CLUSTERS OF GALAXIES:

WHERE COSMOLOGY
AND ASTROPHYSICS ^ASTRONOMY COLLIDE

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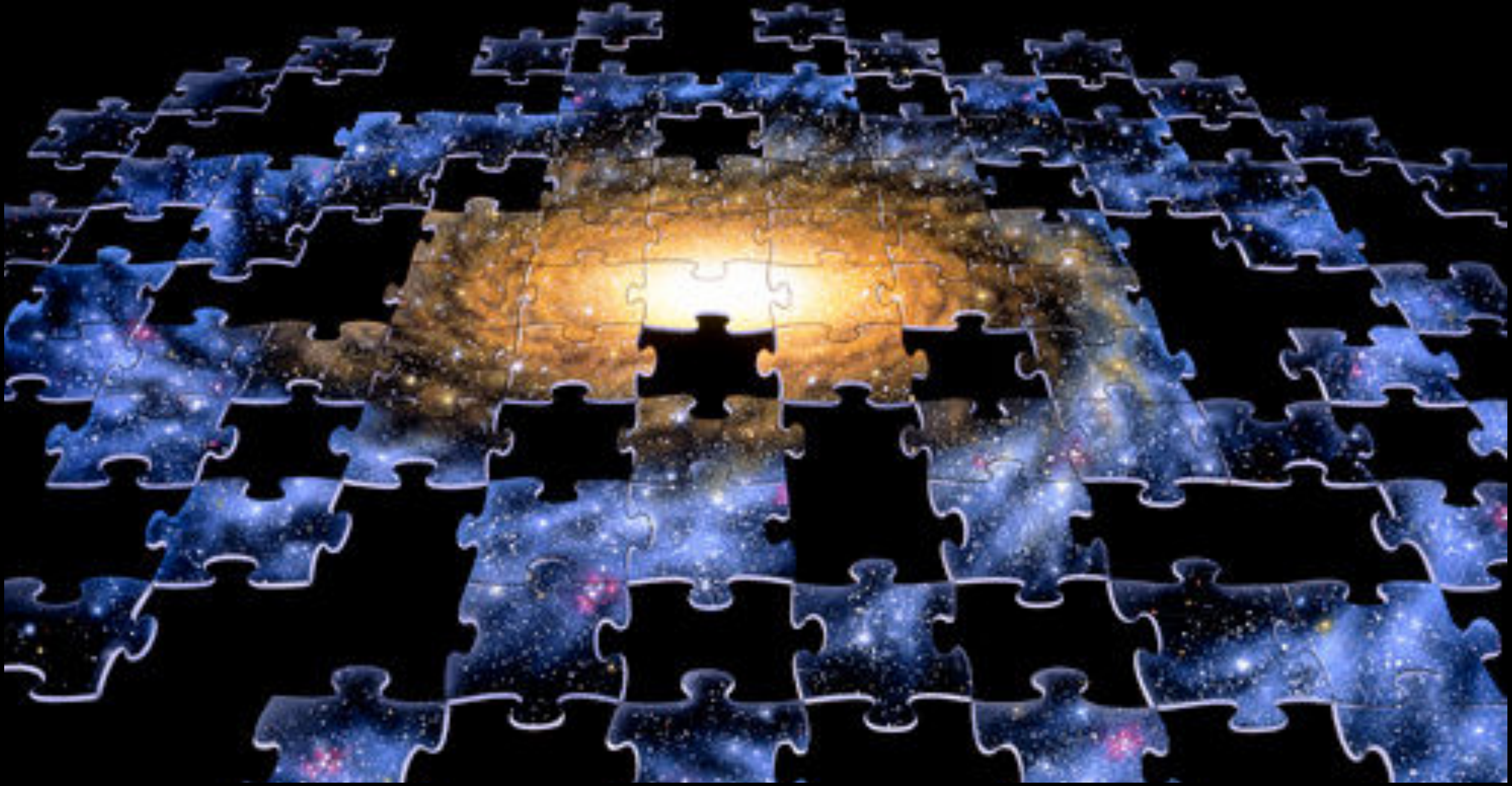
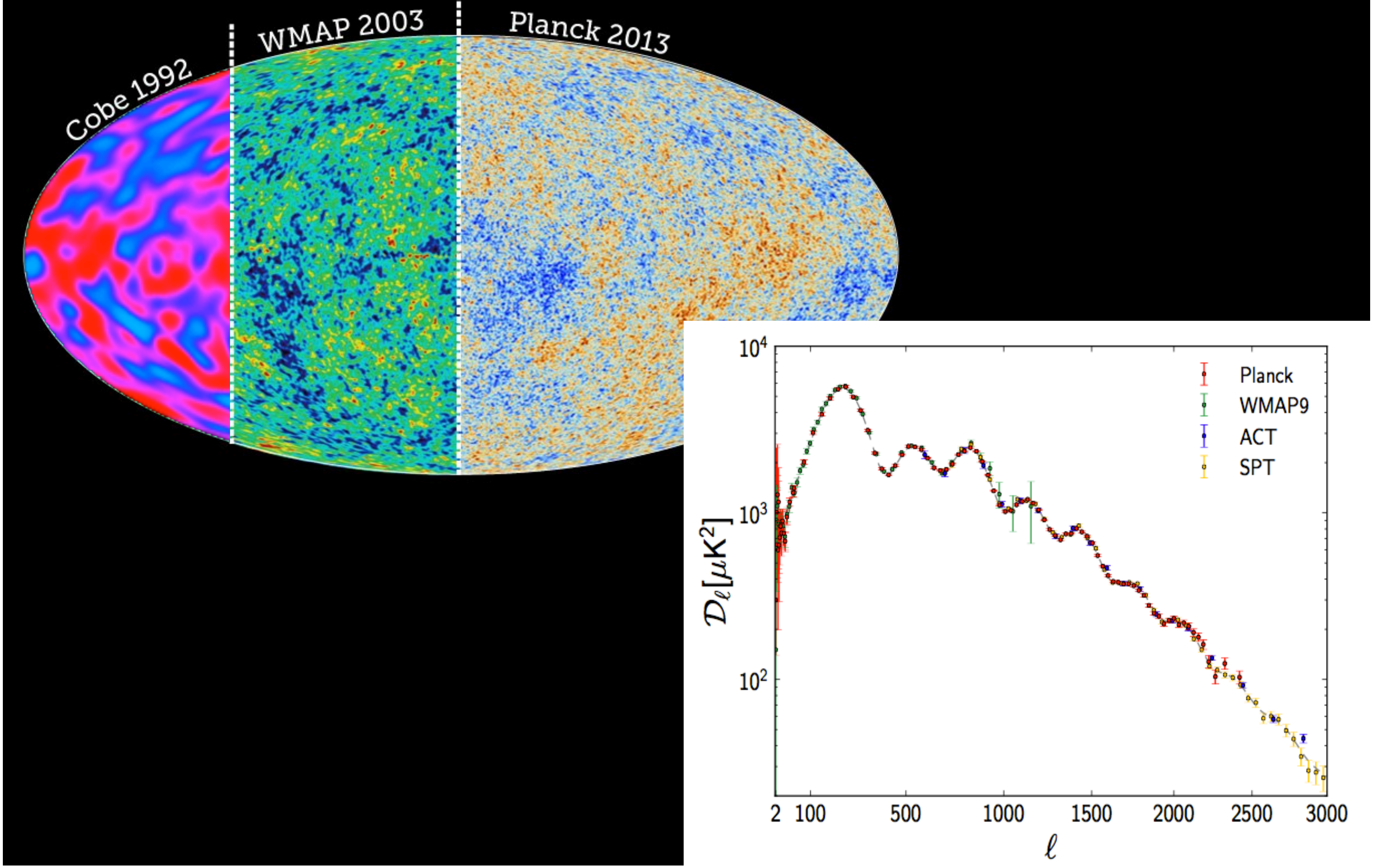
THE HOLY GRAIL OF COSMOLOGY

- What is the make-up of the Universe?
- What is the present-day cosmic expansion rate?
- How is the expansion rate evolving?
- What is the large-scale geometry of space-time?
- What is the nature of dark matter?
- What is the nature of dark energy?

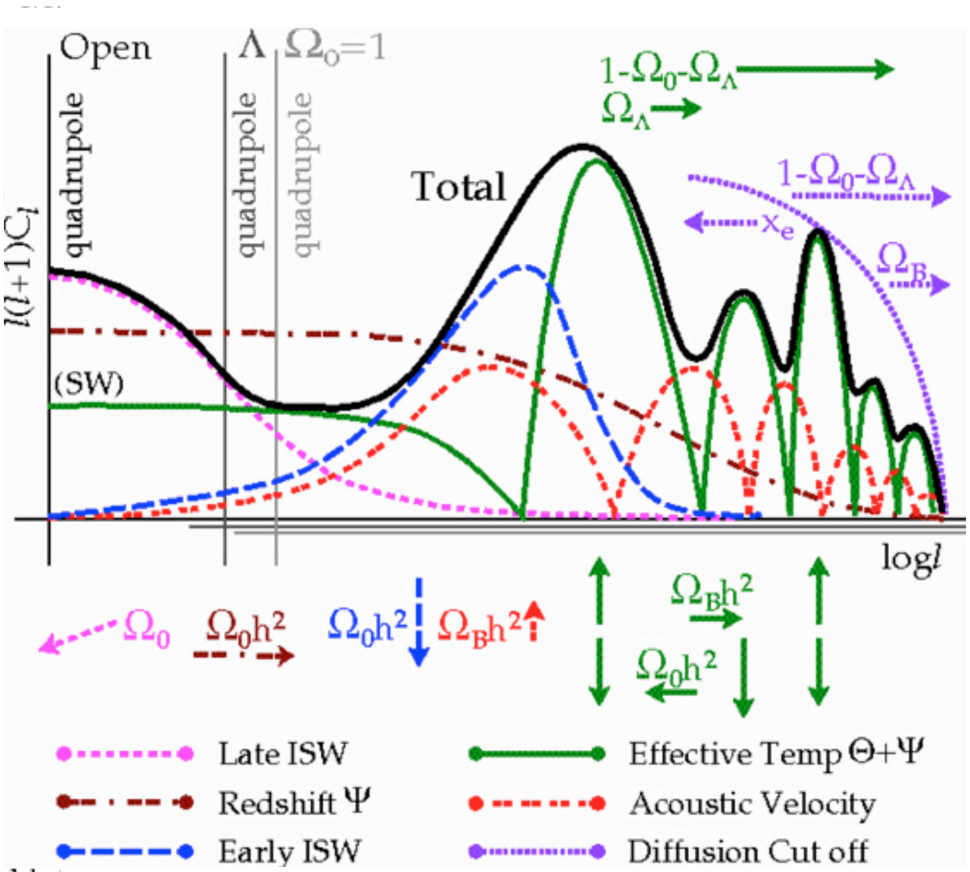
- How was galaxy formation, and the observed large-scale structure traced by the galaxies, seeded?



CMB EXPERIMENTS HERALDED THE AGE OF PRECISION COSMOLOGY



Age of universe	t_0
Hubble constant	H_0
Baryon density	Ω_b
Physical baryon density	$\Omega_b h^2$
Dark matter density	Ω_c
Physical dark matter density	$\Omega_c h^2$
Dark energy density	Ω_Λ
Curvature fluctuation amplitude, $k_0 = 0.002$ Mpc^{-1} [b]	$\Delta^2_{\mathcal{R}}$
Fluctuation amplitude at $8h^{-1}$ Mpc	σ_8
$l(l+1)C_{220}^{TT}/2\pi$	C_{220}
Scalar spectral index	n_s
Redshift of matter-radiation equality	$z_{\rm eq}$
Angular diameter distance to matter-radiation eq.[c]	$d_A(z_{\rm eq})$
Redshift of decoupling	z_*
Age at decoupling	t_*
Angular diameter distance to decoupling [c,d]	$d_A(z_*)$
Sound horizon at decoupling [d]	$r_s(z_*)$
Acoustic scale at decoupling [d]	$l_A(z_*)$
Reionization optical depth	τ
Redshift of reionization	$z_{\rm reion}$
Age at reionization	$t_{\rm reion}$



Parameters for Extended Models

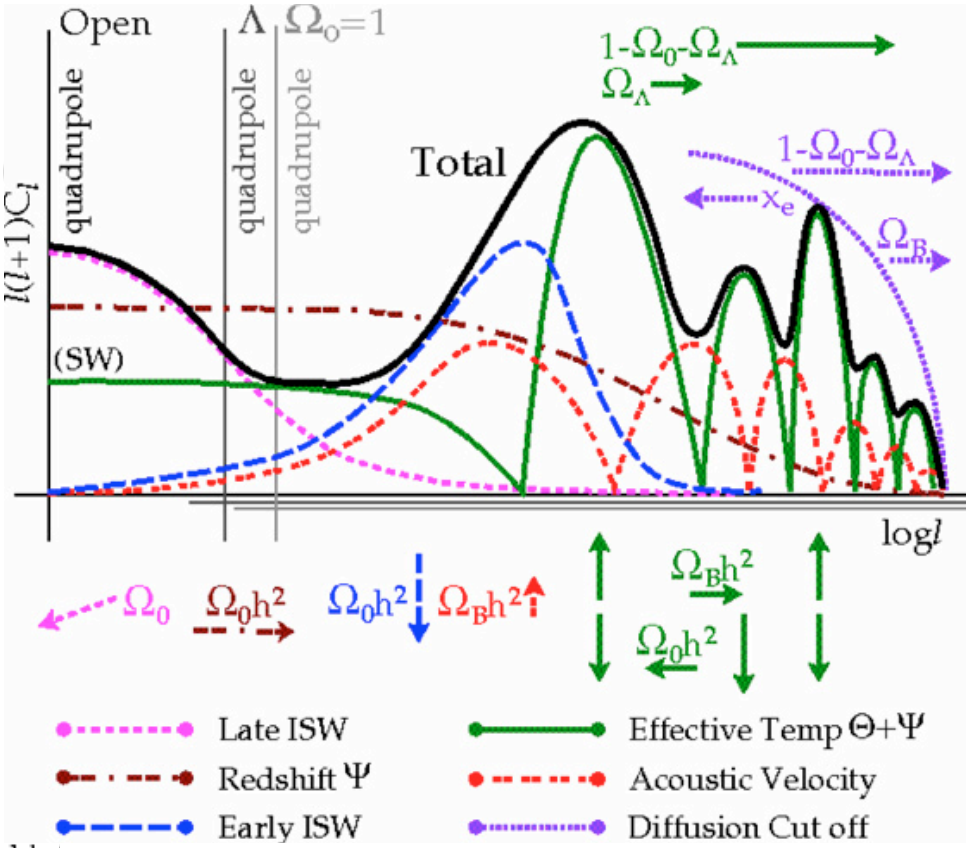
Total density [f]	$\Omega_{\rm tot}$
Equation of state [g]	w_0, w_1
Tensor to scalar ratio, $k_0 = 0.002$ Mpc^{-1} [b,h]	r
Running of spectral index, $k_0 = 0.002$ Mpc^{-1} [b,i]	$dn_s/d\ln k$
Neutrino density [j]	$\Omega_\nu h^2$
Neutrino mass [j]	$\sum m_\nu$
Number of light neutrino families [k]	$N_{\rm eff}$

Locations and amplitudes of the peaks in the CMB power spectrum depend on values of both astrophysical and cosmological parameters.

The Minimal Model

Just Six Numbers?

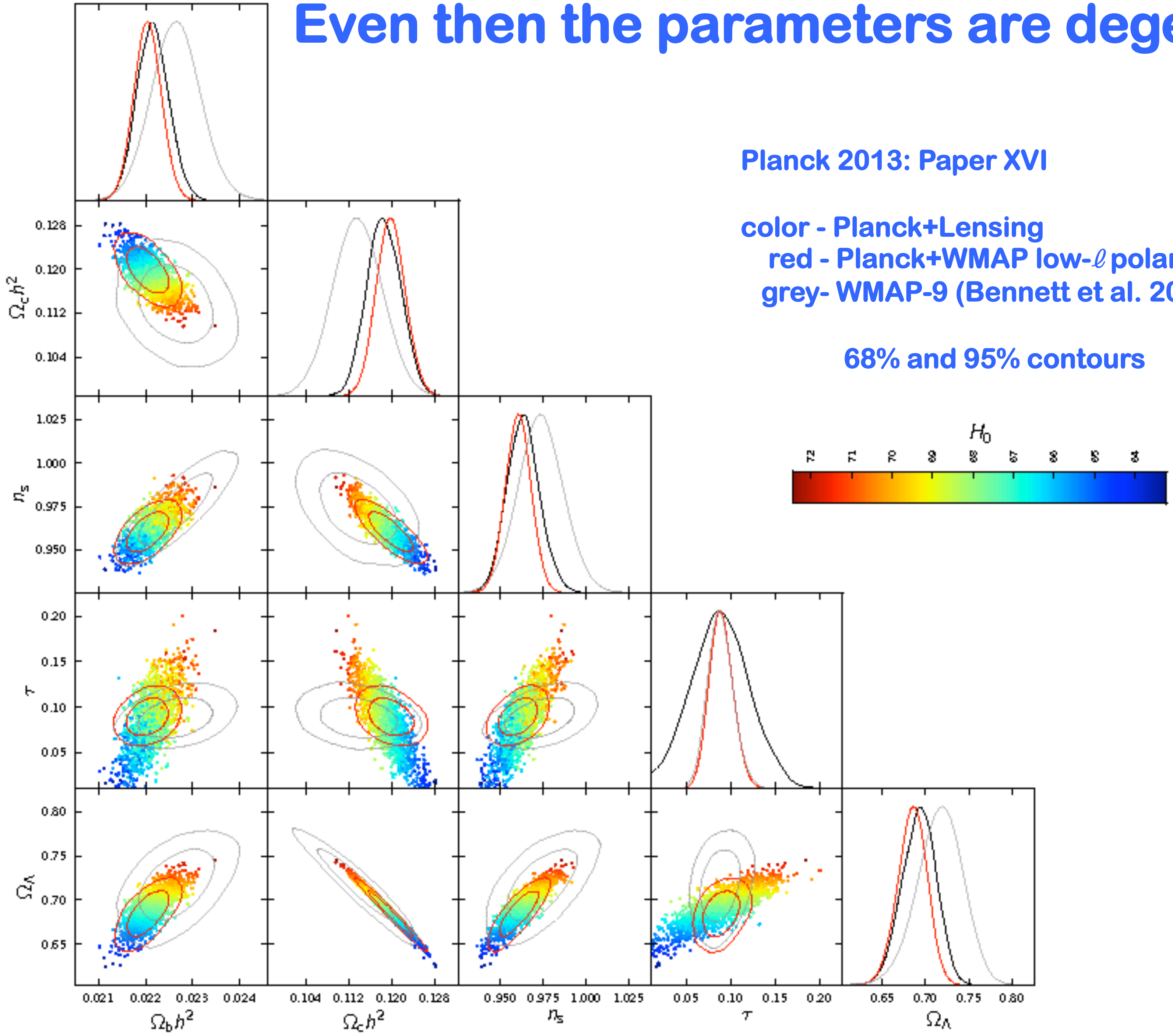
Age of universe	t_0
Hubble constant	H_0
Baryon density	Ω_b
Physical baryon density	$\Omega_b h^2$
Dark matter density	Ω_c
Physical dark matter density	$\Omega_c h^2$
Dark energy density	Ω_Λ
Curvature fluctuation amplitude, $k_0 = 0.002\ \mathrm{Mpc}^{-1}$ b	$\Delta^2_{\mathcal{R}}$
Fluctuation amplitude at $8h^{-1}$ Mpc	σ_8
$l(l+1)C^{TT}_{220}/2\pi$	C_{220}
Scalar spectral index	n_s
Redshift of matter-radiation equality	z_{eq}
Angular diameter distance to matter-radiation eq.[c]	$d_A(z_{\mathrm{eq}})$
Redshift of decoupling	z_*
Age at decoupling	t_*
Angular diameter distance to decoupling [c,d]	$d_A(z_*)$
Sound horizon at decoupling [d]	$r_s(z_*)$
Acoustic scale at decoupling [d]	$l_A(z_*)$
Reionization optical depth	τ
Redshift of reionization	z_{reion}
Age at reionization	t_{reion}



Parameters for Extended Models

Total density [f]	Ω_{tot}	
Equation of state [g]	w_0, w_1	W_0= -1
Tensor to scalar ratio, $k_0 = 0.002\ \mathrm{Mpc}^{-1}$ [b,h]	r	
Running of spectral index, $k_0 = 0.002\ \mathrm{Mpc}^{-1}$ [b,i]	$dn_s/d\ln k$	0
Neutrino density [j]	$\Omega_\nu h^2$	
Neutrino mass [j]	$\sum m_\nu$	0.06 eV
Number of light neutrino families [k]	N_{eff}	3

Even then the parameters are degenerate



Planck 2013: Paper XVI

color - Planck+Lensing
red - Planck+WMAP low-ℓ polarization
grey- WMAP-9 (Bennett et al. 2012)

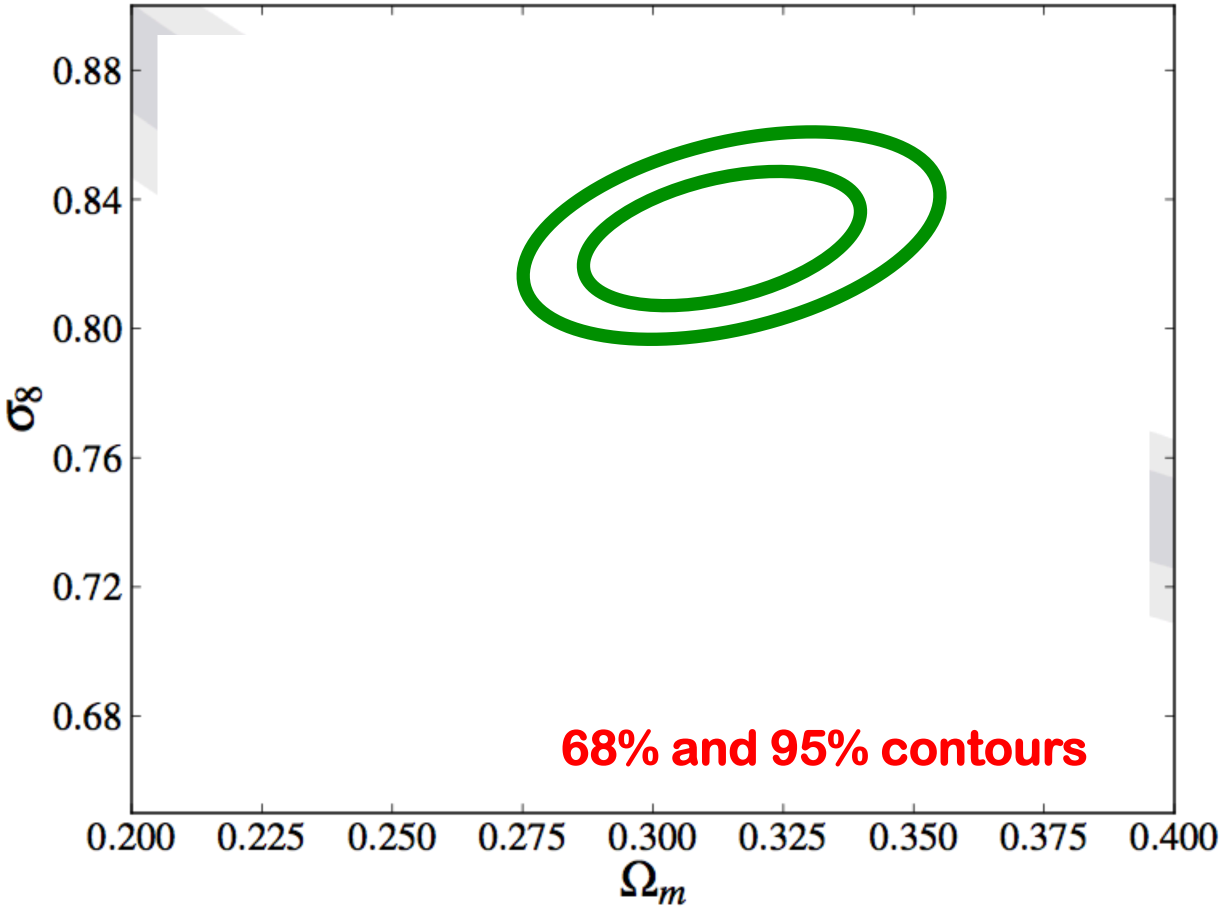
68% and 95% contours

EVEN THEN, THE PARAMETERS ARE DEGENERATE

FOCUS ON THE $\Omega_m - \sigma_8$ PLANE

$\Omega_m = 0.315 \pm 0.017$
Ho = 67.3 ± 1.2
$\sigma_8 = 0.829 \pm 0.012$

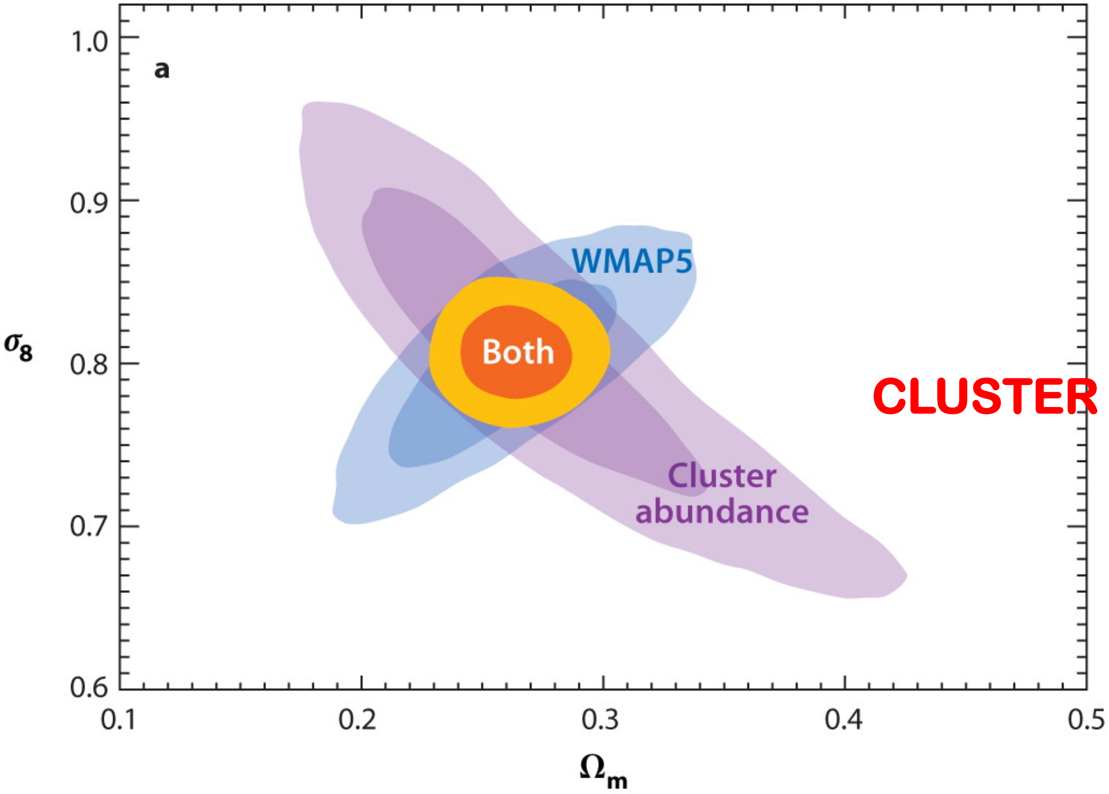
68% confidence Interval



68% and 95% contours

Ade et al. 2013: Planck Collaboration XVI

USE OF COMPLEMENTARY PROBES CAN GREATLY REDUCE UNCERTAINTIES



CLUSTER ABUNDANCE

Allen SW, et al. 2011. (from Rozo et al. 2010)
Annu. Rev. Astron. Astrophys. 49:409–70

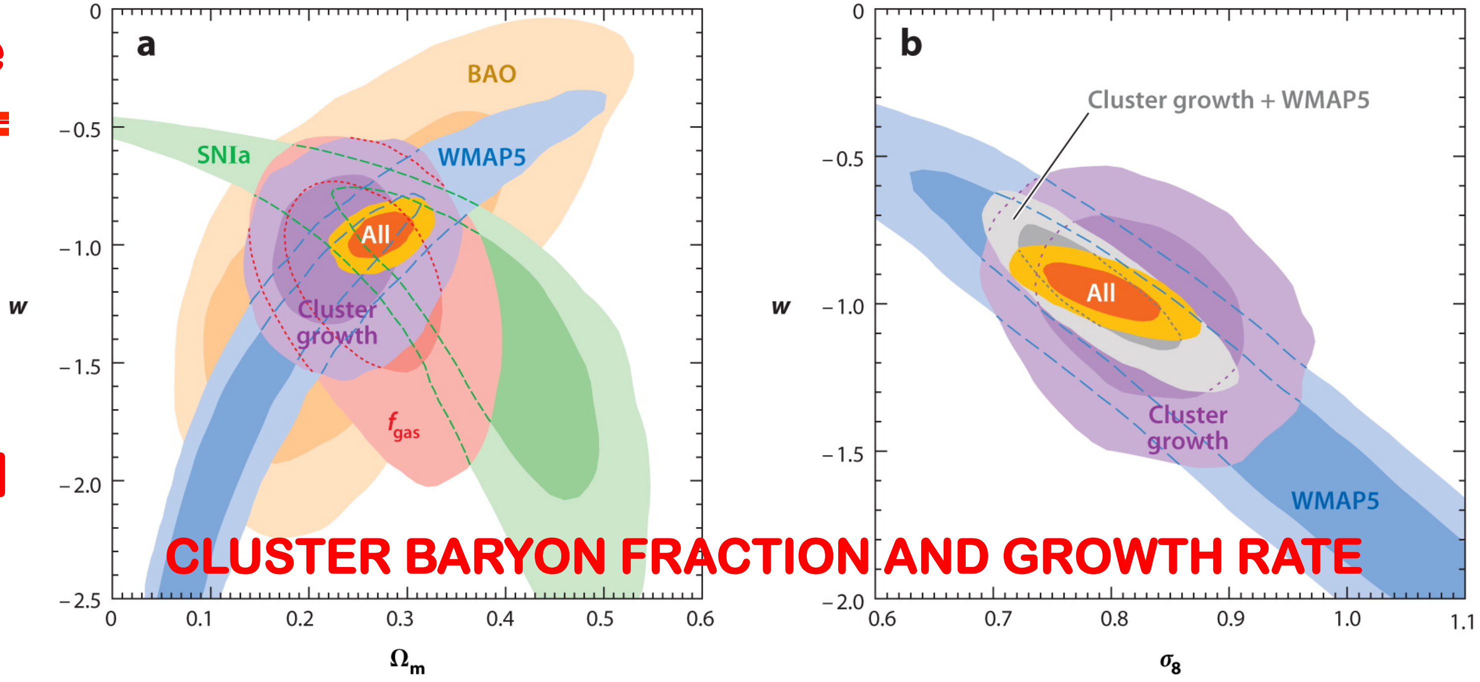
CMB MEASURES PARAMETERS AT HI-Z
CLUSTERS/LSS MEASURE PARAMETERS AT LOW-Z

CLUSTERS CAN ALSO CONSTRAINT OTHER COSMOLOGICAL PARAMETER

$w - \Omega_m$ Plane

Dark Energy EOS: $w = P/\rho$

Cosmological constant Λ: $w = -1$

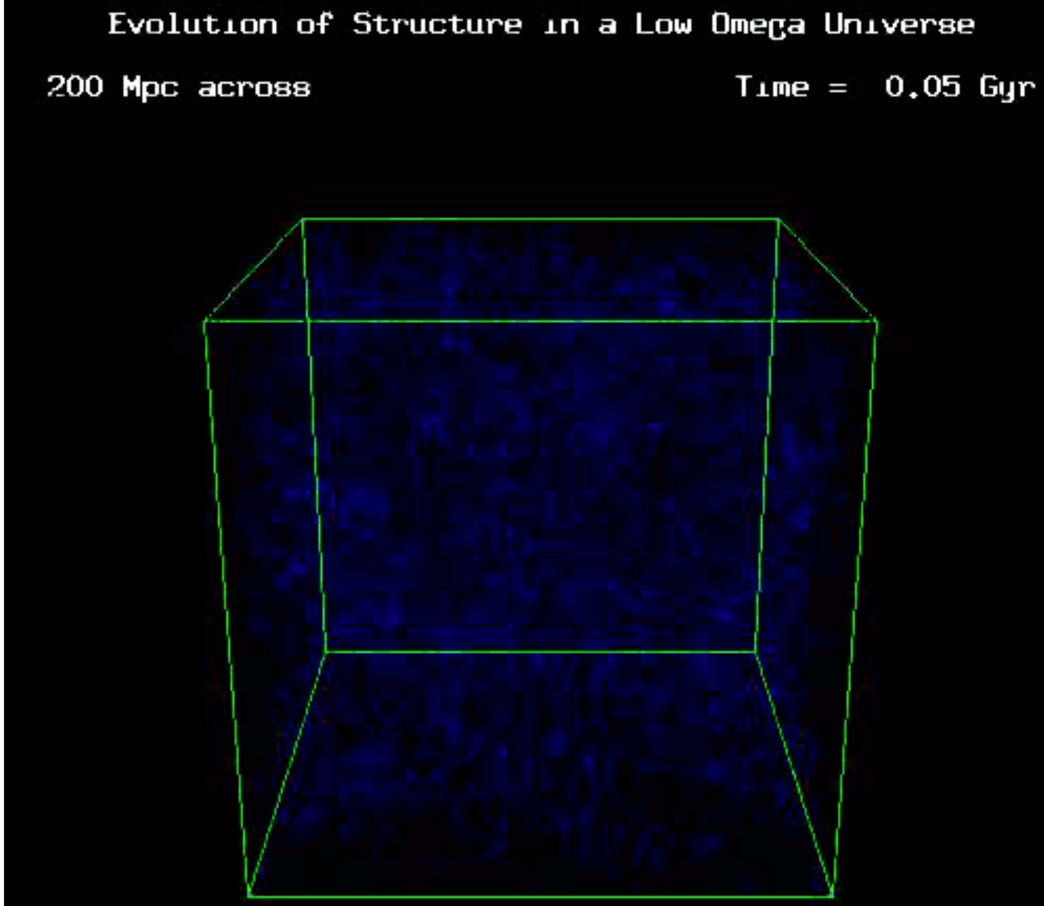


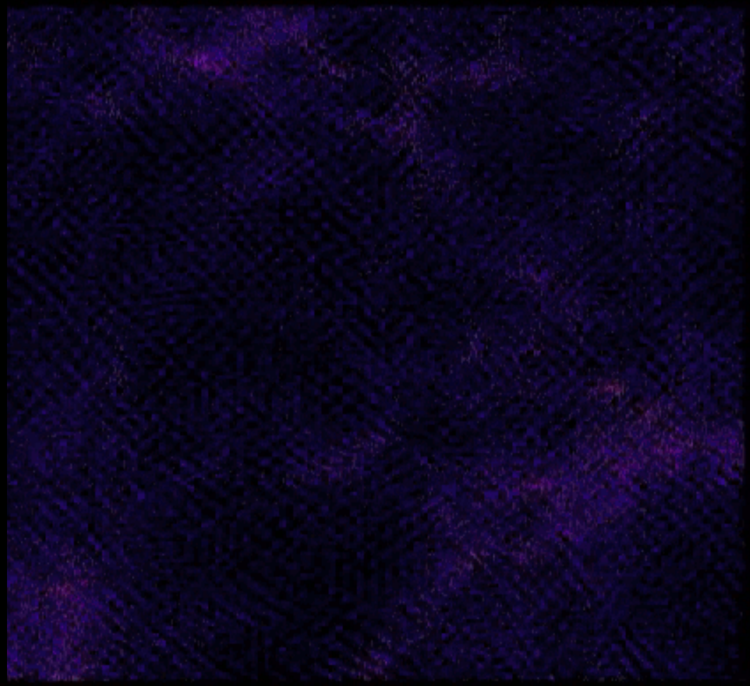
CLUSTER BARYON FRACTION AND GROWTH RATE

CMB MEASURES PARAMETERS AT HI-Z
CLUSTERS/LSS MEASURE PARAMETERS AT LOW-Z

Allen, S.W. *et al.* arXiv:1307.8152

WHY ARE CLUSTERS USEFUL COSMO PROBES?



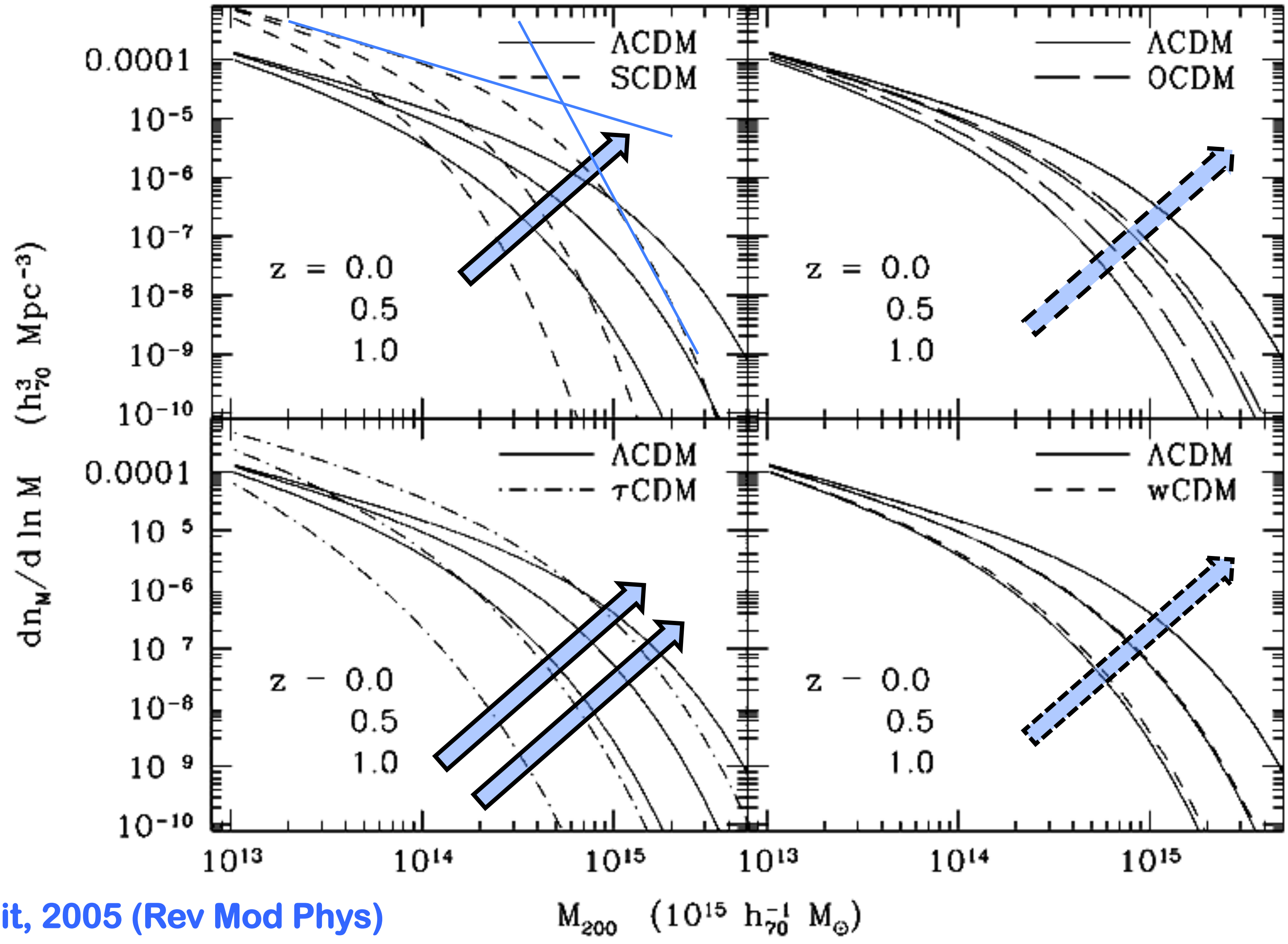


Hierarchical clustering:

Massive structures are built up thru mergers of smaller structures

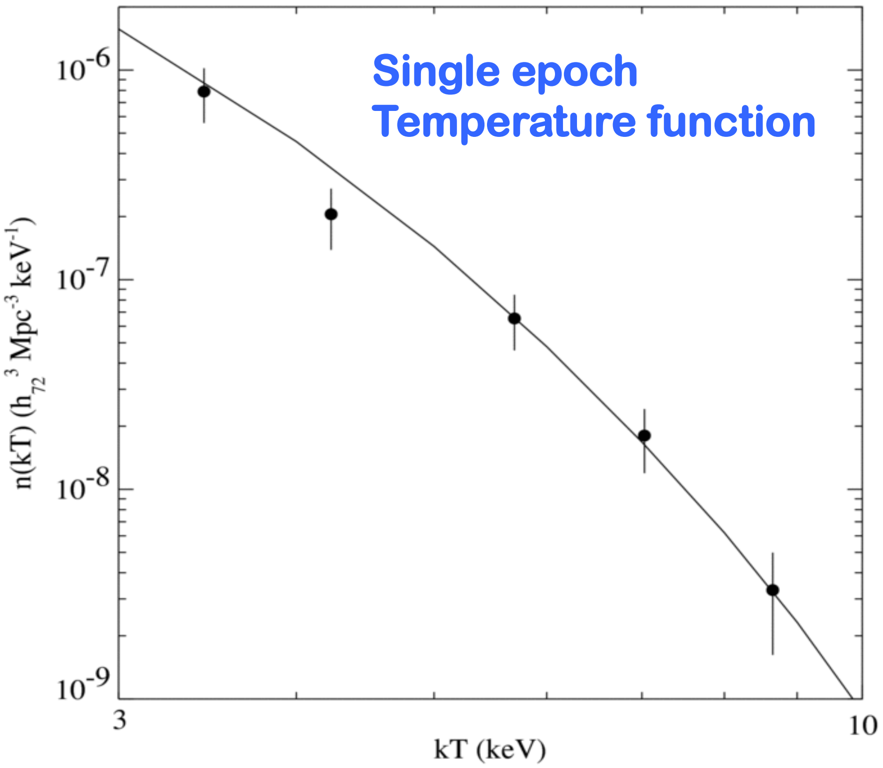
Cluster formation is ongoing.
Rate of assembly depends of cosmology.

CLUSTER MASS FUNCTION AND ITS GROWTH IS A PROBE OF RECENT COSMOLOGICAL EVOL.

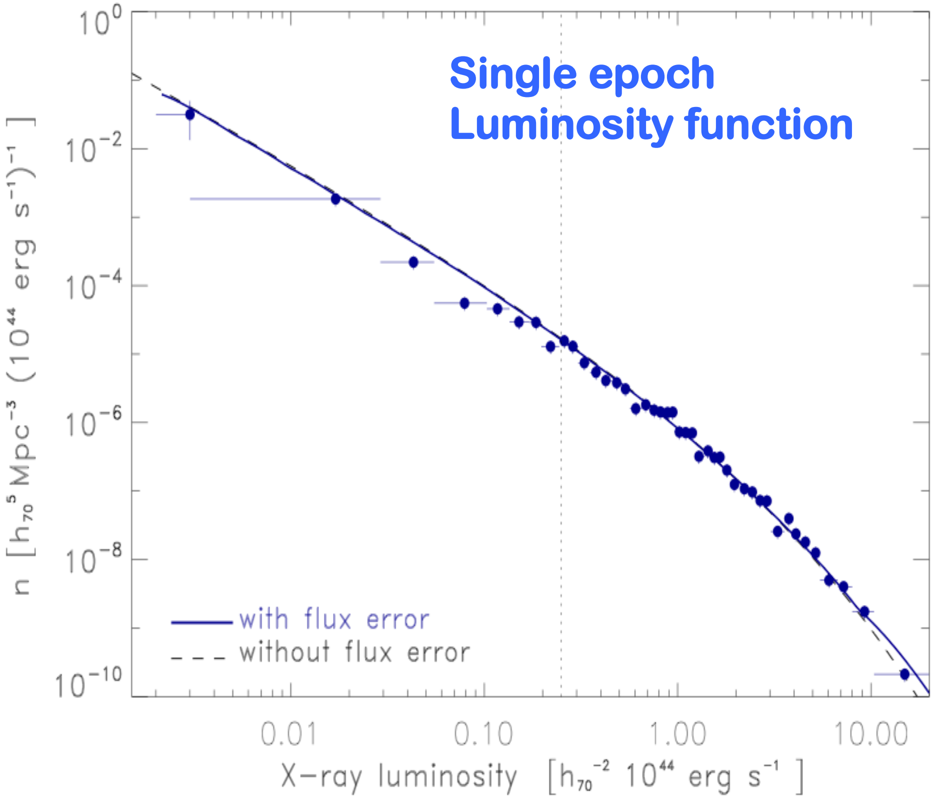


Voit, 2005 (Rev Mod Phys)

WE CAN MEASURE CLUSTER SZE, OPTICAL AND X-RAY PROPERTIES



Single epoch
Temperature function



Single epoch
Luminosity function

Henry et al. 2009:
HIFLUGCS cluster temperature function

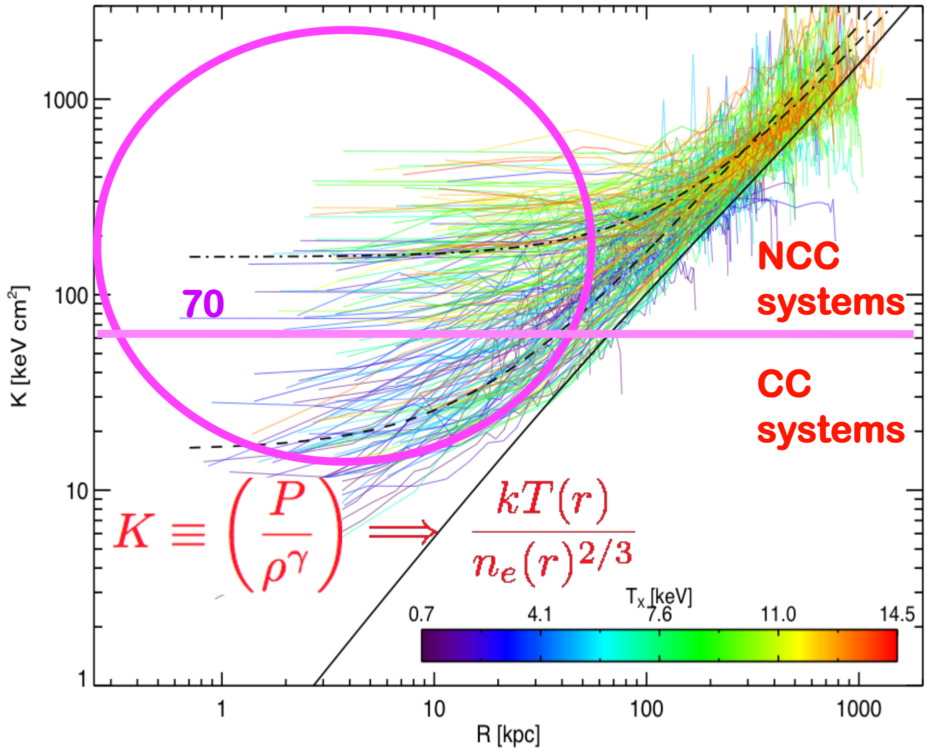
Bohringer et al 2014:
REFLEX II cluster luminosity function

NEED TO FIND OBSERVABLE THAT BEST MAPS TO MASS
~~AND DOES SO PREDICTABLY OVER A RANGE OF REDSHIFTS:~~

MASS-OBSERVABLE PROBLEM

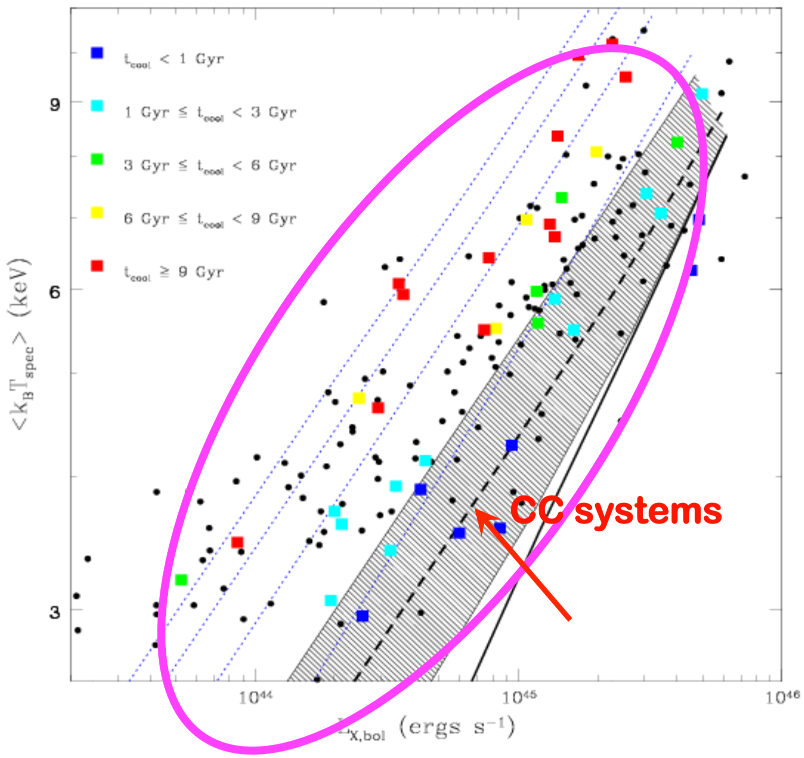
LET US CONSIDER X-RAY LUMINOSITY

LARGE SCATTER IN L-T PLOT DUE TO LARGE VARIATIONS IN CLUSTER CORE ENTROPY → ASTROPHYSICS.



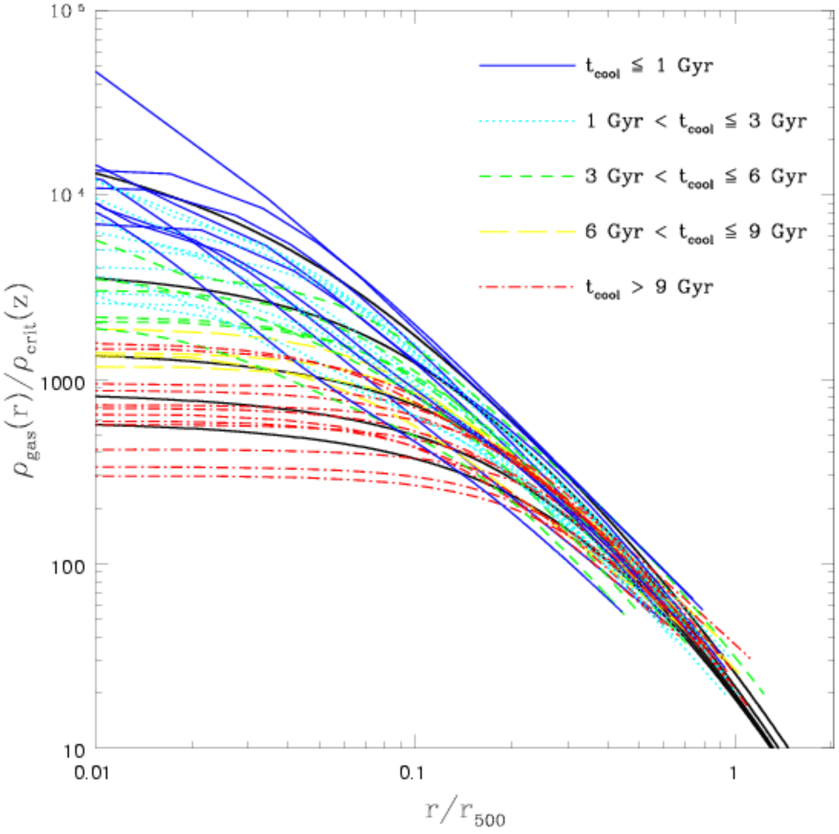
$$K \equiv \left(\frac{P}{\rho^{\gamma}}\right) \Longrightarrow \frac{kT(r)}{n_e(r)^{2/3}}$$

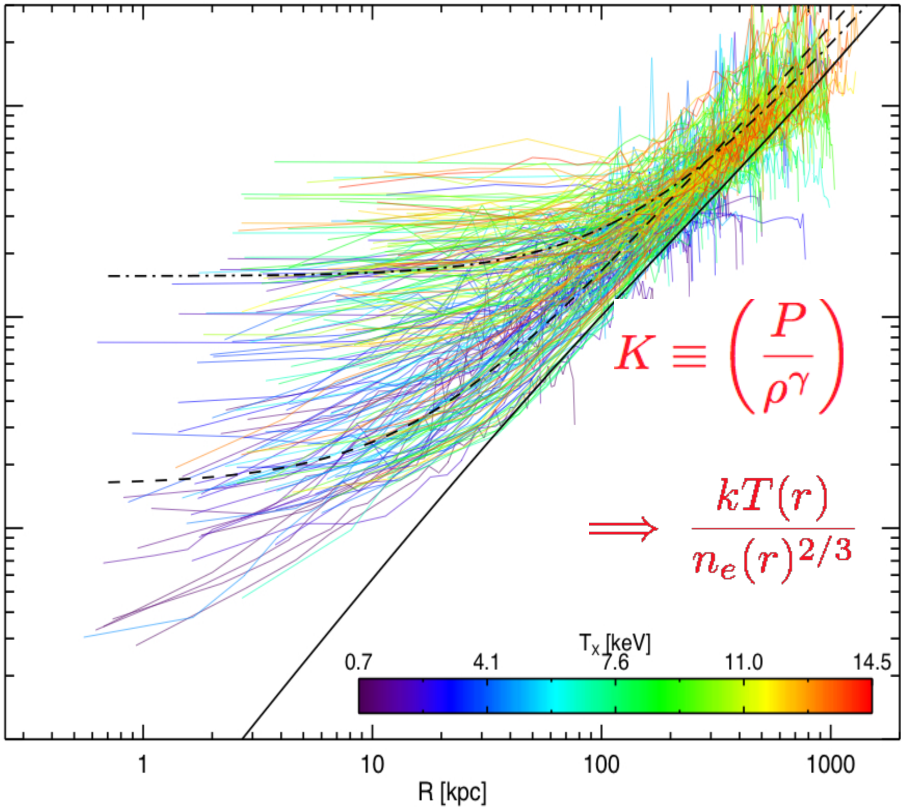
McCarthy et al 2008
Cavagnolo et al 2008



At fixed T, ~10 scatter in Lx

CLUSTER ENTROPY – DENSITY CORRELATION



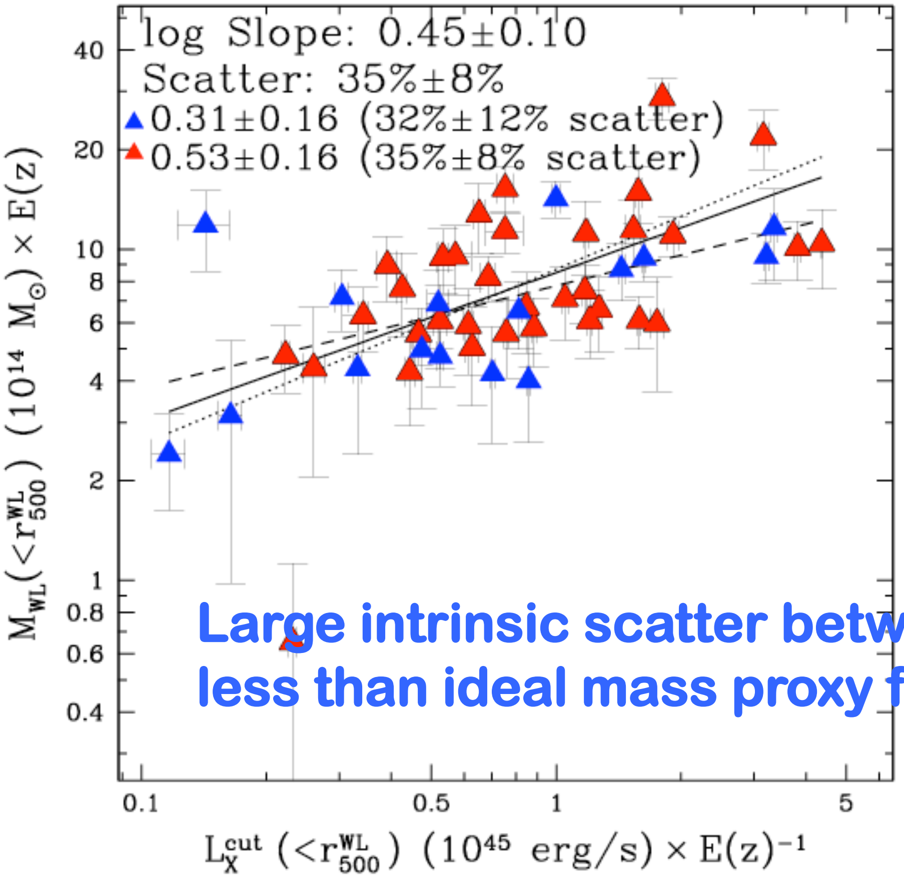


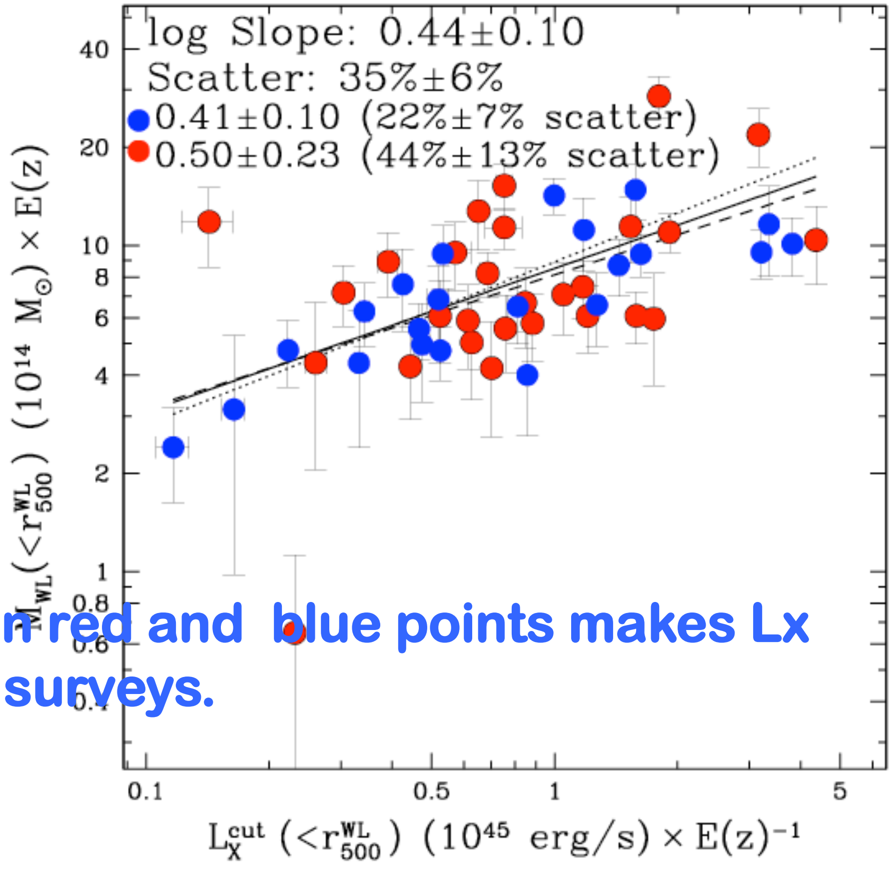
$$K \equiv \left(\frac{P}{\rho^{\gamma}}\right)$$

$$\Longrightarrow \frac{kT(r)}{n_e(r)^{2/3}}$$

Cavagnolo et al 2008

CCCP Mass-Observable Luminosity Relationship





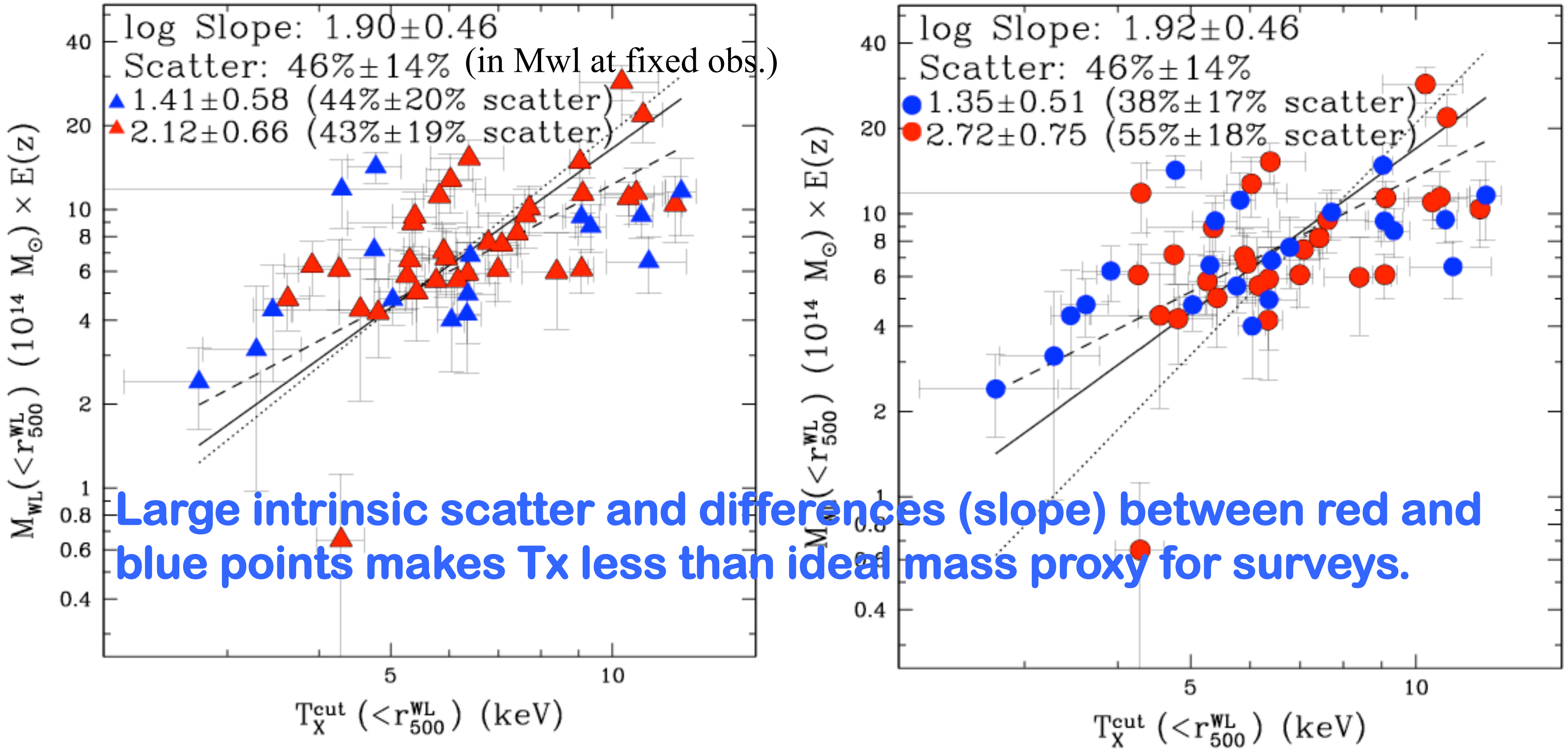
Large intrinsic scatter between red and blue points makes Lx less than ideal mass proxy for surveys.

▲ **K(20 kpc) < 70 keV cm^2**
▲ **K(20 kpc) > 70 keV cm^2**

● **D_{BCG} < 0.01 Mpc**
● **D_{BCG} > 0.01 Mpc**

Mahdavi et al. 2013

CCCP Mass-Temperature Relationship



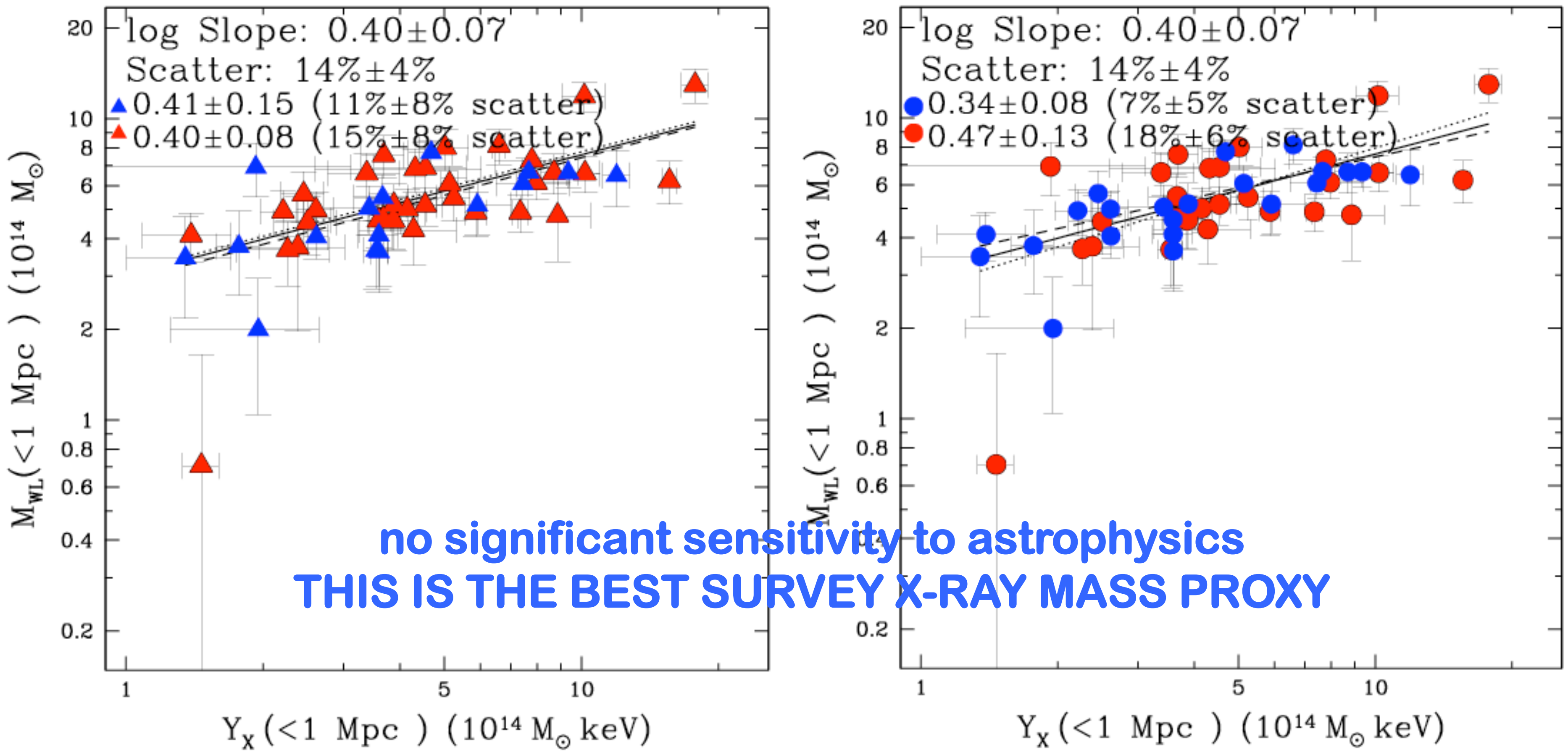
Large intrinsic scatter and differences (slope) between red and blue points makes Tx less than ideal mass proxy for surveys.

▲ K(20 kpc) < 70 keV cm^2 **● D_{BCG} < 0.01 Mpc**

▲ K(20 kpc) > 70 keV cm^2 **● D_{BCG} > 0.01 Mpc** **Mahdavi et al. 2013**

CCCP Mass-Yx Relationship

Yx= Mgas*T



no significant sensitivity to astrophysics

THIS IS THE BEST SURVEY X-RAY MASS PROXY

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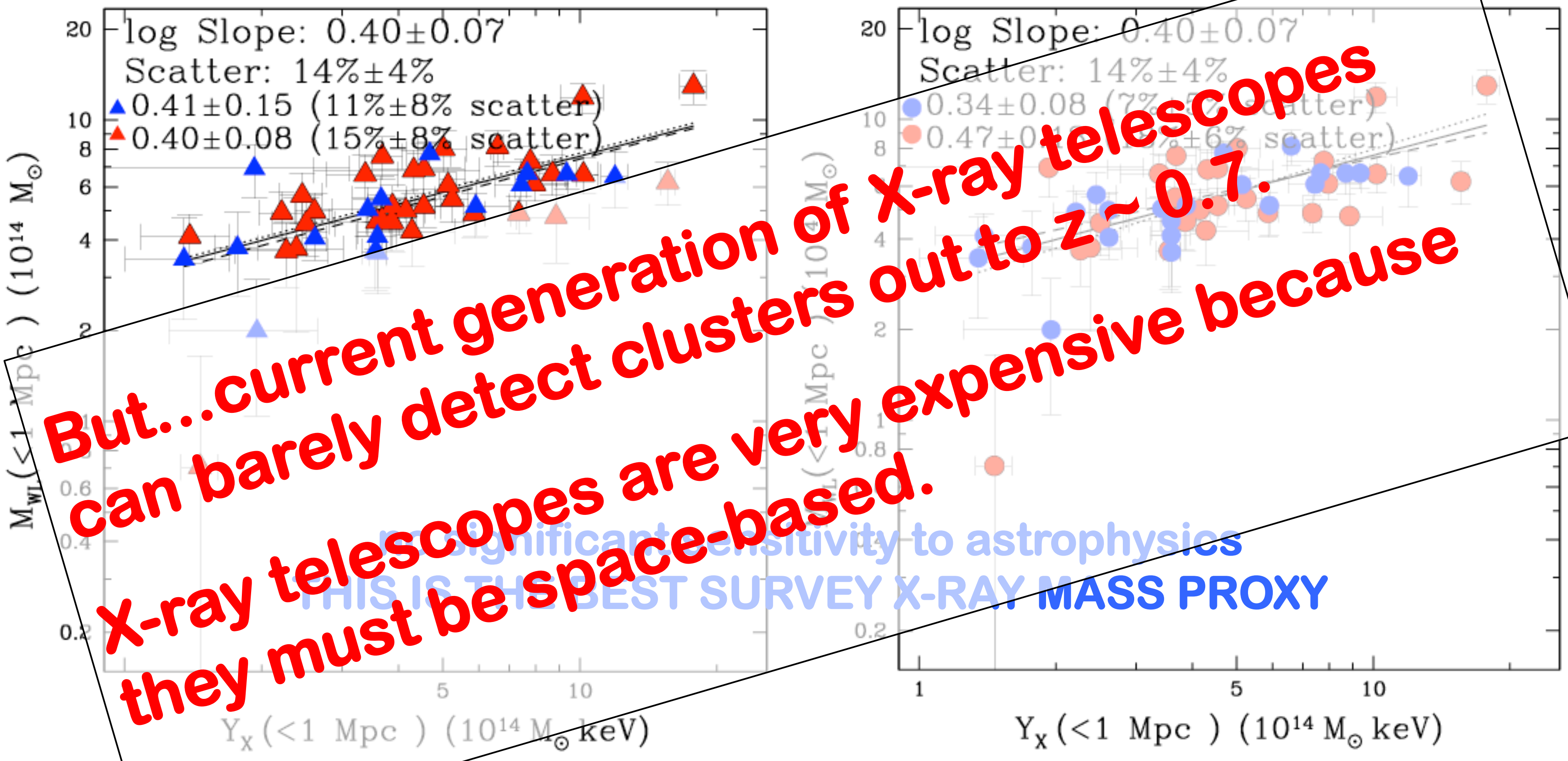

But…current generation of X-ray telescopes can barely detect clusters out to z ~ 0.7.

X-ray telescopes are very expensive because they must be space-based.

no significant sensitivity to astrophysics

THIS IS THE BEST SURVEY X-RAY MASS PROXY

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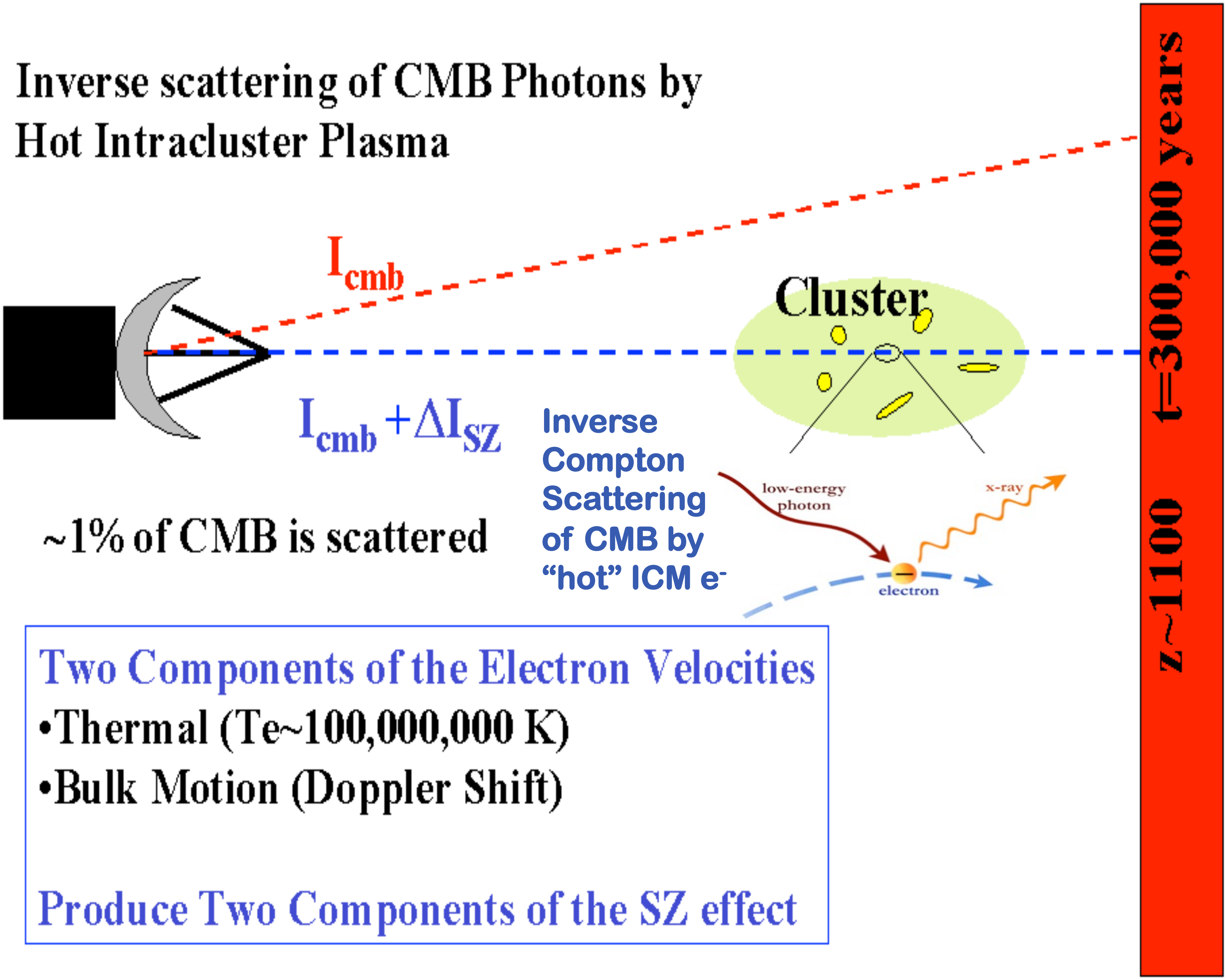
Mahdavi et al. 2013

CURRENT MICROWAVE EXPERIMENTS THAT STUDY THE CMB CAN ALSO DETECT CLUSTERS VIA SZ EFFECT



Inverse scattering of CMB Photons by Hot Intracluster Plasma

~1% of CMB is scattered

Inverse Compton Scattering of CMB by "hot" ICM e^-

Two Components of the Electron Velocities

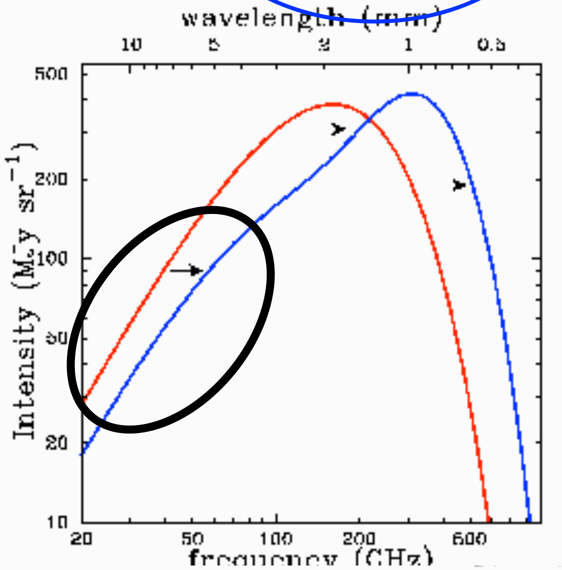
- Thermal (Te~100,000,000 K)
- Bulk Motion (Doppler Shift)

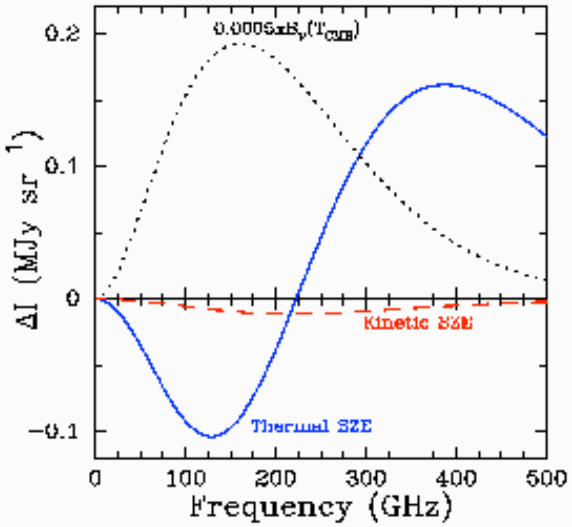
Produce Two Components of the SZ effect

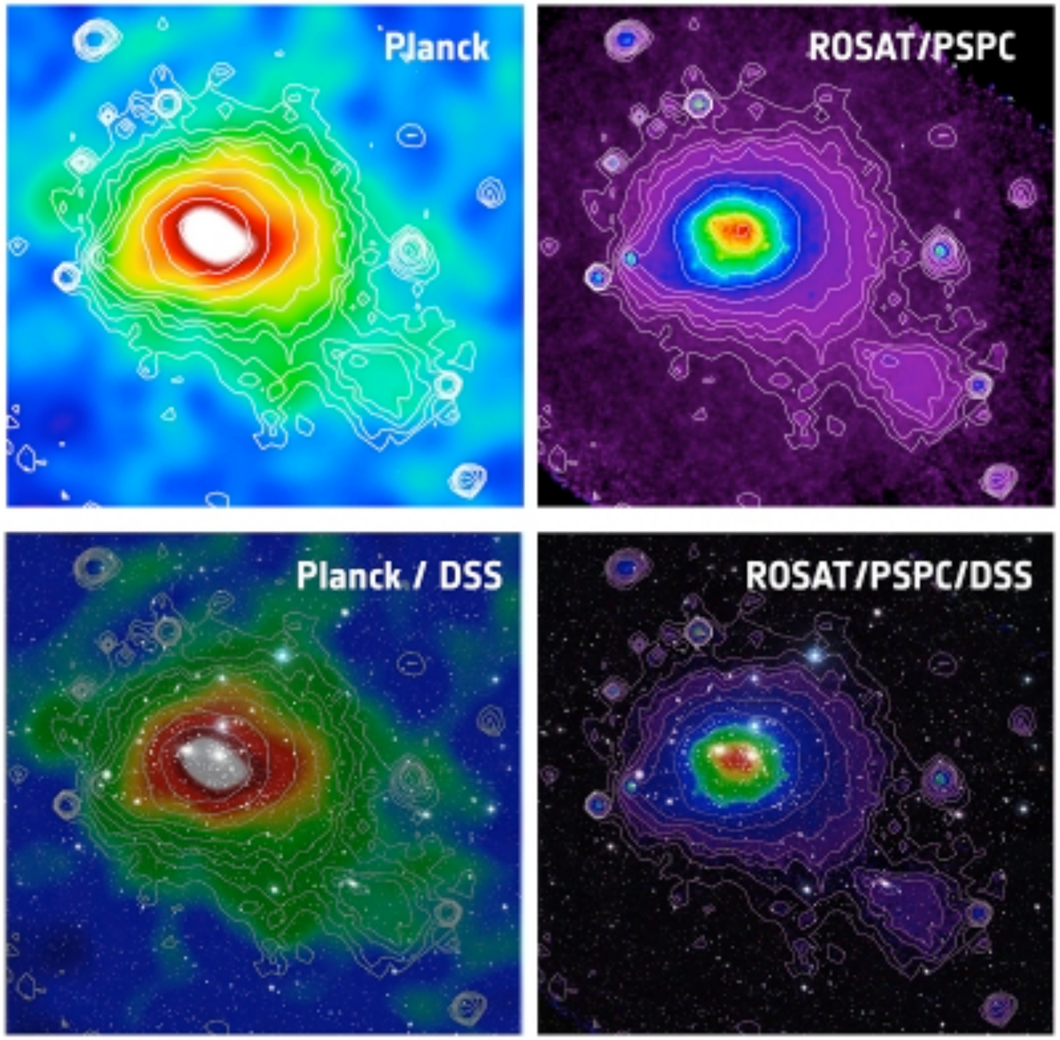
DETECTING CLUSTERS VIA SZ EFFECT

$$\frac{\Delta T}{T_{\mathrm{CMB}}} = g(x) \int dl\, n_e(l)\, \frac{k_B\, T_e(l)}{m_e c^2}\, \sigma_T = y$$

(compton y parameter)



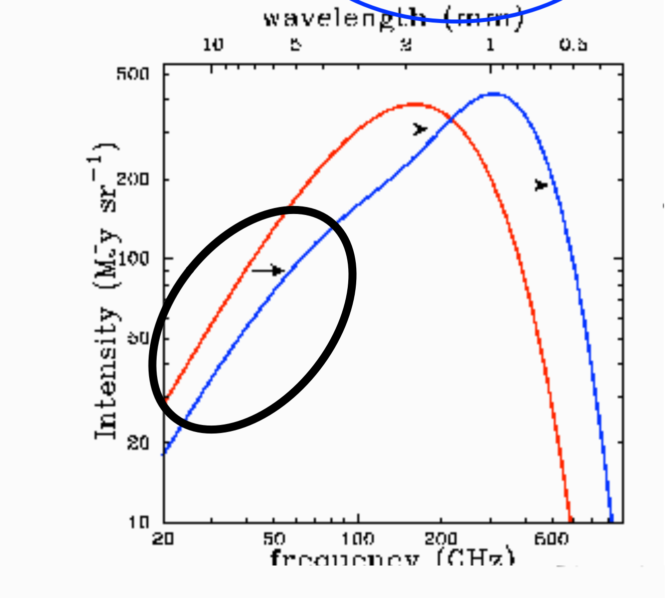


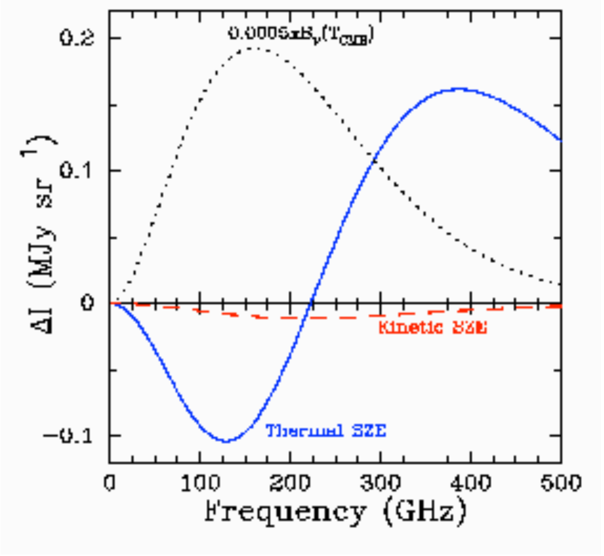


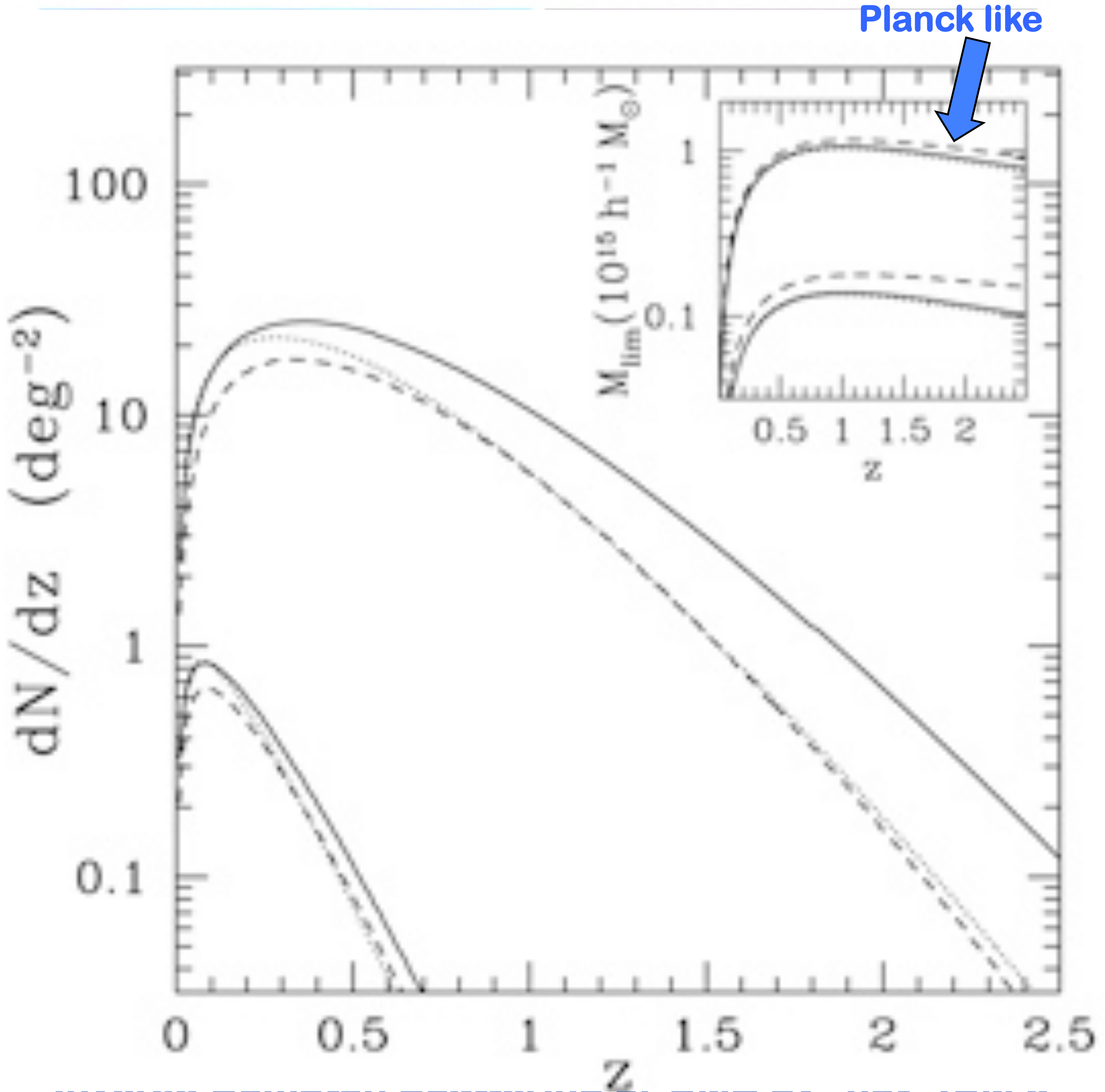
Inverse Compton Scattering of CMB by “hot” ICM e$^-$

DETECTING CLUSTERS VIA SZ EFFECT

$$\frac{\Delta T}{T_{\rm CMB}} = g(x)\int dl\, n_e(l)\,\frac{k_B\, T_e(l)}{m_e c^2}\,\sigma_T = y$$ (compton y parameter)

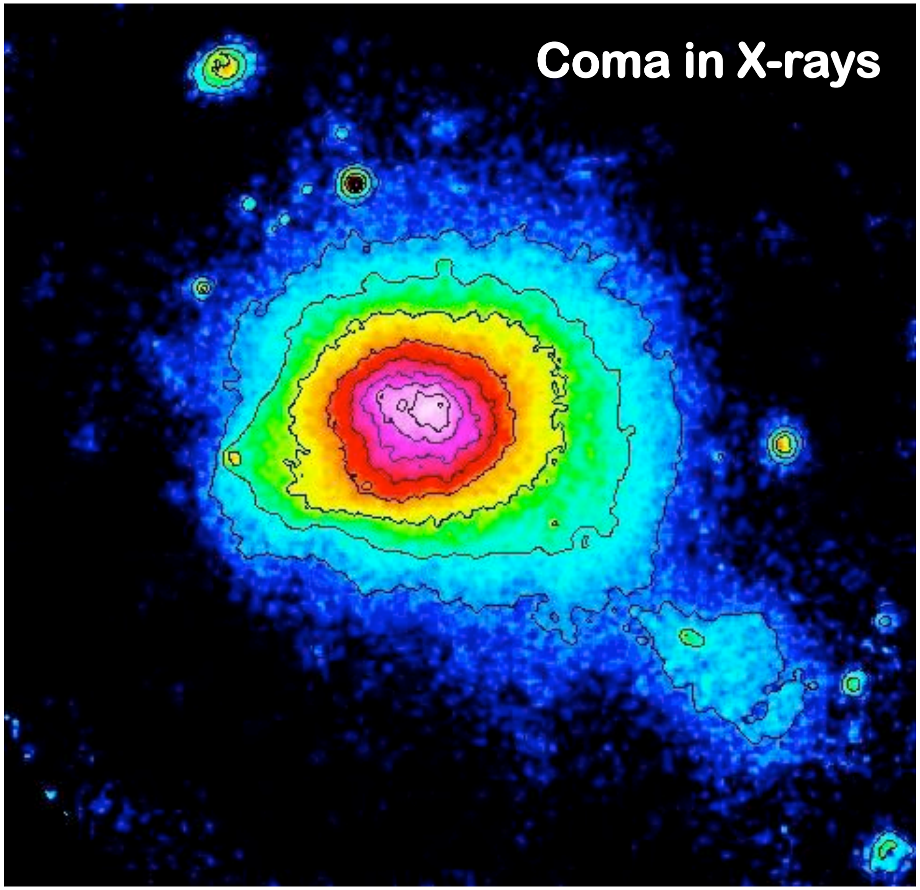






Inverse Compton scattering of CMB by "hot" ICM's

PLANCK SZ CLUSTER ANALYSIS:
PREMISED ON MEASURING CLUSTER MASS FUNCTION



HSE: $$\frac{dP}{dr} = -\frac{GM(r)\rho(r)}{r^2}$$

CLUSTERS ARE LARGELY DARK
mass cannot be easily measured

PLANCK MEASURE Ysz

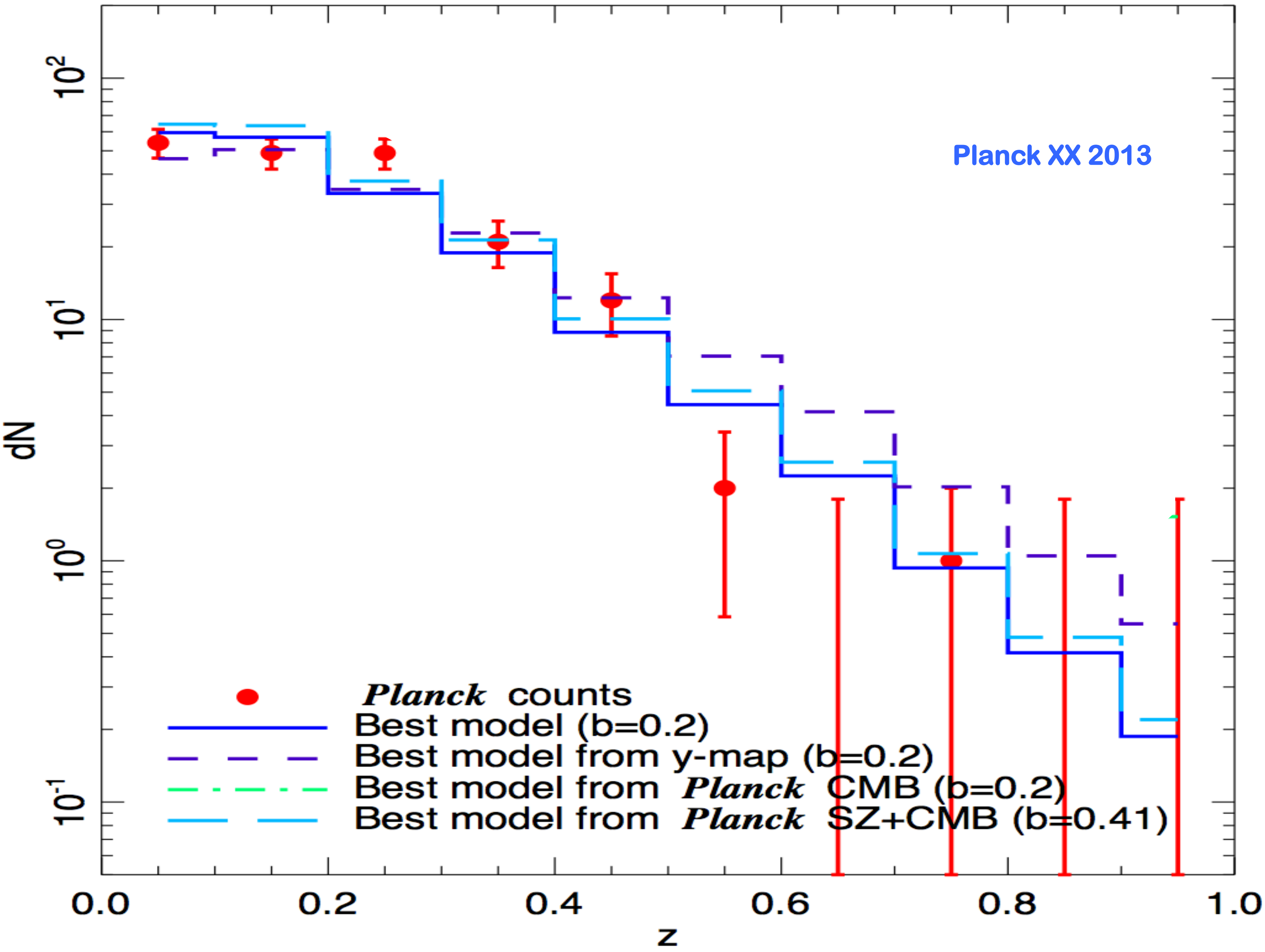
FOR SUBSET OF CLUSTERS WITH X-RAY DATA, USE X-RAY DATA TO ESTIMATE MASS: Mx

Mx IS A BIASED ESTIMATOR OF TRUE MASS M: **Mx = ξ M**

PLANCK: $\xi = [\ 0.7, 1.0\ ]$
$< \xi > \ = 0.8$

USE RESULTING Ysz – M TO DERIVE MASSES OF ALL OTHER CLUSTERS (MASS-OBSERVABLE)

IF USE <ξ> = 0.6 INSTEAD OF 0.8, THE TENSION IS RESOLVED



Planck XX 2013

FOCUS ON THE $\Omega_m - \sigma_8$ PLANE

PRIMARY CMB RESULTS

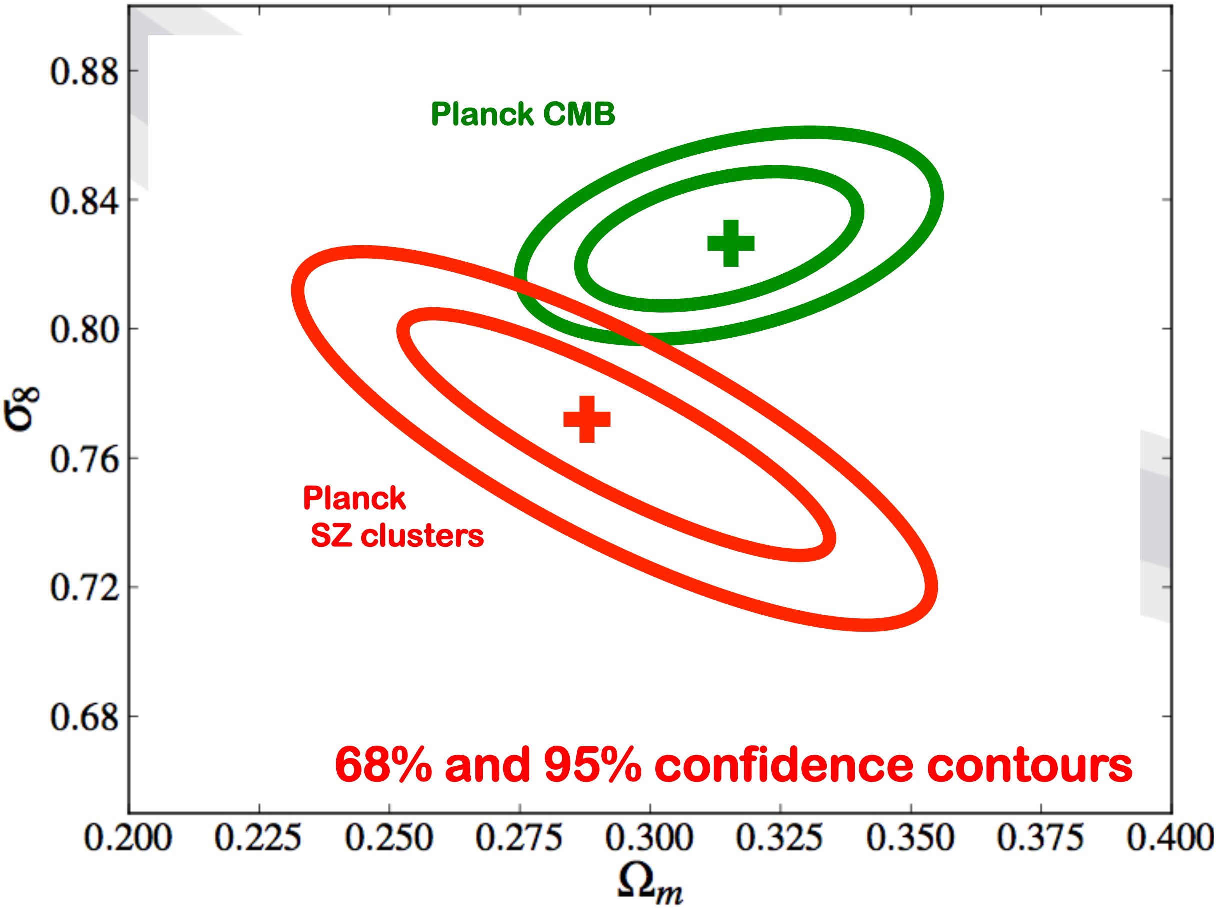
$\Omega_m = 0.315 \pm 0.017$
Ho = 67.3 ± 1.2
$\sigma_8 = 0.829 \pm 0.012$

LOCAL ESTIMATE OF Ho
Ho = 73.8 ± 2.4

From clusters:

$\Omega_m = 0.29 \pm 0.02$
$\sigma_8 = 0.77 \pm 0.012$

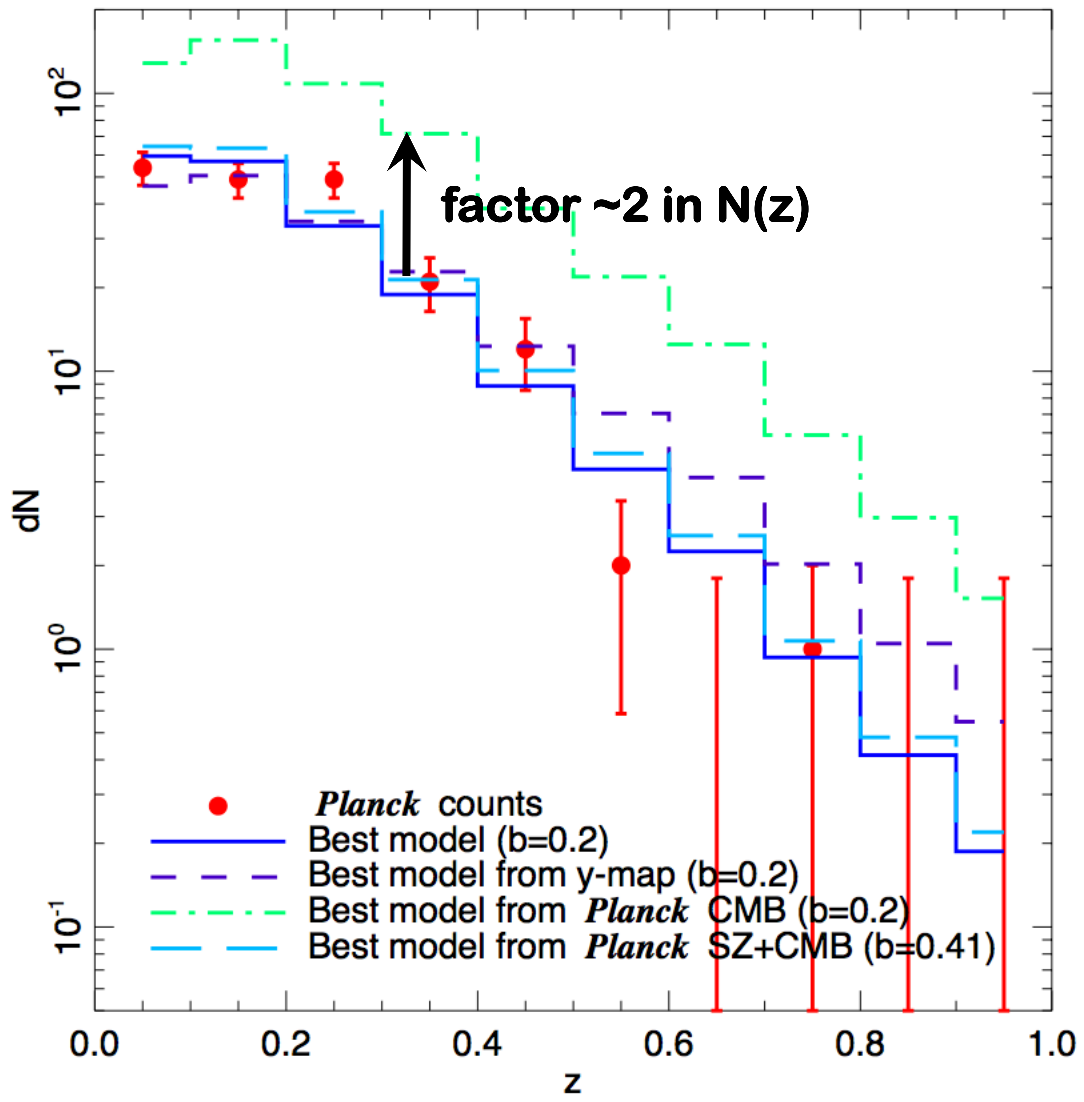
Ade et al. 2013: Planck Collaboration XX/XXI



Planck CMB is measuring cosmology at t ~ 370,000 yrs.

Planck Clusters gives cosmology at more recent epoch.

FYI: THE DIFFERENCE MAY NOT SEEM LIKE MUCH, BUT…



SO WHAT'S GOING ON?

◆Systematics in the Planck CMB data

Spergel et al. (2014) and others have looked at this.
Moves CMB results towards Clusters but not enough.

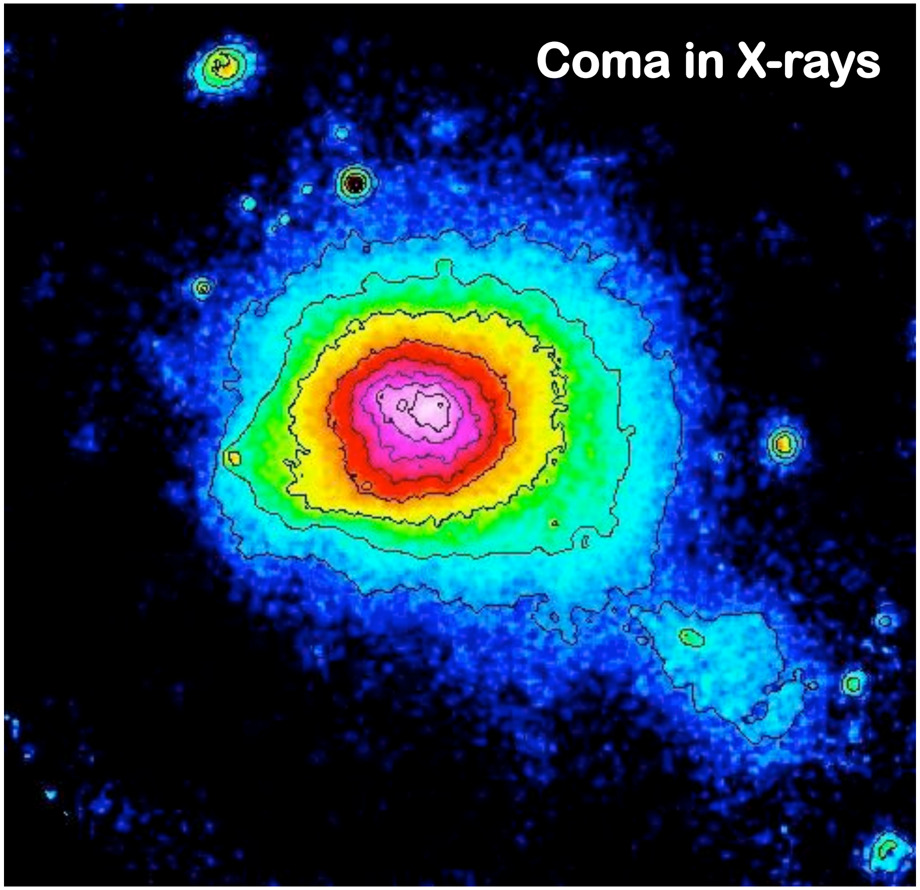
◆Systematics in the Planck SZ Cluster analysis

Focus of CCCP analysis.

◆Failure of the vanilla (six-parameter) model ➔ new physics

Exploits the fact that CMB and Cluster measurements are at different epoch. (Premature in light of above but interesting proposals are circulating.)

PLANCK SZ CLUSTER ANALYSIS:
PREMISED ON MEASURING CLUSTER MASS FUNCTION


Coma in X-rays

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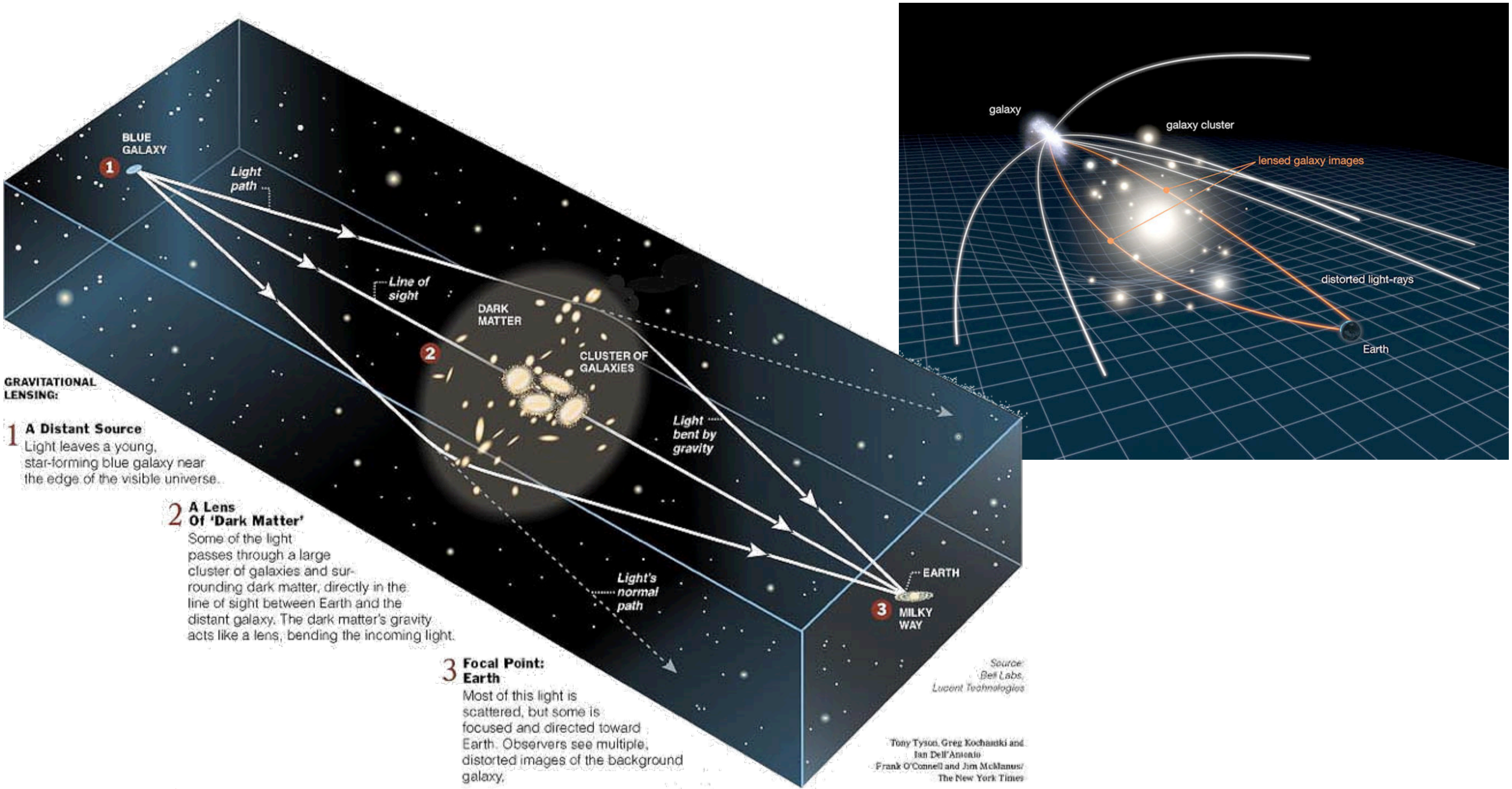
USE RESULTING Ysz – M TO DERIVE MASSES OF ALL OTHER CLUSTERS (MASS-OBSERVABLE)

IF USE $<\xi> = 0.6$ INSTEAD OF 0.8, THE TENSION IS RESOLVED

WE CAN EMPIRICALLY ESTABLISH Ysz – M FOR CLUSTERS IN THE NEARBY UNIVERSE – USING WEAK GRAV LENSING!



GRAVITATIONAL LENSING:

1 **A Distant Source**
Light leaves a young, star-forming blue galaxy near the edge of the visible universe.

2 **A Lens Of 'Dark Matter'**
Some of the light passes through a large cluster of galaxies and surrounding dark matter, directly in the line of sight between Earth and the distant galaxy. The dark matter's gravity acts like a lens, bending the incoming light.

3 **Focal Point: Earth**
Most of this light is scattered, but some is focused and directed toward Earth. Observers see multiple, distorted images of the background galaxy.

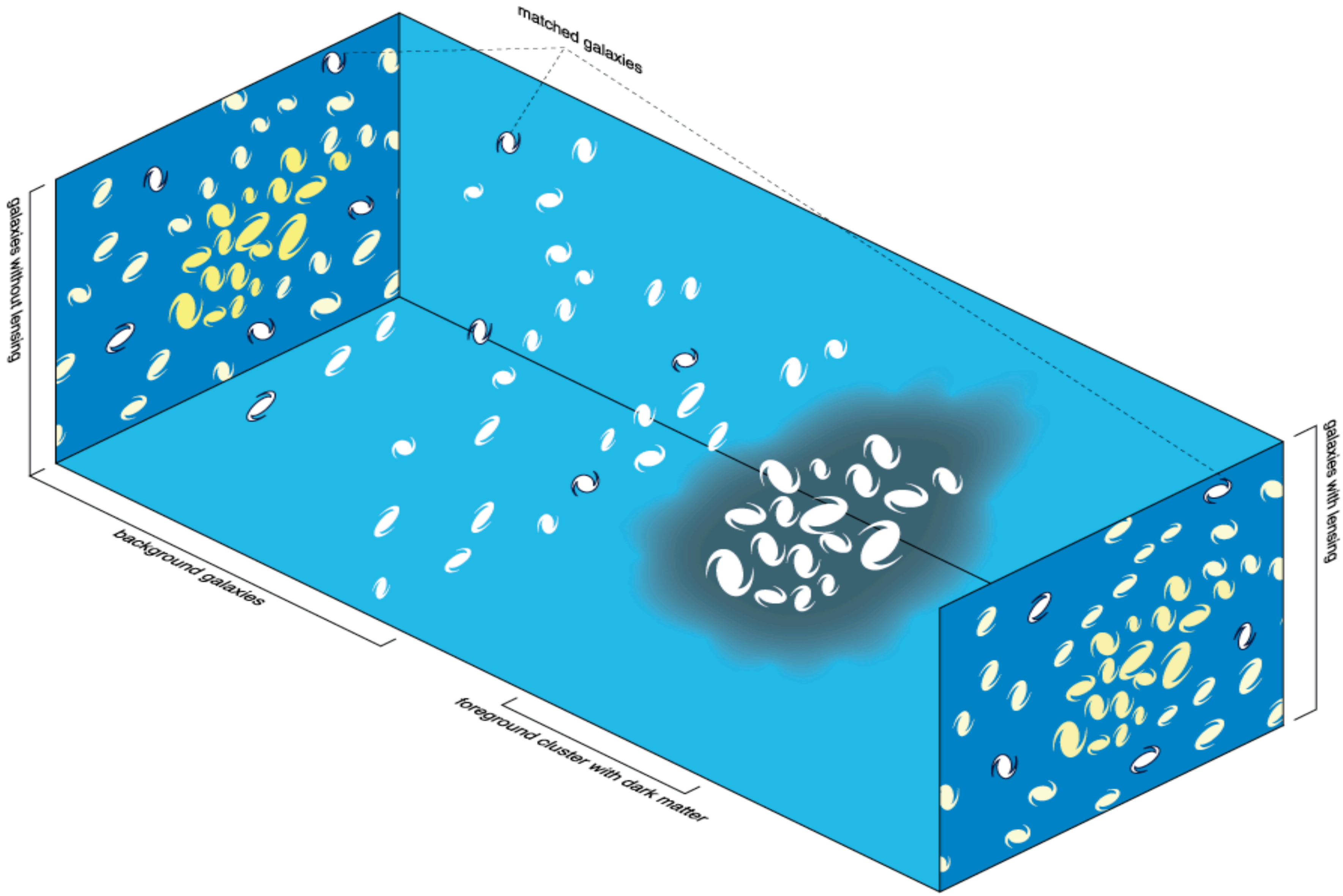
Source: Bell Labs, Lucent Technologies

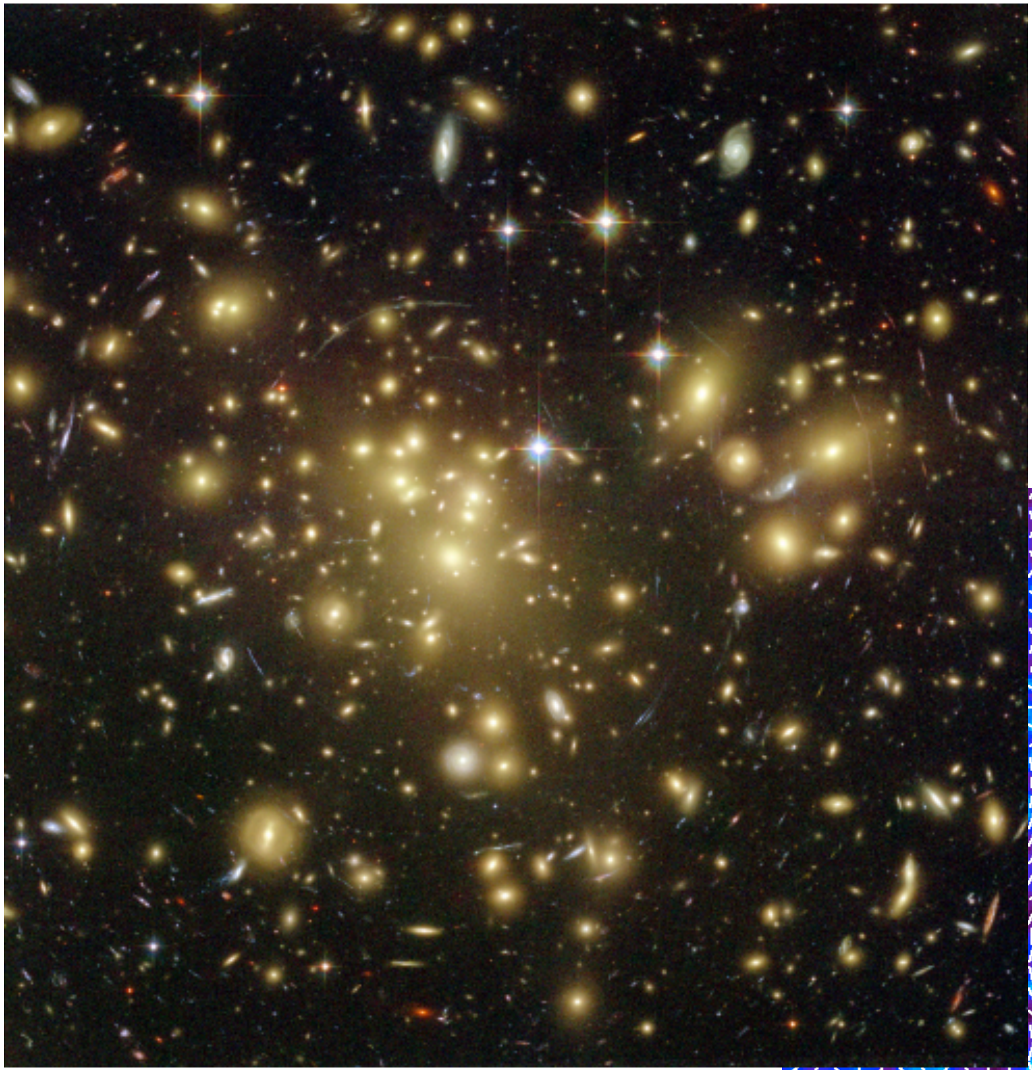
Tony Tyson, Greg Kochanski and Ian Dell'Antonio
Frank O'Connell and Jim McManus/ The New York Times

CCCP

Canadian Cluster Comparison Project

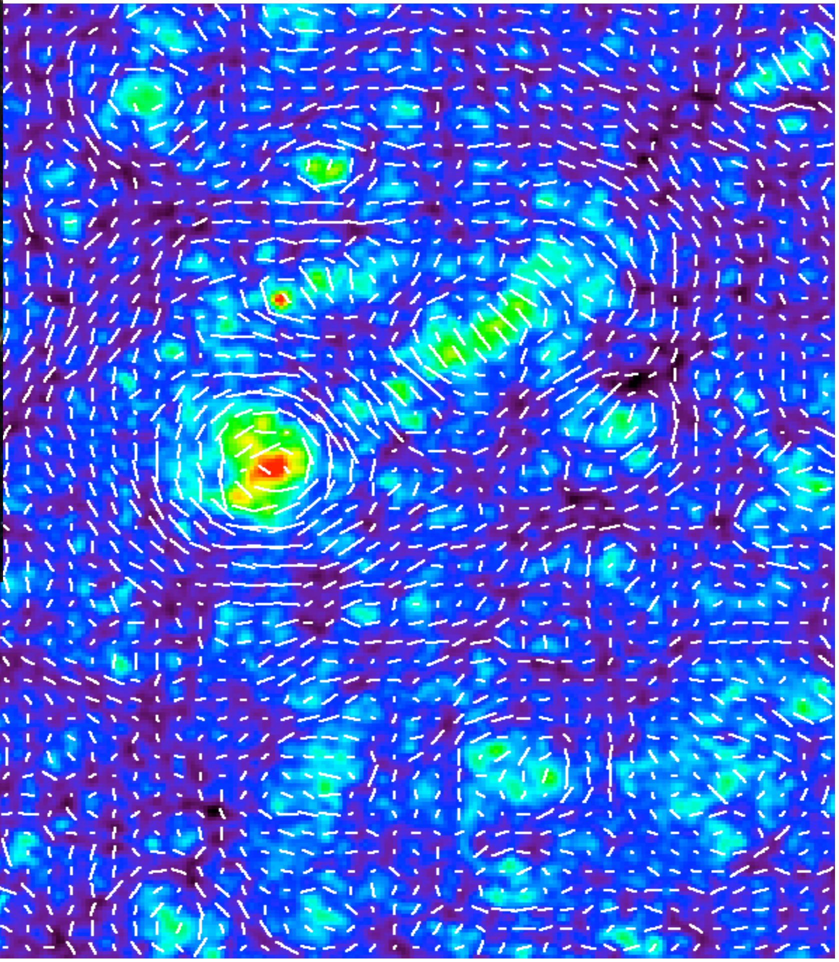
it's good for the masses!


matched galaxies
galaxies without lensing
background galaxies
foreground cluster with dark matter
galaxies with lensing



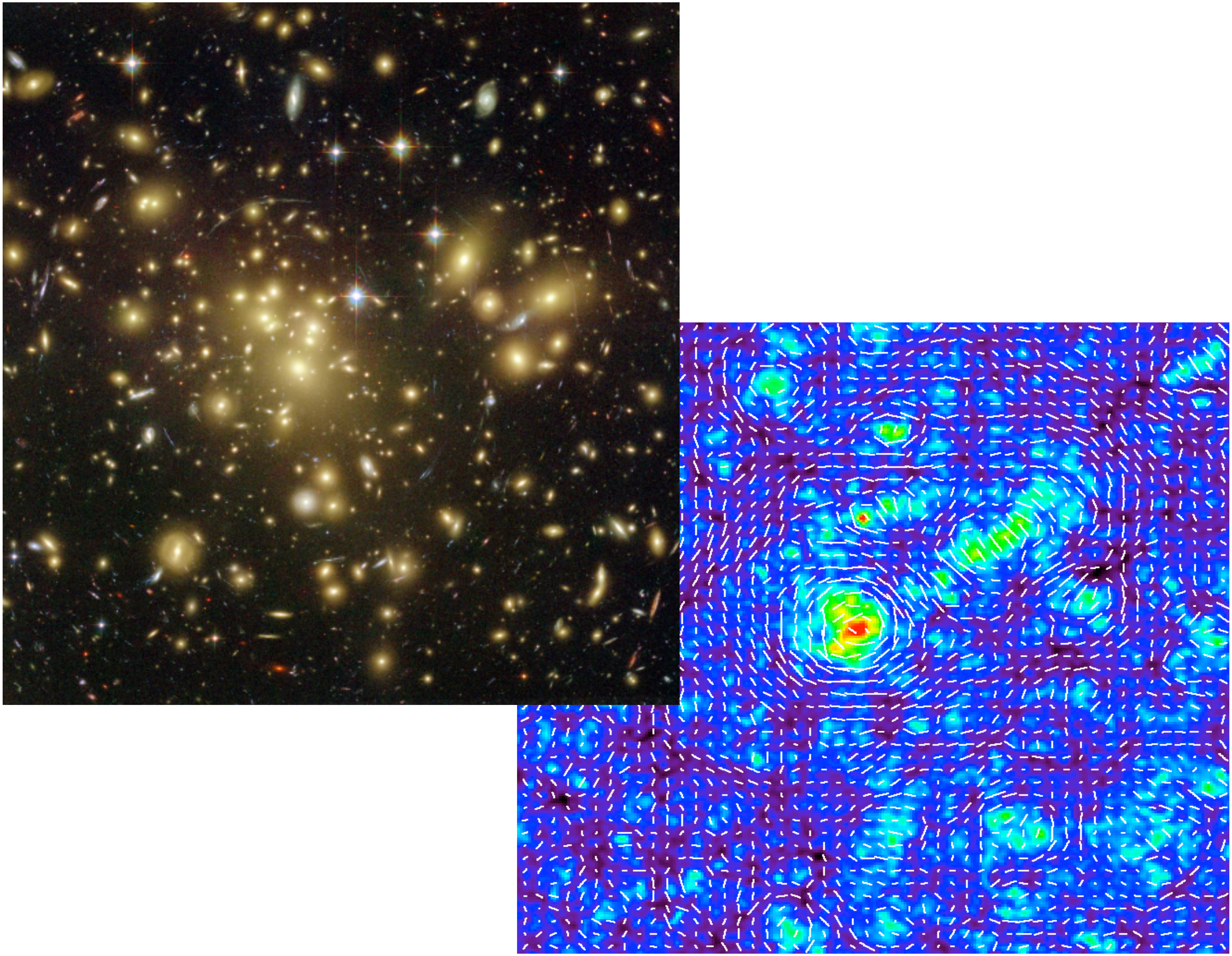
$$\begin{aligned} \gamma_1 &= \tfrac{1}{2}(\partial_1^2 - \partial_2^2)\psi \\ \gamma_2 &= \partial_1\partial_2\psi, \end{aligned}$$

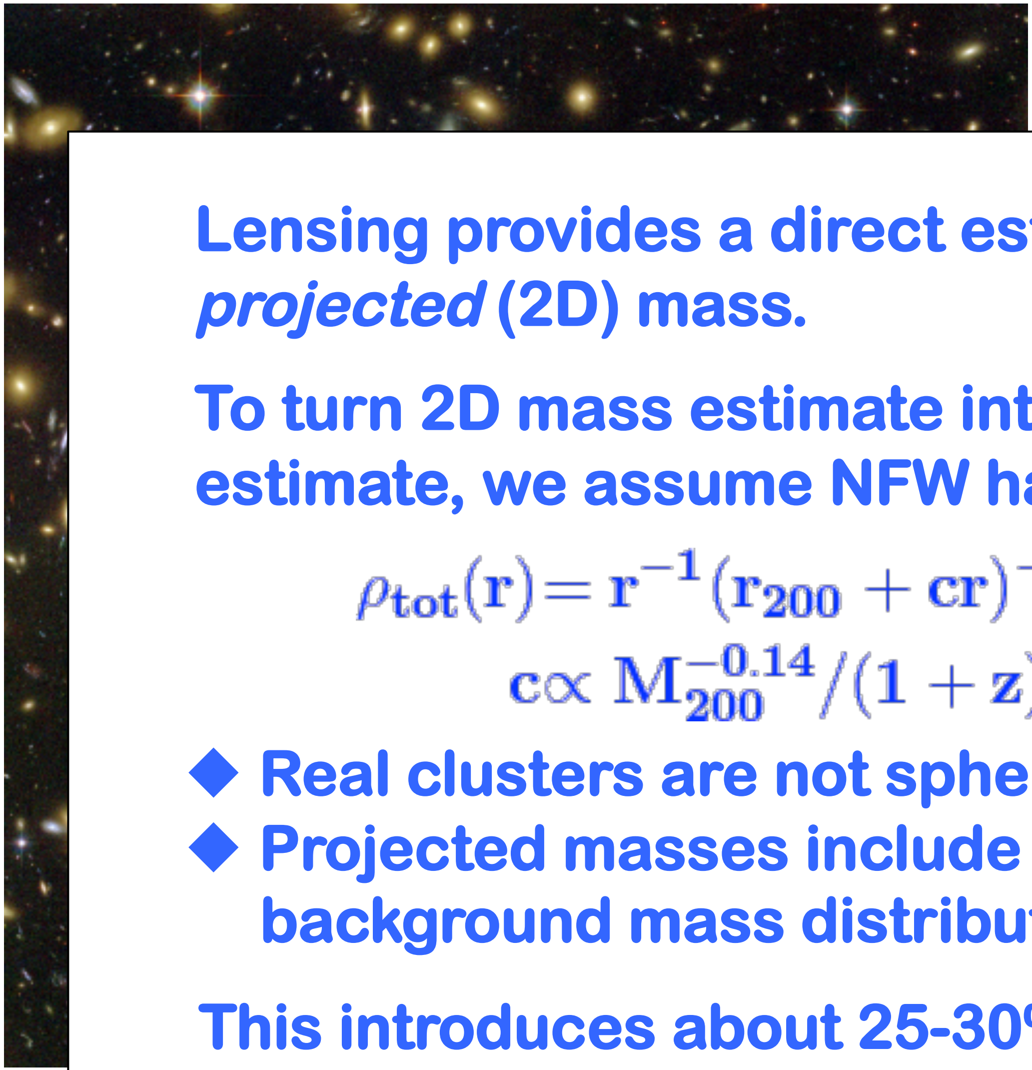
$$\kappa = \frac{1}{2}(\partial_1^2 + \partial_2^2)\psi,$$

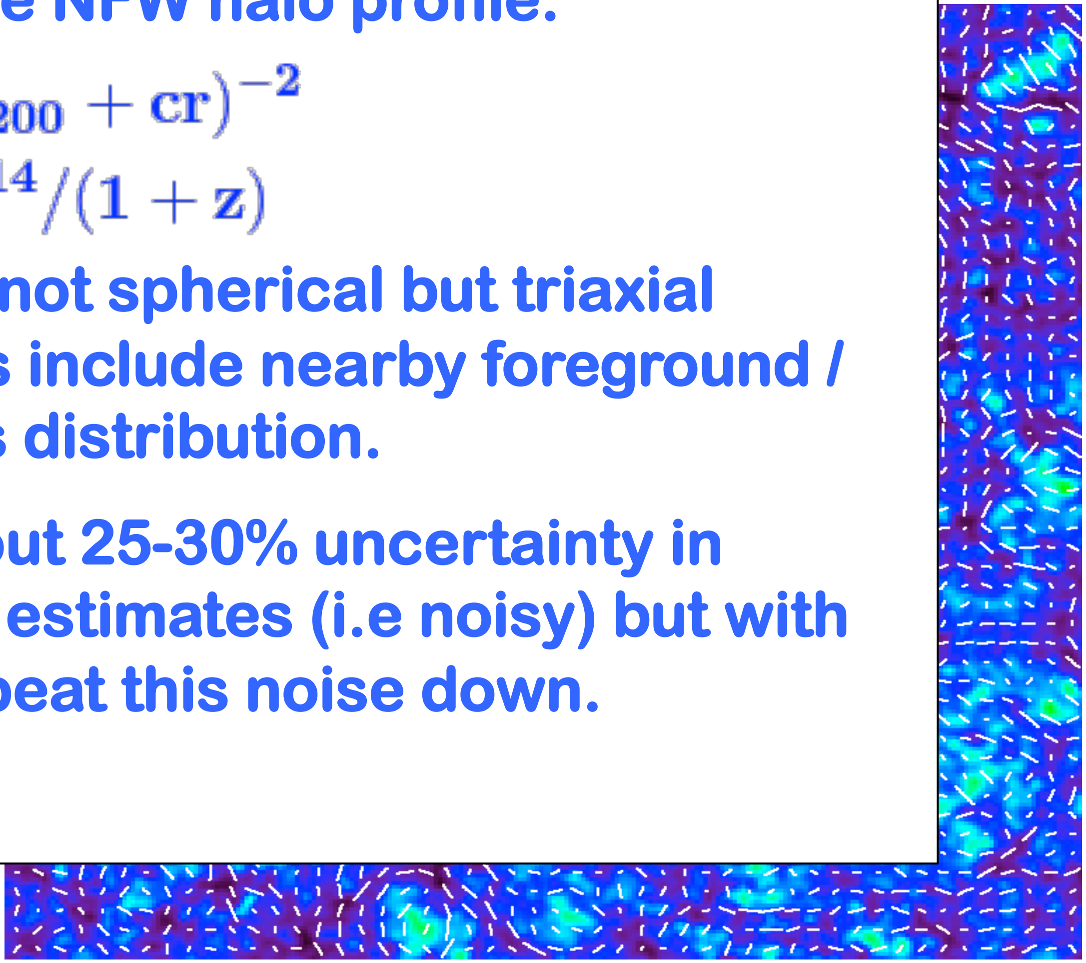


$$\kappa(\theta) = \frac{\Sigma(\theta)}{\Sigma_{\rm crit}},$$

$$\Sigma_{\rm crit} = \frac{c^2}{4\pi G}\frac{D_{\rm OS}}{D_{\rm OL}D_{\rm LS}},$$







Lensing provides a direct estimate of the *projected* (2D) mass.

To turn 2D mass estimate into 3D mass estimate, we assume NFW halo profile:

$$\rho_{\mathrm{tot}}(\mathrm{r}) = \mathrm{r}^{-1}(\mathrm{r}_{200} + \mathrm{cr})^{-2}$$

$$\mathrm{c} \propto \mathrm{M}_{200}^{-0.14}/(1+\mathrm{z})$$

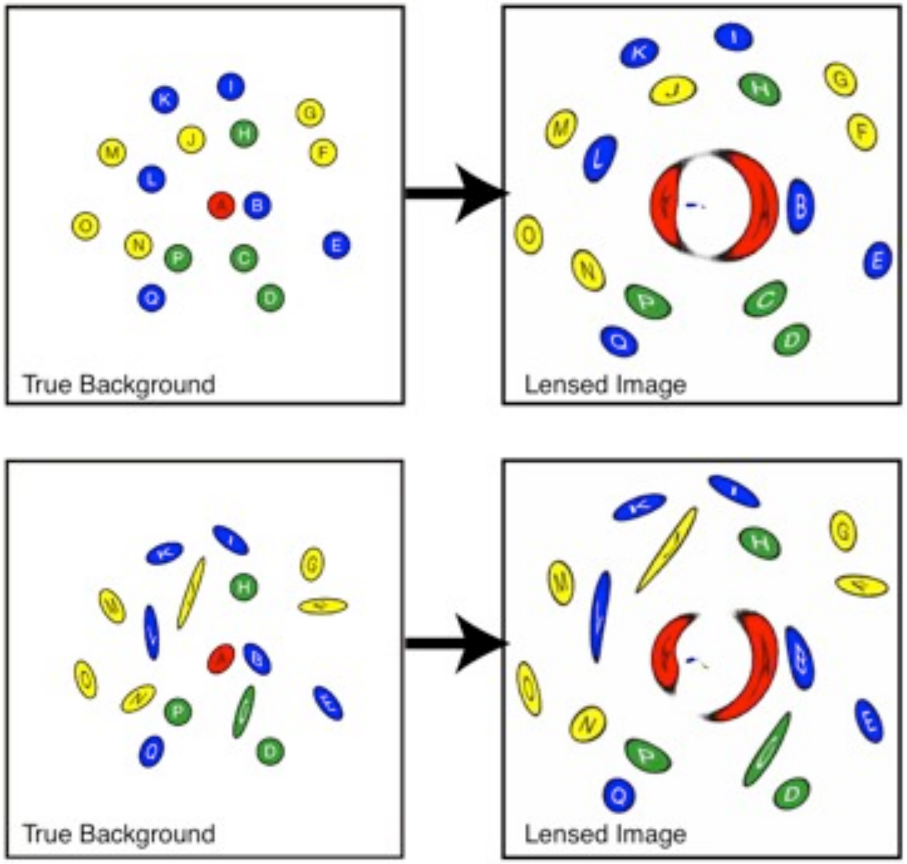
- Real clusters are not spherical but triaxial
- Projected masses include nearby foreground / background mass distribution.

This introduces about 25-30% uncertainty in individual WL mass estimates (i.e noisy) but with many objects, can beat this noise down.

MEASURING SHEAR: THEORETICALLY SIMPLE, IN PRACTISE…

SOURCES OF NOISE:

Random intrinsic shape of galaxies.



Atmospheric seeing and telescope point spread function

Background noise in the CCD image

Foreground and cluster galaxies

Faint unresolved galaxies

Distance between lens and background galaxies

UNDERSTANDING SYSTEMATIC OFFSETS:

We have undertaken a thorough analysis of the entire pipeline to understand and quantify different sources of systematic biases:

$$\gamma_i^{obs} = (1+\mu)\ \gamma_i^{true} + \cancel{c}$$

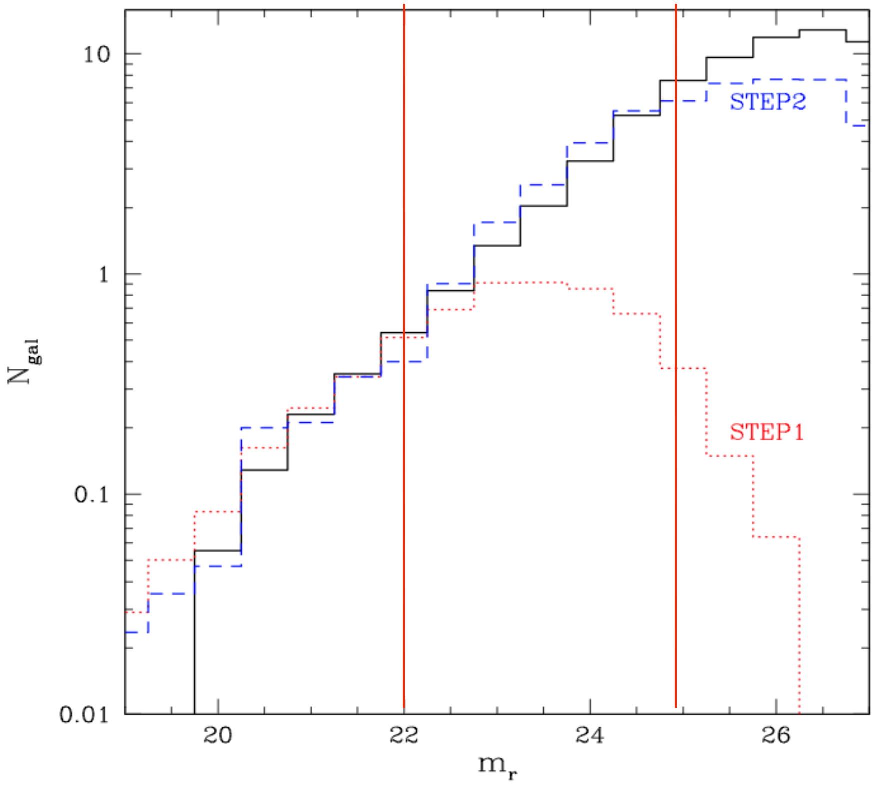
For cluster work: not important due to azimuthal avrg

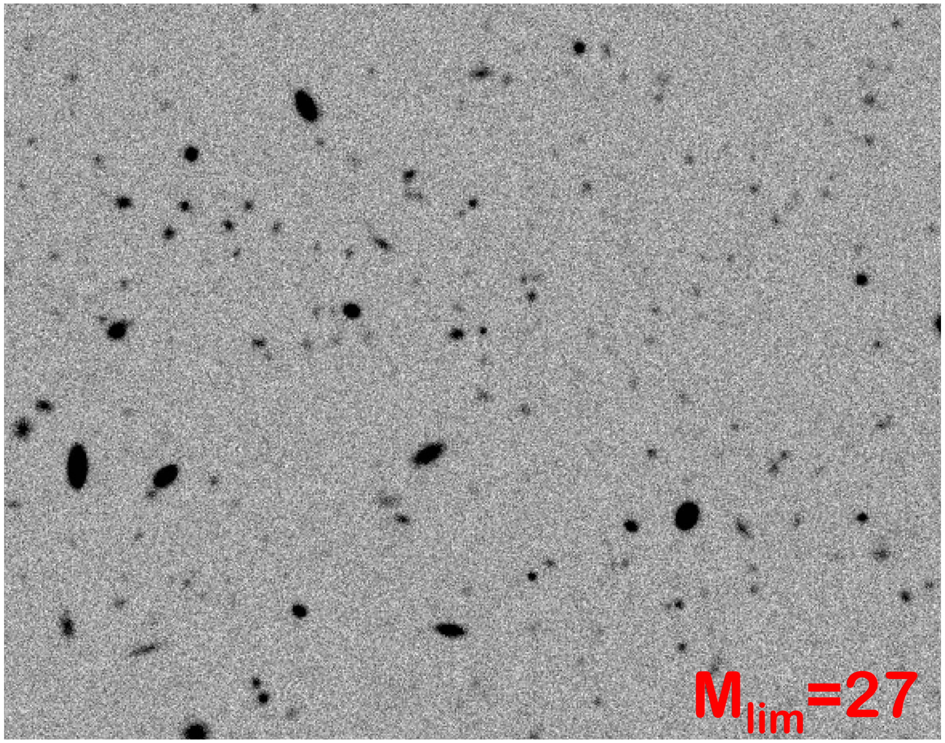
- Start with an input mock galaxy distribution
  - correct number counts and redshift distribution
  - appropriate ellipticity distribution (mag dependent)
- Apply a known shear due to intervening lens → "truth"
- Create a lensed image; add "appropriate" noise level
- Impose correct PSF – size (seeing) and distortions
- Analyze mock images via identical pipeline/approach
- Compare results to true input to determine multiplicative and additive biases.

MOCK IMAGES MUST MATCH OBSERVATIONS IN ALL ASPECTS!

MOST IMPORTANT FINDINGS

MOCK IMAGES MUST INCLUDE GALAXIES AT LEAST 1.5 MAGNITUDES FAINTER THAN THE LIMITING MAGNITUDE OF SOURCES USED IN THE LENSING ANALYSIS – EVEN IF THESE GALAXIES ARE UNRESOLVED.





MOST IMPORTANT FINDINGS

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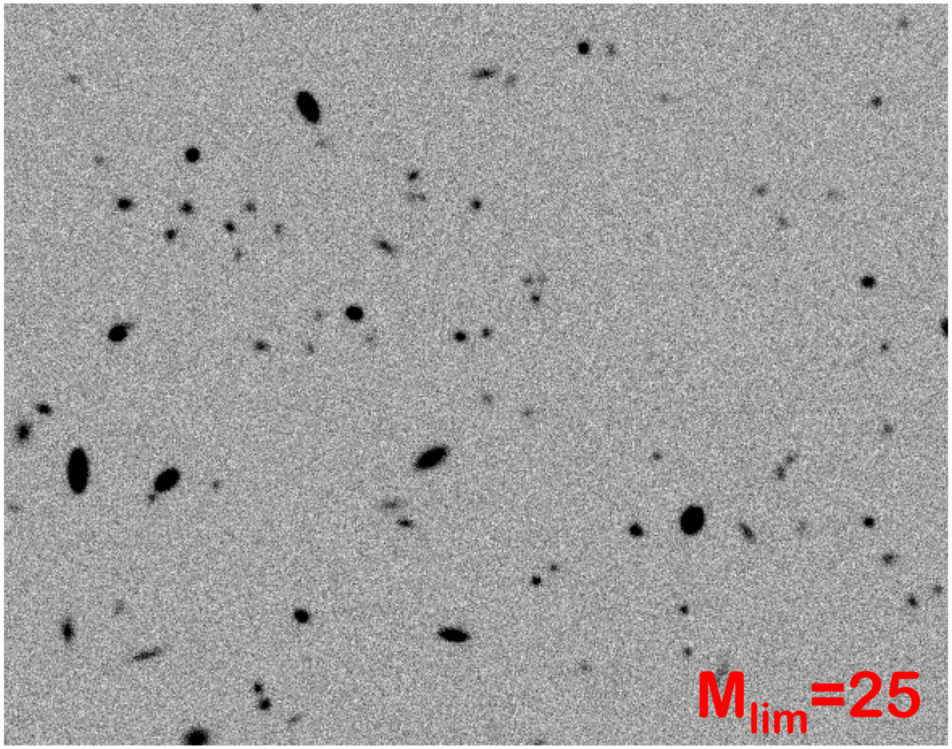
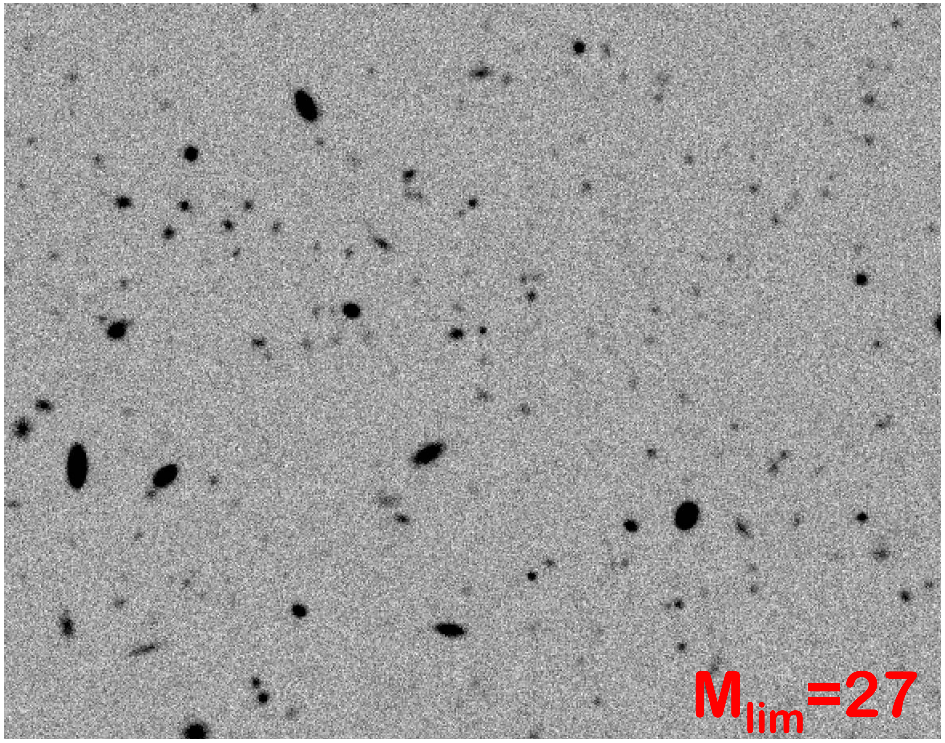
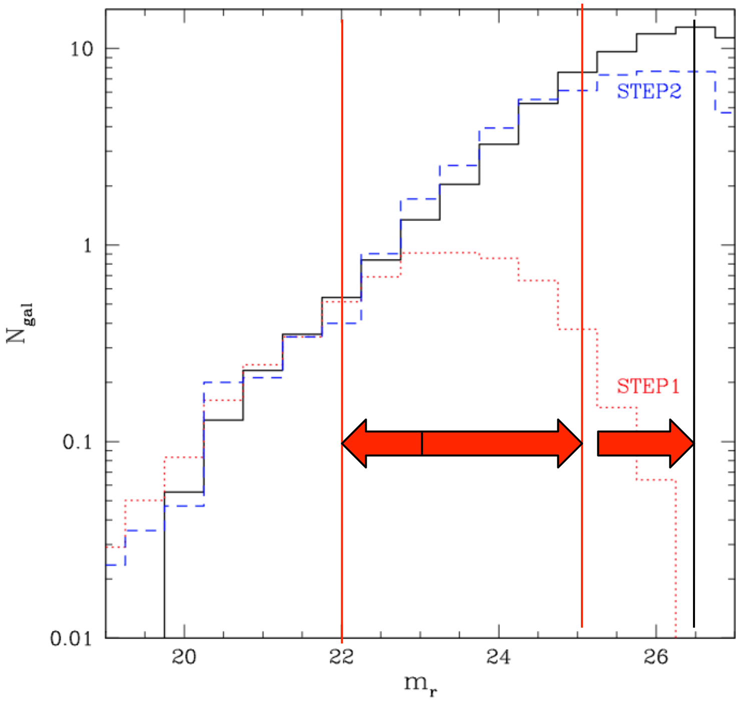
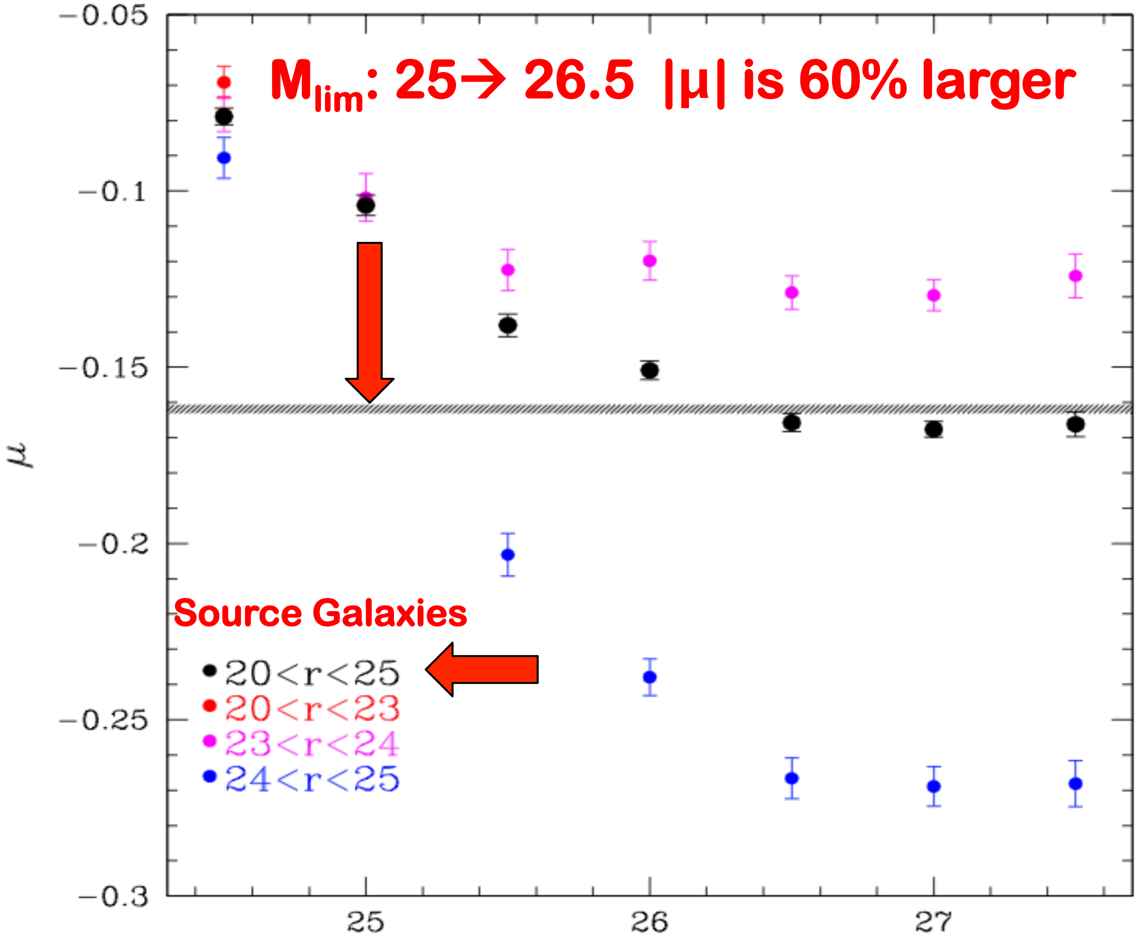




FAINT UNRESOLVED GALAXIES IMPACT SHAPES OF BRIGHTER SOURCE GALAXIES VIA BLENDING

GOING FROM STEP2 TO GEMS GALAXY COUNTS, THE GREATEST CHANGE IN |μ| RESULTS FROM INCLUSION OF UNRESOLVED FAINT GALAXIES IN THE SIMULATIONS.





M_{lim}: 25→ 26.5 |μ| is 60% larger

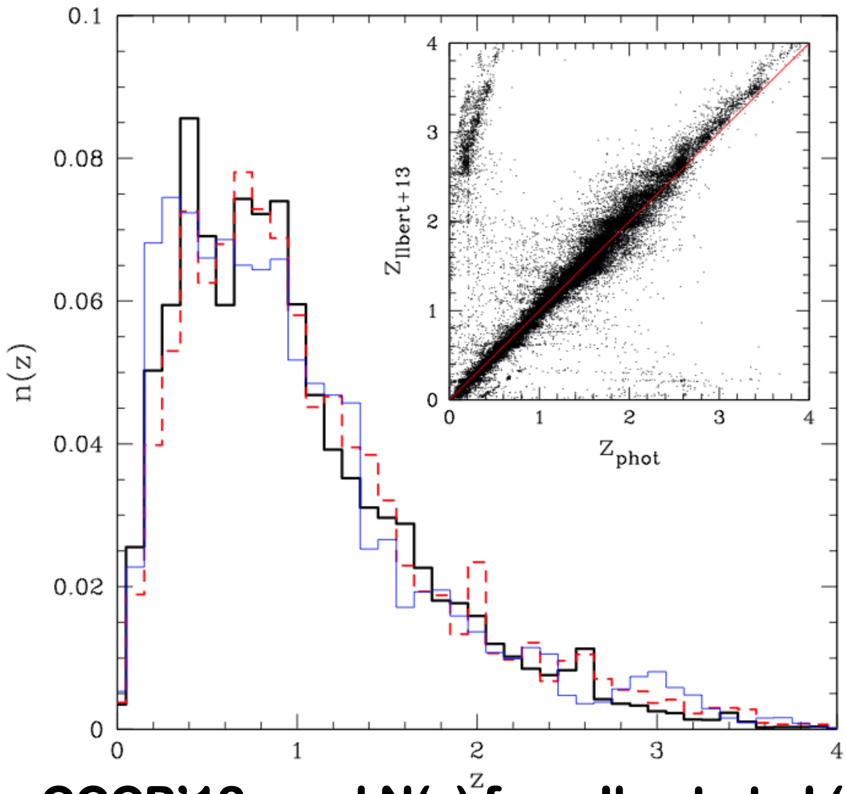
Source Galaxies

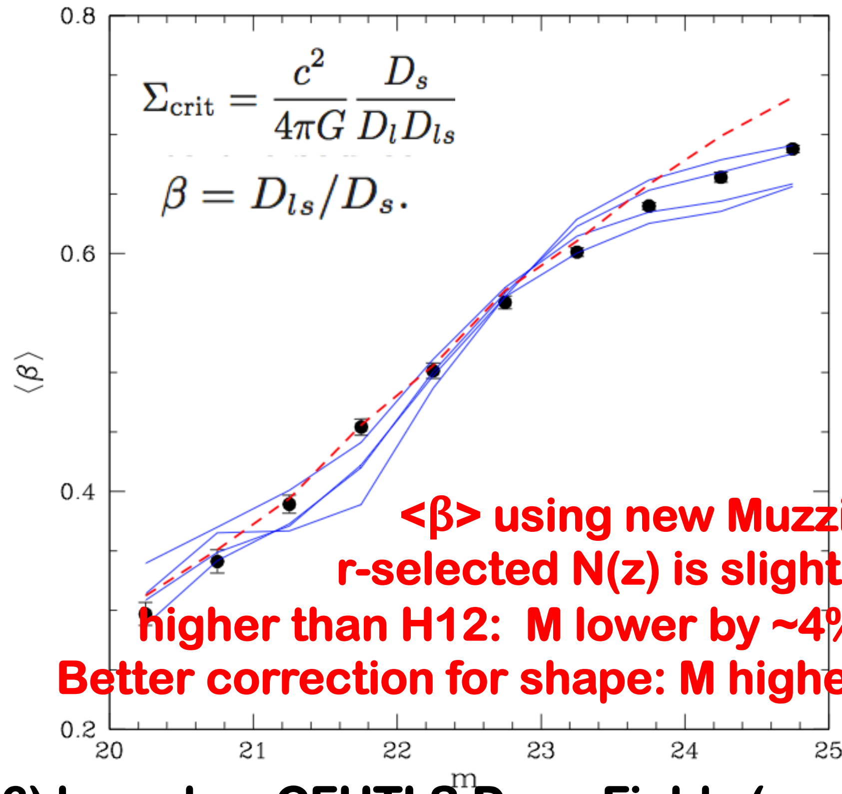
- ● 20<r<25
- ● 20<r<23
- ● 23<r<24
- ● 24<r<25

Mock image includes correct counts to m_{lim}

MOST IMPORTANT FINDINGS

CORRECT SOURCE REDSHIFT DISTRIBUTION IS KEY
THIS IS THE DOMINANT SOURCE OF SYSTEMATIC UNCERTAINTY





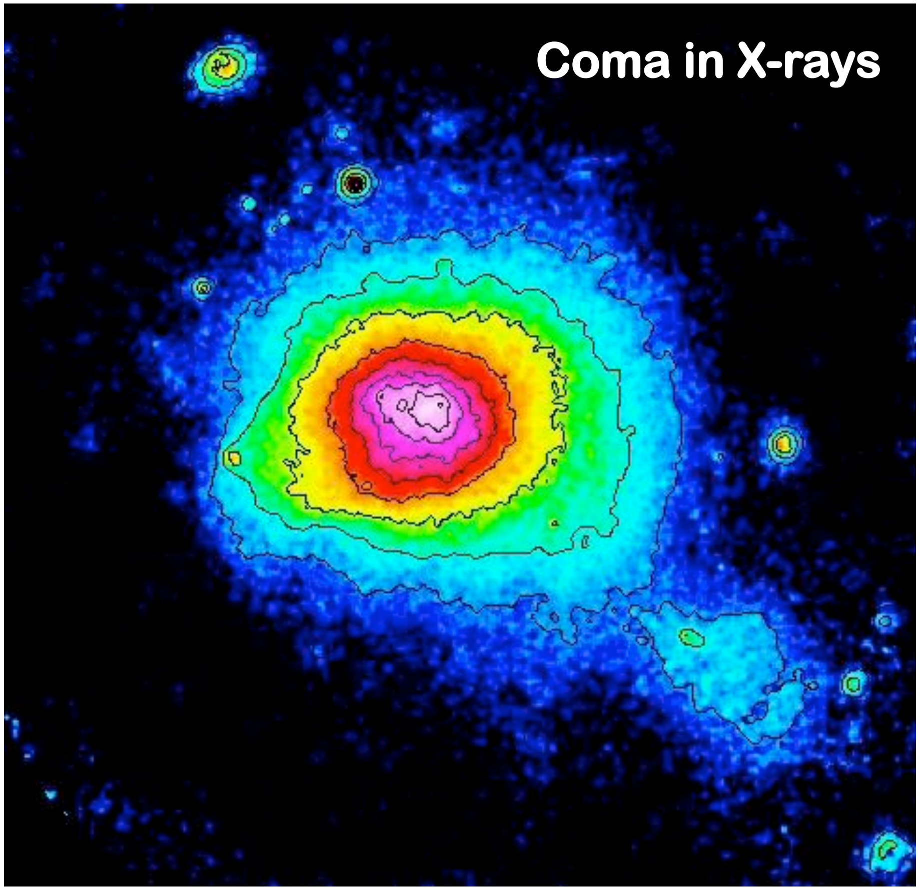
$$\Sigma_{\rm crit} = \frac{c^2}{4\pi G}\frac{D_s}{D_l D_{ls}}$$

$$\beta = D_{ls}/D_s.$$

<β> using new Muzzin r-selected N(z) is slightly higher than H12: M lower by ~4%. Better correction for shape: M higher.

- — CCCP'12 used N(z) from Ibert et al (2006) based on CFHTLS Deep Fields (ugriz) Ibert et al (2009) based on COSMOS-30: no NIR photometry (not shown) →WtG
- --- New Ibert et al (2013): COSMOS/UltraVISTA with deep NIR data and calibrated against zCOSMOS.
- — Muzzin r-selected N(z) using COSMOS/UltraVISTA: 29 bands from 0.15-24 µm and also calibrated against zCOSMOS

PLANCK SZ CLUSTER ANALYSIS:
PREMISED ON MEASURING CLUSTER MASS FUNCTION



HSE: $$\frac{dP}{dr} = -\frac{GM(r)\rho(r)}{r^2}$$

CLUSTERS ARE LARGELY DARK
mass cannot be easily measured

PLANCK MEASURE Ysz

FOR SUBSET OF CLUSTERS WITH X-RAY DATA, USE X-RAY DATA TO ESTIMATE MASS: Mx

Mx IS A BIASED ESTIMATOR OF TRUE MASS M: $\boxed{Mx = \xi M}$

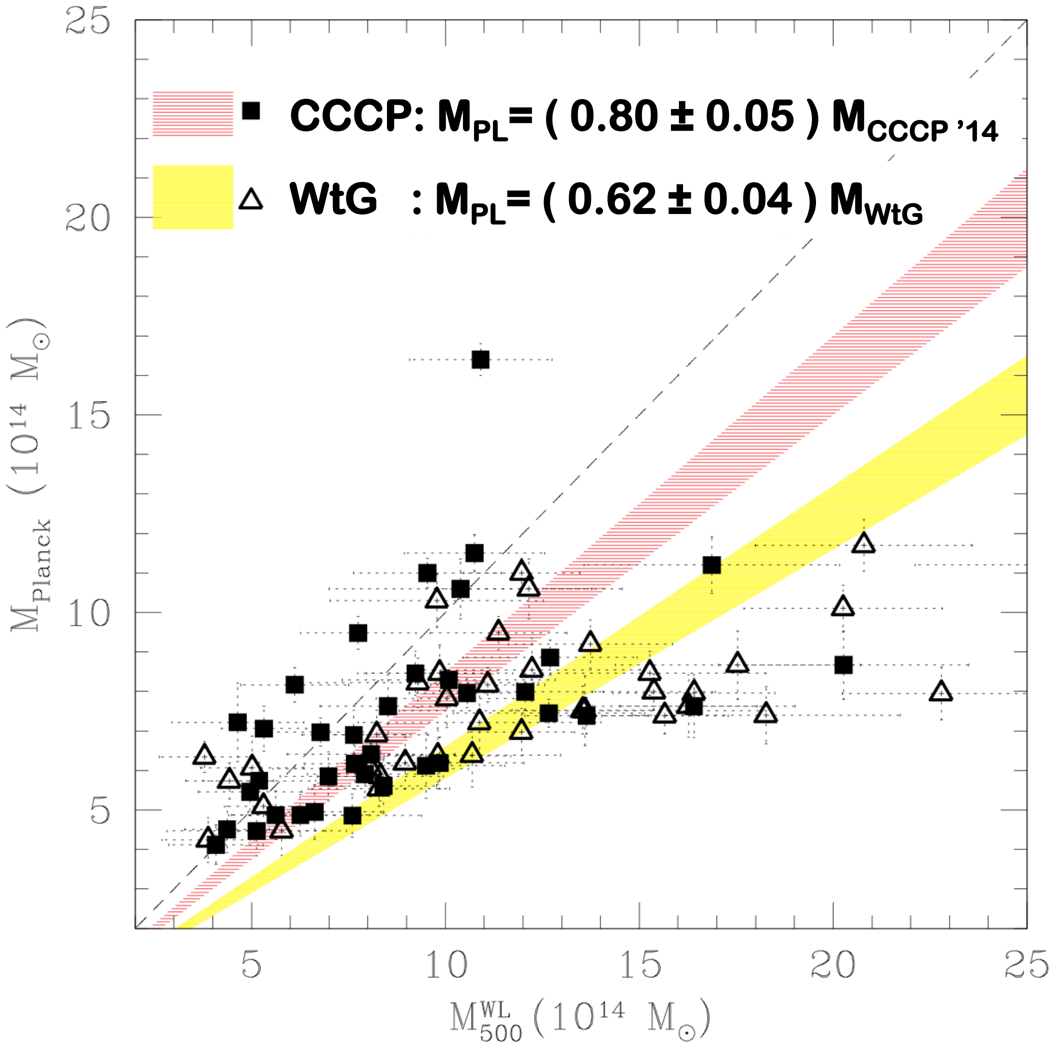
PLANCK: $\xi = [\, 0.7, 1.0 \,]$
$< \xi > \, = 0.8$

USE RESULTING Ysz – M TO DERIVE MASSES OF ALL OTHER CLUSTERS (MASS-OBSERVABLE)

IF USE <ξ> = 0.6 INSTEAD OF 0.8, THE TENSION IS RESOLVED

AND, COMBINING EVERYTHING TOGETHER…

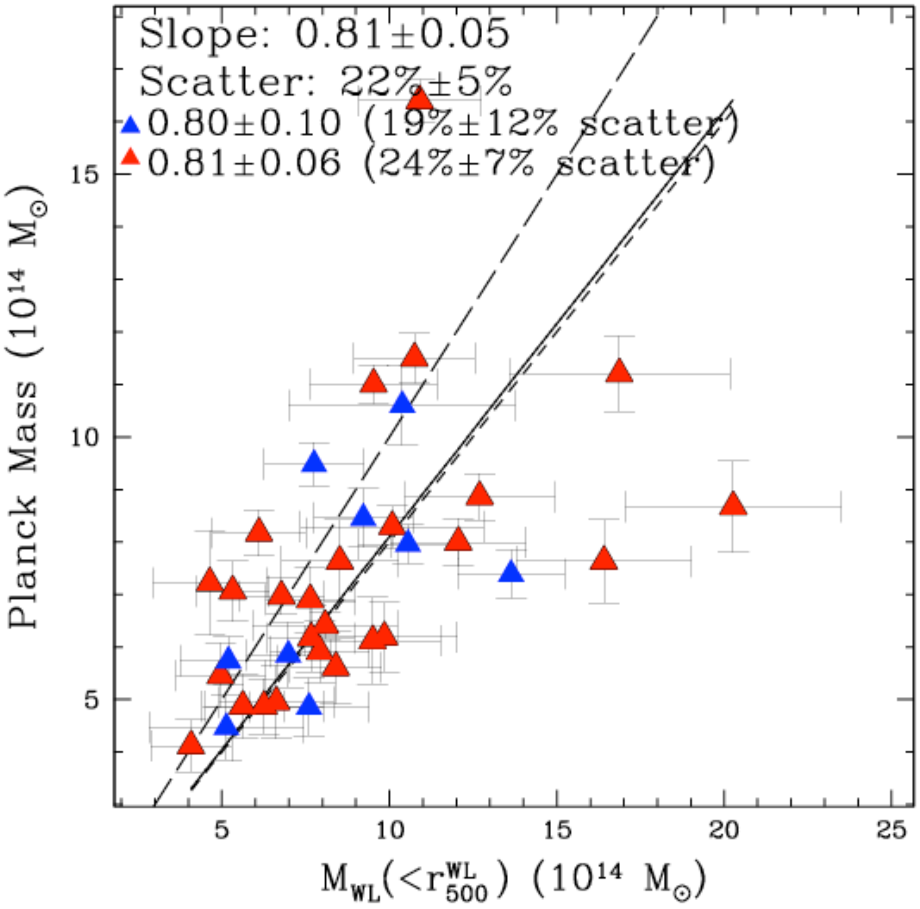
WE COMPARE TO PLANCK MASSES

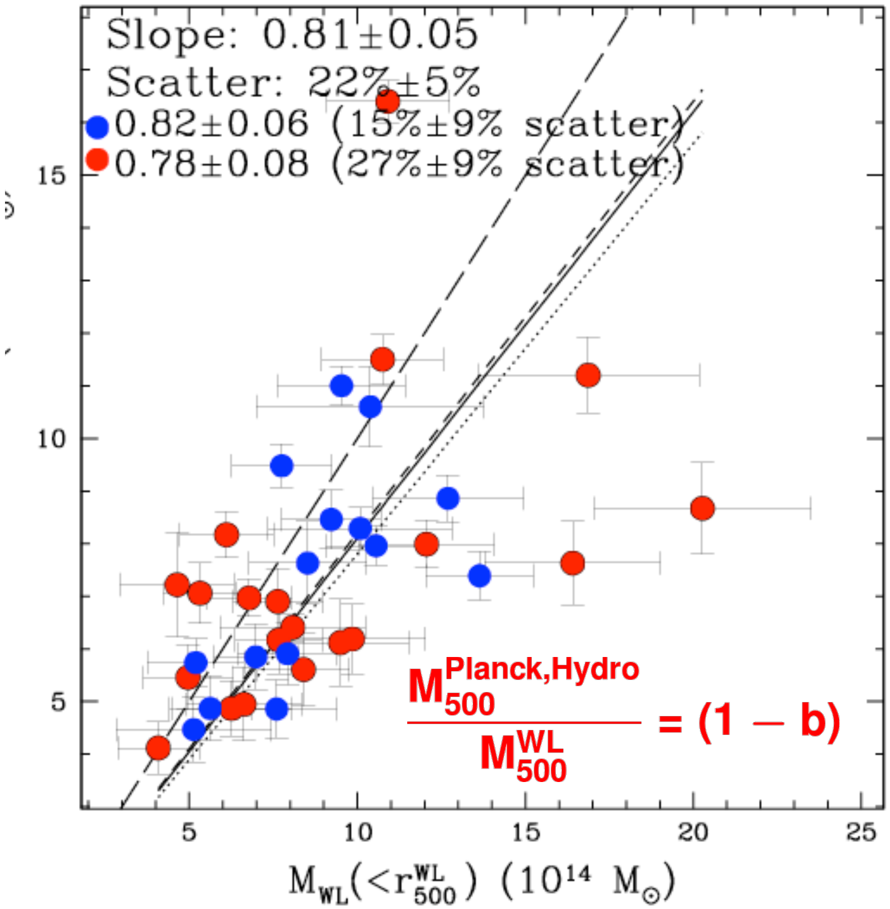


$$\frac{M_{500}^{Planck,Hydro}}{M_{500}^{WL}} = \xi = 0.8$$

THE VALUE OF ξ WITH CCCP MASSES IS SAME AS THAT ASSUMED IN PLANCK COSMOLOGY ANALYSIS.

TENSION BETWEEN PLANCK CLUSTER ANALYSIS AND PLANCK CMB ANALYSIS REMAINS.





$$\frac{M_{500}^{Planck,Hydro}}{M_{500}^{WL}} = (1 - b)$$

▲ K(20 kpc) < 70 keV cm^2

▲ K(20 kpc) > 70 keV cm^2

● D_{BCG} < 0.01 Mpc

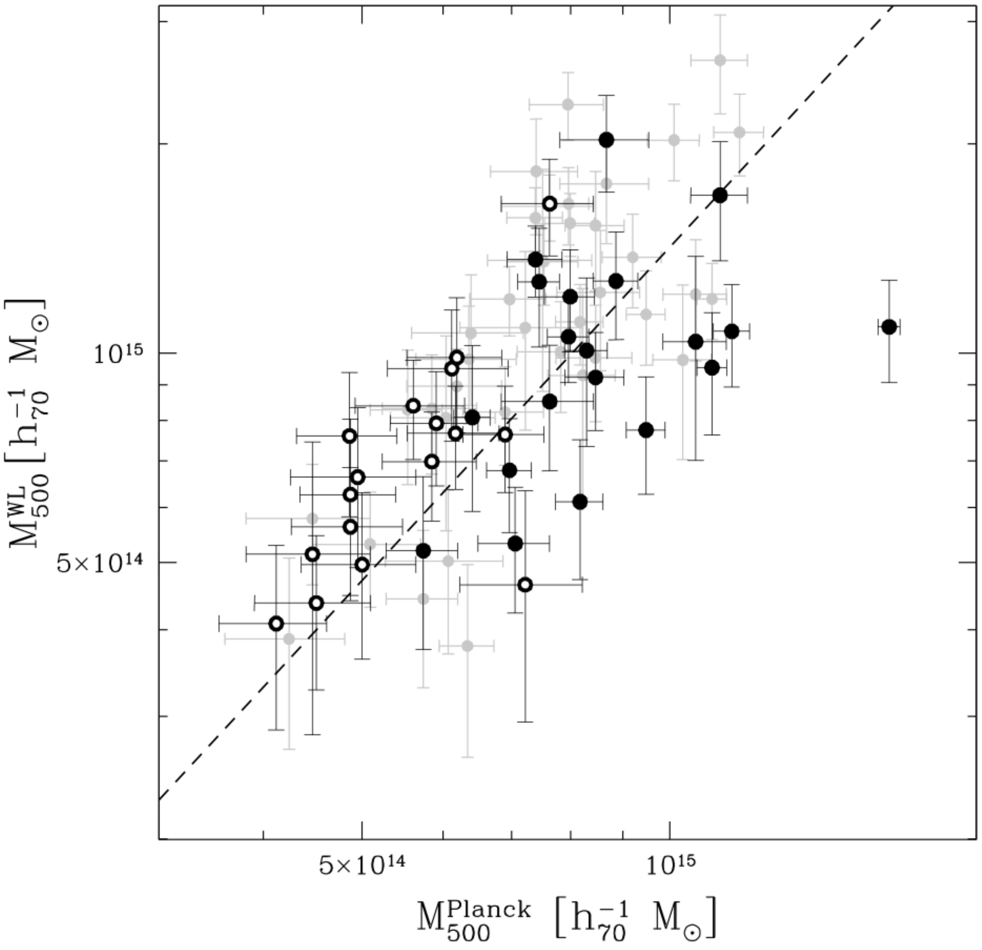
● D_{BCG} > 0.01 Mpc

NO DIFFERENCE BETWEEN COOL CORE & NON-COOL CORE SYSTEMS

NO DIFFERENCE BETWEEN RELAXED & UNRELAXED SYSTEMS

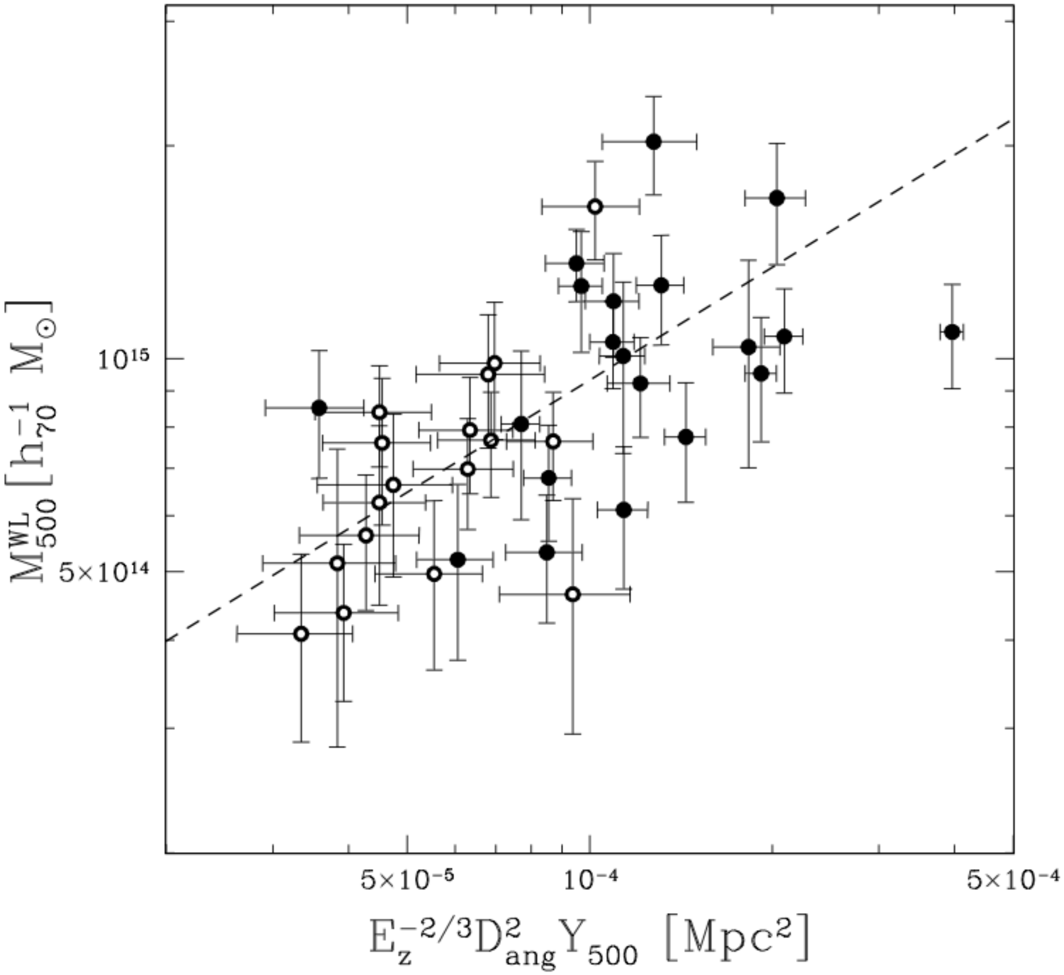
WE FIND MASS DEPENDENCE BETWEEN Mpl - Mwl

$$\frac{M_{Planck}}{10^{15}h_{70}^{-1}\mathrm{M}_\odot} = 0.800^{+0.041}_{-0.039} \times \left(\frac{M_{\mathrm{CCCP}}}{10^{15}h_{70}^{-1}\mathrm{M}_\odot}\right)^{0.66\pm0.17}$$



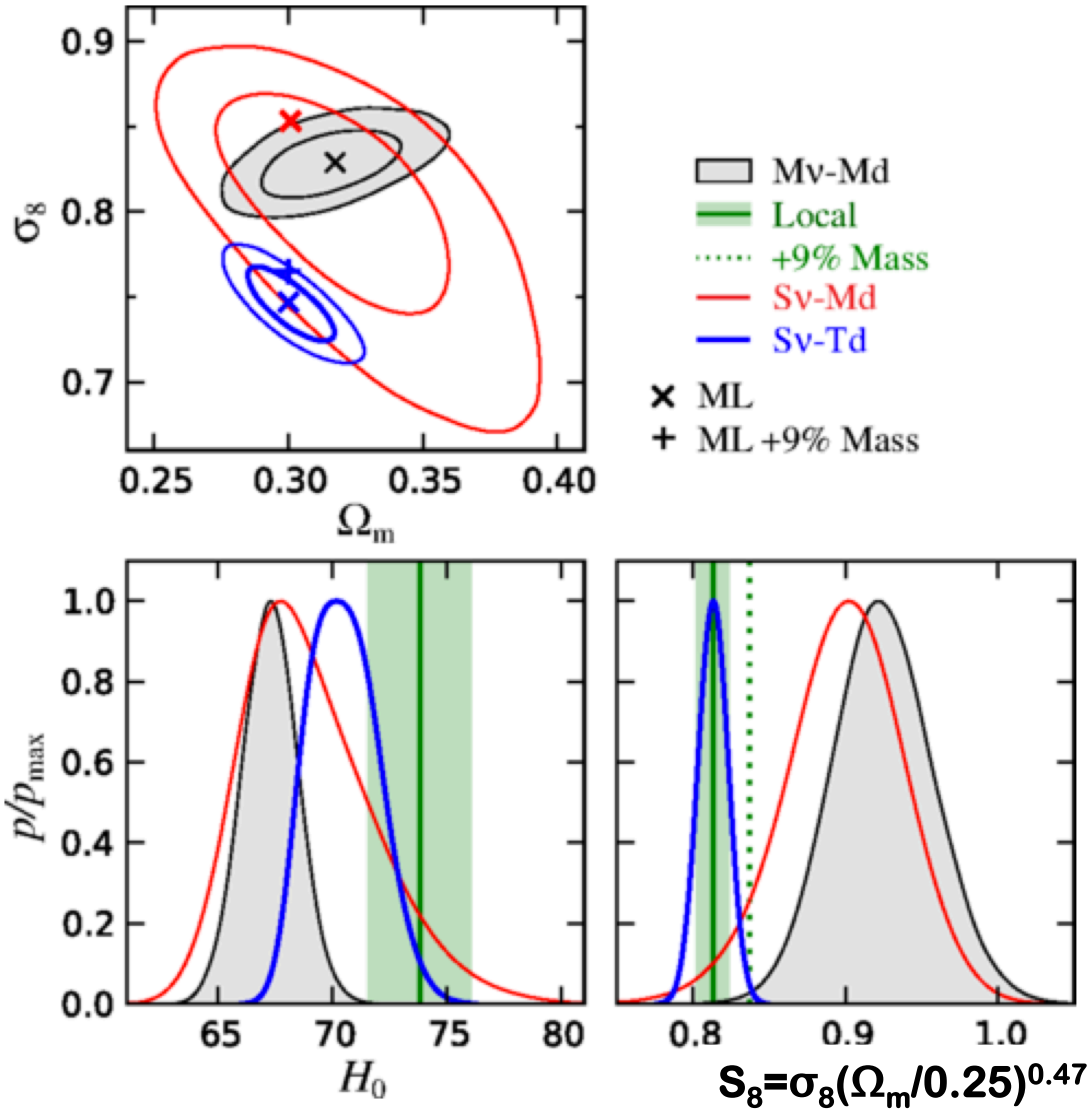
PRELIMINARY MASS-Ysz SCALING RELATION

$$\frac{M_{500}^{\mathrm{WL}}}{10^{15} h_{70}^{-1}\mathrm{M}_\odot} = 0.93^{+0.056}_{-0.053} \times \left(\frac{10^4 \times D_{\mathrm{ang}}^2 Y_{500}}{E(z)^{2/3}\mathrm{Mpc}^2}\right)^{0.53\pm0.13}$$



CONSISTENT WITH PLANCK SCALING: 0.56

THIS IS ALL VERY EXCITING…
SO DOES THIS MEAN NEW PHYSIS?

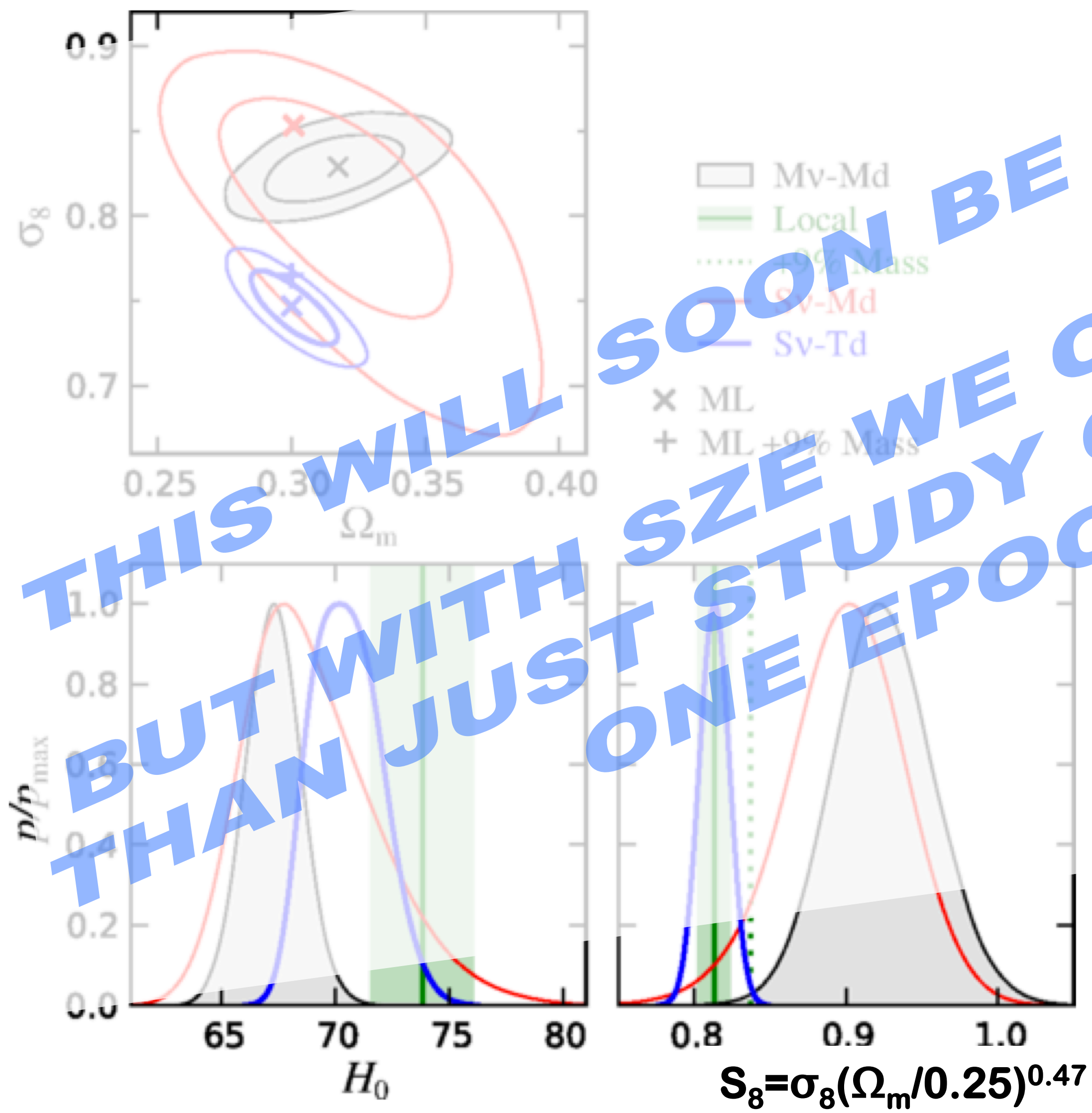


TENSION BTW HI-Z & LO-Z PARAMETERS CAN BE RESOLVED:

ONE EXTRA STERILE ν

ΔN_{eff} =1
M_s ~ 0.4-0.8 eV

THIS IS ALL VERY EXCITING…
SO DOES THIS MEAN NEW PHYSIS?



THIS WILL SOON BE RESOLVED…

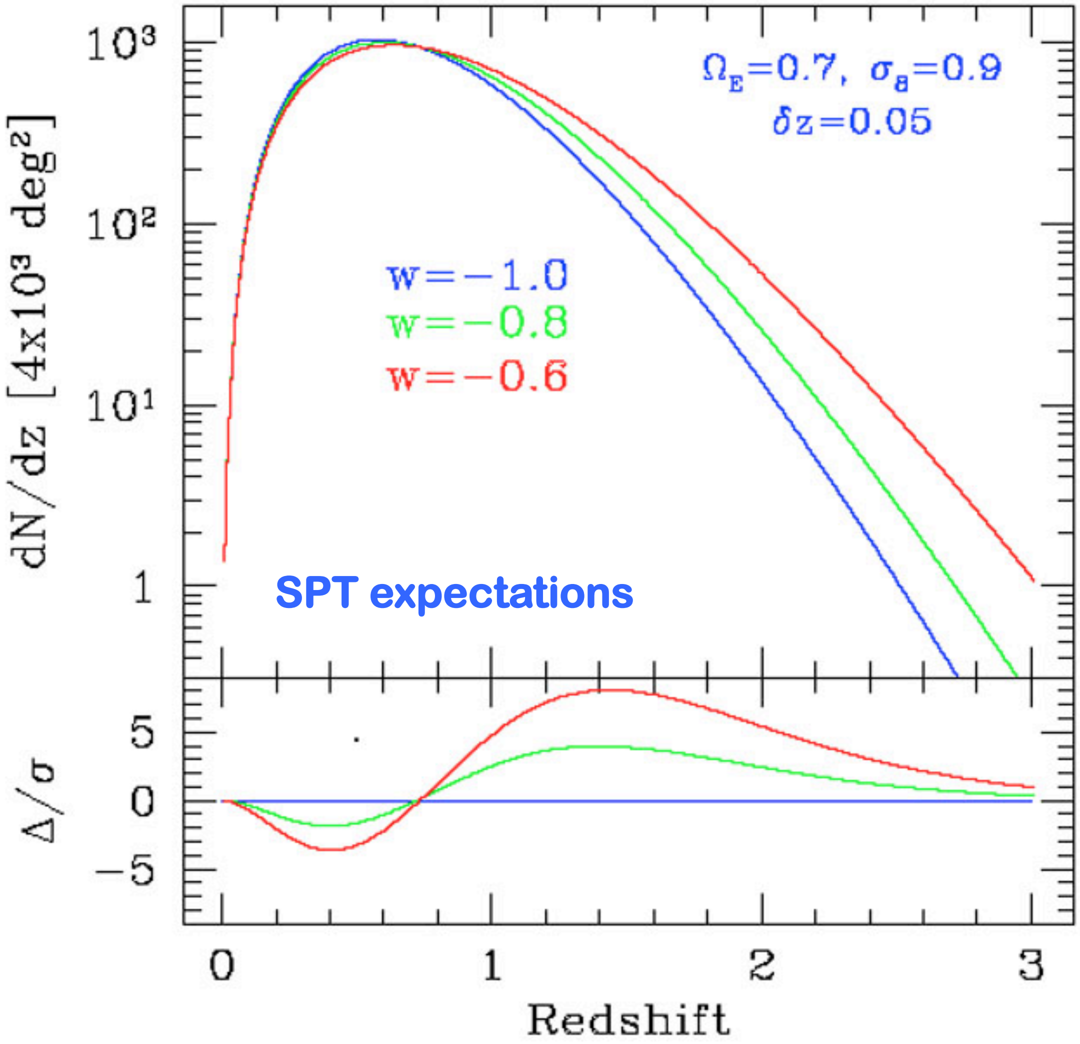
BUT WITH SZE WE CAN DO MORE THAN JUST STUDY CLUSTERS AT ONE EPOCH…

TENSION BTW HI-Z & LO-Z PARAMETERS CAN BE RESOLVED:

ONE EXTRA STERILE ν

$\Delta N_{eff}=1$
$M_s \sim 0.4\text{-}0.8$ eV

DEEP CLUSTER COUNTS FROM GROUND-BASED SZE SURVEYS

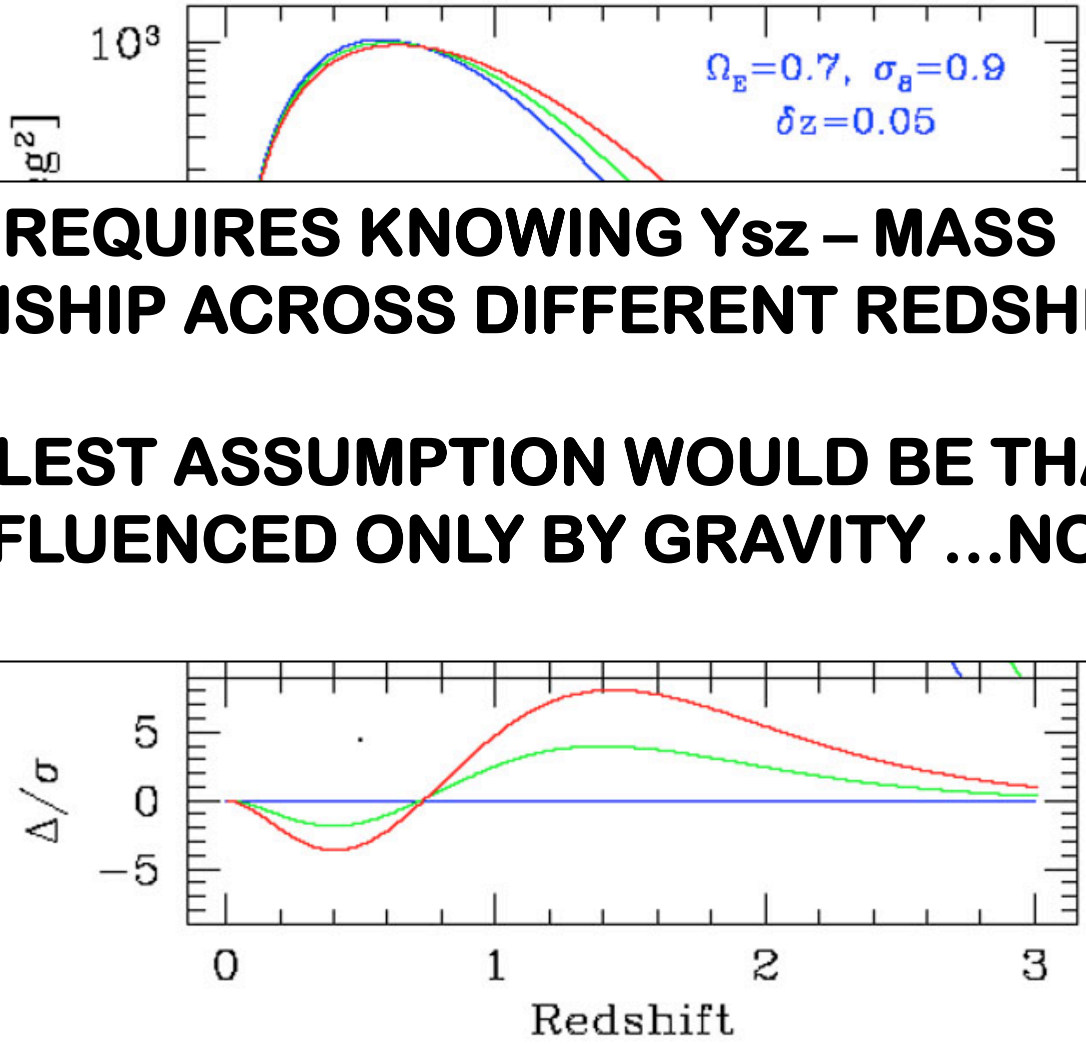


SPT expectations

cluster counts: SZE

Frieman et al. 2008
Carlstrom et al. 2002

DEEP CLUSTER COUNTS FROM GROUND-BASED SZE SURVEYS



BUT THIS REQUIRES KNOWING Ysz – MASS RELATIONSHIP ACROSS DIFFERENT REDSHIFT.

THE SIMPLEST ASSUMPTION WOULD BE THAT THE GAS IS INFLUENCED ONLY BY GRAVITY …NO EVOL.

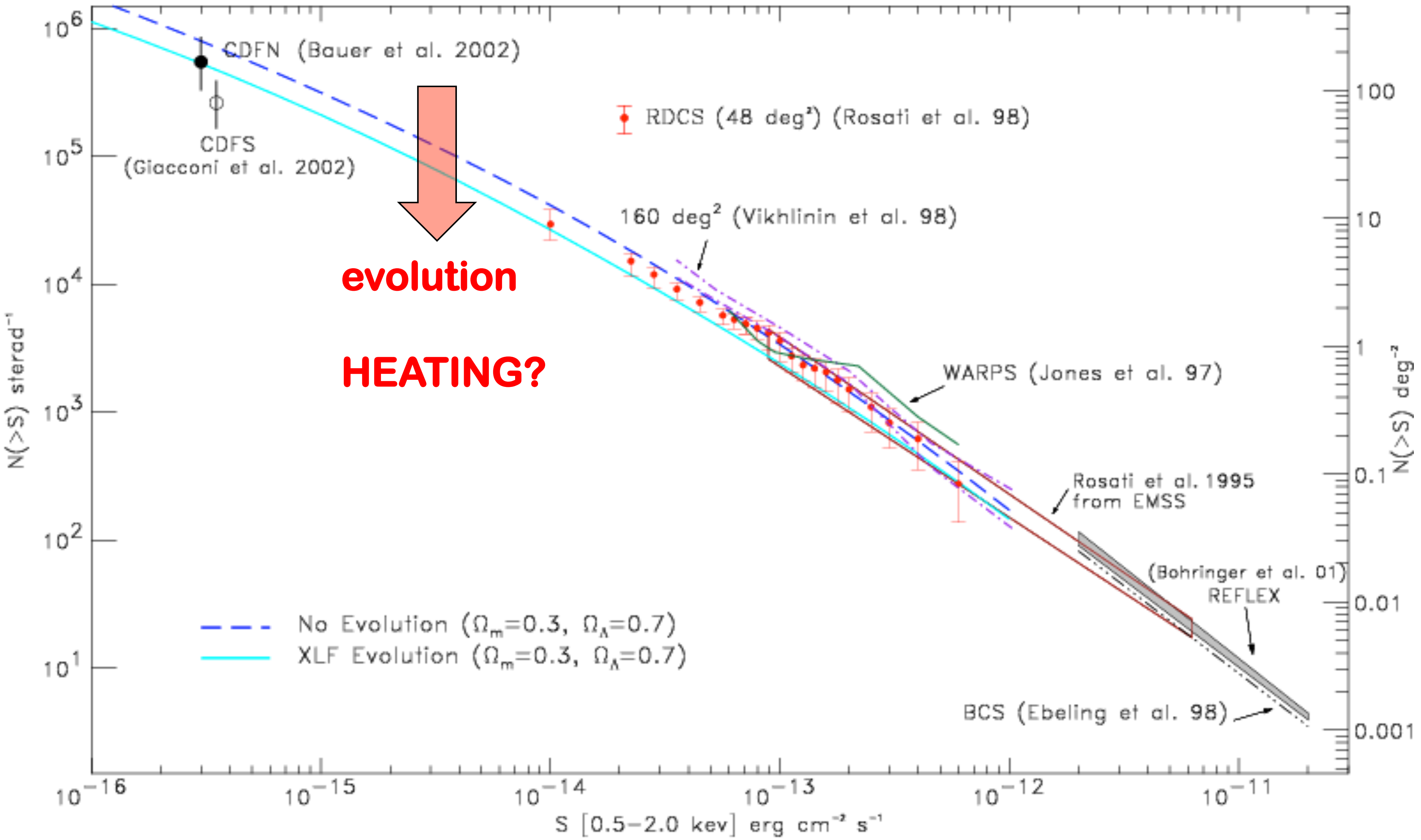
cluster counts: SZE

Frieman et al. 2008
Carlstrom et al. 2002

GAS IS HEATED BY ACCRETION SHOCKS

CLUSTER NUMBER COUNTS VS. X-RAY FLUX

faintest sources live at an earlier epoch → evolution and astrophysics

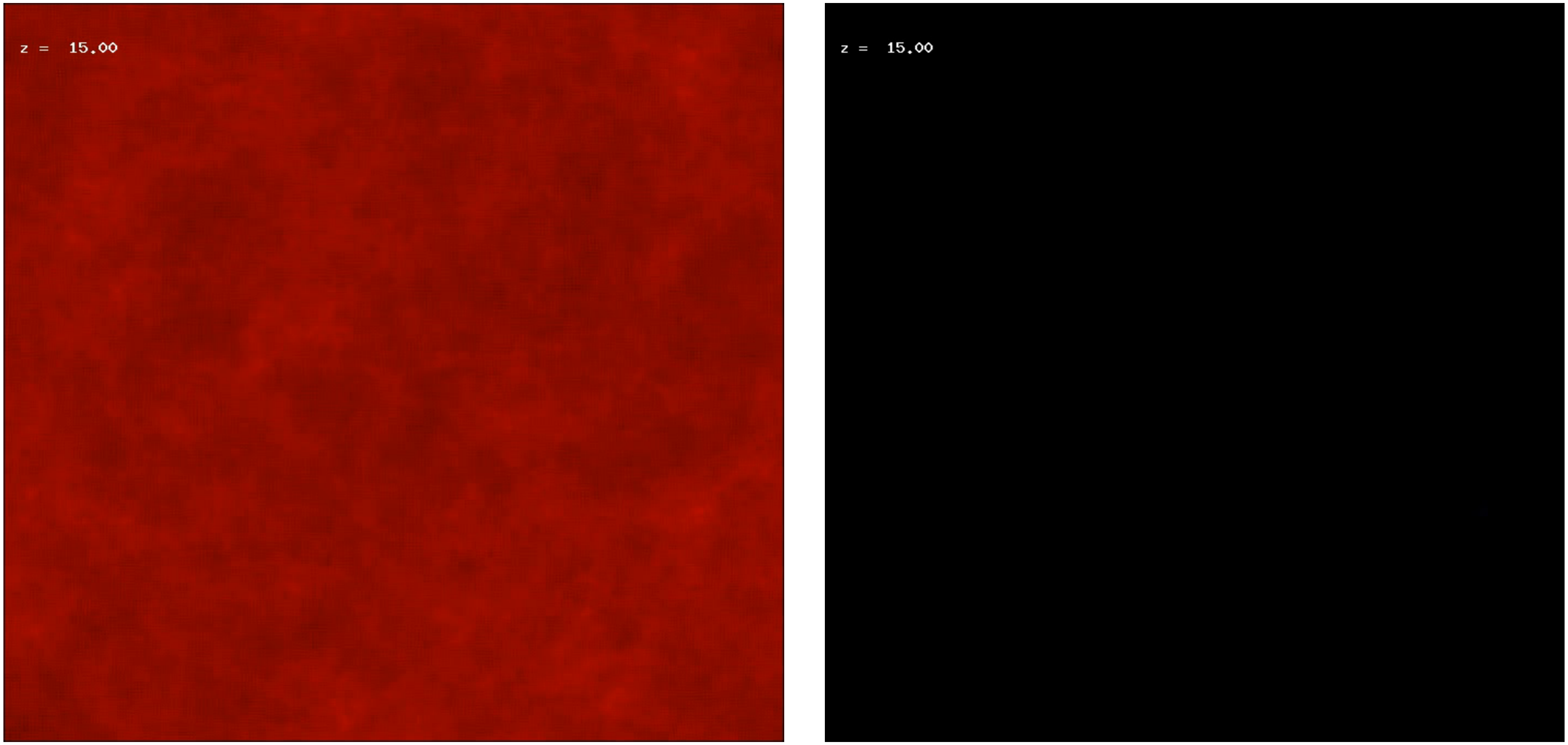


evolution

HEATING?

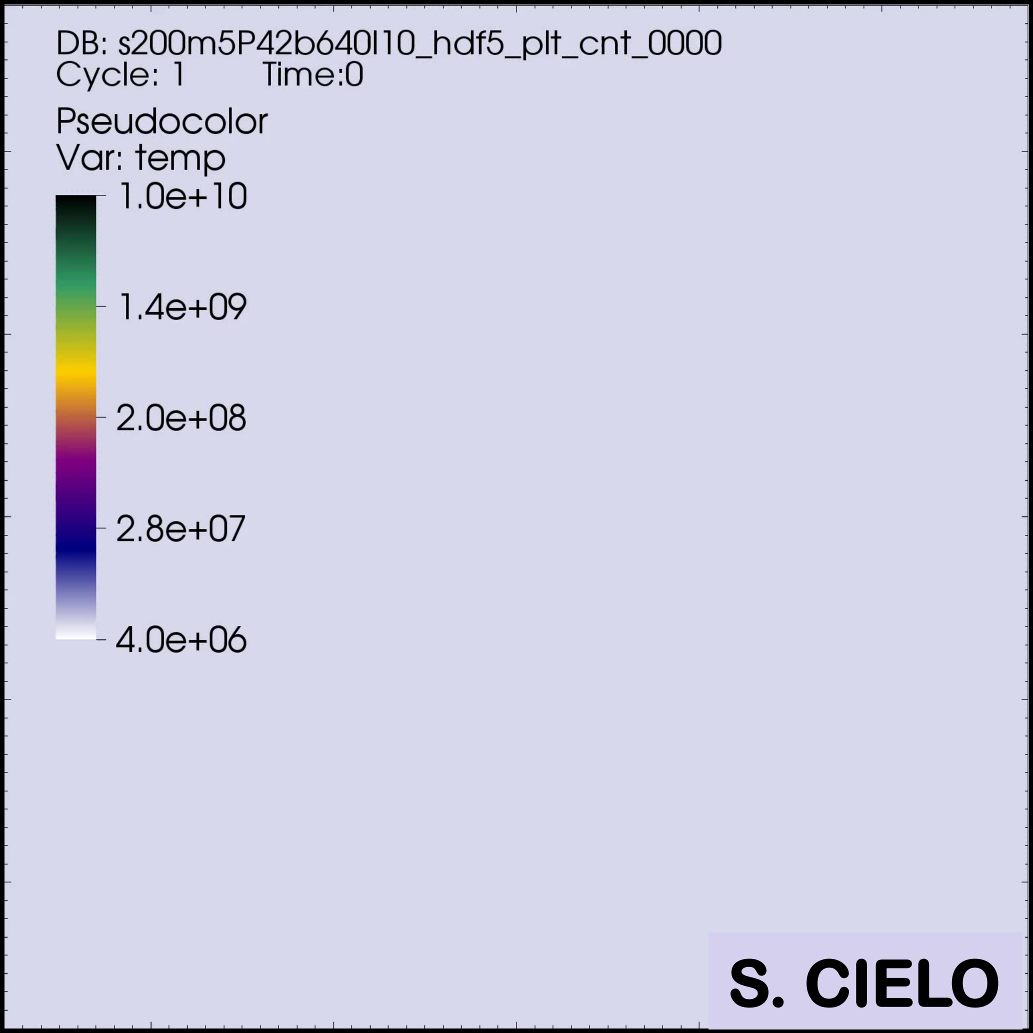
cluster counts: x-ray flux

BUT…GAS CAN ALSO BE HEATED BY LARGE-SCALE GALACTIC OUTFLOWS POWERED BY SUPERNOVAE, STELLAR WINDS & RADIATION PRESSURE”



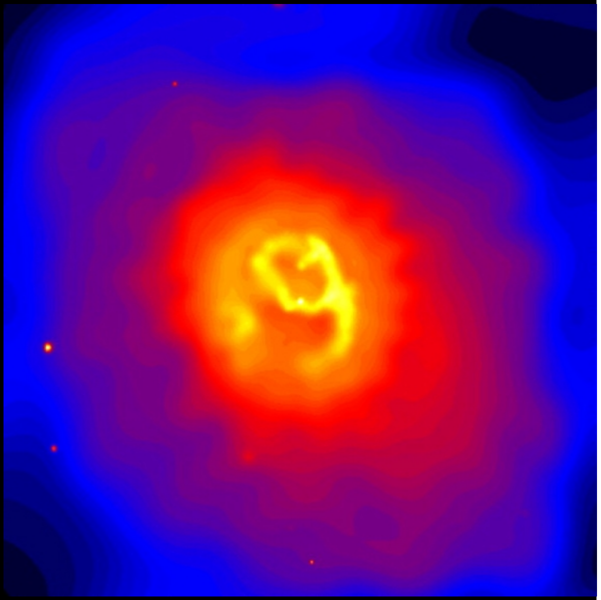
F. DURIER

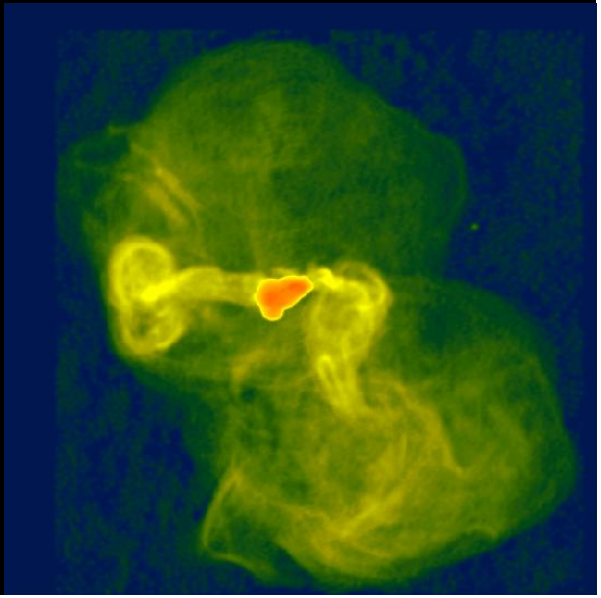
AND BY JETS AND WINDS FROM BLACK HOLES



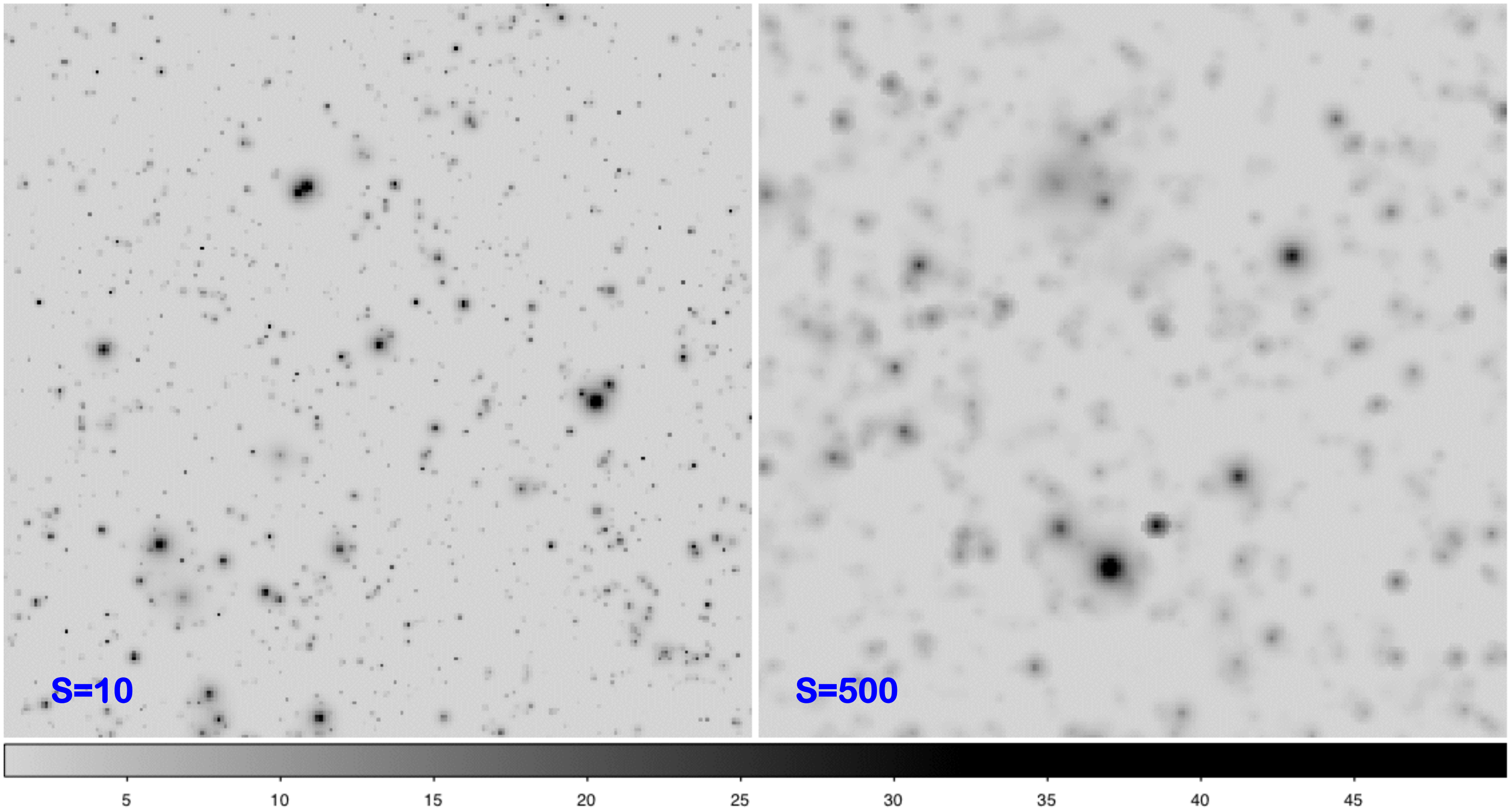
S. CIELO

REALISTIC AGN FEEDBACK IN COSMO SIMS: F. DURIER/ G. NOVAK





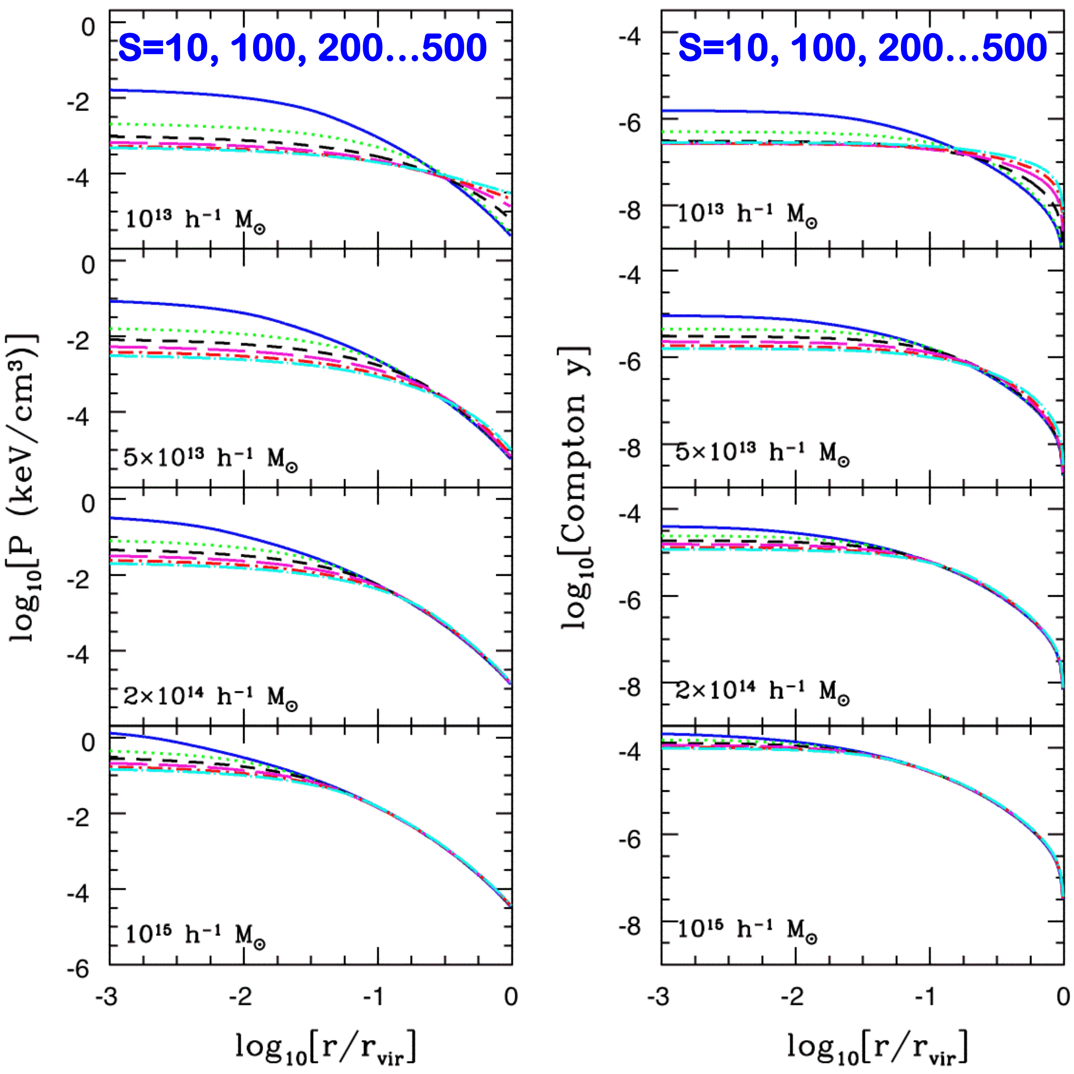
Implications Of Varying Entropy Core Values: y-maps



0°.85 Square Section Of 2°X2° SZ Sky Map: σ_8=0.9; M > 10^{13} h^{-1} $M_\odot$
(uniform core entropy with no evolution; res=14" ; only thermal SZ)

Holder, McCarthy, Babul

Implications Of Varying Entropy Core Values: SZE



At a given mass, larger S results in:

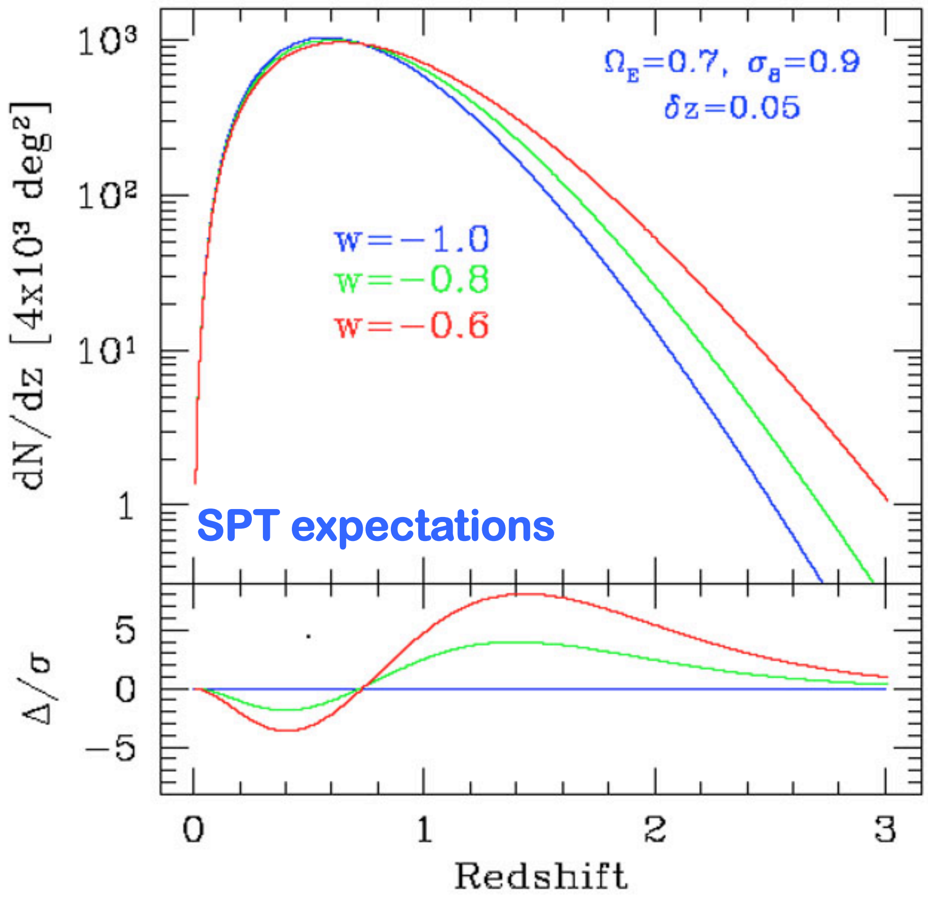
- lower amplitude,
- flatter proj. y-profiles,
- higher signal outside the core

With increasing mass, the fractional change is lower.

Changes are negligible for $M > 10^{14}\ M_\odot$

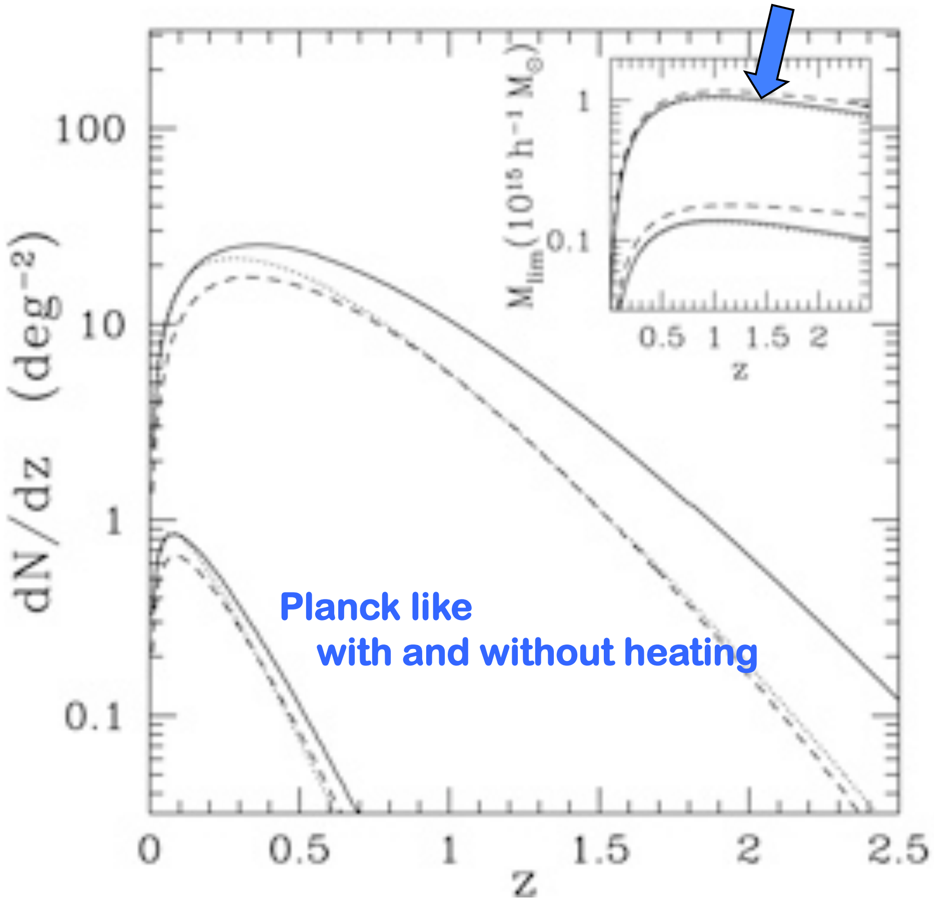
Holder, McCarthy, Babul

CLUSTER COUNTS IN SZE SURVEYS



SPT expectations

Planck like



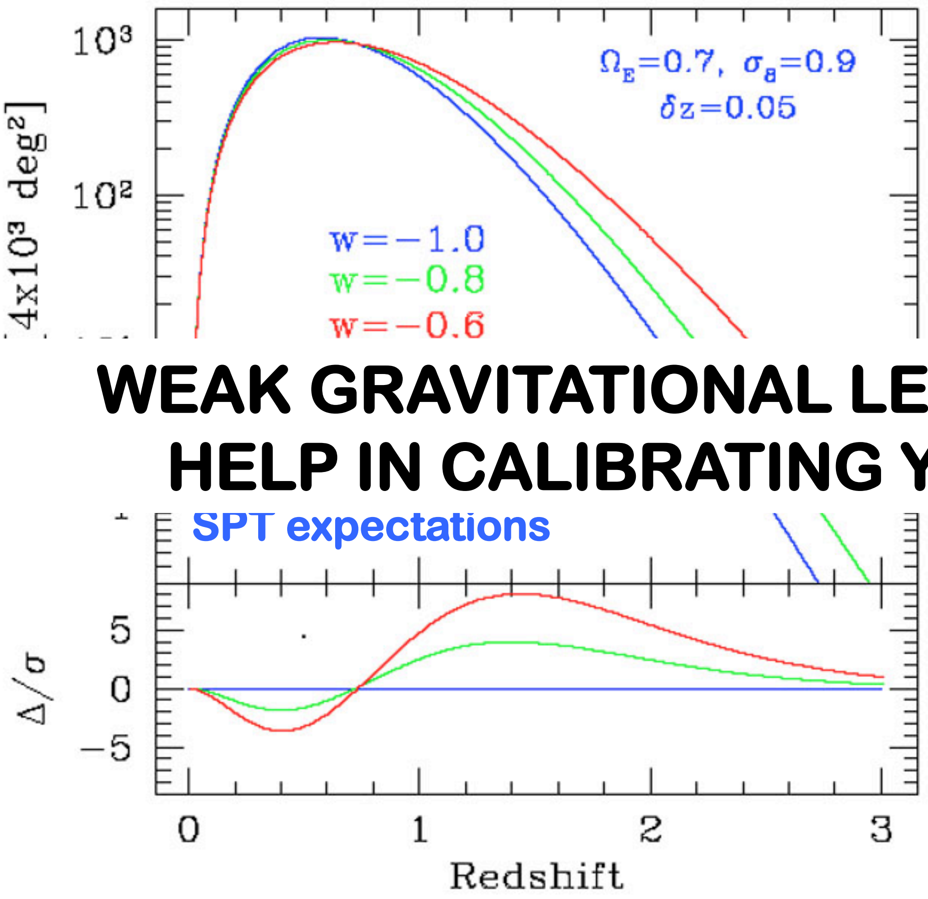
Planck like
with and without heating

ASTROPHYSICAL EFFECTS CAN MIMIC COSMOLOGICAL TRENDS

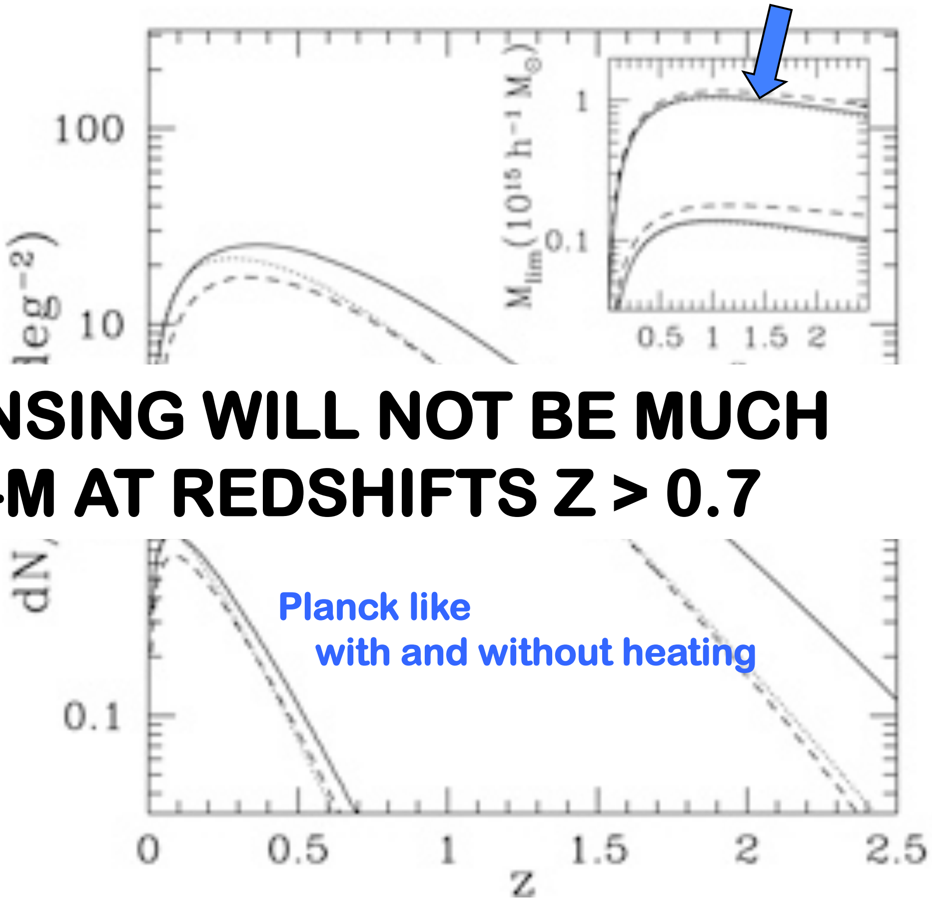
cluster counts: SZE

Frieman et al. 2008
Carlstrom et al. 2002

CLUSTER COUNTS IN SZE SURVEYS



SPT expectations



Planck like

Planck like
with and without heating

WEAK GRAVITATIONAL LENSING WILL NOT BE MUCH HELP IN CALIBRATING Y-M AT REDSHIFTS Z > 0.7

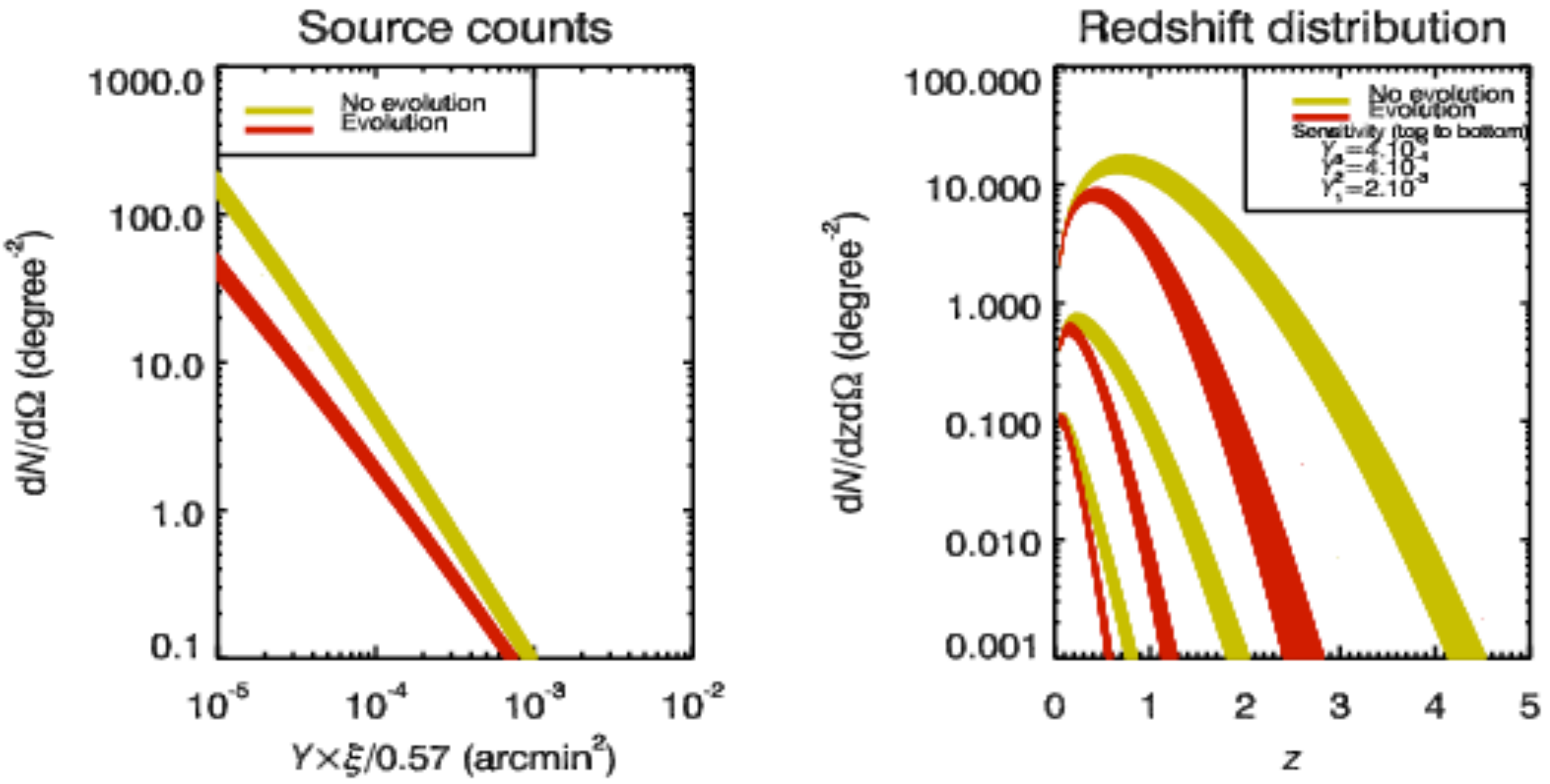
ASTROPHYSICAL EFFECTS CAN MIMIC COSMOLOGICAL TRENDS

cluster counts: SZE

Frieman et al. 2008
Carlstrom et al. 2002

QUANTIFYING EFFECTS OF ASTROPHYSICS VS. COSMOLOGY

REQUIRES GOOD UNDERSTANDING OF THE PHYSICS AND HIGH FIDELITY SIMULATIONS



Source counts

Redshift distribution

Delsart, Barbosa, Blanchard 2010

Canadian Cluster Comparison Project

“it’s good for the masses!”

CCCP

C5

CASCADIA TO CAPE TOWN
COMPUTATIONAL
COSMOLOGY
COLLABORATORY