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Constrain Massive Cluster Formation with SDSS

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YITP, Kyoto, Mar 2019


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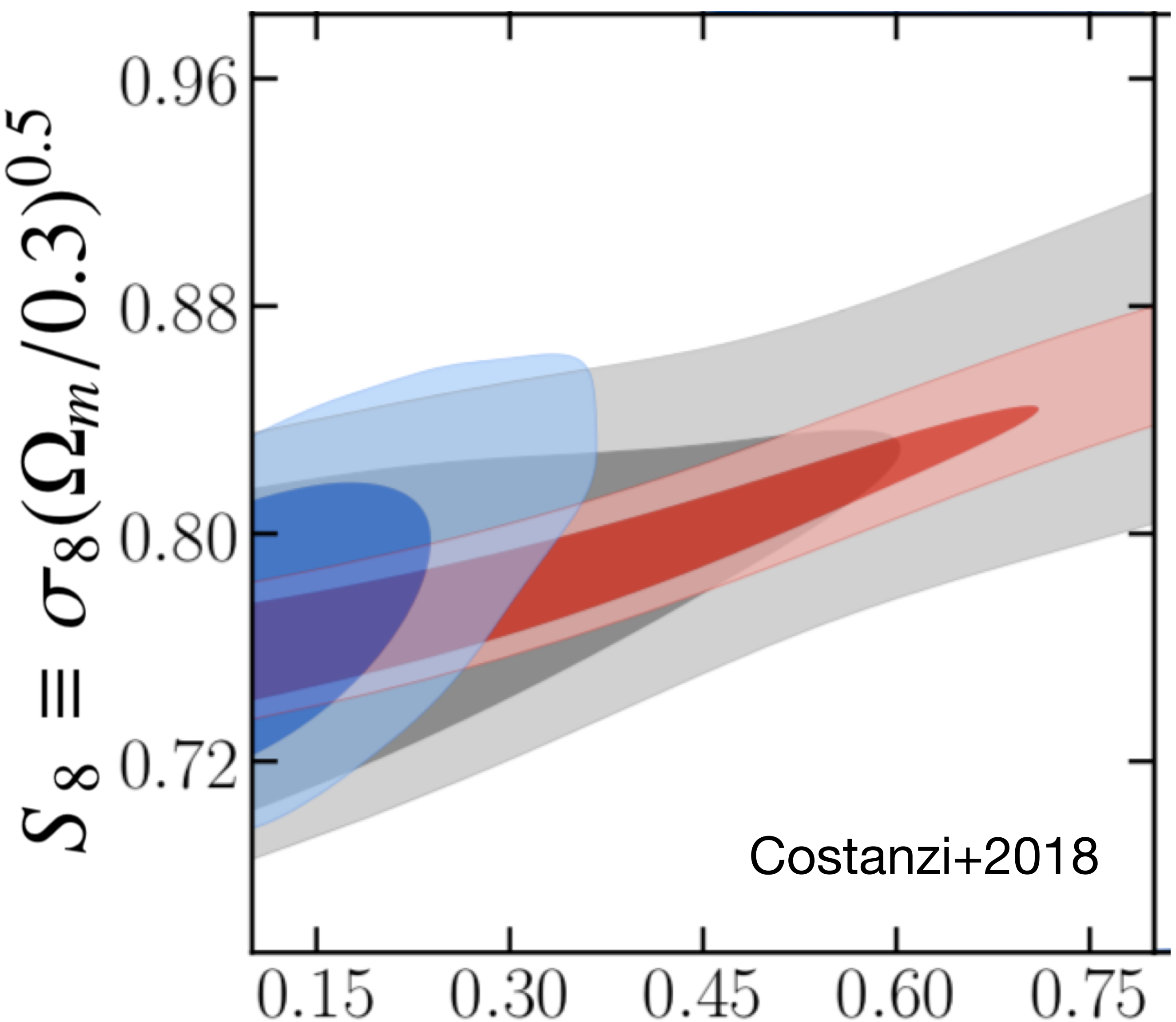
Cluster cosmology: mass-observable relation

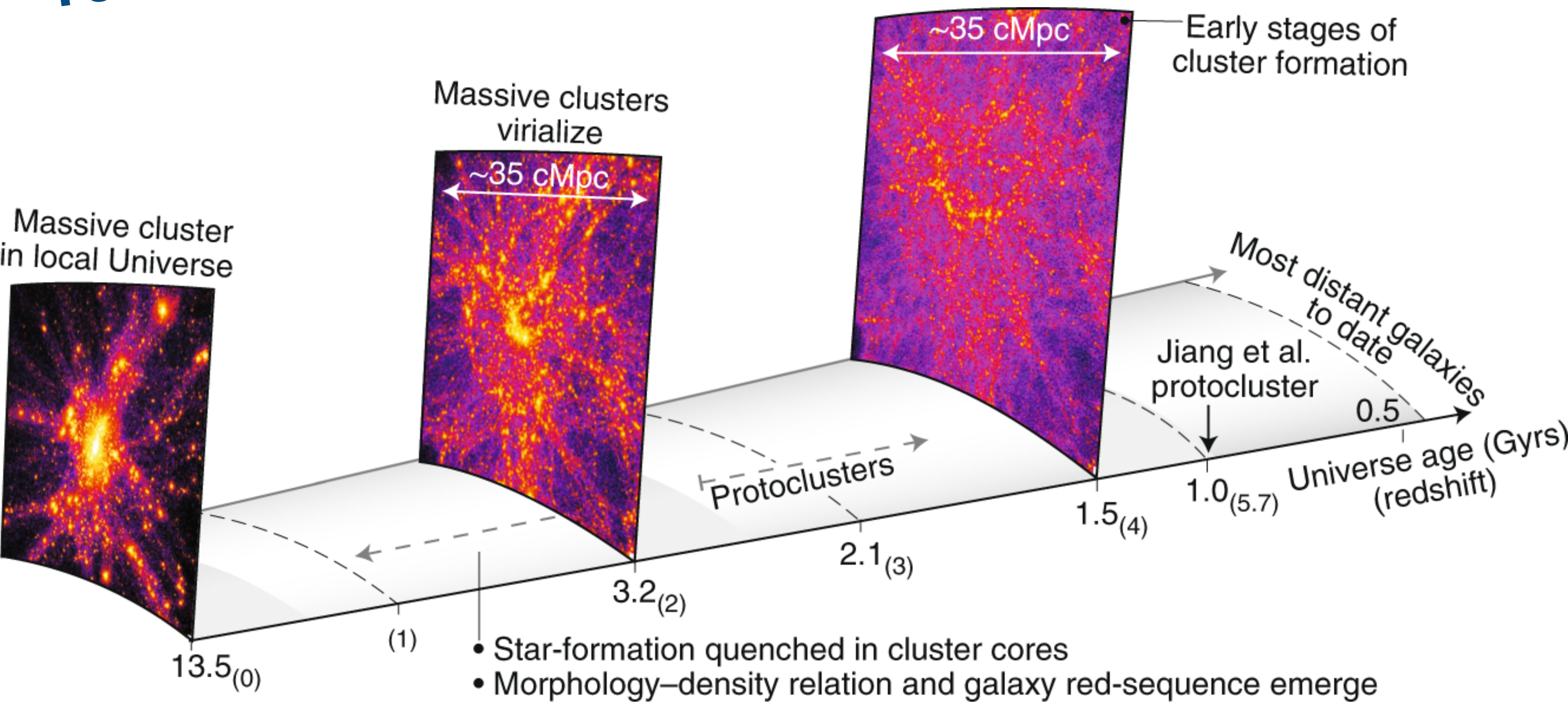
The scatter in the mass-observable relation is THE most important source of systematic uncertainty in cluster cosmology. (observables: richness, Lx, Tx, SZ, etc)

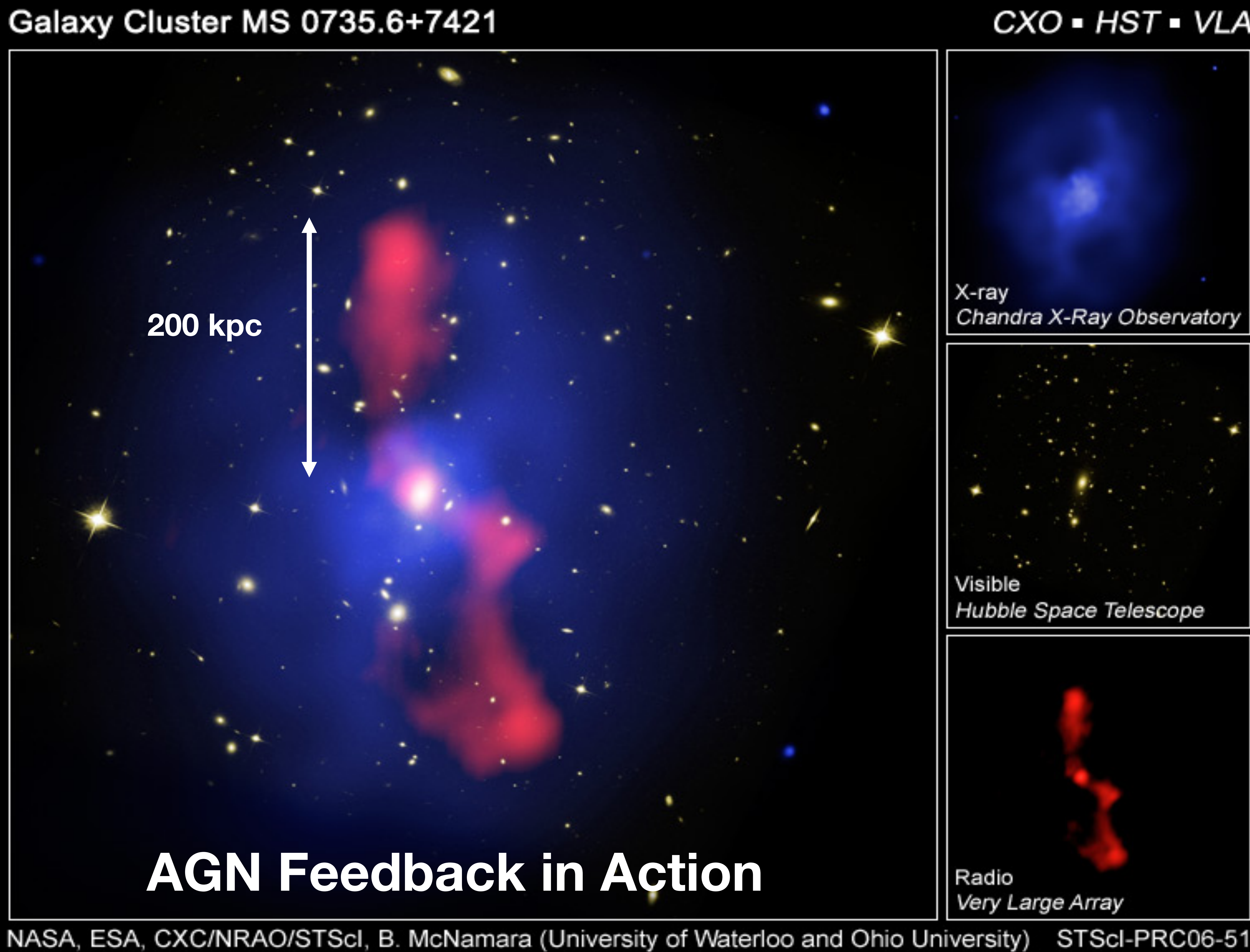


Scatter in the mass-richness relation

More from Hendrik, Elisabeth, Miyatake, and Chiaki 's talks

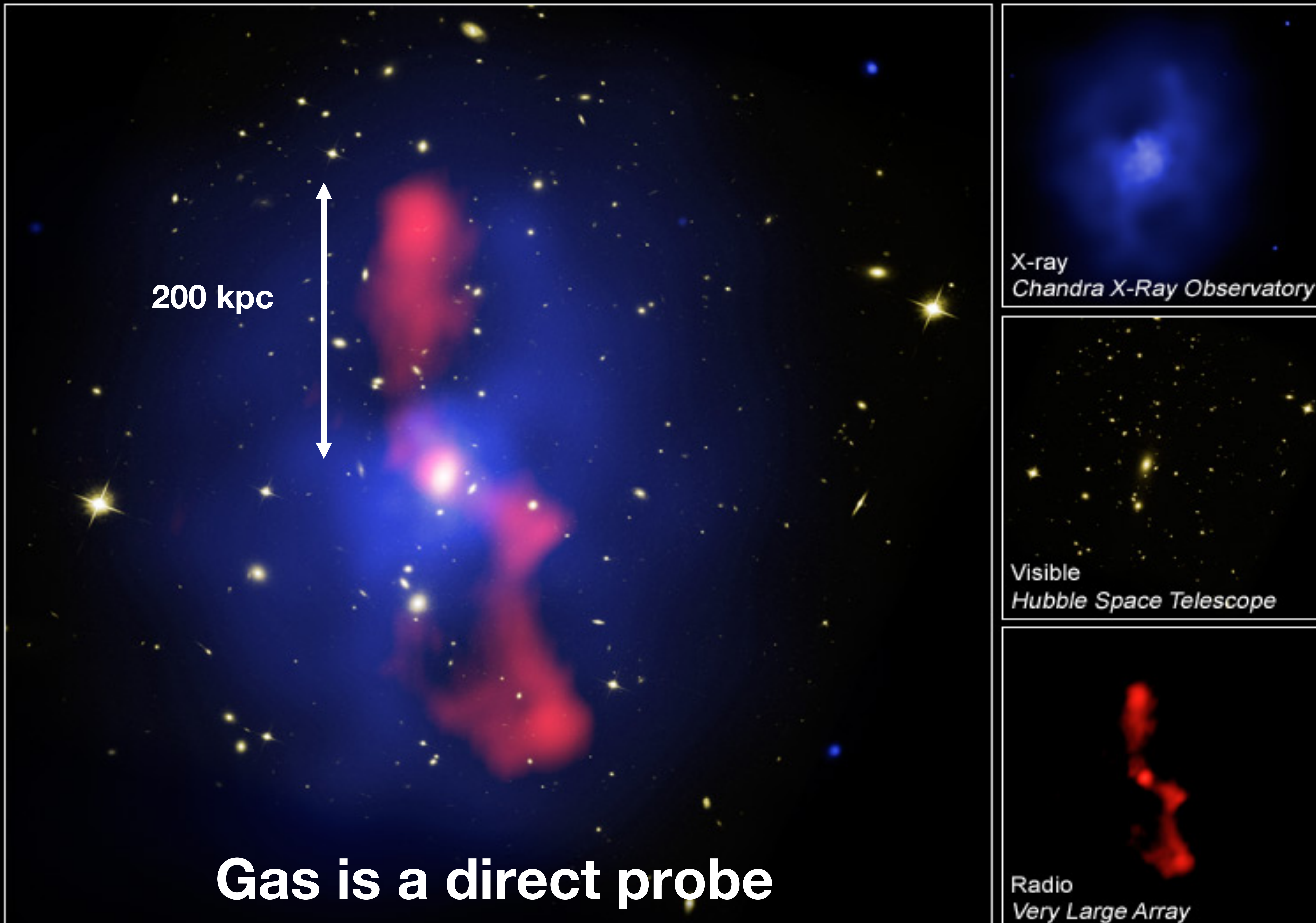
You can ***marginalize over marching-learn*** **or solve for the astrophysics**




Galaxy Cluster MS 0735.6+7421
CXO ▪ HST ▪ VLA
200 kpc
AGN Feedback in Action
X-ray
Chandra X-Ray Observatory
Visible
Hubble Space Telescope
Radio
Very Large Array
NASA, ESA, CXC/NRAO/STScI, B. McNamara (University of Waterloo and Ohio University)
STScI-PRC06-51

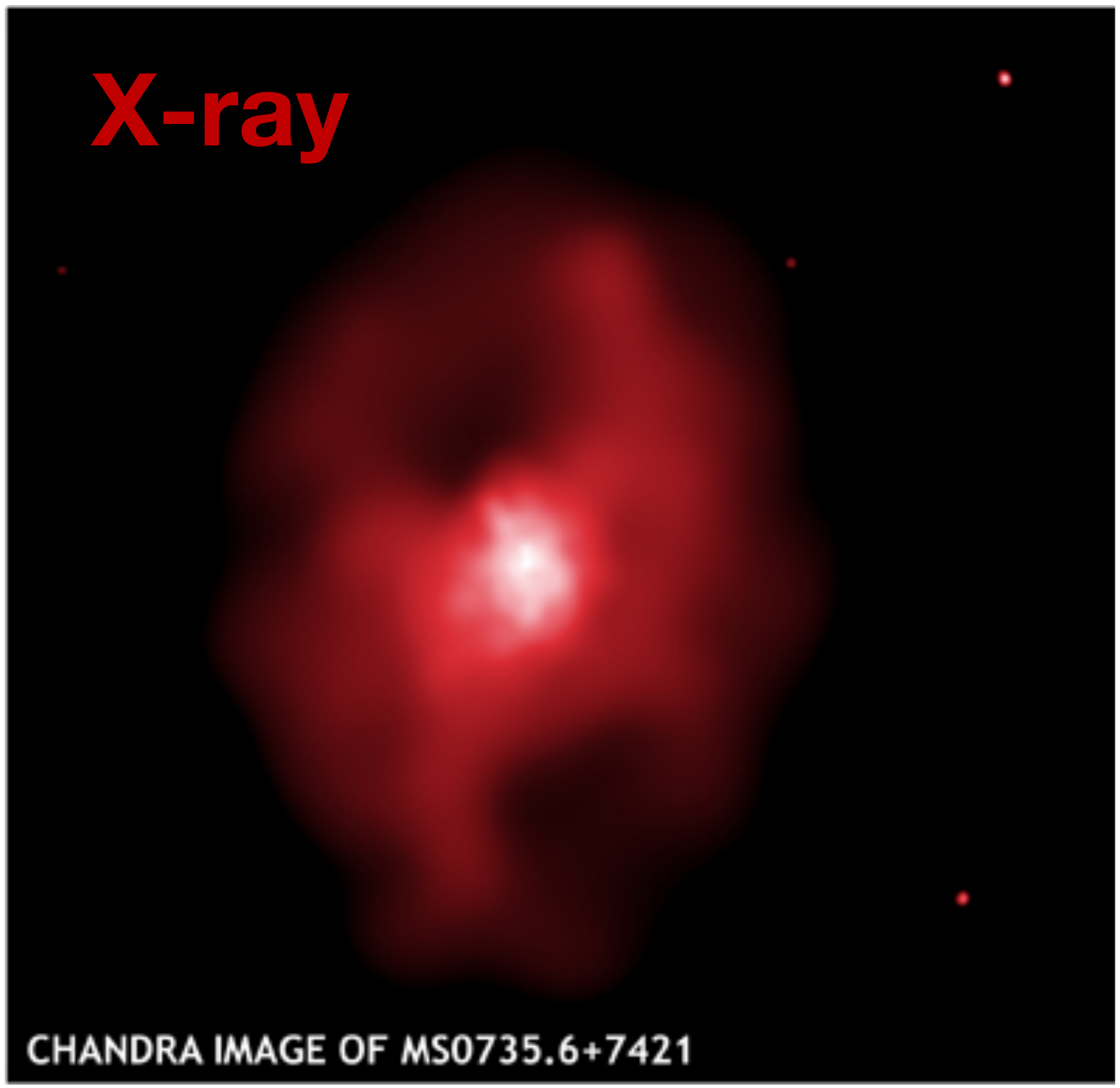
Galaxy Cluster MS 0735.6+7421

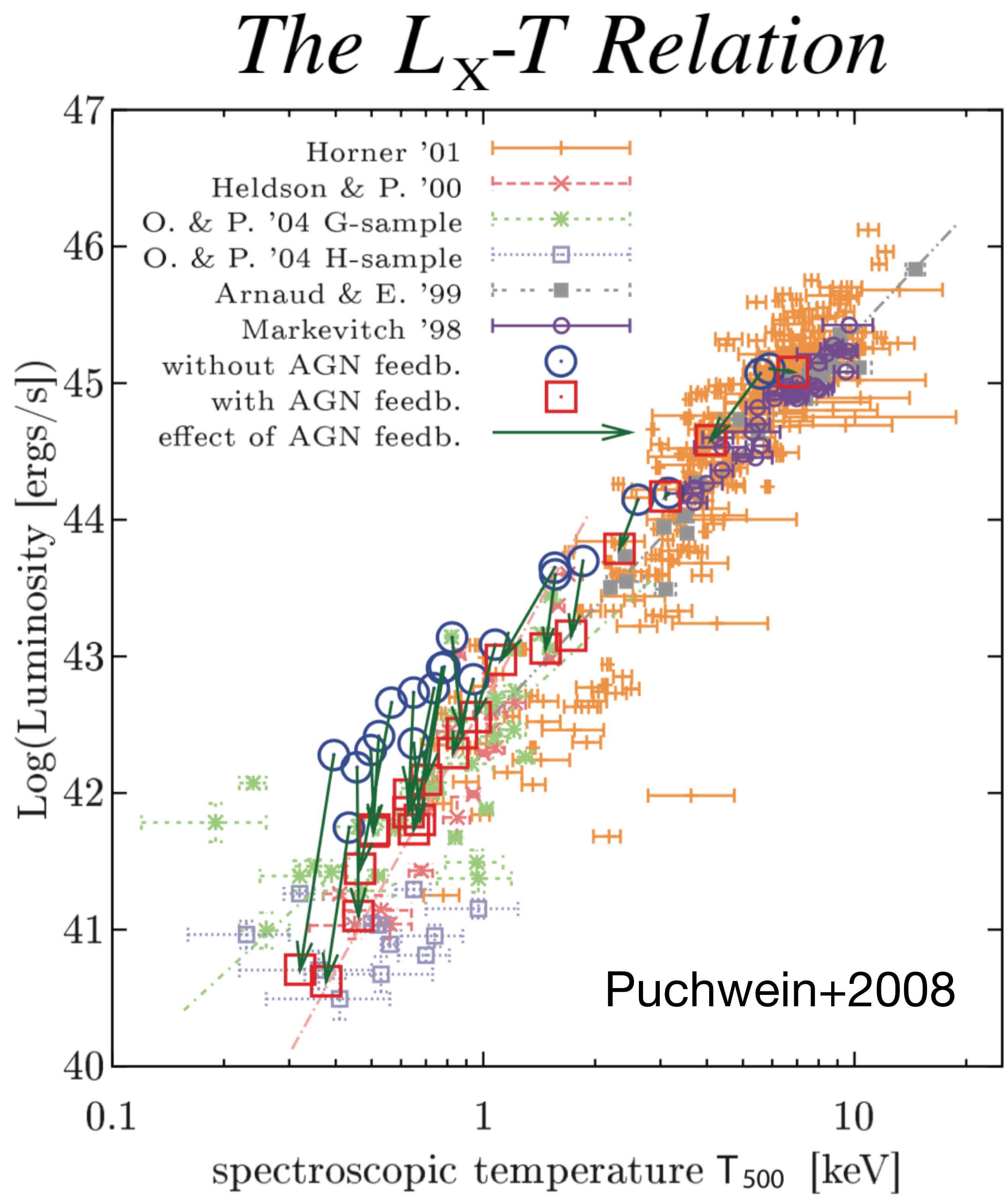
CXO ▪ HST ▪ VLA



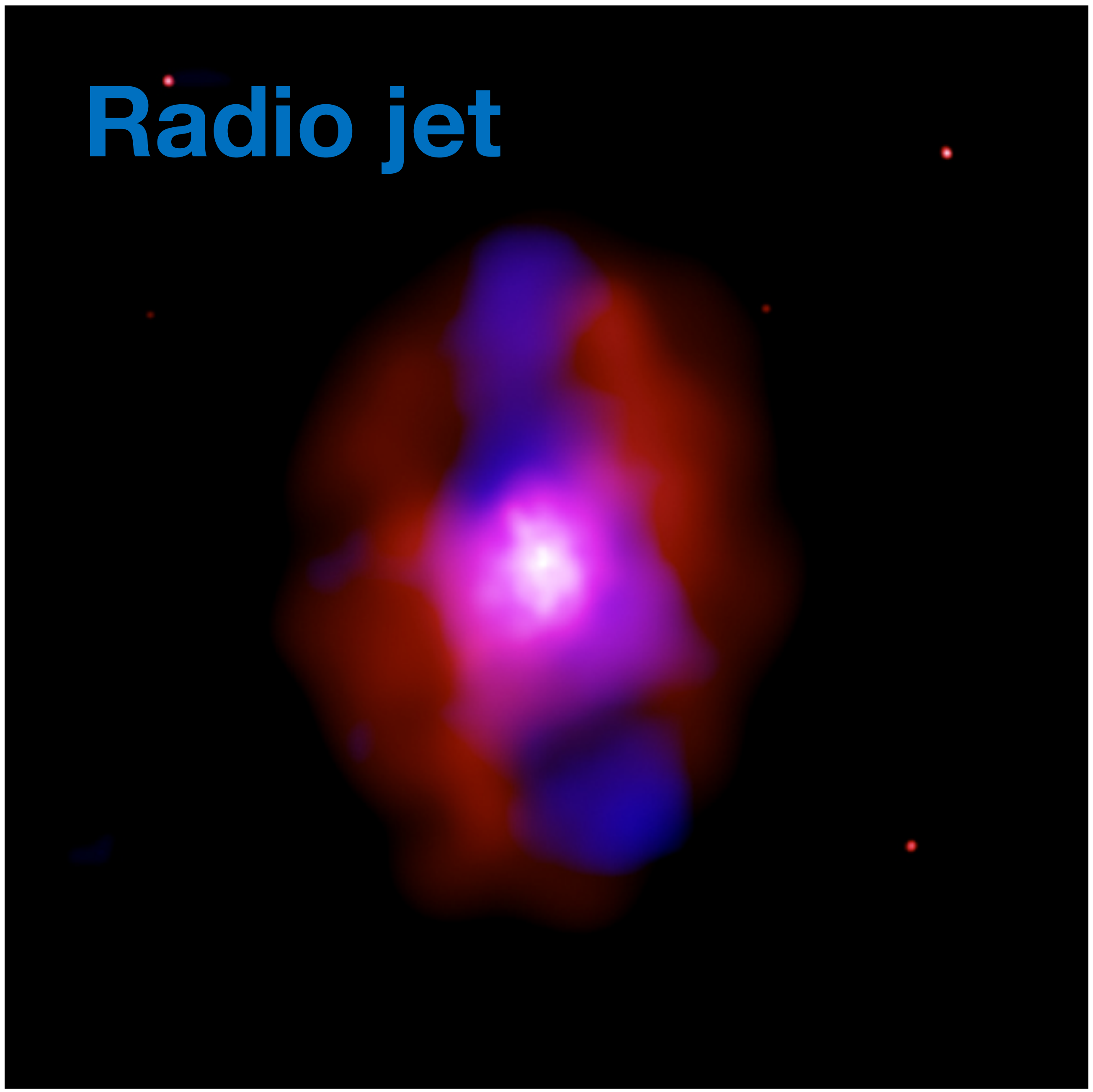
NASA, ESA, CXC/NRAO/STScI, B. McNamara (University of Waterloo and Ohio University) STScI-PRC06-51

You can use X-ray gas to constrain AGN feedback

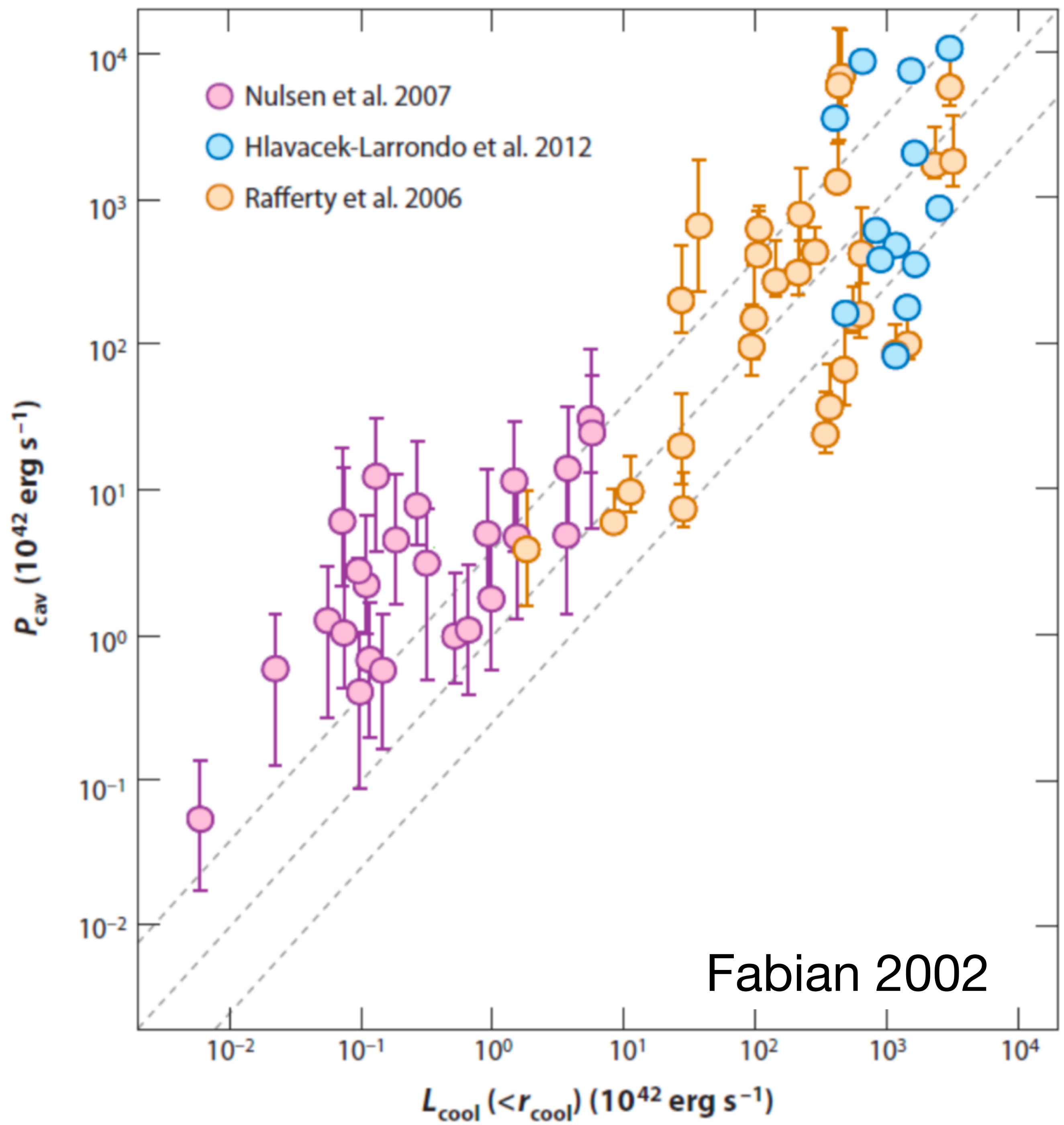




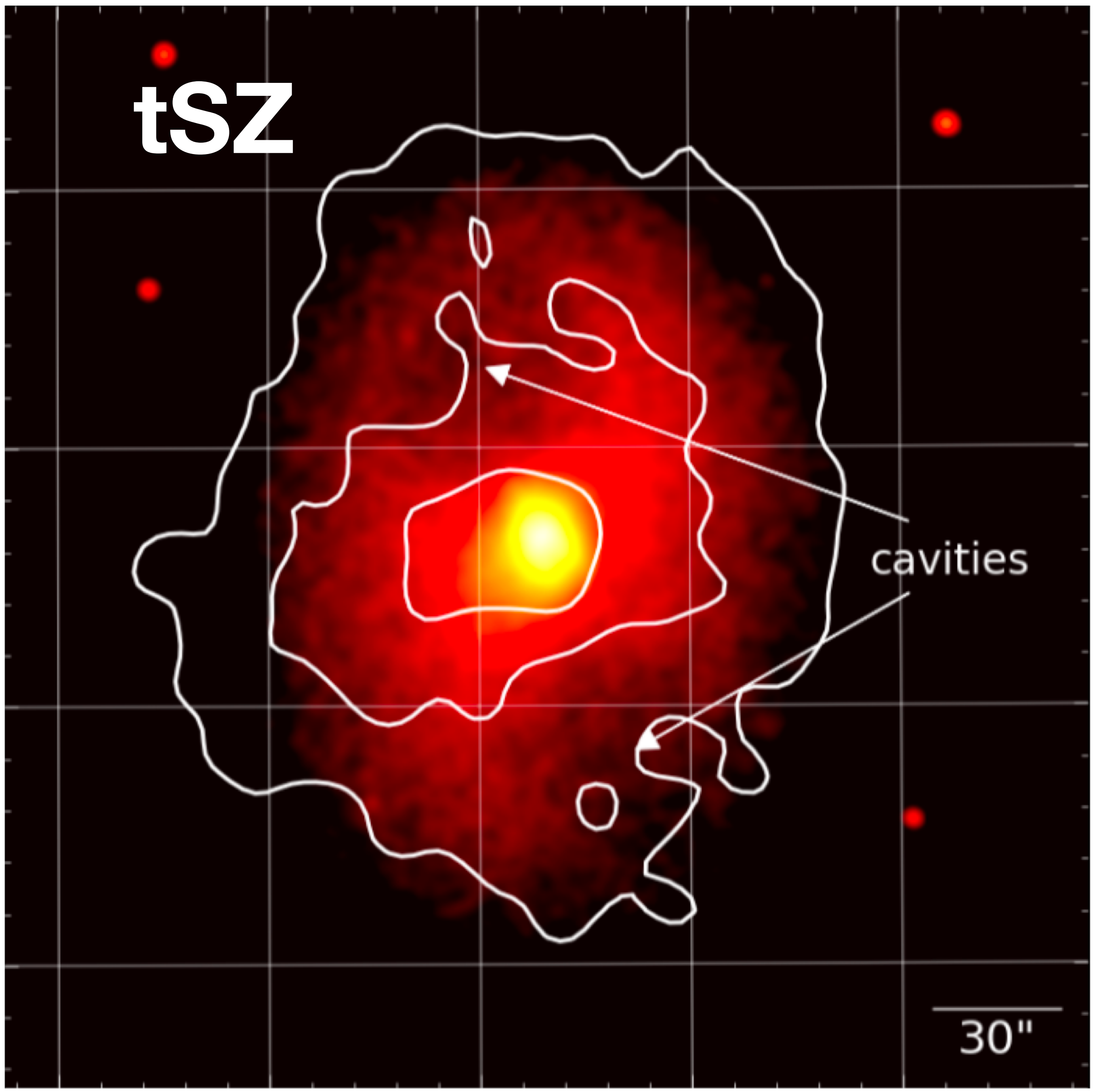
You can use Radio to constrain AGN feedback



Jet Heating Power vs. Cooling luminosity

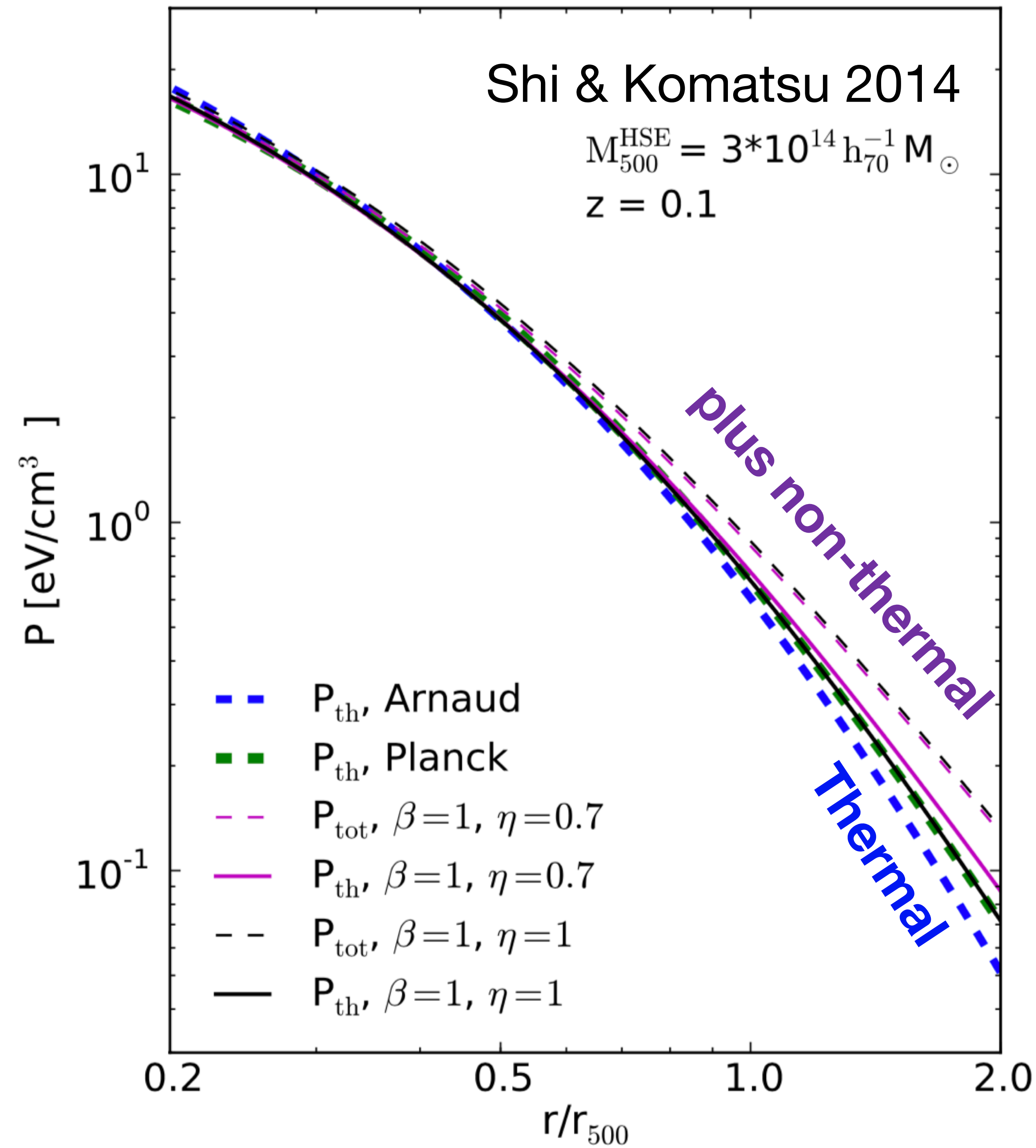


You can also use Sunyaev Zeldovich effect



Abdulla et. al. 2018

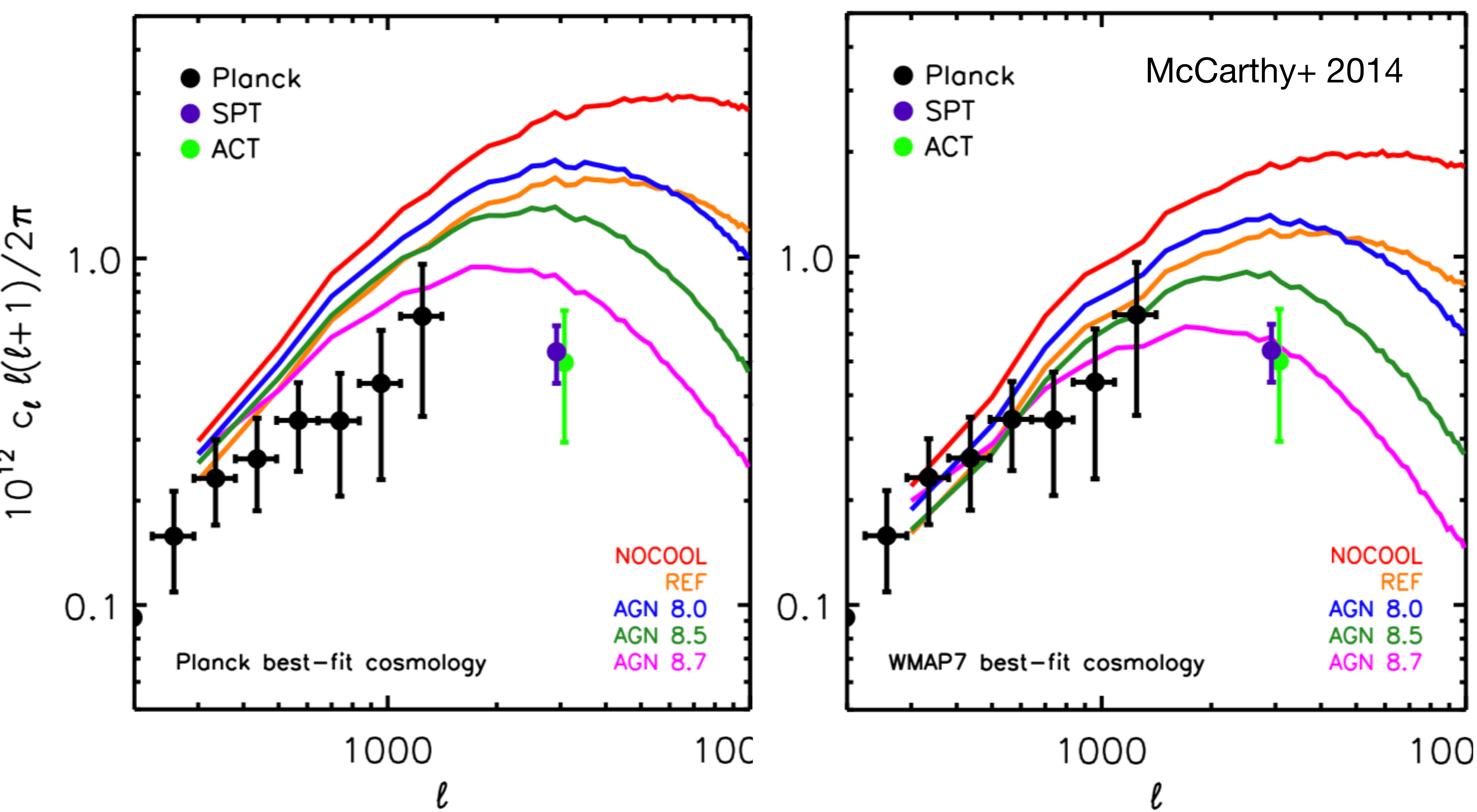
Analytical model for non-thermal pressure



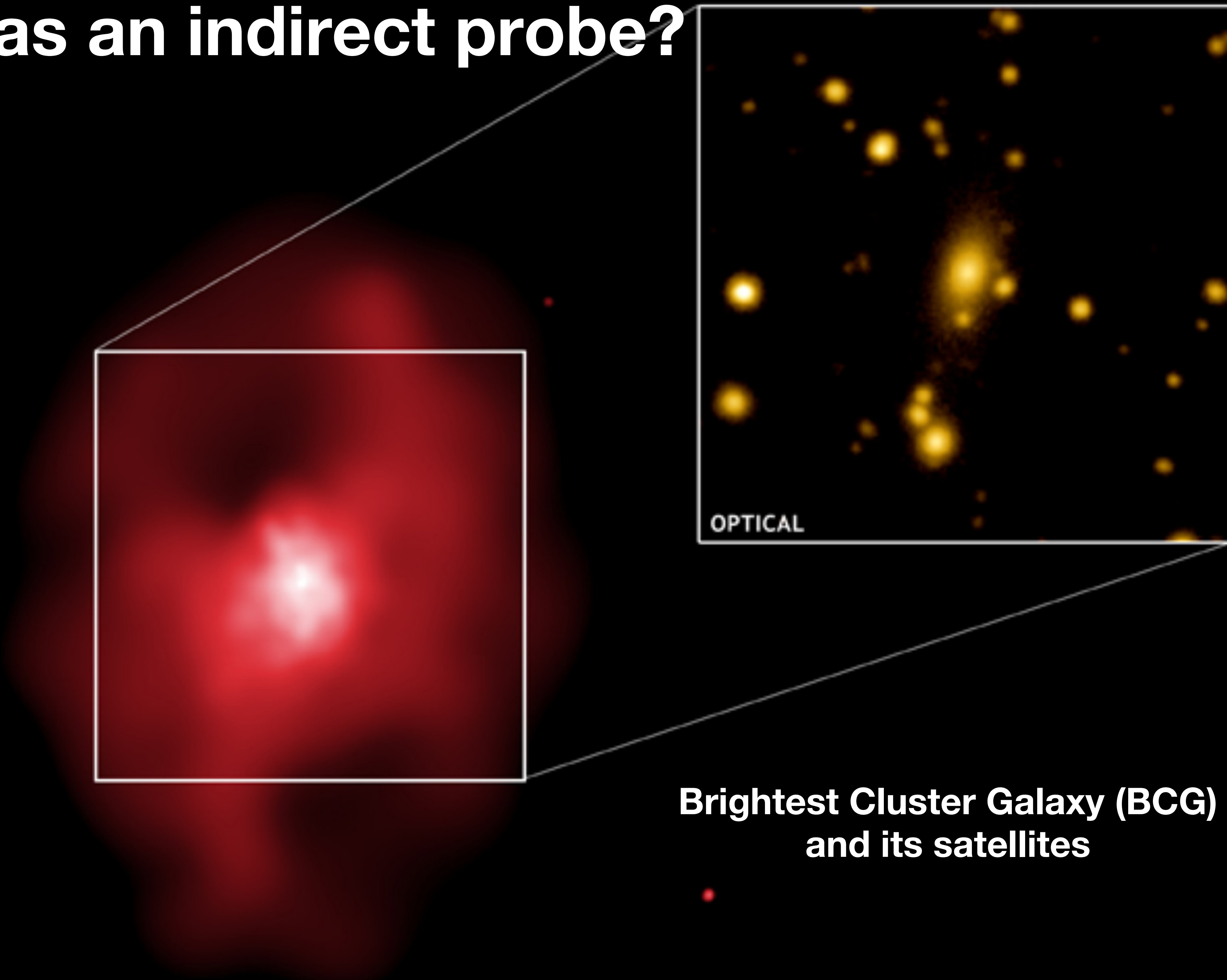
AGN feedback favors WMAP7 over Planck?

Nobody likes Planck . . .

TSZ angular power spectra



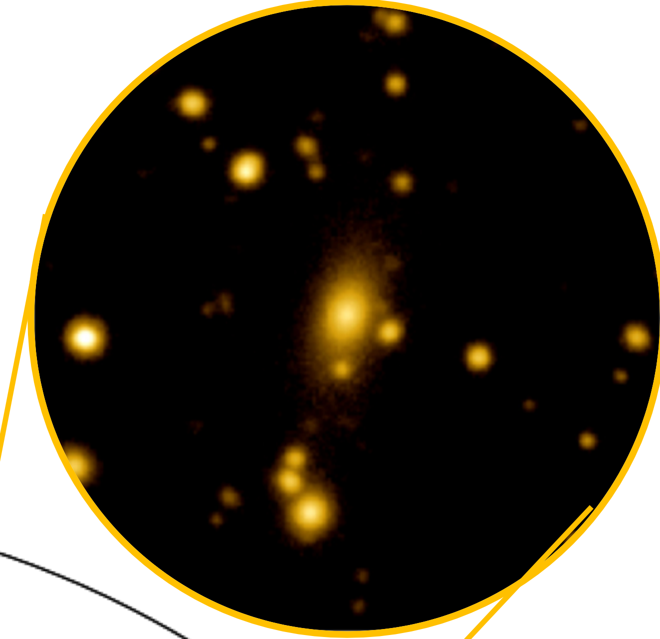
Optical as an indirect probe?

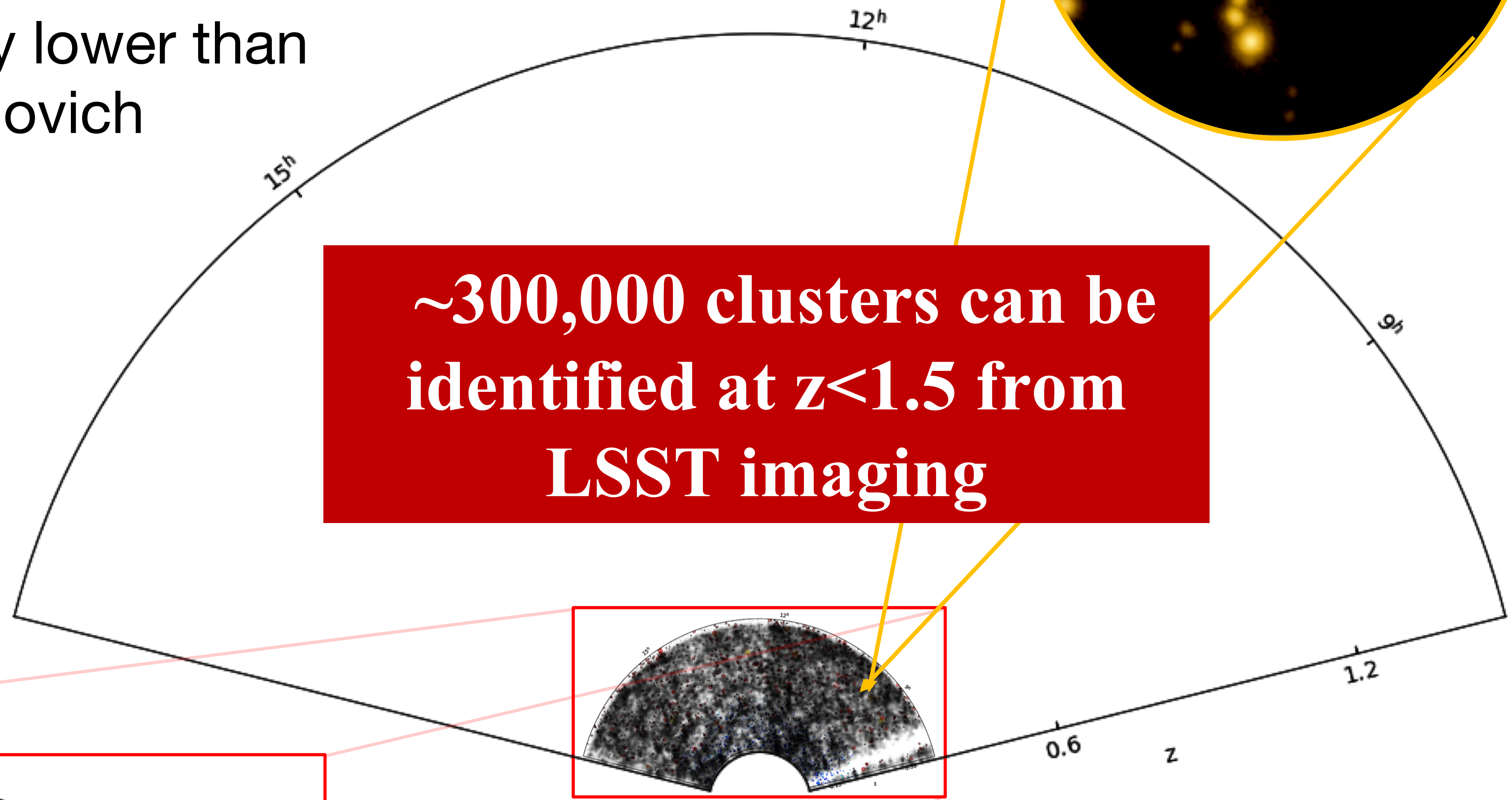


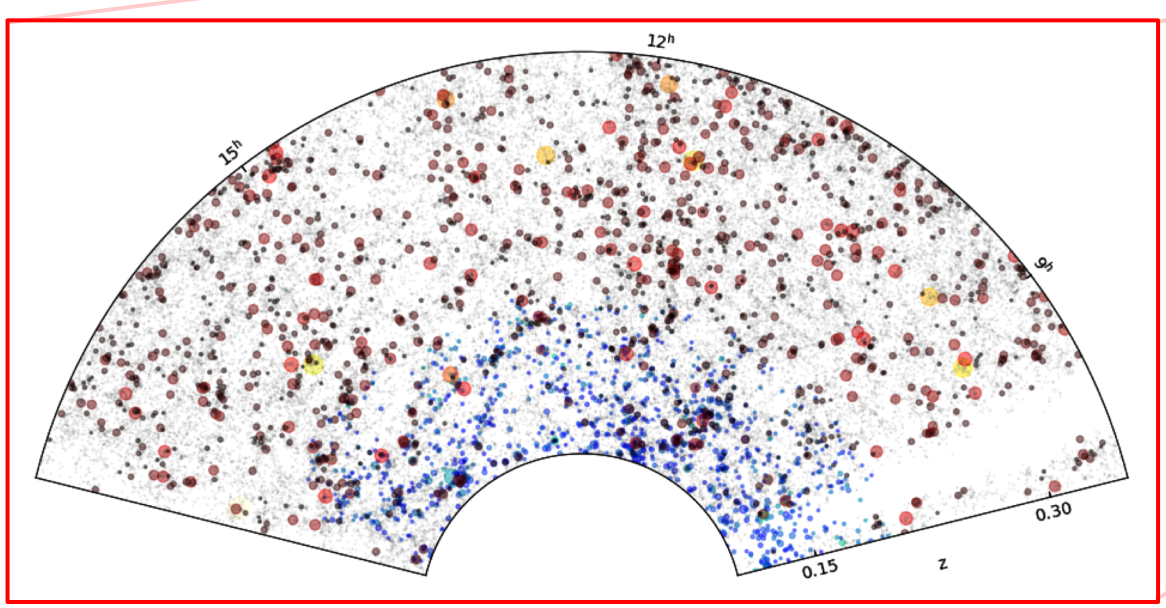
Brightest Cluster Galaxy (BCG)
and its satellites

Optical Clusters in the Stage-IV Era

Optical+NIR from LSST can select clusters (z~0.5-1.5) down to mass thresholds significantly lower than X-ray or Sunyaev-Zeldovich detection.

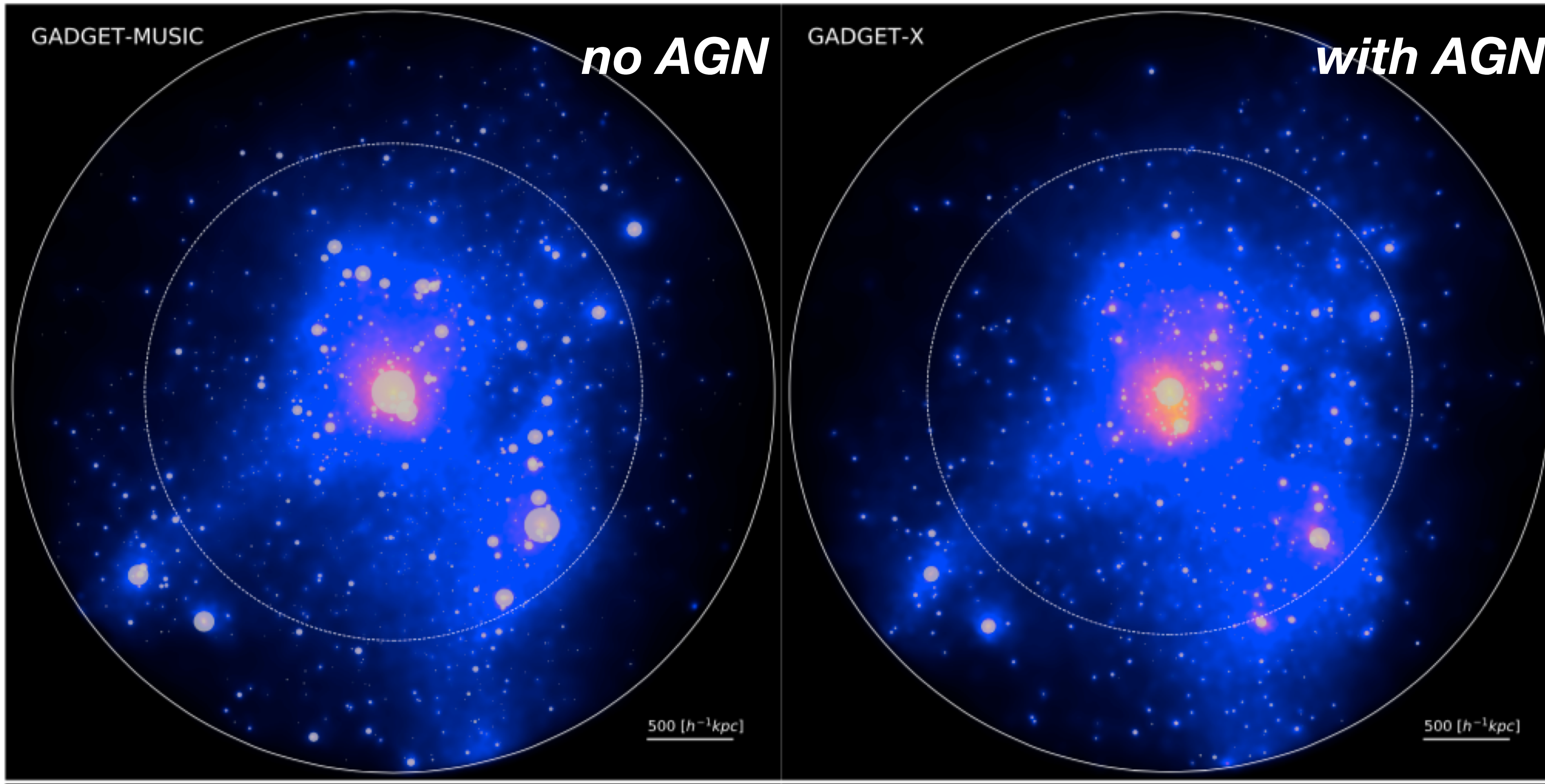


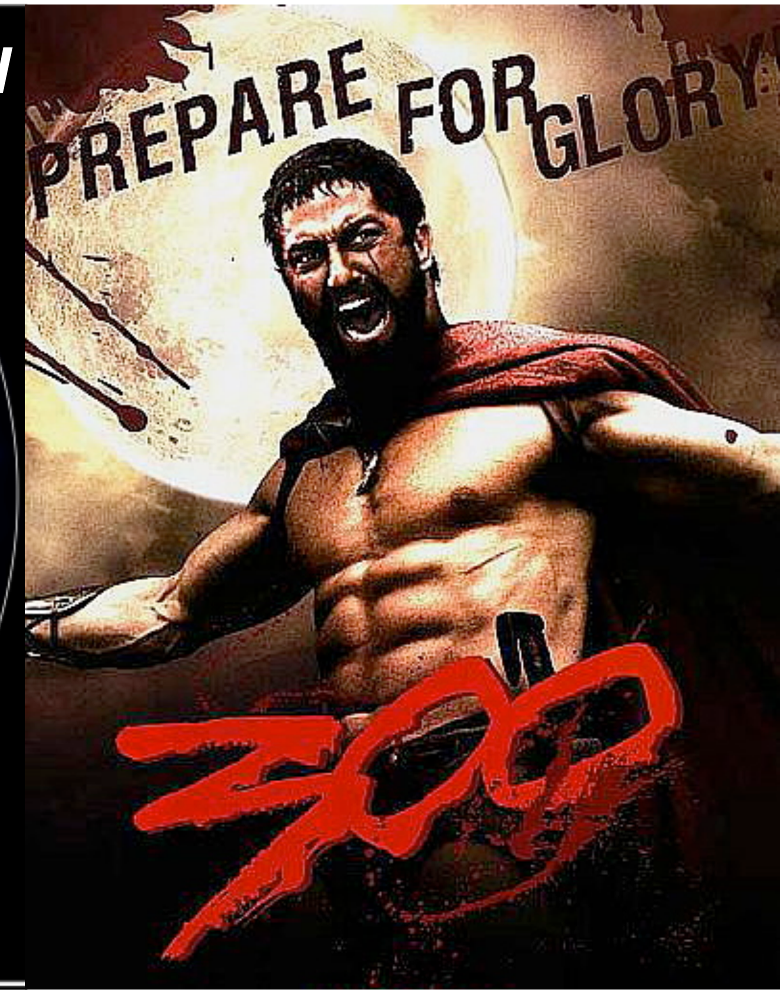




SDSS redMaPPer:
~10,000 clusters at z<0.35

The Three Hundred



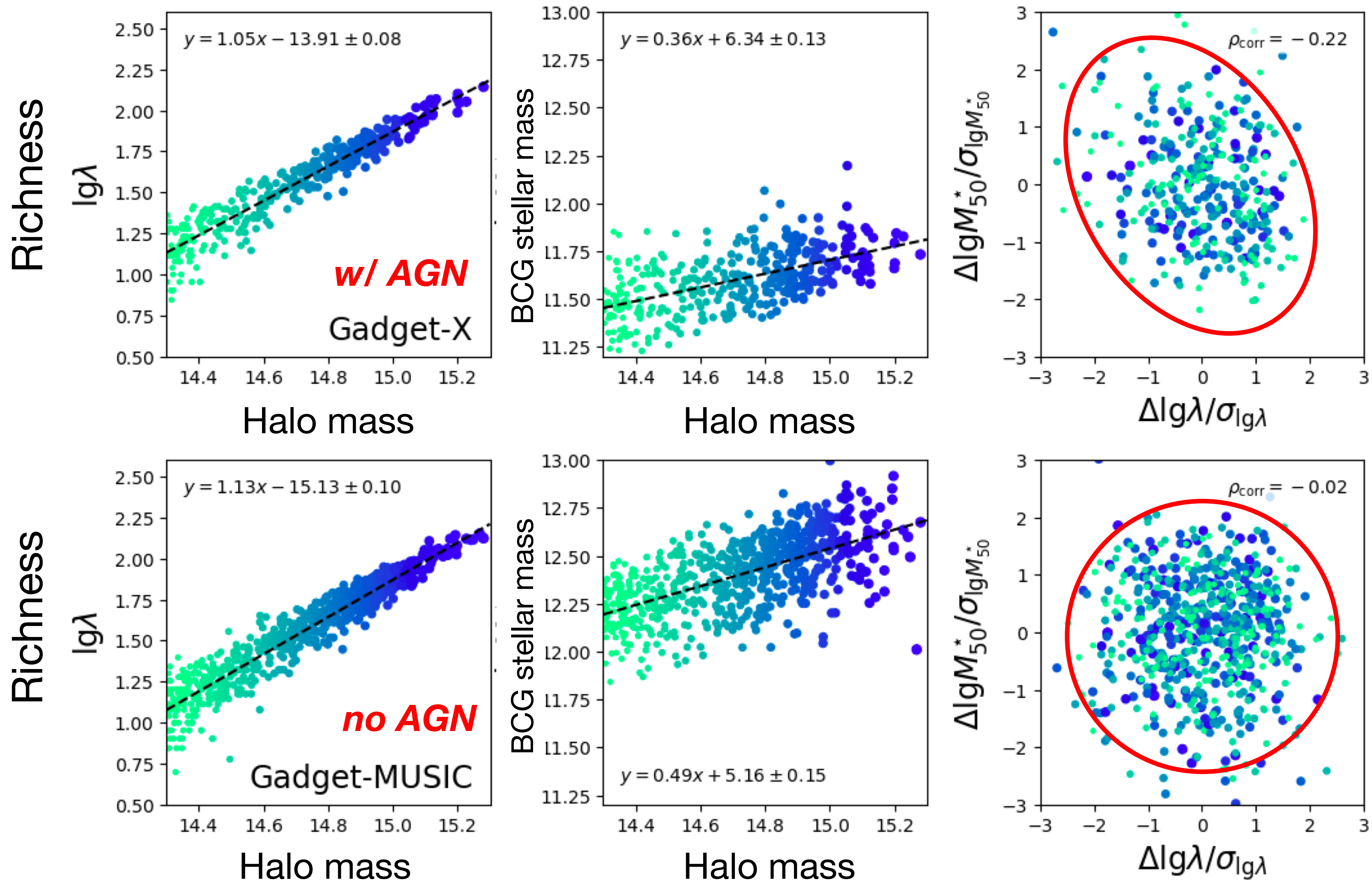


Zoom-in hydro-simulation of massive clusters selected from MPDL

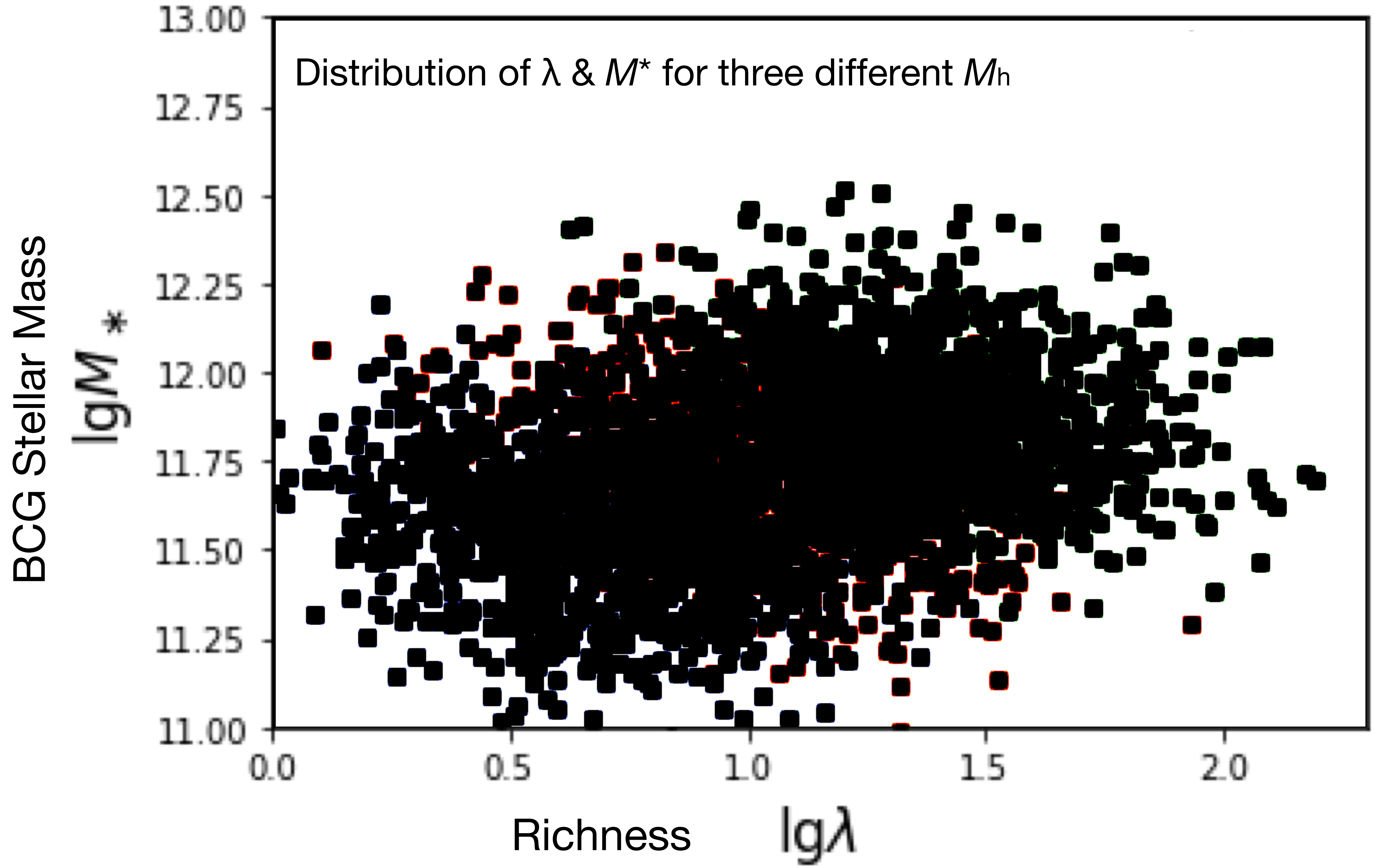
Same initial density field, with different galaxy formation recipes

The 300 Simulation (Cui+ 2018)

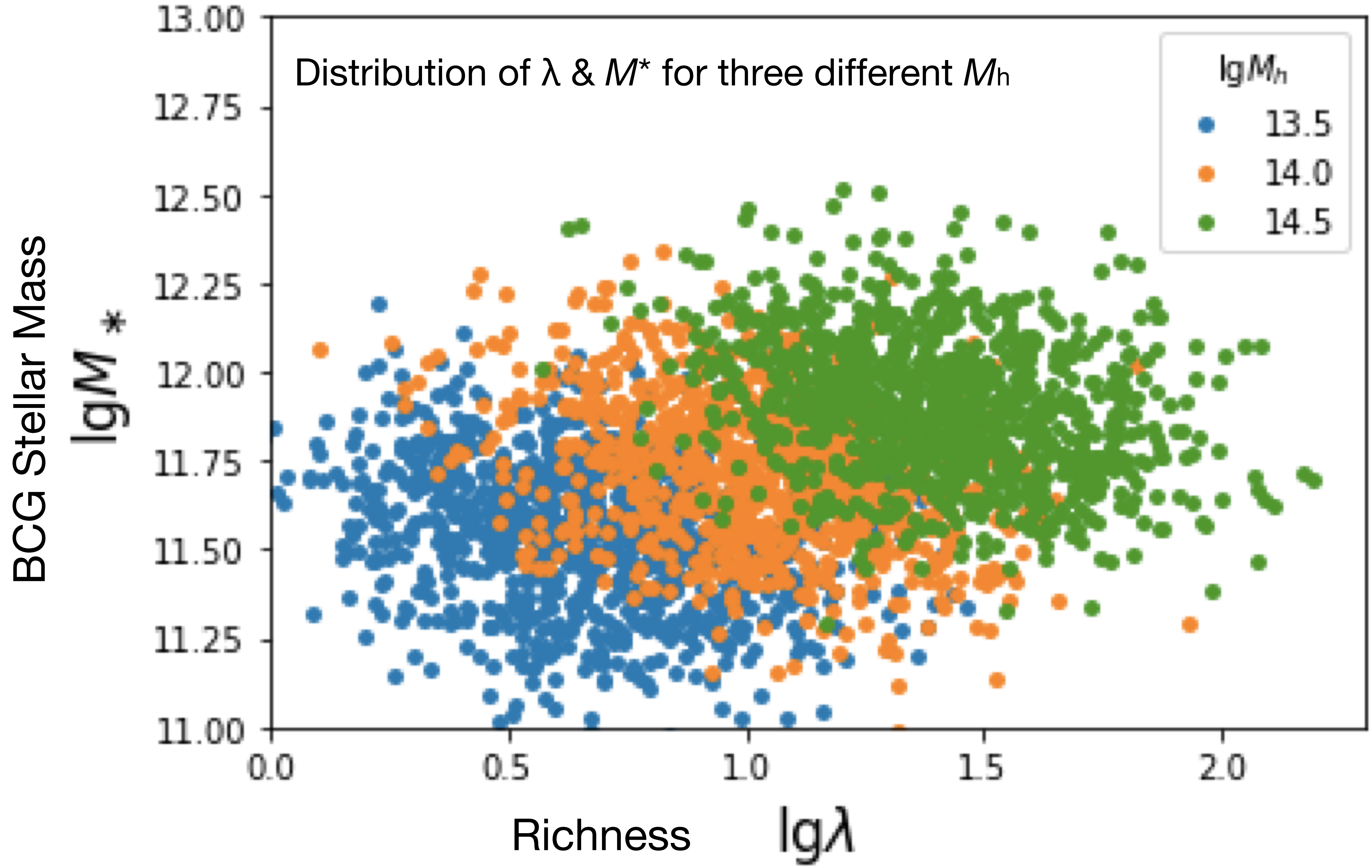
The 300 predicts ***negative*** correlation btw satellite richness and BCG stellar mass **at fixed halo mass**



Observed BCG mass – satellite richness correlation



With negative correlation at fixed halo mass

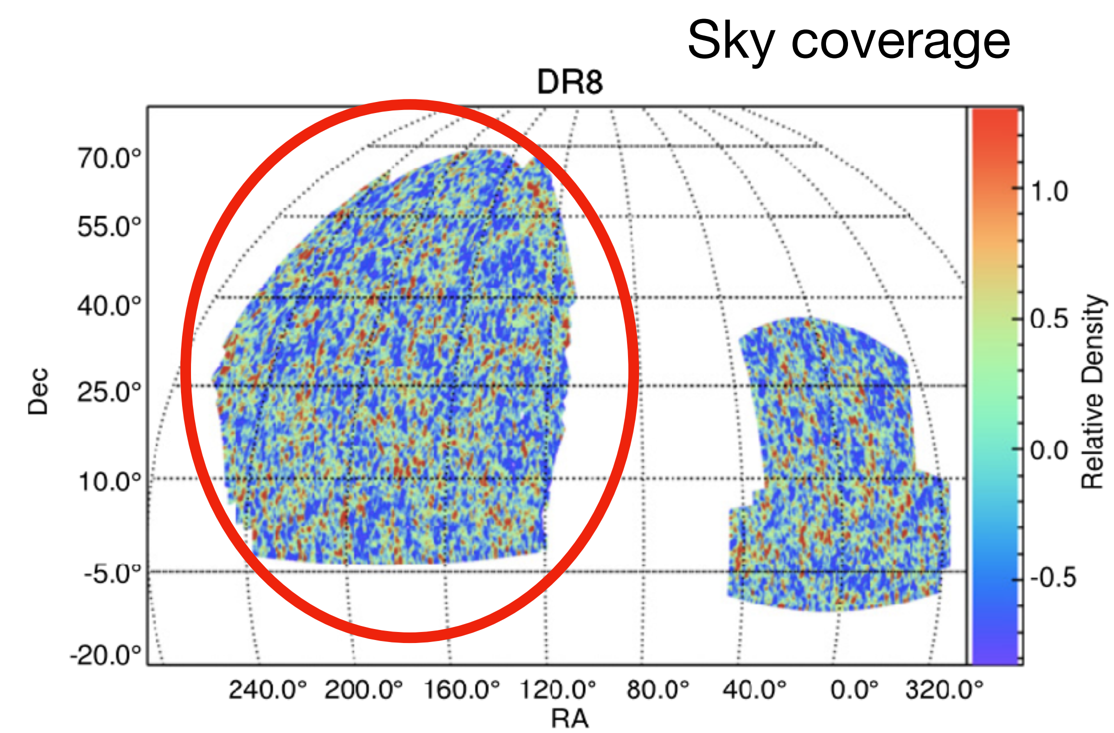


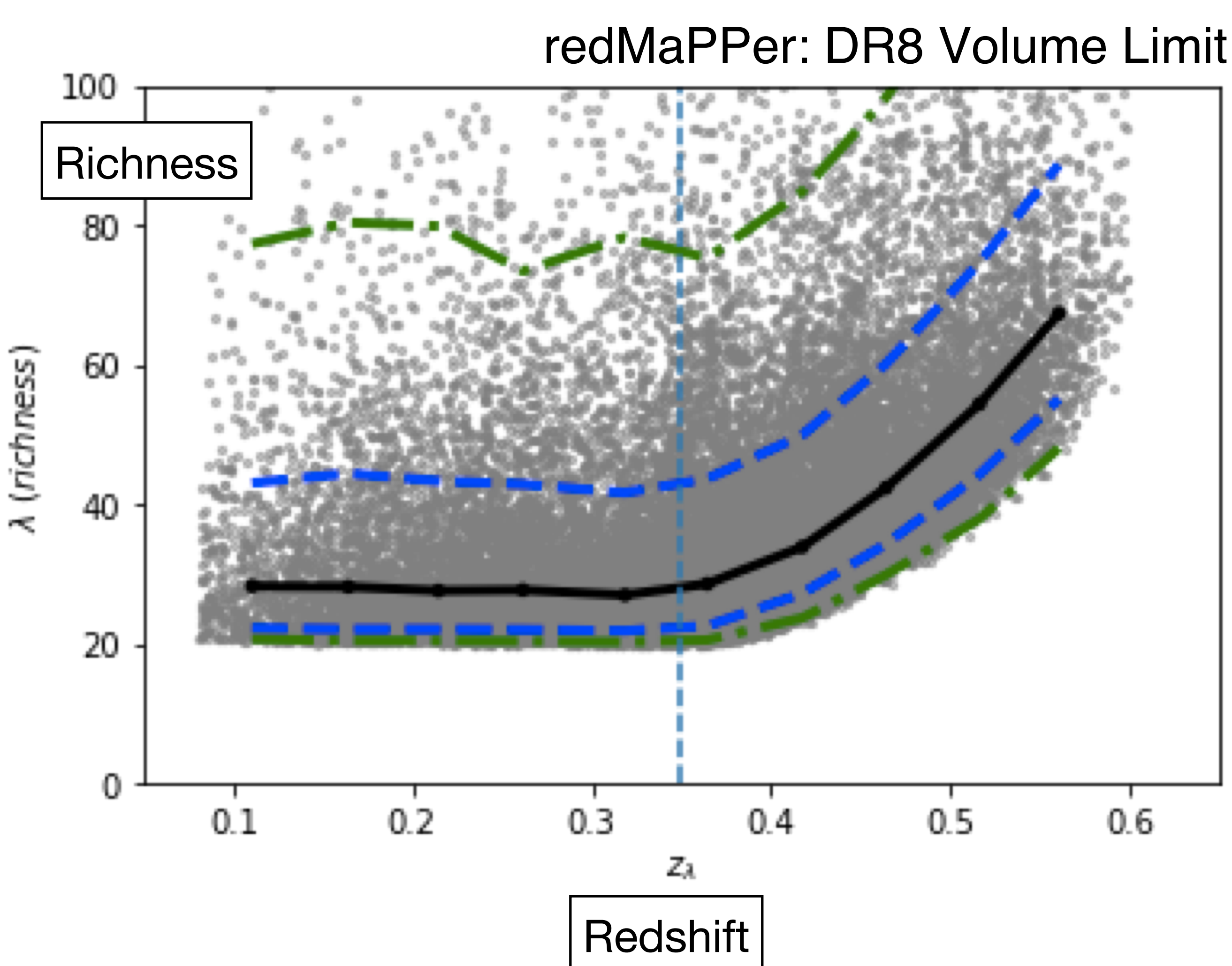
Strong constraint on cluster formation physics!

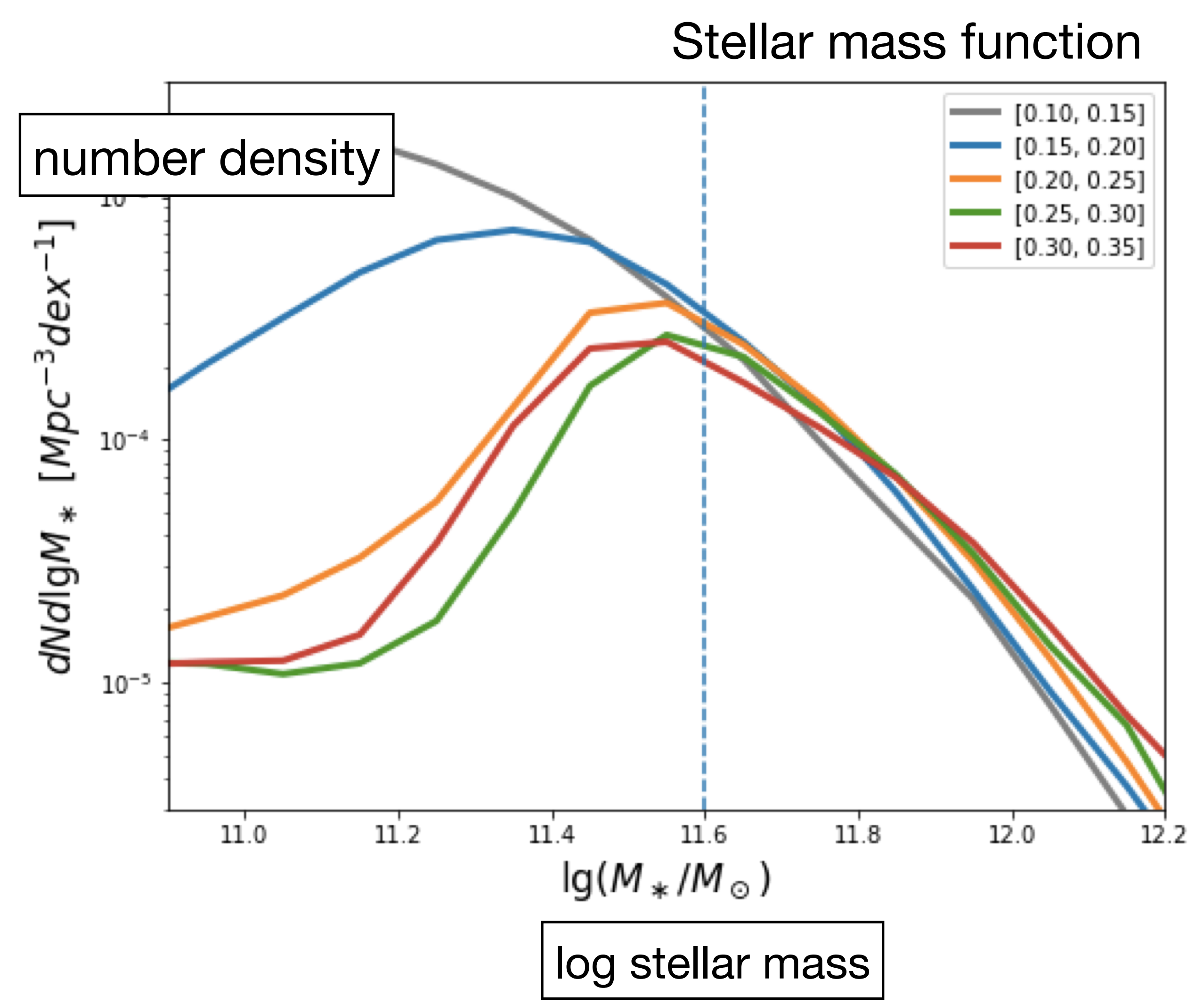
redMaPPer cluster catalog

- redMaPPer (Rykoff+ 2014, SDSS *DR8*)
  red-sequence filter on photometric data
- BCG stellar mass (Chen+ 2012, SDSS/BOSS *DR12*)

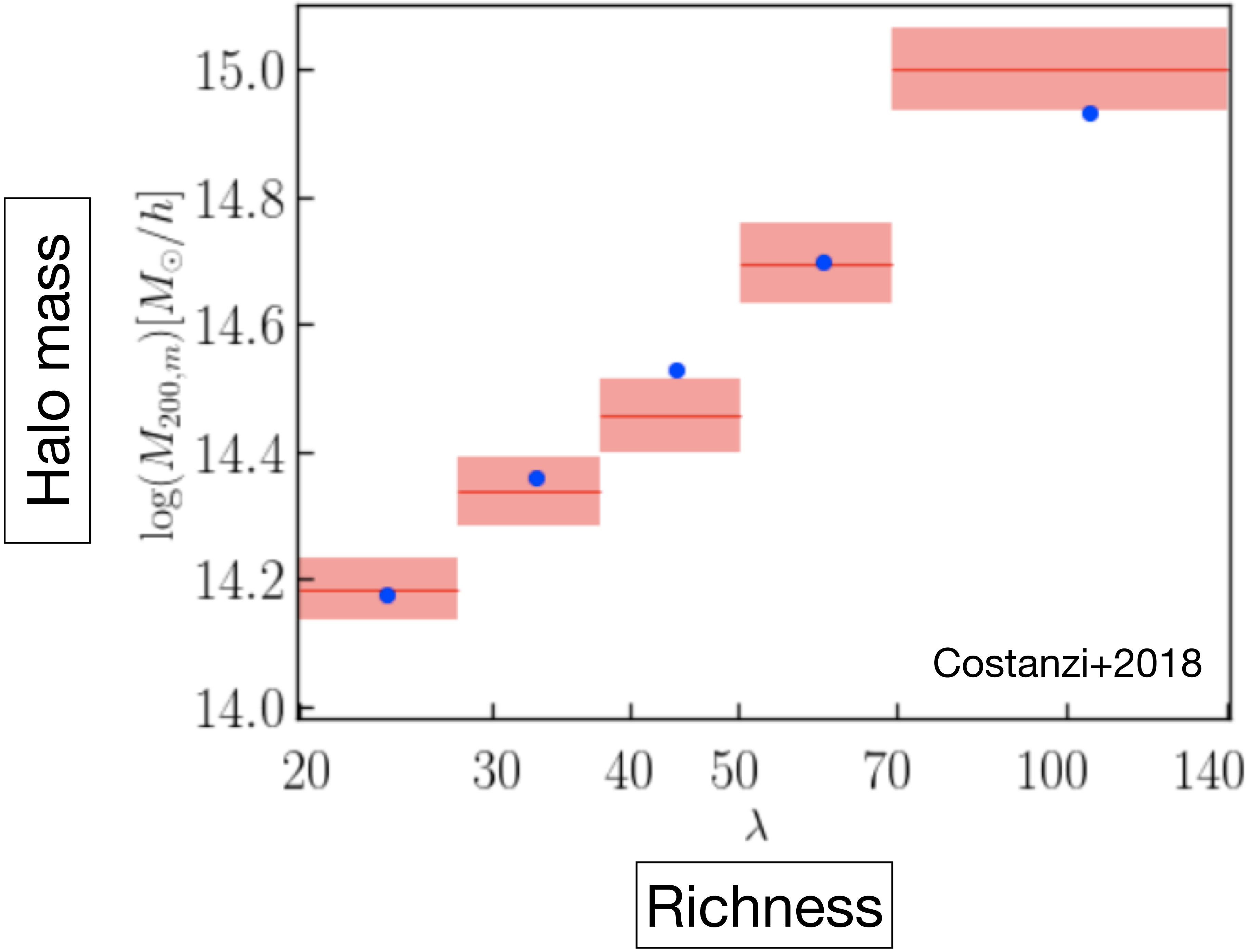
- $0.17 < z < 0.35$, $\lambda \geq 20$ (N=6412, North Cap)
- $\log_{10} M^*/M_\odot \geq 11.6$ (N=4590)







Weak Lensing (WL) cluster masses



Model

- Halo mass function (fixed for now, marginalize over cosmology in the future)
- **2D Gaussian** distribution for **(log *λ*, log *M**)** *at fixed halo mass*

power law

halo mass-richness relation

$$\langle \lg\lambda \rangle = \lg[\lambda_0 (M/M_0)^{\alpha_\lambda}]$$

$$\sigma(\lg\lambda) = \begin{cases} \sigma_{\lg\lambda} & \text{for } M \leqslant M_0 \\ \sigma_{\lg\lambda} + \beta_\lambda \lg(M/M_0) & \text{for } M > M_0 \end{cases}$$

varying scatter

stellar-to-halo mass relation

$$\langle \lg m^* \rangle = \lg[m_0^* (M/M_0)^{\alpha_*}]$$

$$\sigma(\lg m^*) = \begin{cases} \sigma_{\lg m^*} & \text{for } M \leqslant M_0 \\ \sigma_{\lg m^*} + \beta_* \lg(M/M_0) & \text{for } M > M_0 \end{cases}$$

ρ_{corr} : correlation btw λ and *M**

$$\langle \lg m^* \rangle|_{\lg\lambda} = \langle \lg m^* \rangle + \rho_{\rm corr} \frac{\sigma(\lg m^*)}{\sigma(\lg\lambda)} [\lg\lambda - \langle \lg\lambda \rangle]$$

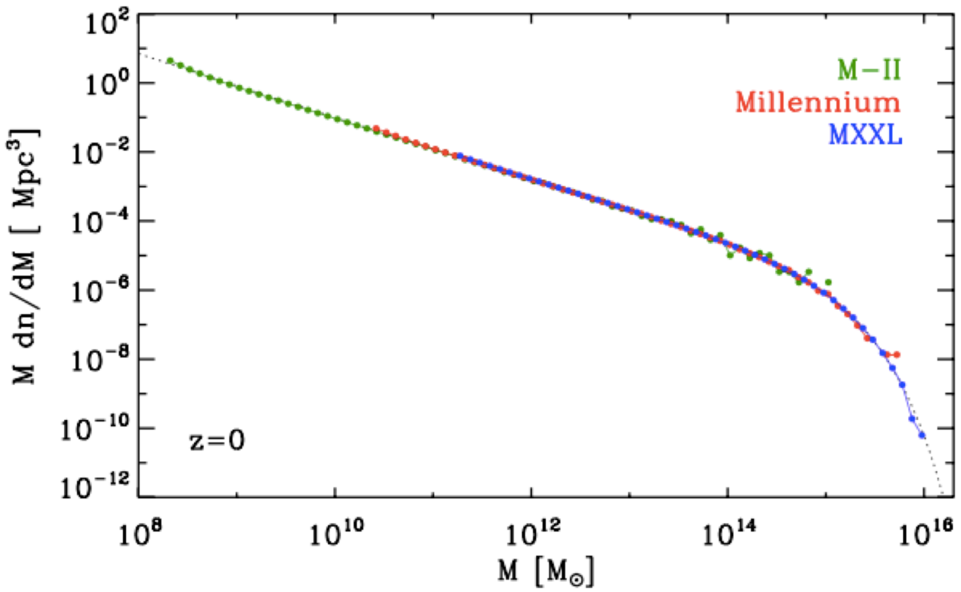
$$\sigma(\lg m^*)|_{\lg\lambda} = \sigma(\lg m^*) \times \sqrt{1 - \rho_{\rm corr}^2}$$

Mock sample for method validation

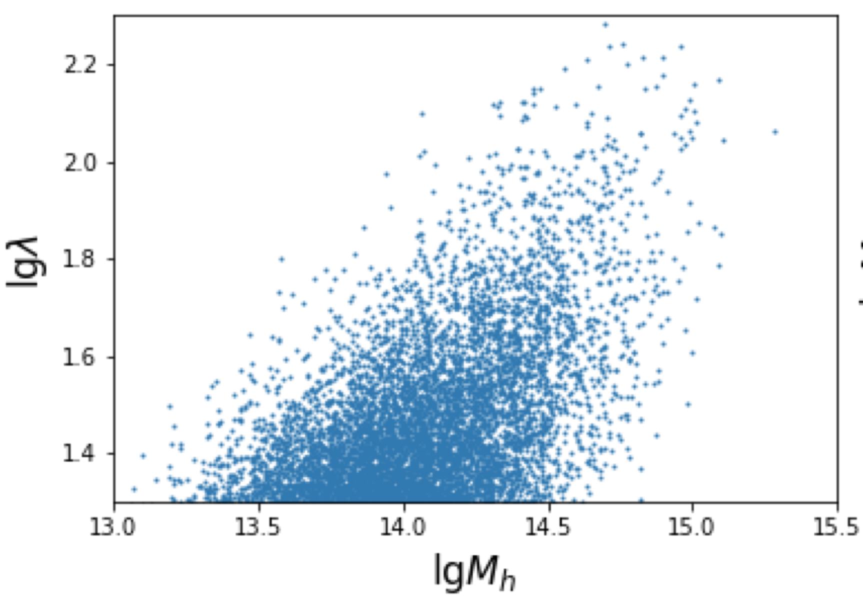
- Generate M_h from halo mass function, assign λ, M^* according to $p(\lambda \mid M_h)$, $p(M^* \mid M_h, \lambda)$

- Apply same sample selection

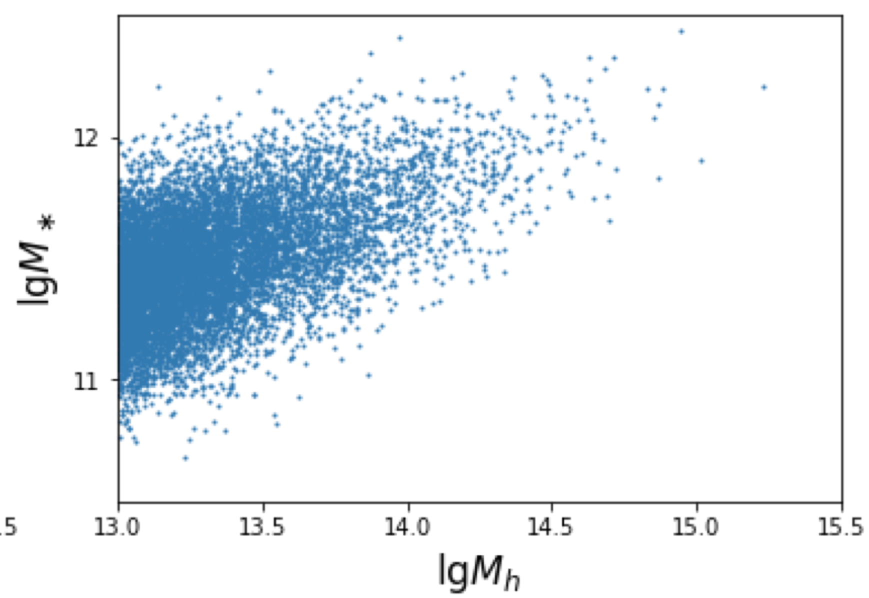
Halo Mass Function



λ | Mh



M* | Mh

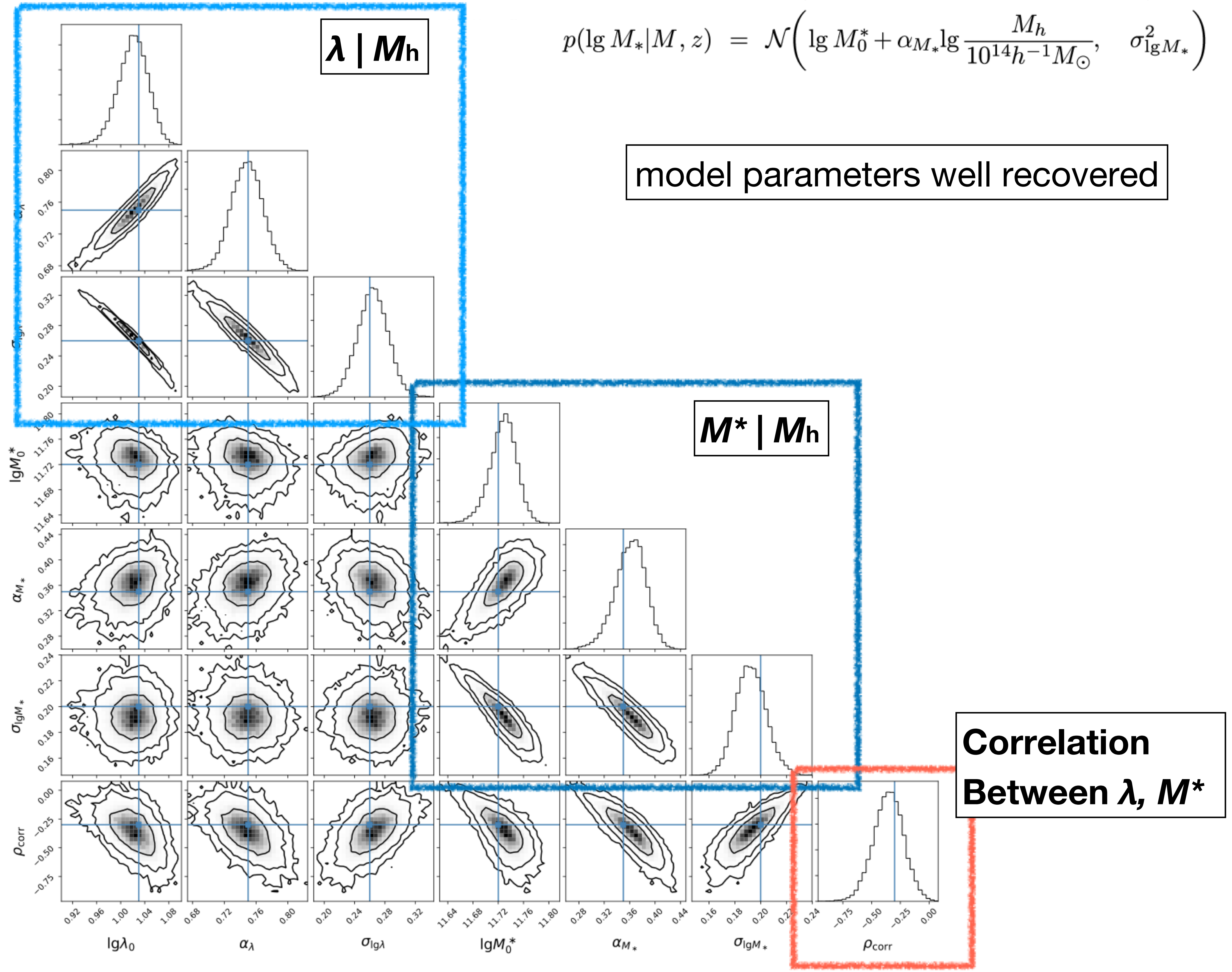


Mock sample results

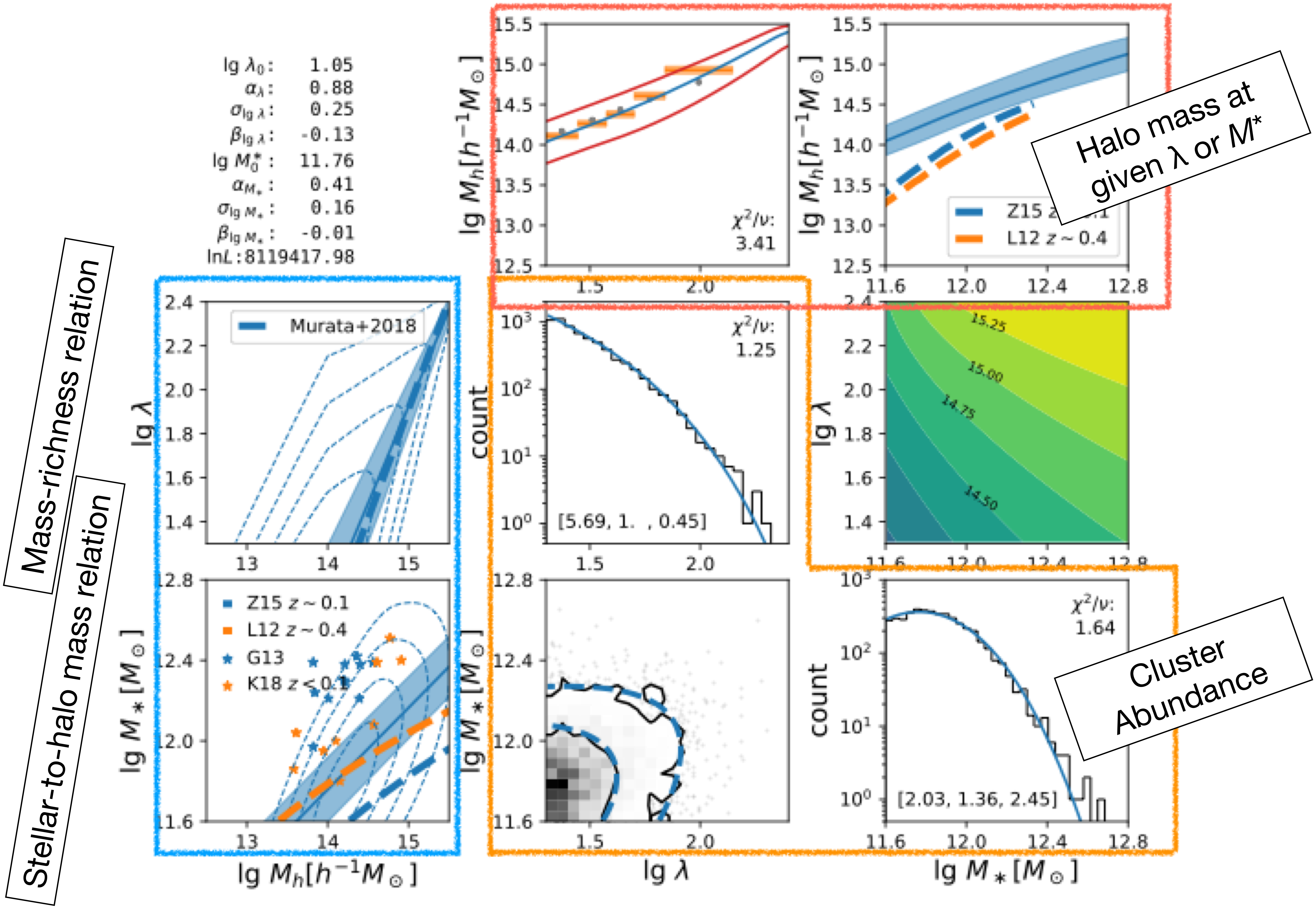
$$p(\lg \lambda | M, z) = \mathcal{N}\left(\lg \lambda_0 + \alpha_\lambda \lg \frac{M_h}{10^{14} h^{-1} M_\odot}, \quad \sigma^2_{\lg \lambda}\right)$$

$$p(\lg M_* | M, z) = \mathcal{N}\left(\lg M_0^* + \alpha_{M_*} \lg \frac{M_h}{10^{14} h^{-1} M_\odot}, \quad \sigma^2_{\lg M_*}\right)$$

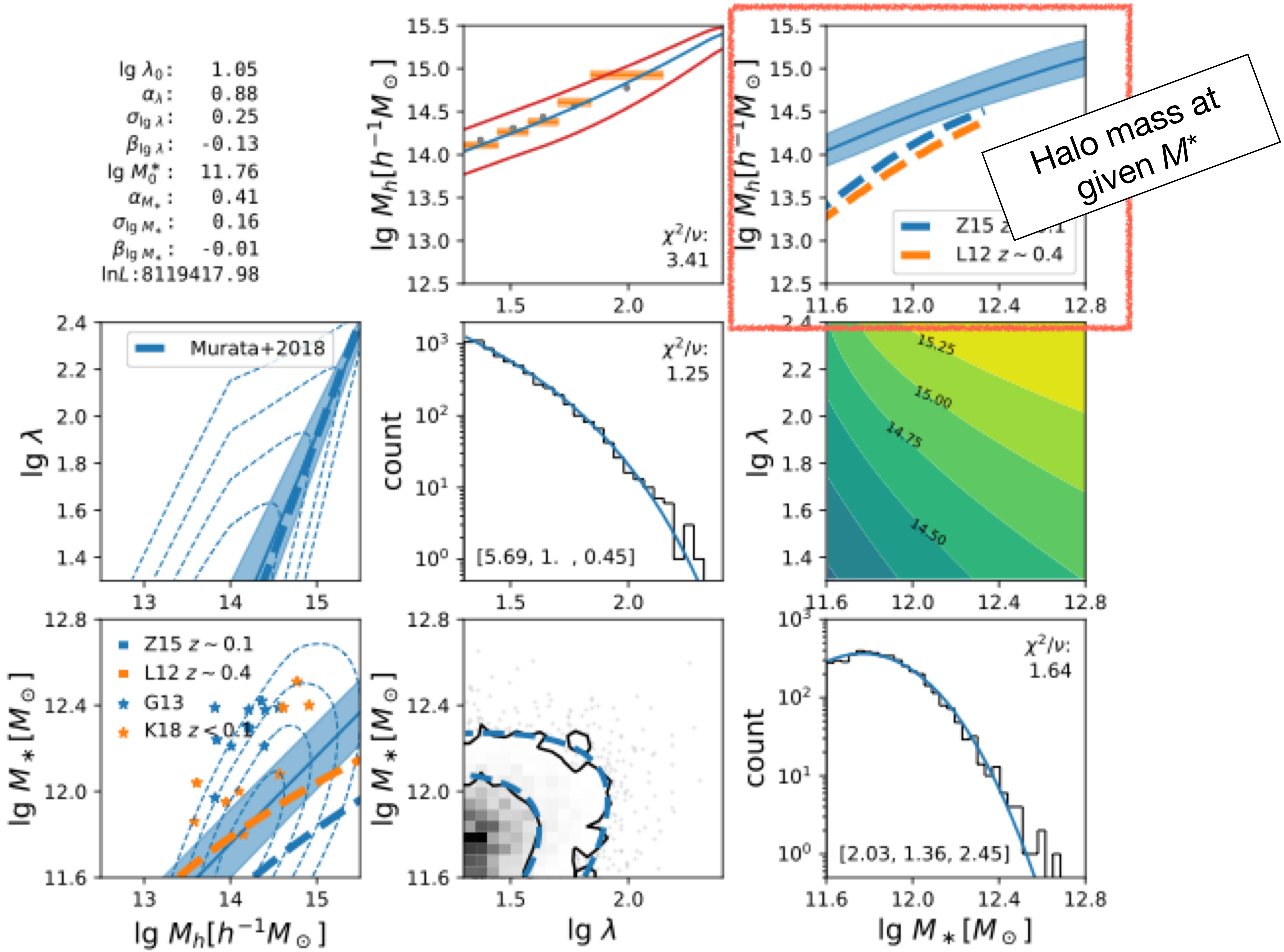
model parameters well recovered



data vs. best-fit model prediction at fixed ρ_{corr}

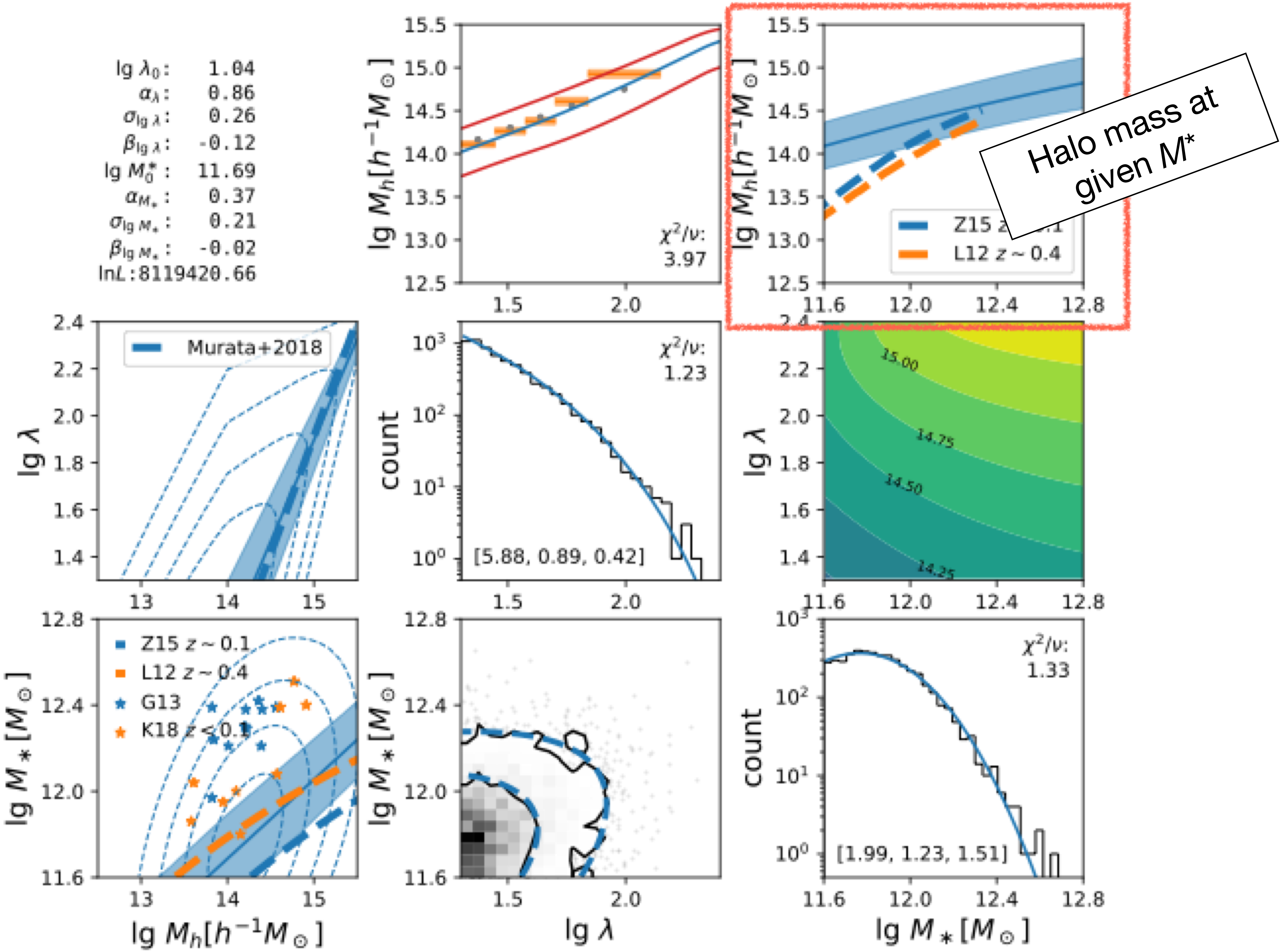


$\rho_{corr} = -0.5$



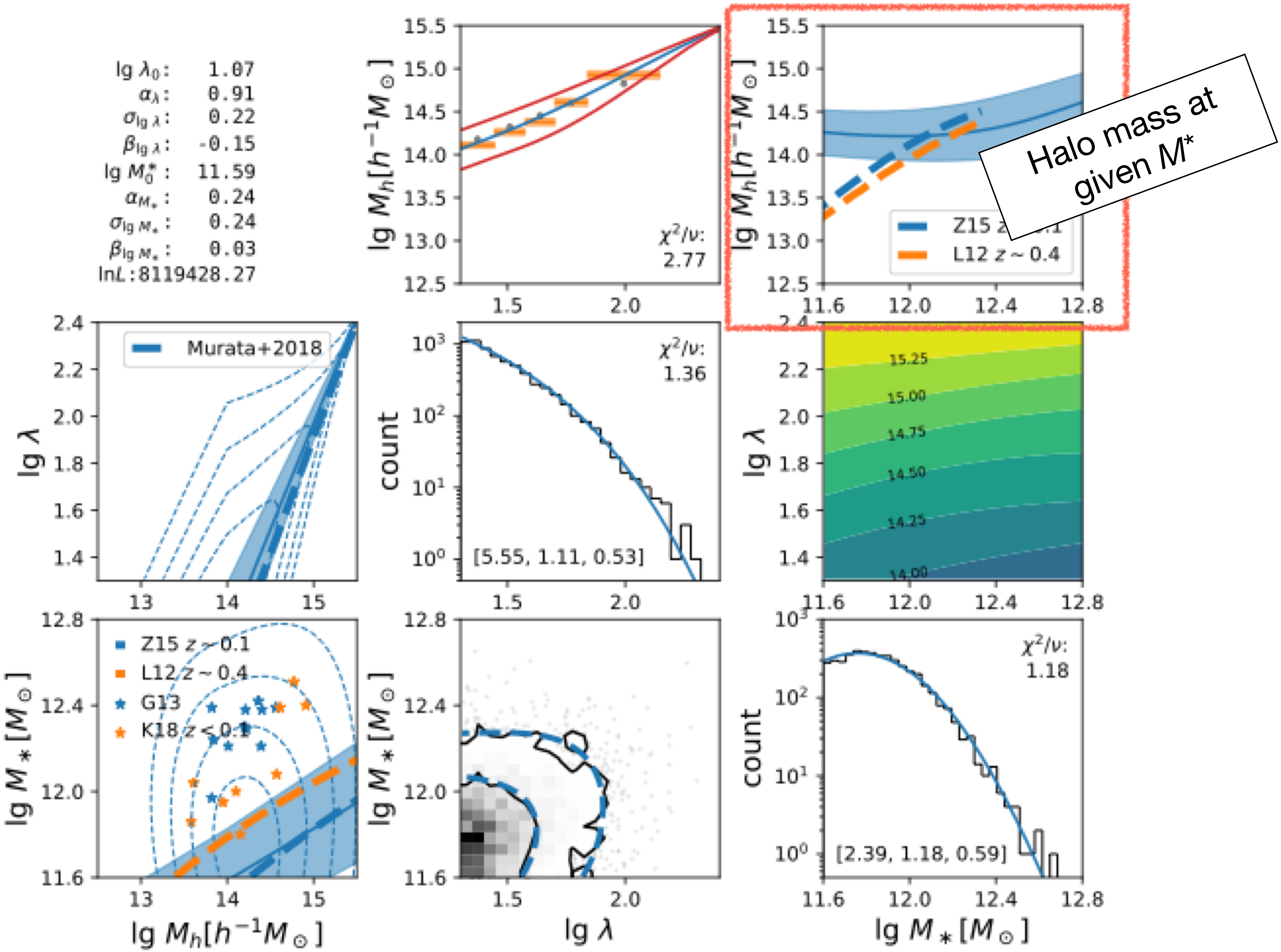
lg λ0: 1.05
αλ: 0.88
σlg λ: 0.25
βlg λ: -0.13
lg M*0: 11.76
αM*: 0.41
σlg M*: 0.16
βlg M*: -0.01
lnL:8119417.98
χ2/ν: 3.41
Z15 z ~ 0.1
L12 z ~ 0.4
Halo mass at given M*
Murata+2018
χ2/ν: 1.25
[5.69, 1. , 0.45]
15.25
15.00
14.75
14.50
G13
K18 z<0.1
χ2/ν: 1.64
[2.03, 1.36, 2.45]
lg Mh[h−1M⊙]
lg λ
count
lg M*[M⊙]

$\rho_{corr} = 0$

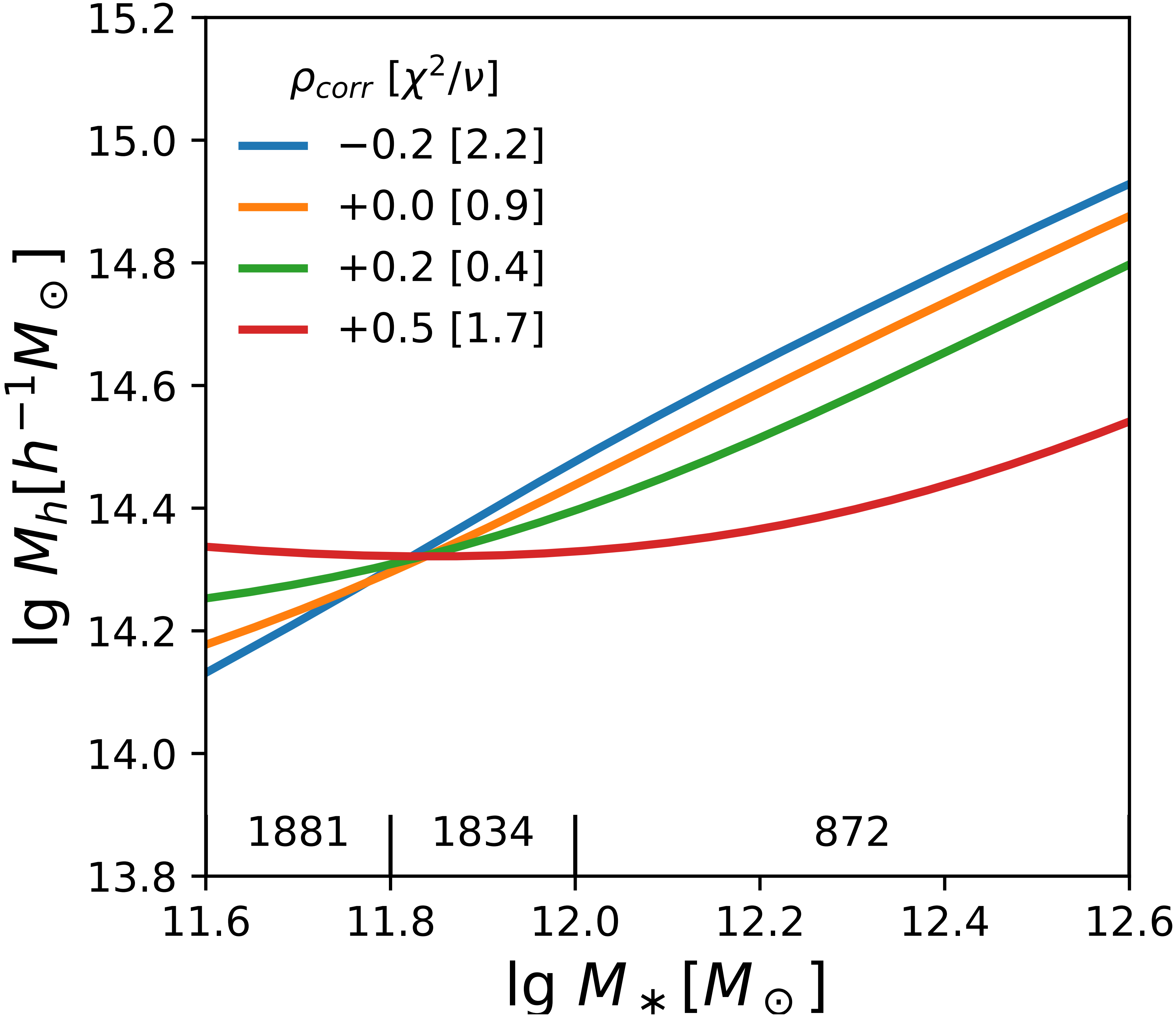


lg λ0: 1.04
αλ: 0.86
σlg λ: 0.26
βlg λ: -0.12
lg M*0: 11.69
αM*: 0.37
σlg M*: 0.21
βlg M*: -0.02
lnL:8119420.66
χ²/ν: 3.97
Z15 z~0.1
L12 z~0.4
Halo mass at given M*
Murata+2018
χ²/ν: 1.23
[5.88, 0.89, 0.42]
15.00
14.75
14.50
14.25
G13
K18 z<0.1
χ²/ν: 1.33
[1.99, 1.23, 1.51]
lg λ
lg Mh[h⁻¹M⊙]
lg M*[M⊙]
count

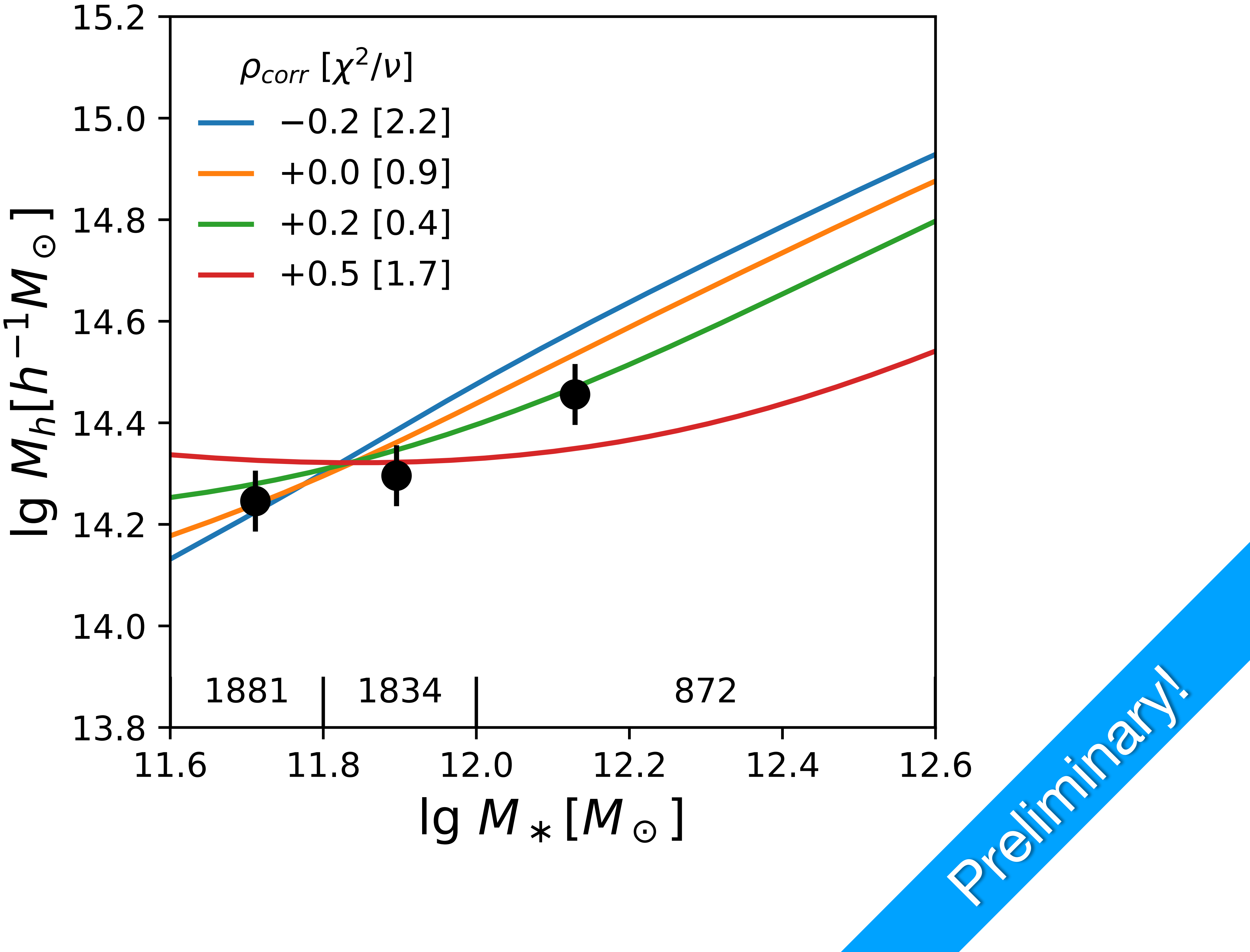
$$\rho_{corr} = +0.5$$


lg λ0: 1.07
αλ: 0.91
σlg λ: 0.22
βlg λ: -0.15
lg M0*: 11.59
αM*: 0.24
σlg M*: 0.24
βlg M*: 0.03
lnL: 8119428.27
χ²/ν: 2.77
χ²/ν: 1.36
[5.55, 1.11, 0.53]
χ²/ν: 1.18
[2.39, 1.18, 0.59]
Murata+2018
Z15 z ~ 0.1
L12 z ~ 0.4
G13
K18 z < 0.1
lg Mh[h⁻¹M⊙]
lg λ
lg M*[M⊙]
count
Halo mass at given M*

WL halo mass at fixed BCG stellar mass can pin down ρ_{corr}



Well, WL tells us ρ_{corr} is close to +0.2



Possible boring explanations

- **We probably need to marginalize over cosmolog**y
- AGN feedback inhibits BCG growth, no doubt
- AGN feedback quenches star formation in satellites, making satellites (a) redder and (b) lighter

  ✓ If (a) -> BCG mass and richness are negatively correlated.

  ✓ If (b) -> BCG mass and richness are positively correlated.
- We probably need to run cluster finding algorithm on simulations.

More exciting explanation

- At fixed halo mass, halos in dense environments have more substructure, i.e., higher (subhalo) richness (*halo assembly bias*)
- BCG *in-situ* growth is suppressed by AGN feedback, but *ex-situ* growth is due to accretion from the intra-cluster medium and hierarchical mergers.
- Next step: looking into the intra-cluster light!

Stay tuned!