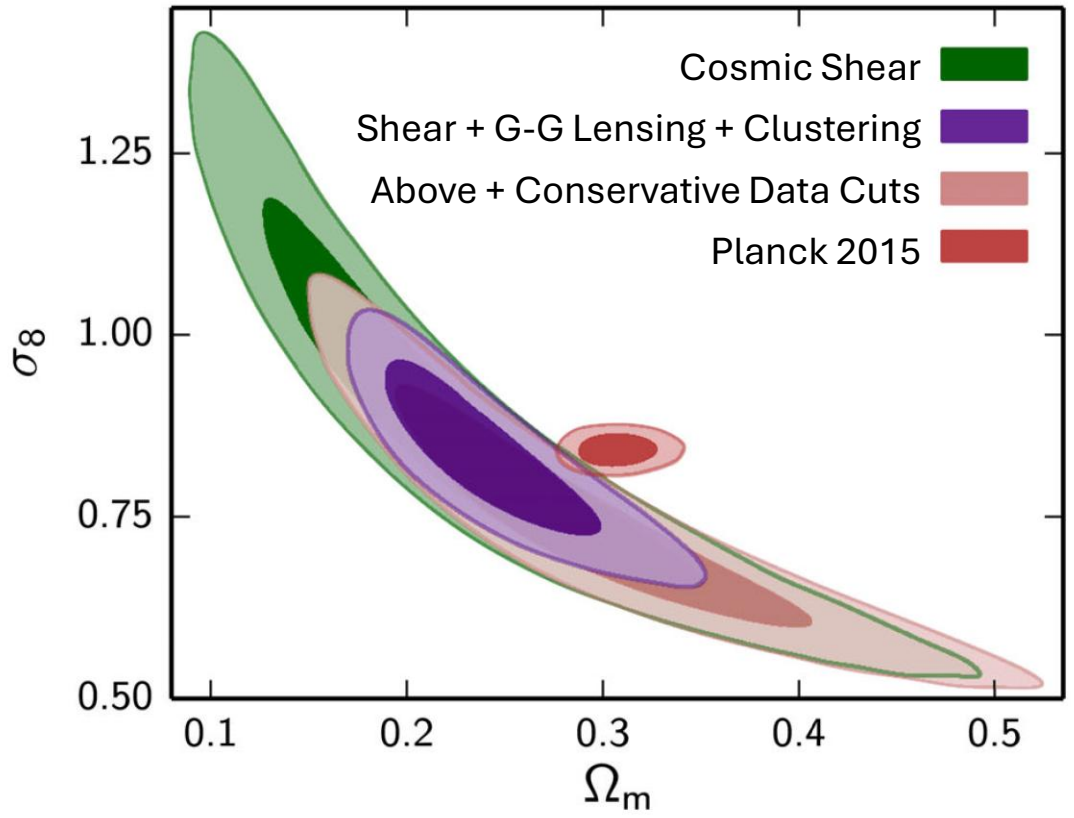
Magnitude gaps, centre-of-mass offsets and asymmetry could link structural properties to the mass histories of clusters

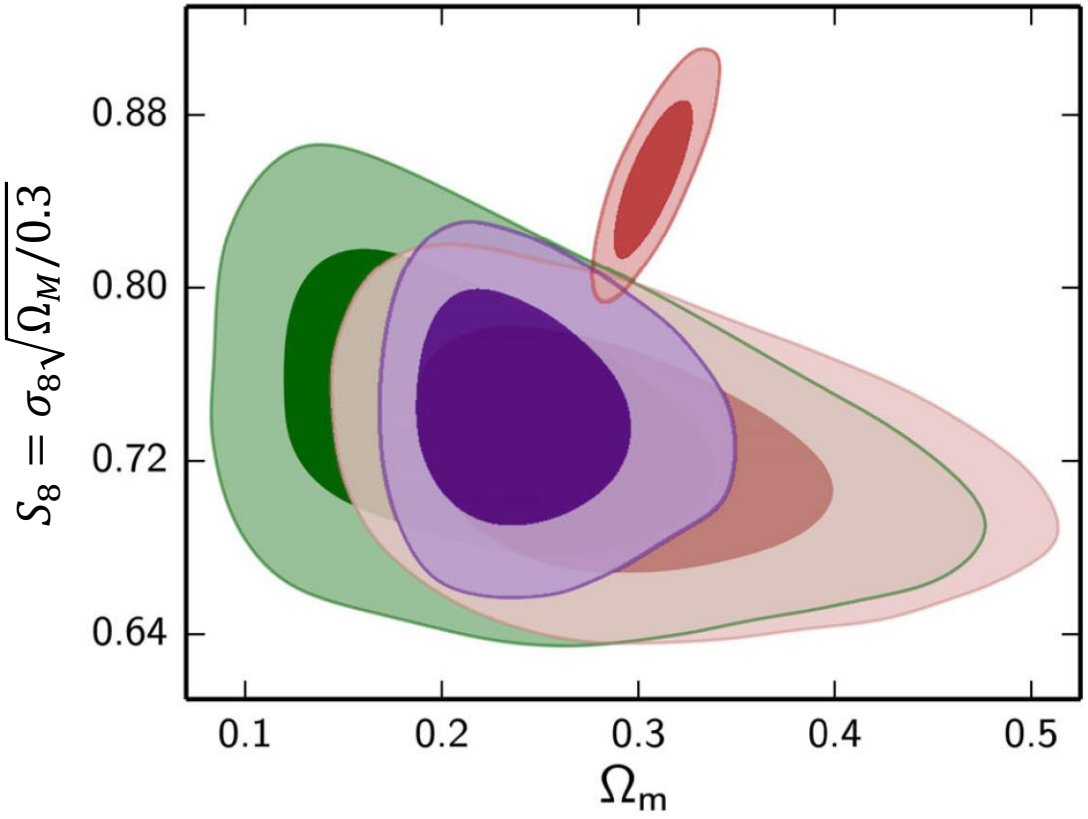
Dynamical state affects other properties, such as gravitational lensing profiles, which provide observational cosmological tests

Thank You

S_8 and σ_8

- $\boldsymbol{\sigma_8}$ describes the amplitude of density fluctuations on an 8 Mpc scale
- $\boldsymbol{S_8}$ normalizes σ_8 by the matter density Ω_m to more easily compare observations to theory

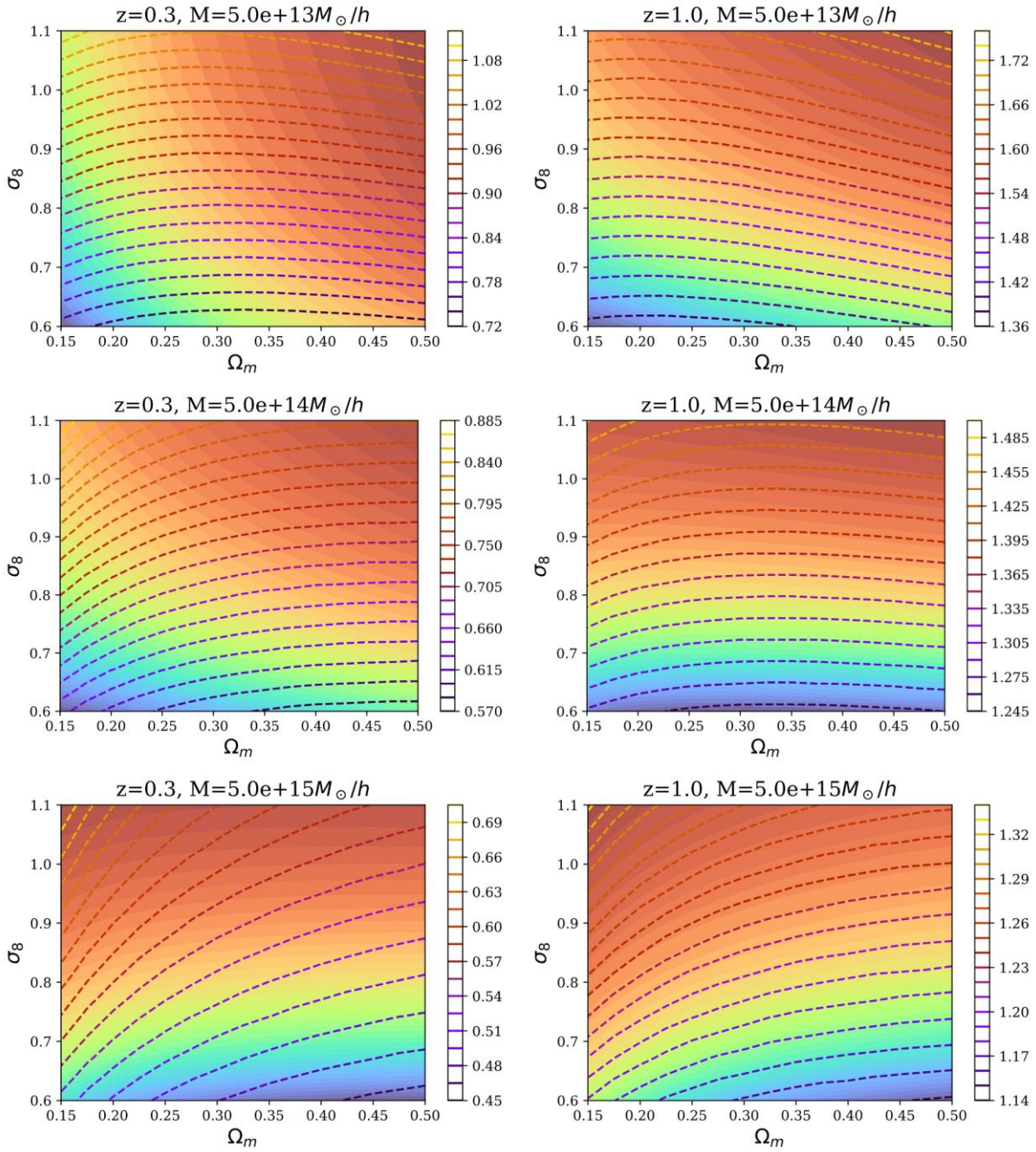




Joudaki et al. (2017)

Splitting the Banana

- The $\boldsymbol{\Omega_m}$ and $\boldsymbol{\sigma_8}$ contours from cluster counts rotate for different halo masses and redshifts
- The rotation in this parameter space is what “cuts off” the degeneracy in their relationship



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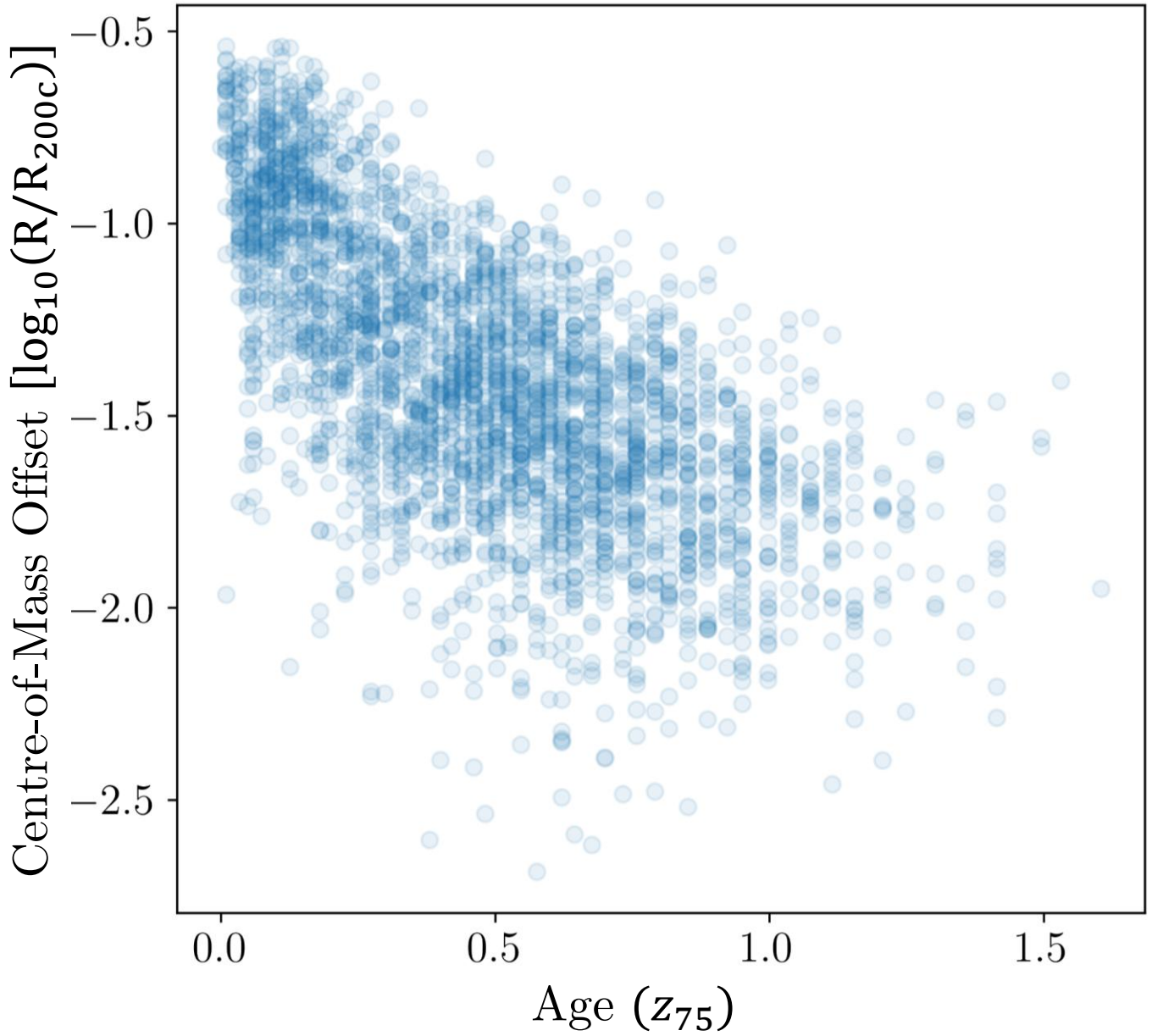
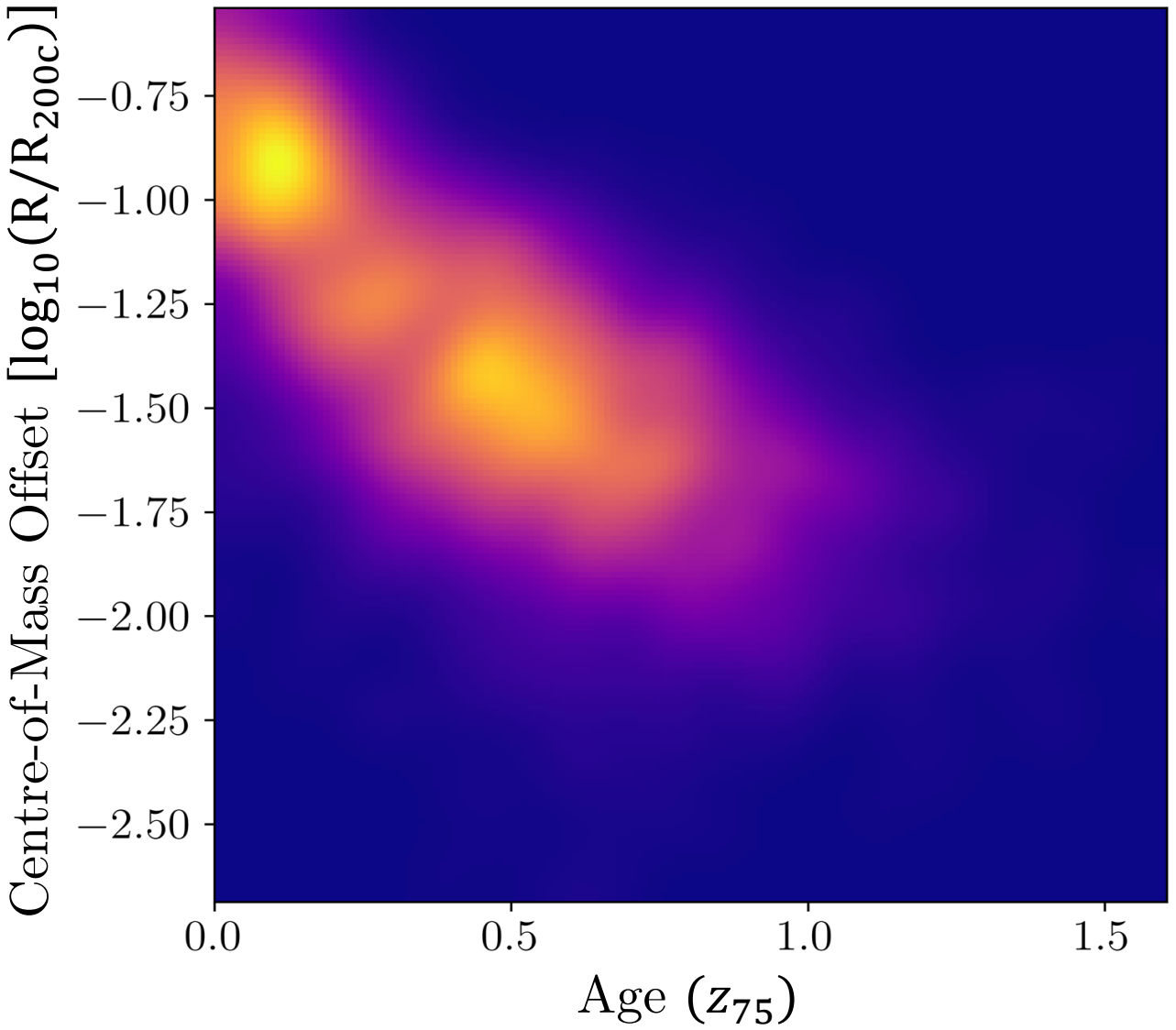


Centre-of-Mass Offset

- There's a correlation between centre-of-mass offset and age z_{75}
- Offsets can be used to select galaxy clusters with different formation histories
  - *These samples can be used to compare old and young systems, and to distinguish between cosmologies*



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