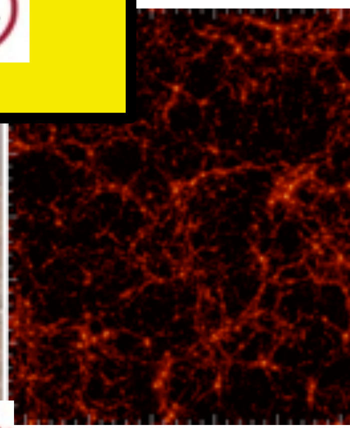
the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

Mar 21 release *ESLAB apr2-5, KITP apr 22-26, 2013*

Sunyaev Zeldovich Theory in the Light of Planck, ACT, SPT cluster observations

CITA ICAT

Dick Bond



CMB@CITA: Boomerang, Acbar, CBI1,2, WMAP, Planck, ACT, Spider, Blast, & ACTpol, ABS, QUIET2;
GBT-Mustang2, CARMA/SZA, SCUBA2, ALMA, CCAT. CMB@CIFAR: these + APEX , SPT, SPTpol, EBEX

Synergy between Clusters & other cosmological probes bond@KITP11

cluster/gp system: since 80s delivered valuable "LSS" constraints

mid-80s Xtra power ξ_{cc} ξ_{cg} => xCDM, x=Λ

P_{pp}(k~1/4h^{-1}Mpc) aka σ_8^{cls} via n_{cl} *major LSS constraint (with shape) on post-COBE.* ***BJ98*** ***CMB+σ_8^{cls}*** *gave* **x=Λ** pre-SN98. & in BOOMerang98+

Use physical observables rather than funneling through halo Mass

i.e., not $n_{cluster}(M_{halo}|z)$ but

$n_{cluster}(Y_{SZ}, M_{lens}, Y_X, L_X, T_X, \sigma_v^2, L_{cl,opt}, Rich, \ldots$ |

z, gold-sample, thresholds)

+ C_L^{SZ}(cuts) +$\xi_{cc}(r|n_{cl})$ +f_{gas}

these all deliver valuable cosmic gastrophysics.

Can they deliver fundamental physics: dark energy EOS?? σ_8 even? primordial non-Gaussianity???

complex systems => theory/obs dispersion/systematics assessment is critical => mock sims for robust measures

Sunyaev-Zeldovich Simulations and ACT, Planck and SPT Cluster Observations

$\rho_g(x,t)$

a~1 now

400 Mpc

ΛCDM

WMAP5

gas density

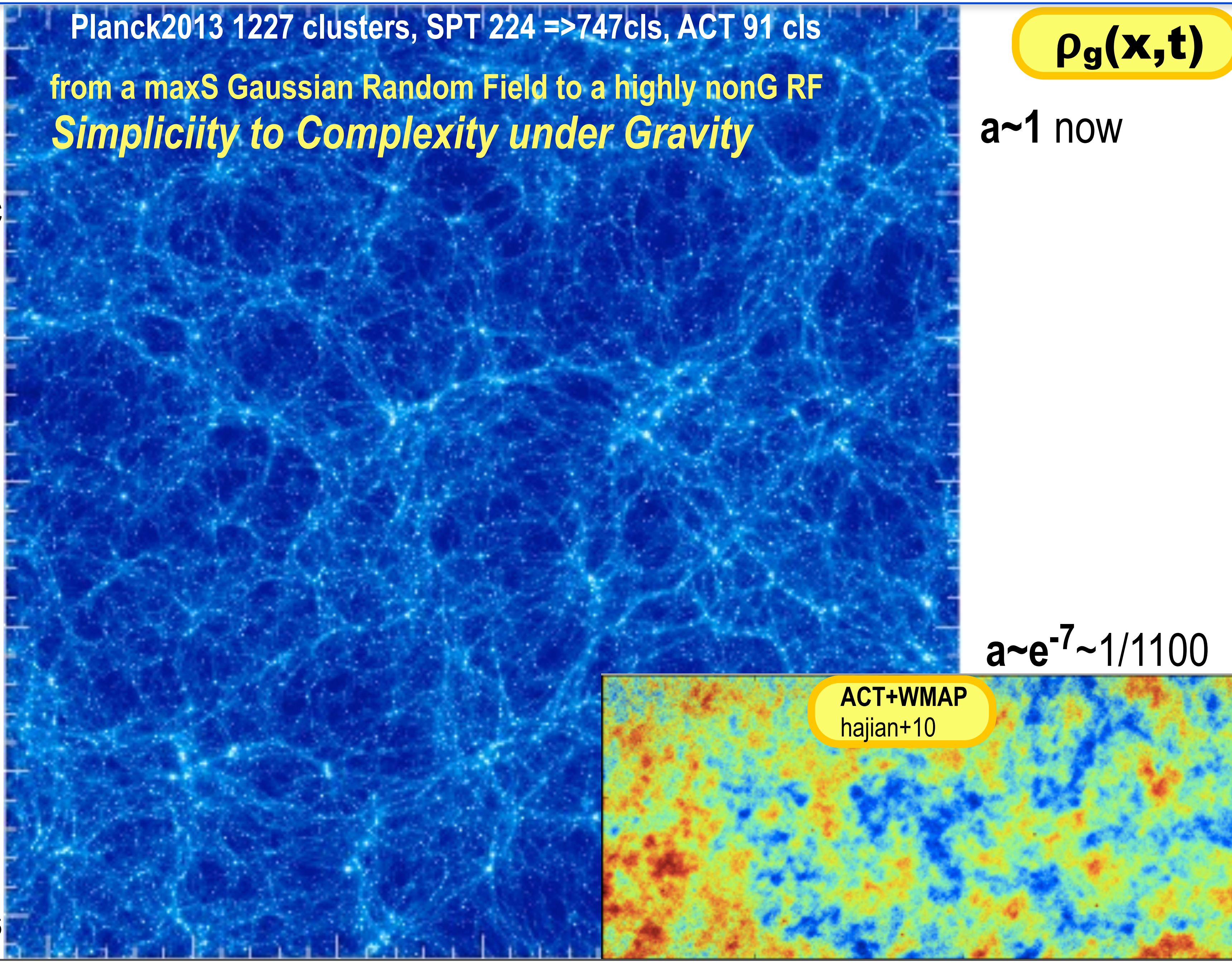
Gadget-3

SF+ SN E+ winds +CRs

512^3

BBPSS10

BBPS1,2,3,4,5



$a \sim e^{-7} \sim 1/1100$

Sunyaev-Zeldovich Simulations and ACT, Planck and SPT Cluster Observations

BBPSS10 BBPS1,2,3,4,5

Hydro Sims include all effects -except of course those not included

(10+10+20 256^3 SPH gas+DM)

(1+1+1 512^3 gas+DM) *ΛCDM + ...*

=> ***Thou Shalt Mock*** *Analytic and semi-analytic treatments cannot intuit the complexity & must be fully calibrated with sims for a useful phenomenology*

turbulent internal bulk flows,

asphericity,

clumping of density & **pressure,**

cosmic web far-field connection thru filaments,

FEEDBACK of Entropy& Energy & Momentum

from stars, black holes, cosmic rays, ...

400 Mpc

ΛCDM

WMAP5

gas density

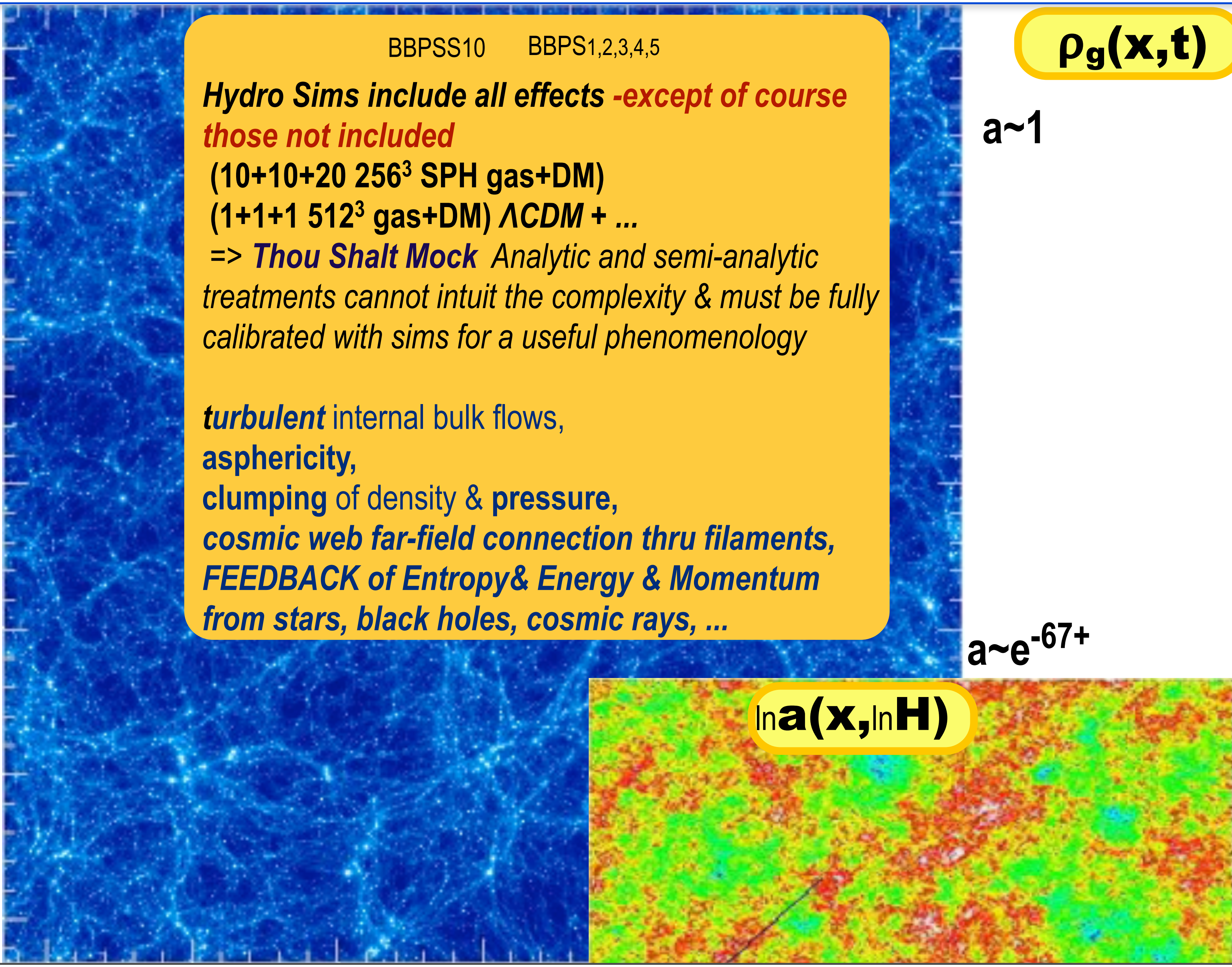
Gadget-3

SF+ SN E+ winds +CRs

512^3

BBPSS10

BBPS1,2,3,4,5



$\rho_g(x,t)$

a~1

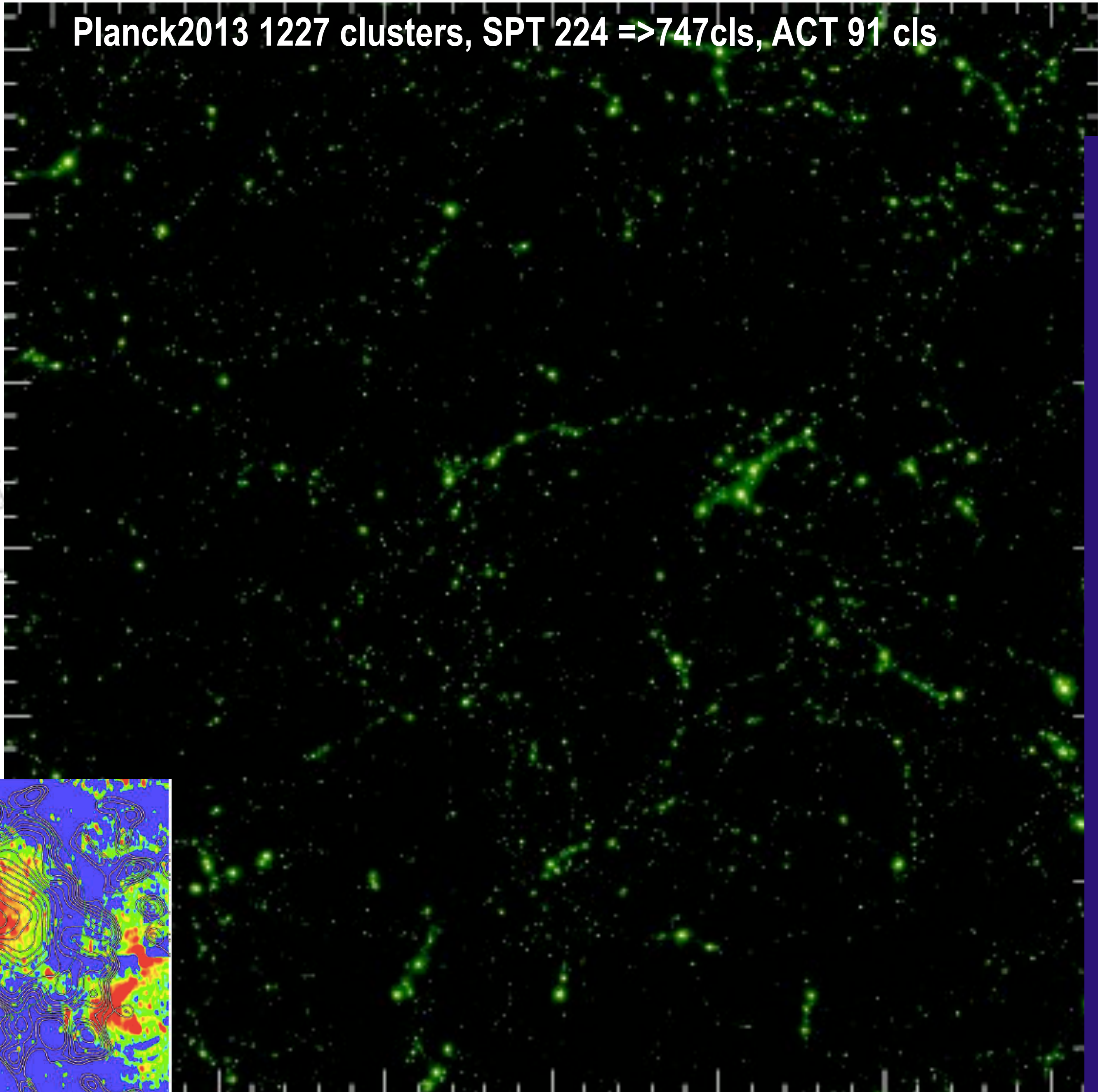
$a \sim e^{-67+}$

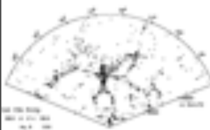
$\ln a(x, \ln H)$

pressure intermittency *in the cosmic web, in cluster-group concentrations probed by* **tSZ**

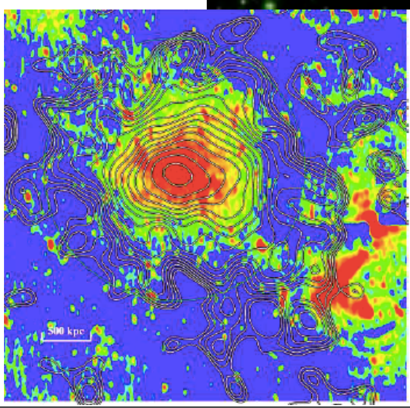
Secondary Anisotropies
(tSZ, kSZ, WL, reion, CIB; hydro)

$p_e(x,t)$





Planck's
Coma
2012.08
pip10



the ***thermal***
Sunyaev
Zeldovich
Probe

$\gamma+e \rightarrow \gamma+e$
Compton
cooling of hot
cosmic web gas

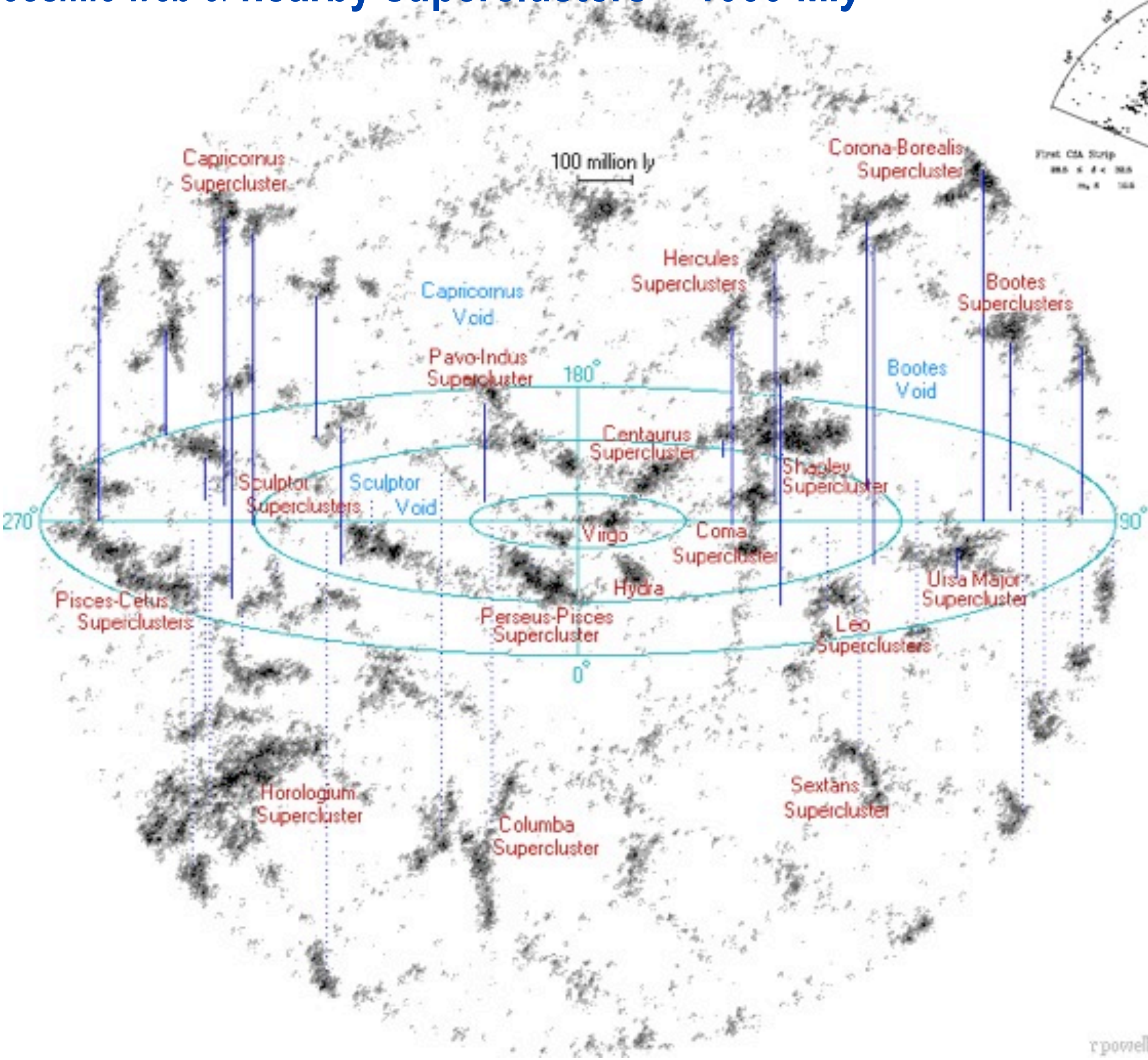
$<\Delta E_\gamma/E_\gamma>$
$=4T_e/m_ec^2$

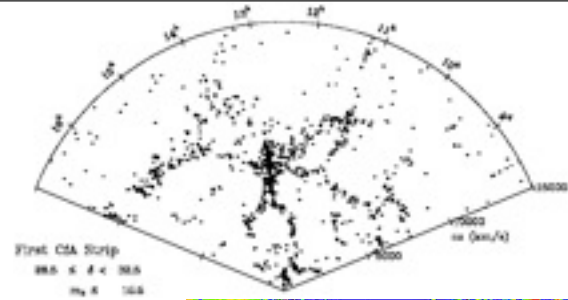
$y = \sigma_T \int p_e$
dline-of-sight

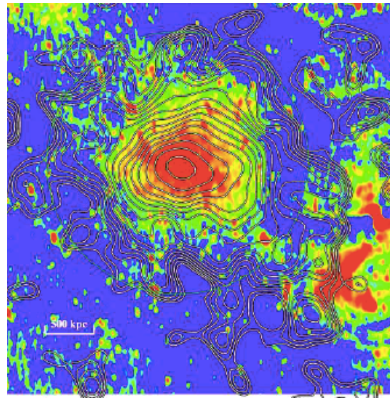
$\Delta T/T = y *$
$(x(e^x+1)/(e^x-1)-4)$,
$x= h\nu/T_\gamma$

$Y_\Delta \sim E_{th} / D_A^2$

cosmic web of **nearby superclusters < 1000 M*ly***





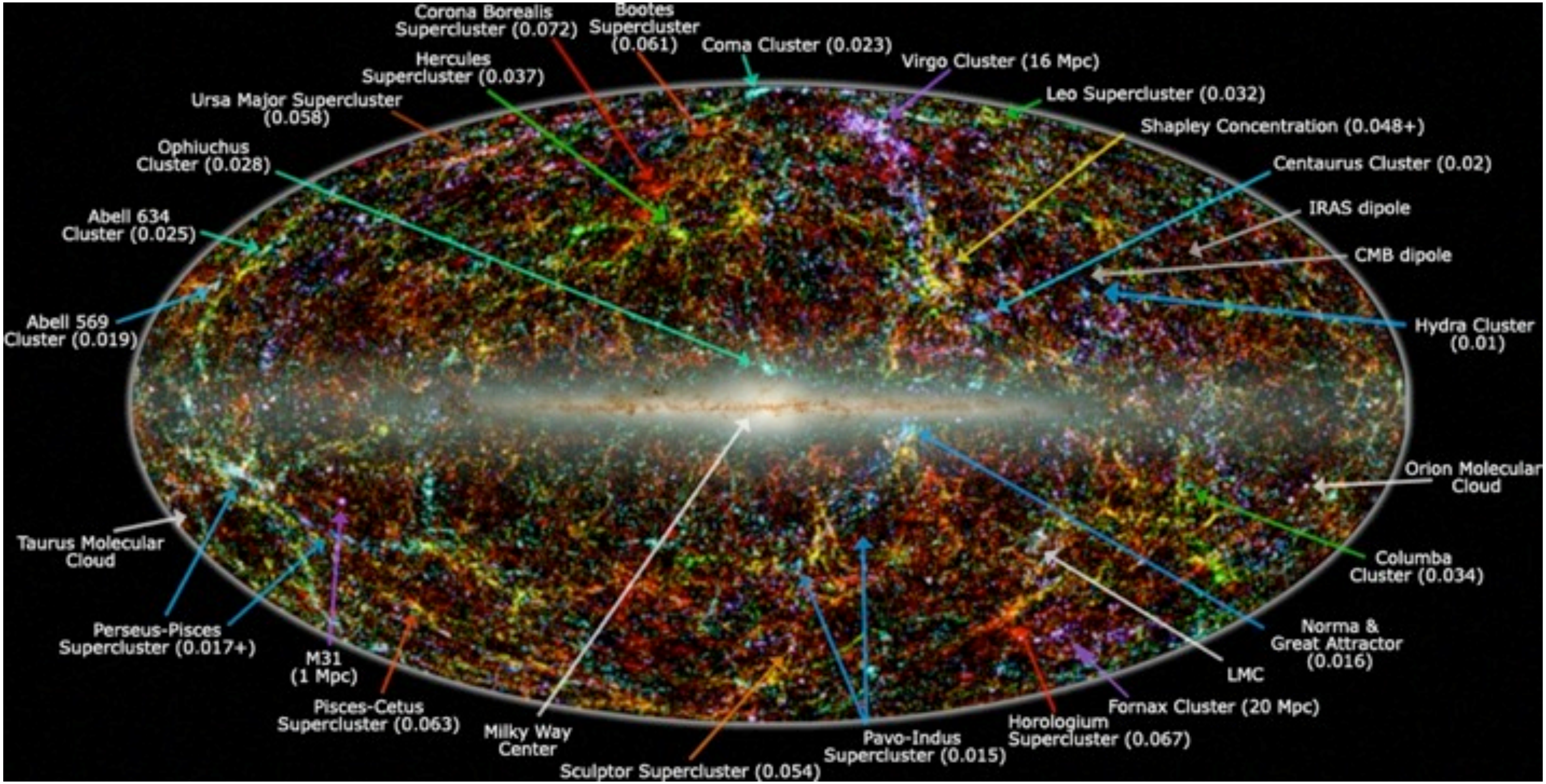


COMA cluster

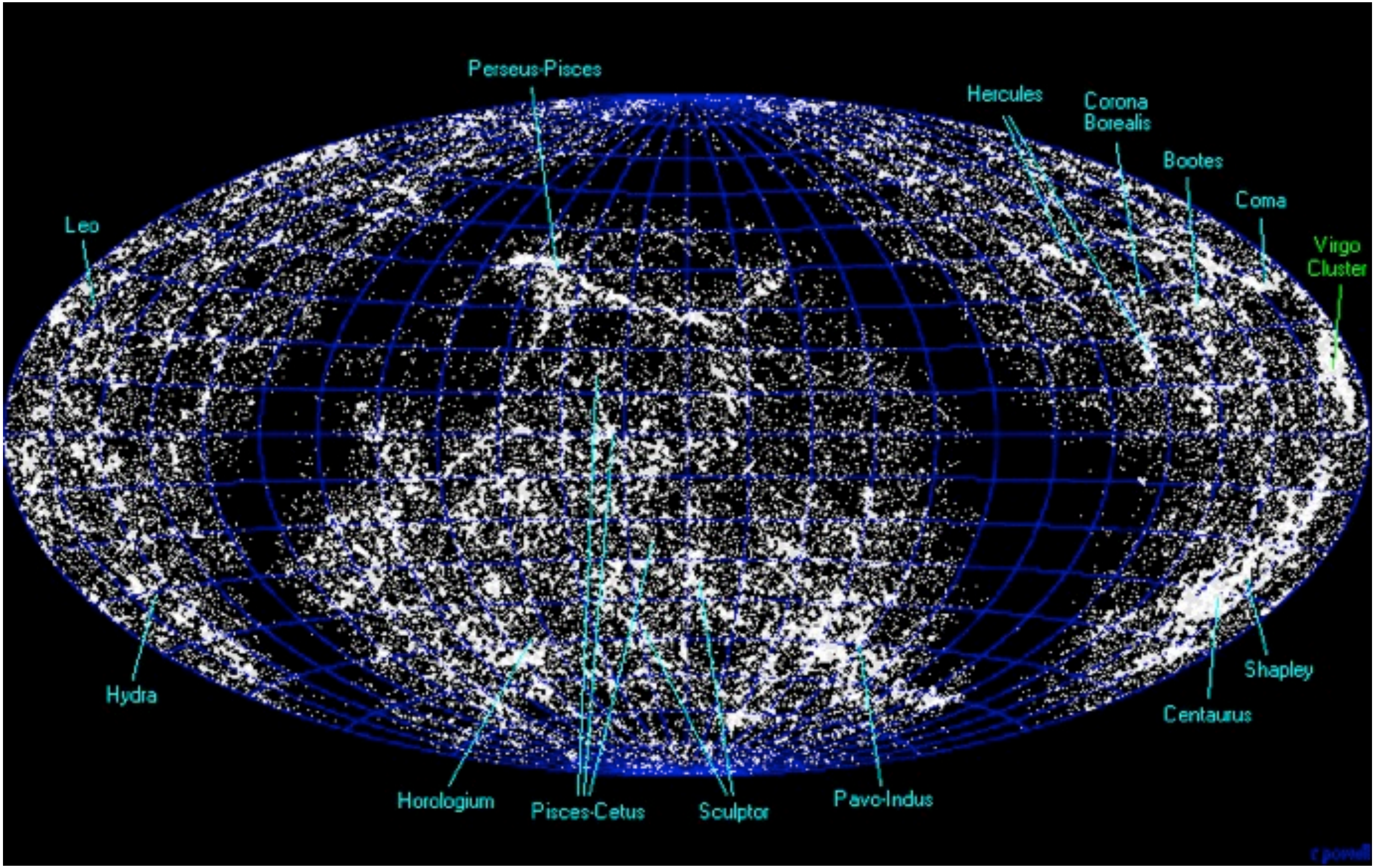
(100 Mpc, z=0.023)

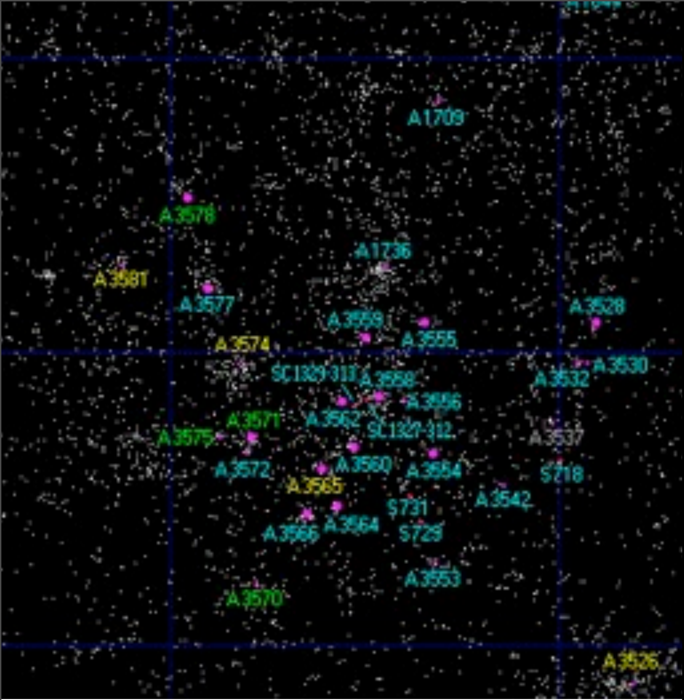
M_{bind}~0.7×10^{15} M⊙

cosmic web of **nearby superclusters** from ***2mass+***



cosmic web of **60000 nearby galaxies**





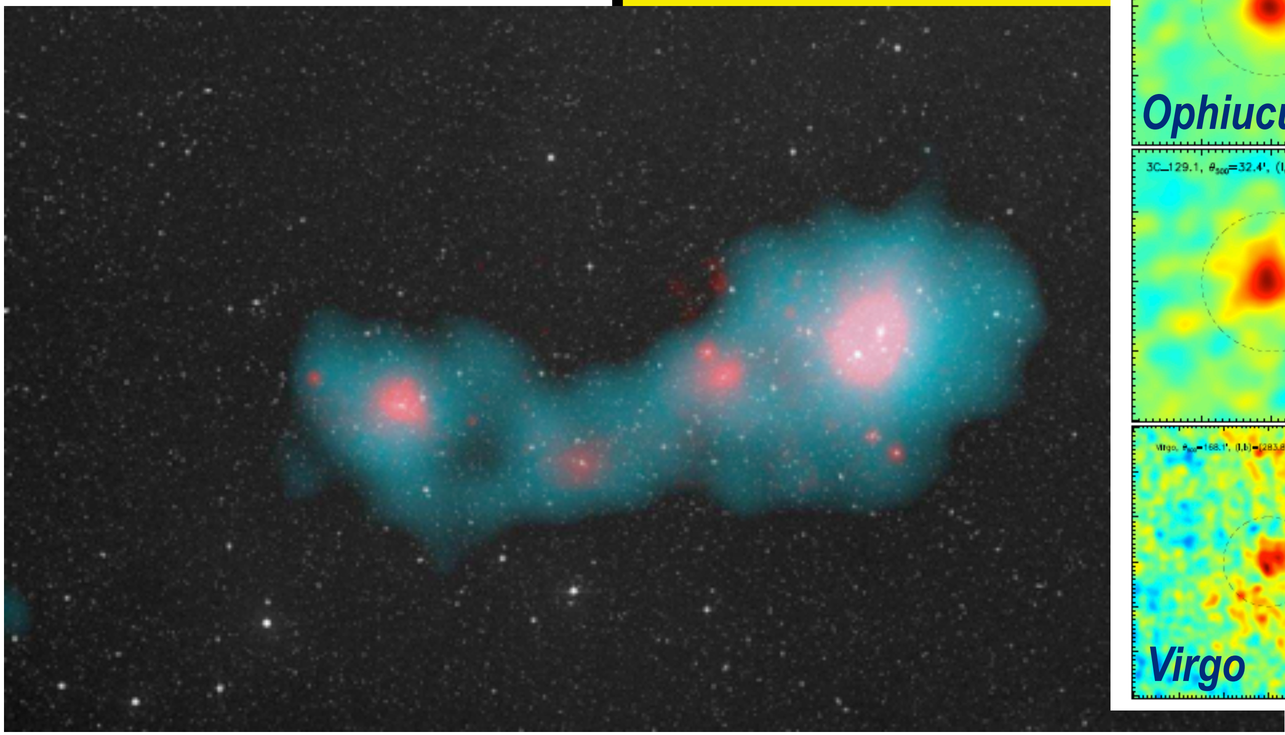
thermal SZ clusters

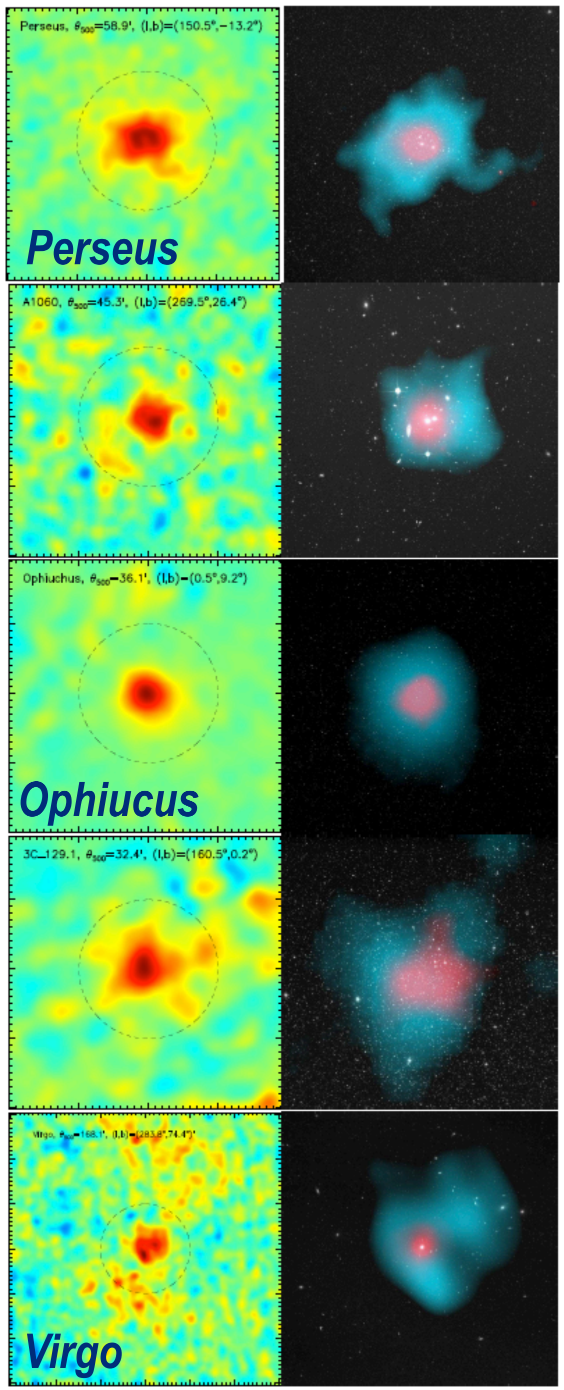
some nearby well-known clusters from Perseus to Virgo

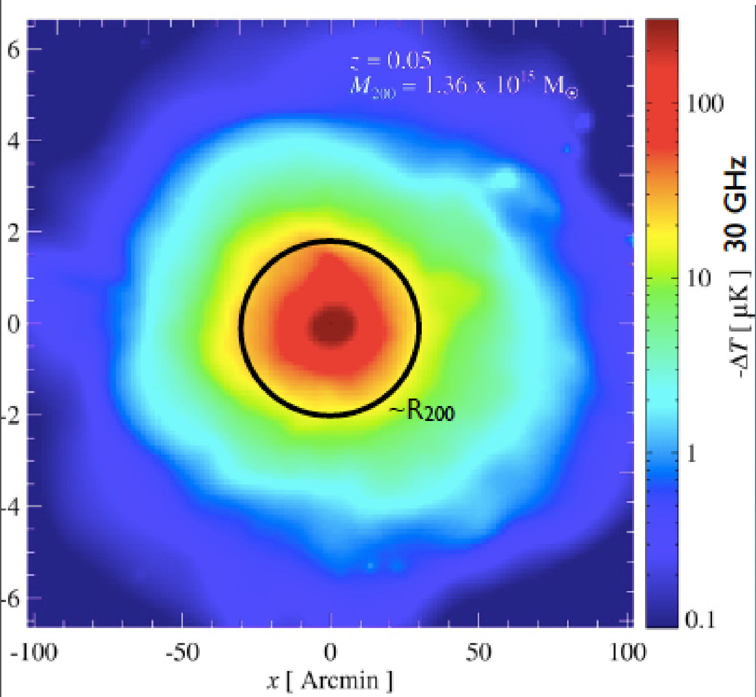
Shapley Supercluster

<overdensity> ~5

M ~$10^{16.8}$ $M_{\odot}$



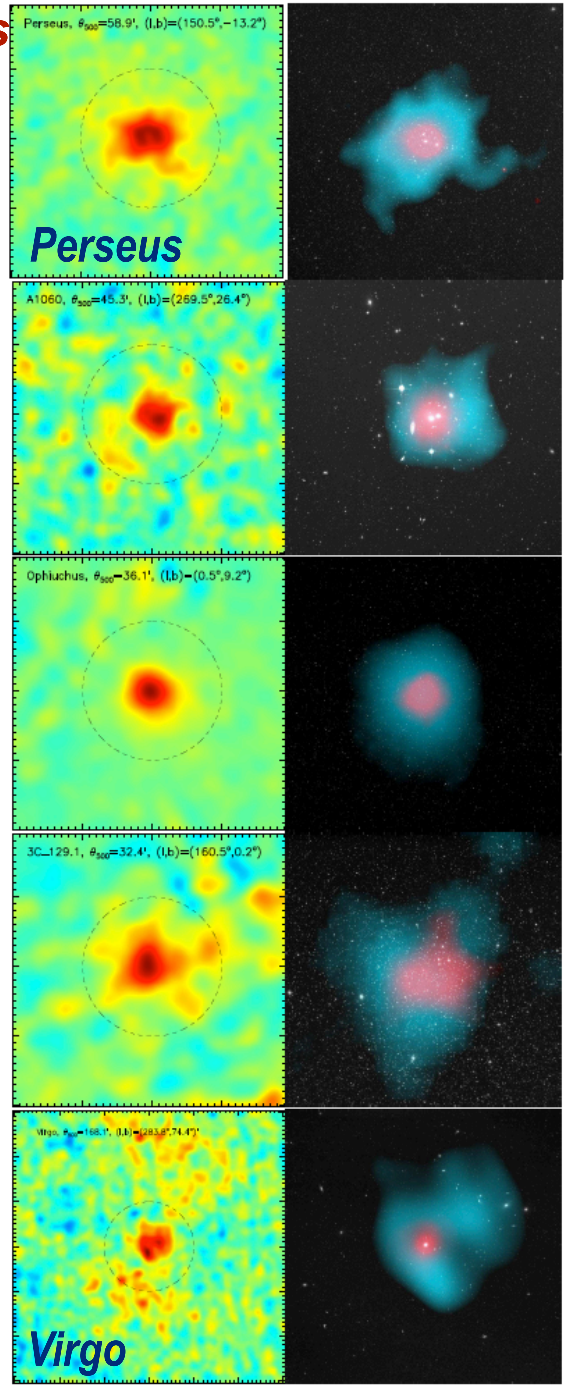




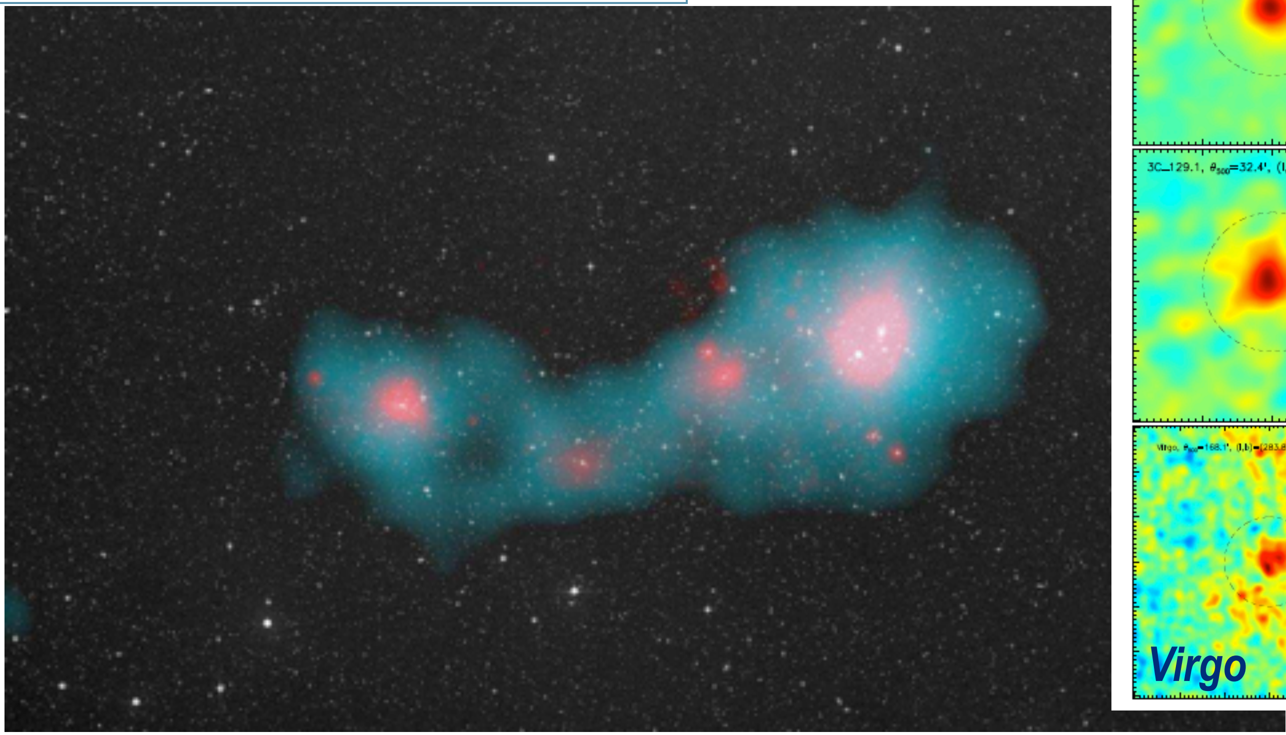
thermal SZ clusters

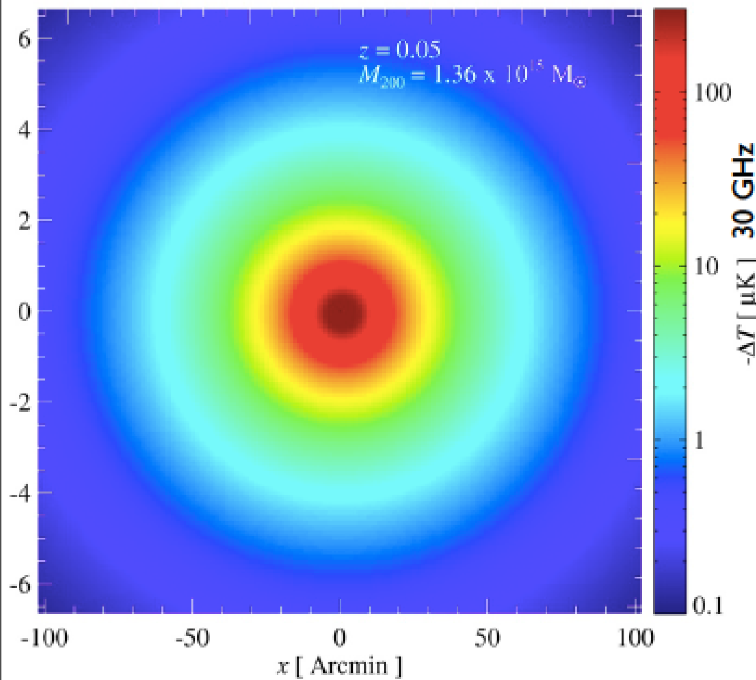
some nearby well-known clusters
from
Perseus to Virgo

cf. gastrophysical simulations



Shapley Supercluster





thermal SZ clusters

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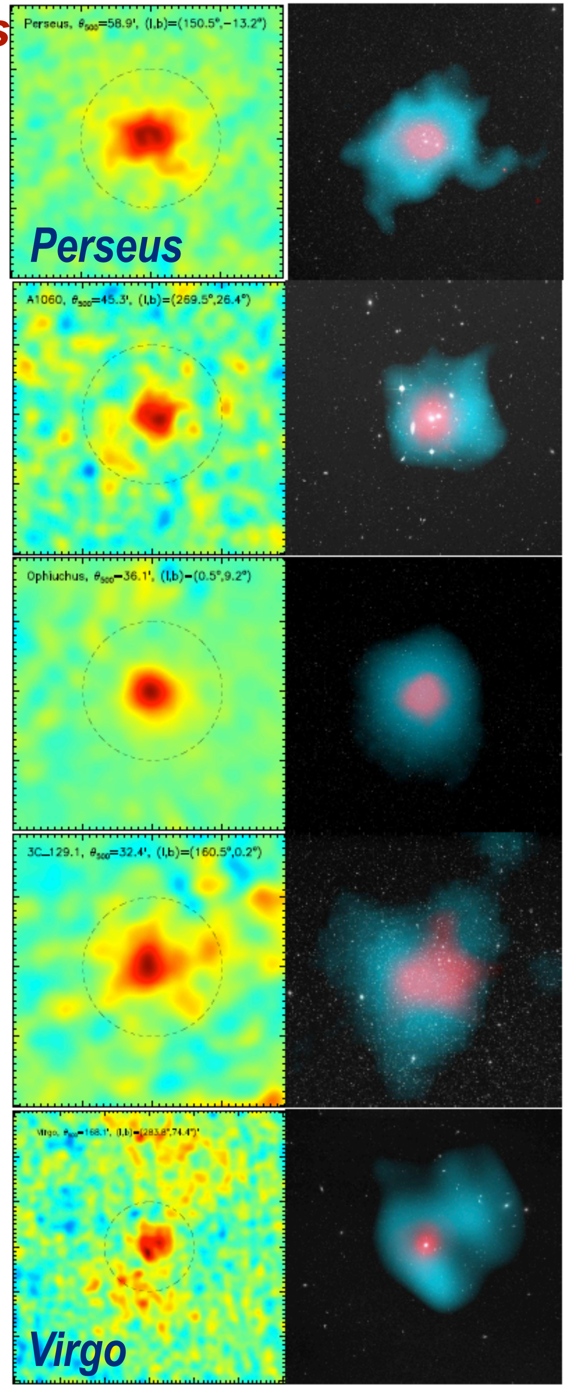

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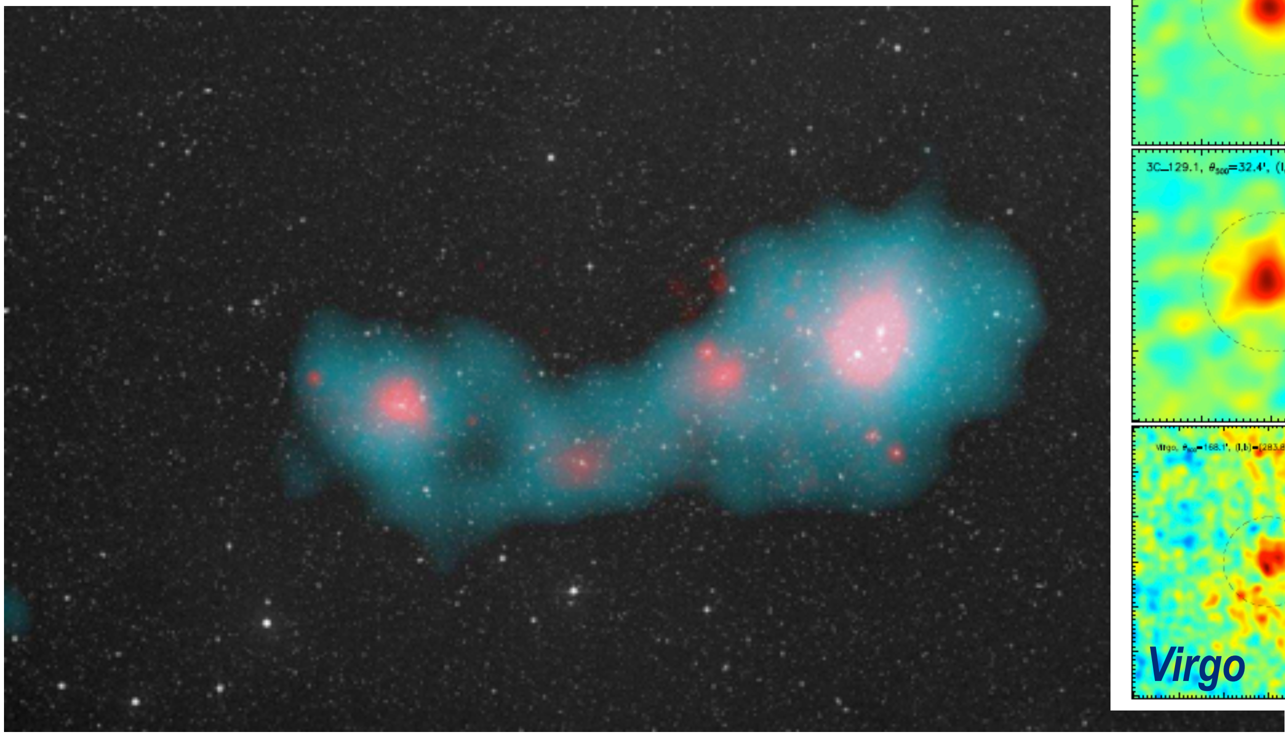

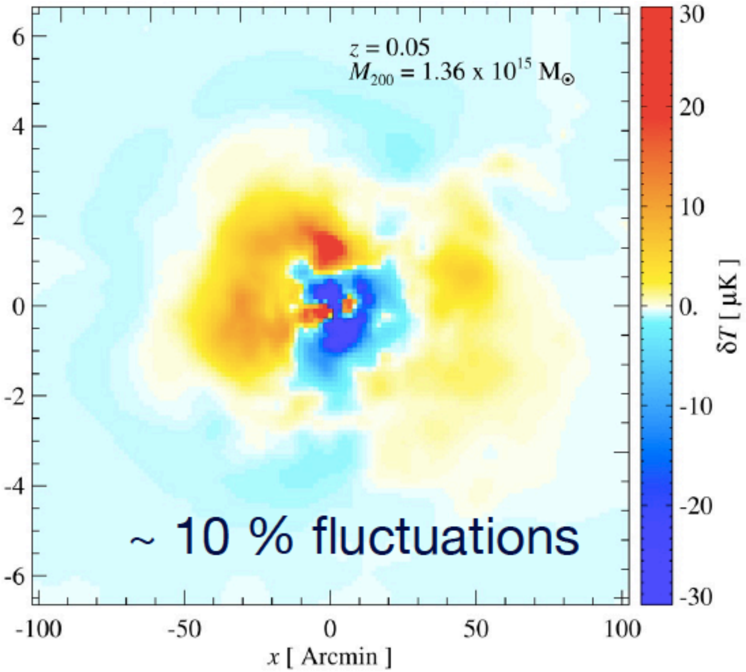

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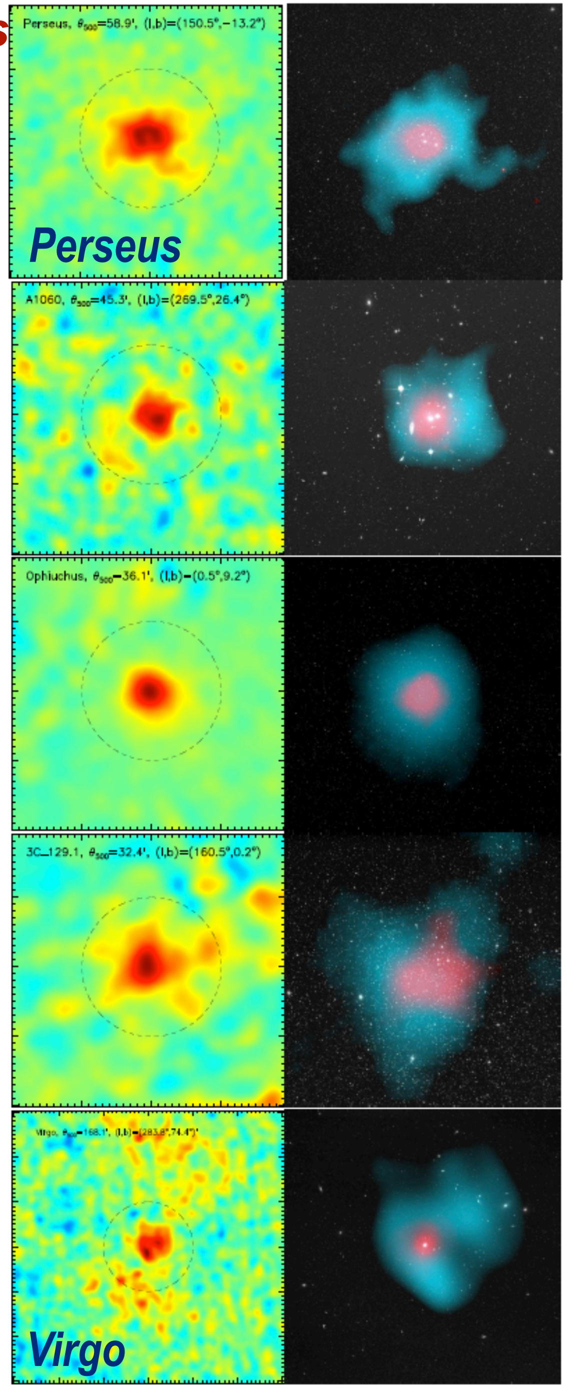

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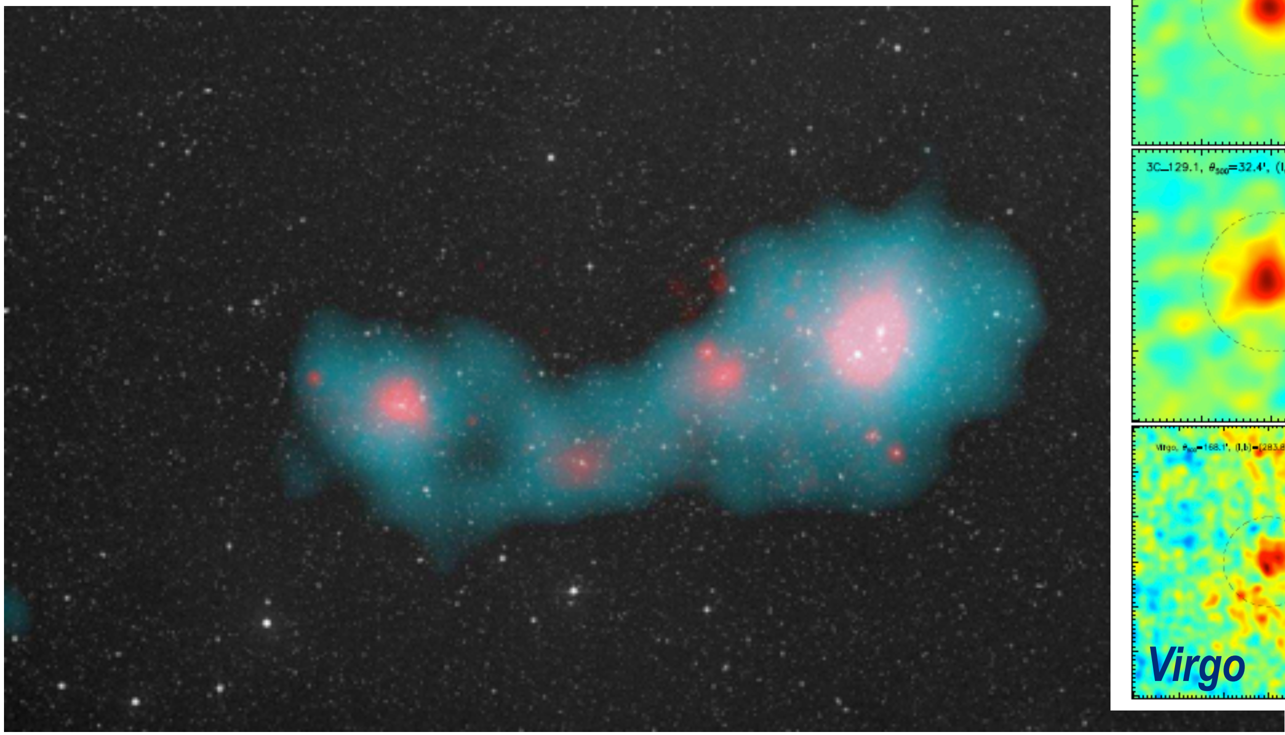

Planck 2012: neo "universal" pressure profile, via SZ from 62 nearby massive cls +Coma

Planck Intermediate Results. ***V. Pressure profiles of galaxy clusters** from the **Sunyaev-Zeldovich effect***

Planck intermediate results. ***X. Physics of the hot gas in the Coma cluster*** ***PUPPY***

$y=\sigma_T \int p_e\, d\text{line-of-sight}$

$\Delta T/T = y * (x(e^x+1)/(e^x-1)-4)$,

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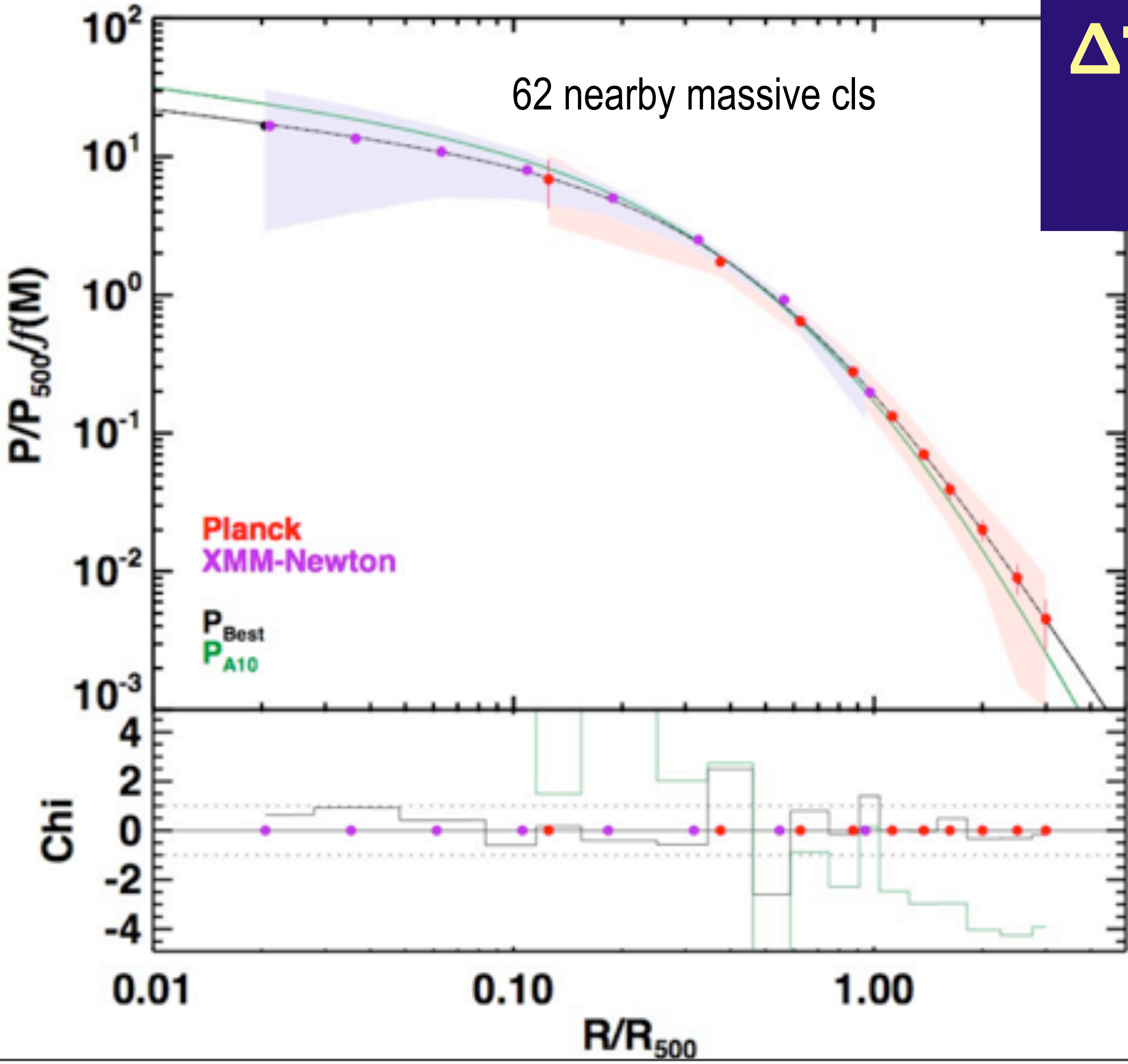
$Y_\Delta \sim E_{th} / D_A^2$



X-ray "universal pressure profile" (Arnaud+10) fails $>R_{500}$

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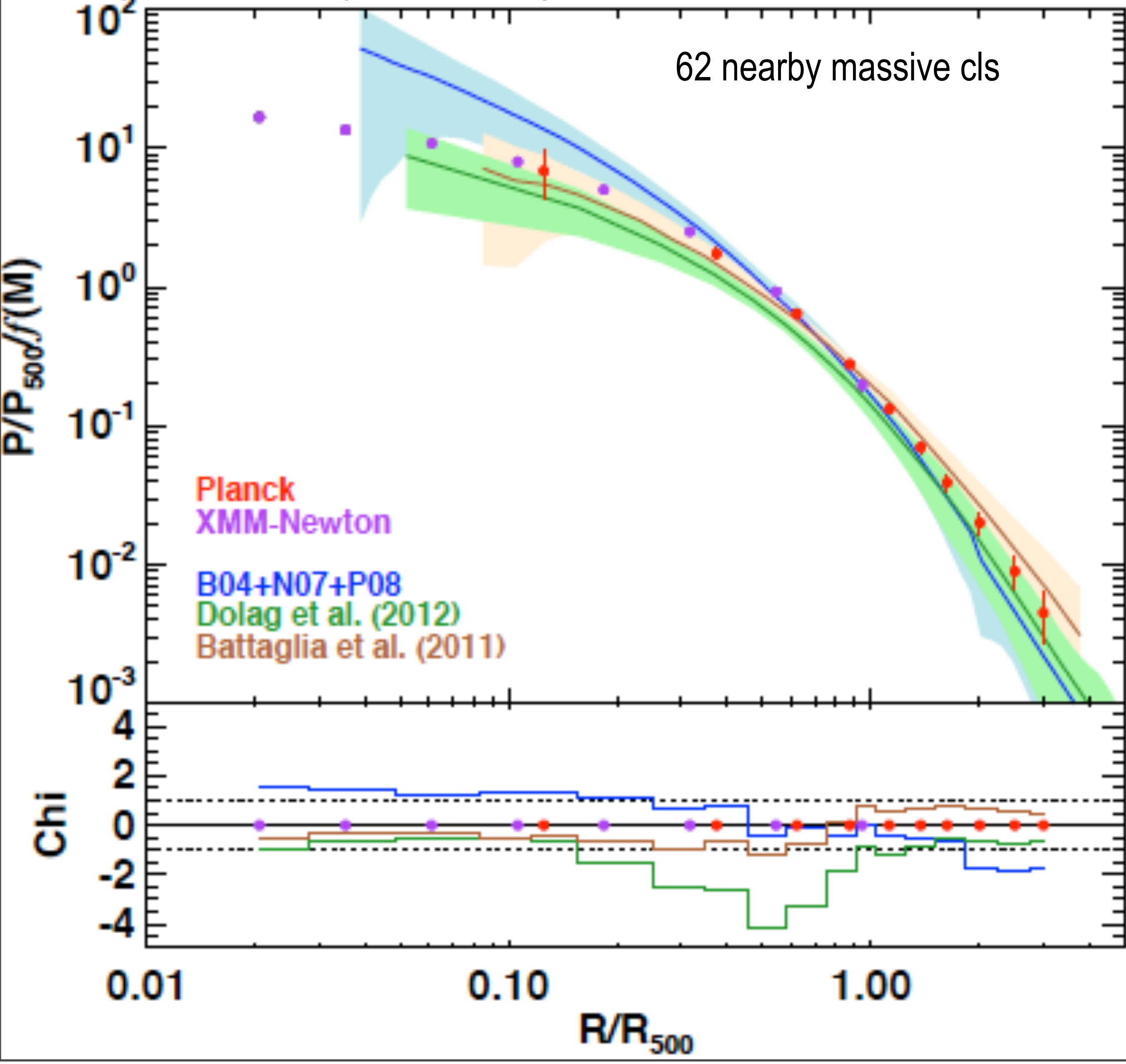
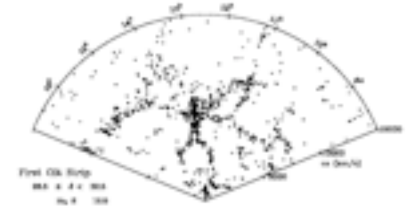
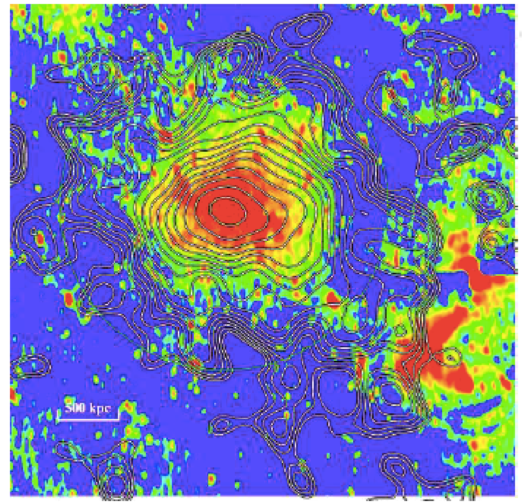






X-ray "universal pressure profile" (Arnaud+10) fails >R_{500}

BBPSS11, BBPS12 **AGN feedback pressure profiles fit > R_{500} SZ data better than other hydro sims. nearly "universal"(M,z)**

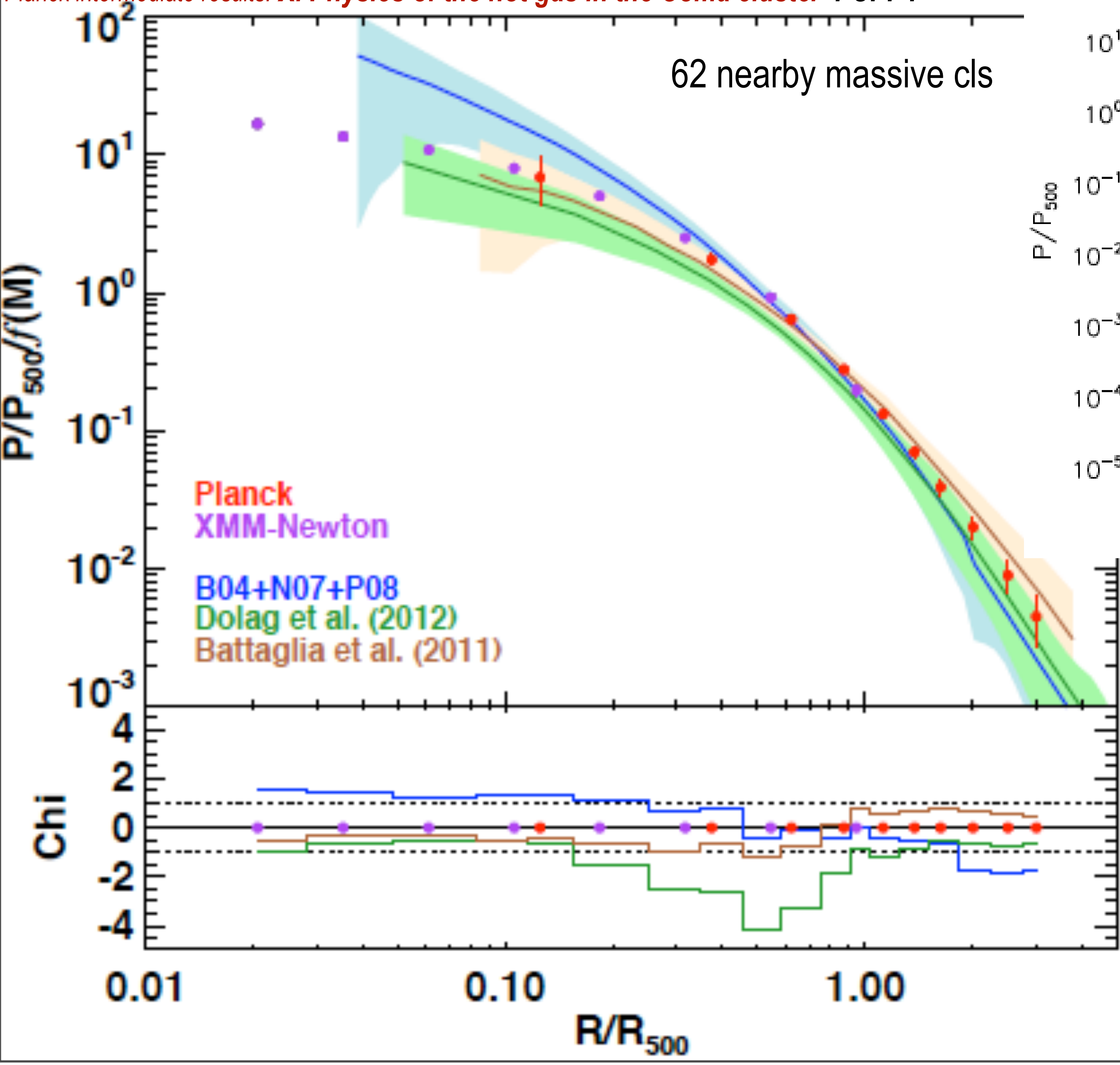
pressure clumping

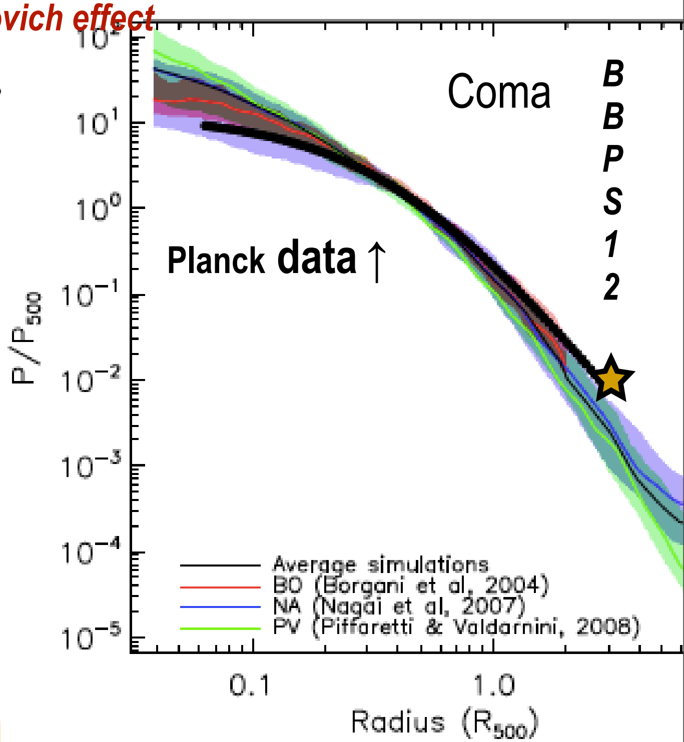
R_{500} ↑ 3 R_{500} => $\delta p/p$ ~0.2 ↑ ~1

Planck 2012: neo “universal” pressure profile, via SZ from 62 nearby massive cls +Coma

Planck Intermediate Results. ***V. Pressure profiles of galaxy clusters from the Sunyaev-Zeldovich effect***

Planck intermediate results. ***X. Physics of the hot gas in the Coma cluster*** ***PUPPY***





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BBPSS11, BBPS12 **AGN feedback pressure profiles fit > R_{500} SZ data better than other hydro sims. nearly “universal”(M,z)**

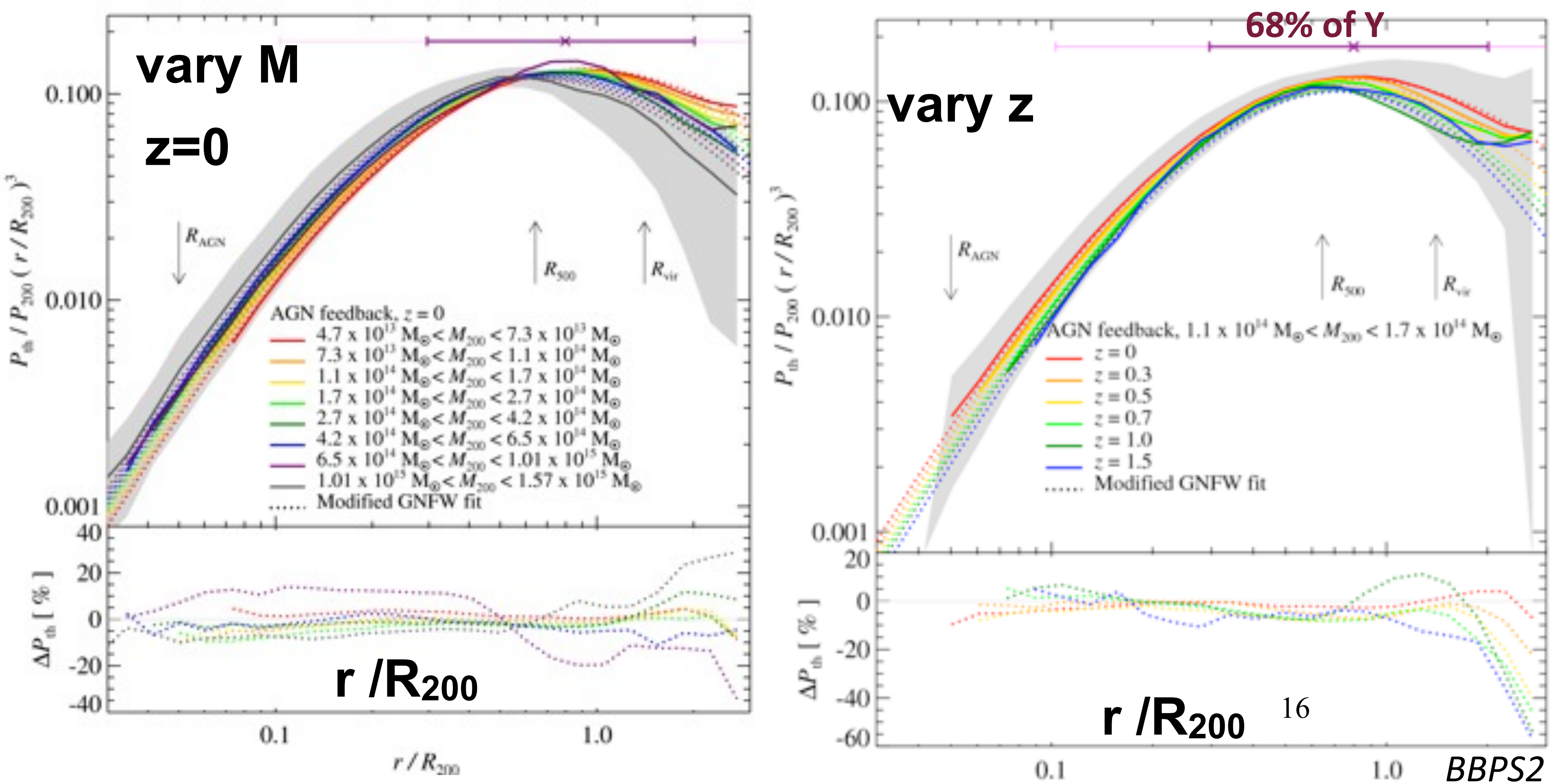
pressure clumping
R_{500} ↑ 3 R_{500} => $\delta p/p$ ~0.2 ↑ ~1

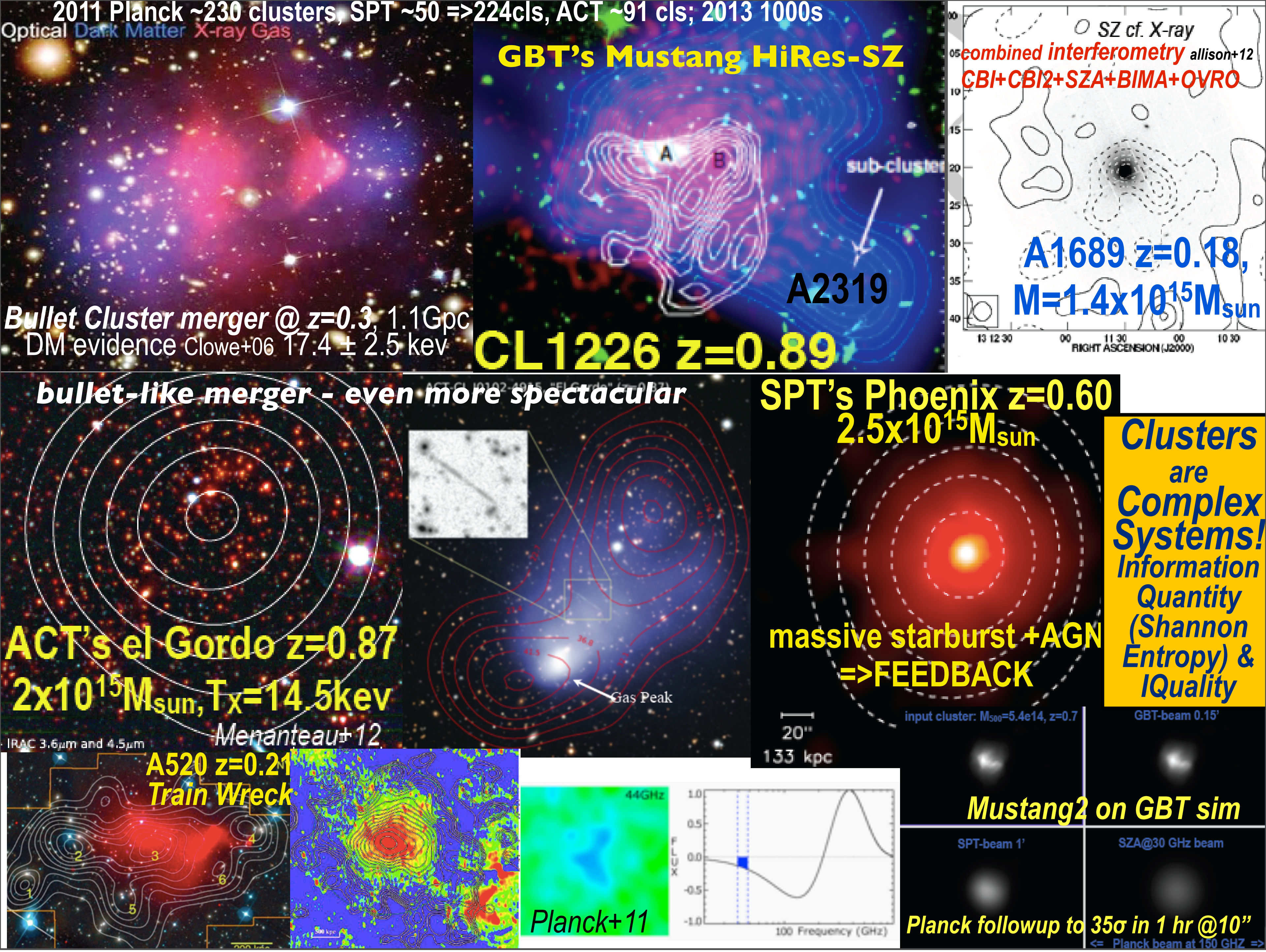
Universal Pressure profile: d*ln* E_{th}(<r)/d*ln* r

& cluster ENTROPIES: coarse-grained information **Universal Entropy Profile?** *sort of, but inference from observations is difficult*

GNFW-fit(M,z) accuracy <10%

extends Arnaud universal profile PUPPY




2011 Planck ~230 clusters, SPT ~50 =>224cls, ACT ~91 cls; 2013 1000s
Optical Dark Matter X-ray Gas
Bullet Cluster merger @ z=0.3, 1.1Gpc
DM evidence Clowe+06 17.4 ± 2.5 kev
GBT's Mustang HiRes-SZ
A
B
sub-cluster
A2319
CL1226 z=0.89
SZ cf. X-ray
combined interferometry allison+12
CBI+CBI2+SZA+BIMA+OVRO
A1689 z=0.18,
M=1.4x10^15 M_sun
RIGHT ASCENSION (J2000)
bullet-like merger - even more spectacular
ACT's el Gordo z=0.87
2x10^15 M_sun, Tx=14.5kev
Menanteau+12
IRAC 3.6μm and 4.5μm
Gas Peak
SPT's Phoenix z=0.60
2.5x10^15 M_sun
massive starburst +AGN
=>FEEDBACK
20"
133 kpc
Clusters
are
Complex
Systems!
Information
Quantity
(Shannon
Entropy) &
IQuality
A520 z=0.21
Train Wreck
44GHz
Planck+11
FLUX
100 Frequency (GHz)
input cluster: M500=5.4e14, z=0.7
GBT-beam 0.15'
Mustang2 on GBT sim
SPT-beam 1'
SZA@30 GHz beam
Planck followup to 35σ in 1 hr @10"
<= Planck beam at 150 GHZ =>

non-thermal/non-equilibrium effects:

Summary: the **running** with $\mathbf{r/R_{200}}$ ***aka resolution*** (e.g., $d\ln E_{th}(<r)/d\ln r$) *of effects influencing* $\mathbf{Y_{SZ500}(M)}$ & C_L^{tSZ} for low & high **M** @ z=0, 1

turbulent internal bulk flows $\mathbf{P_{kin}/P_{th}}$

asphericity 1-c/a gas cf. DM

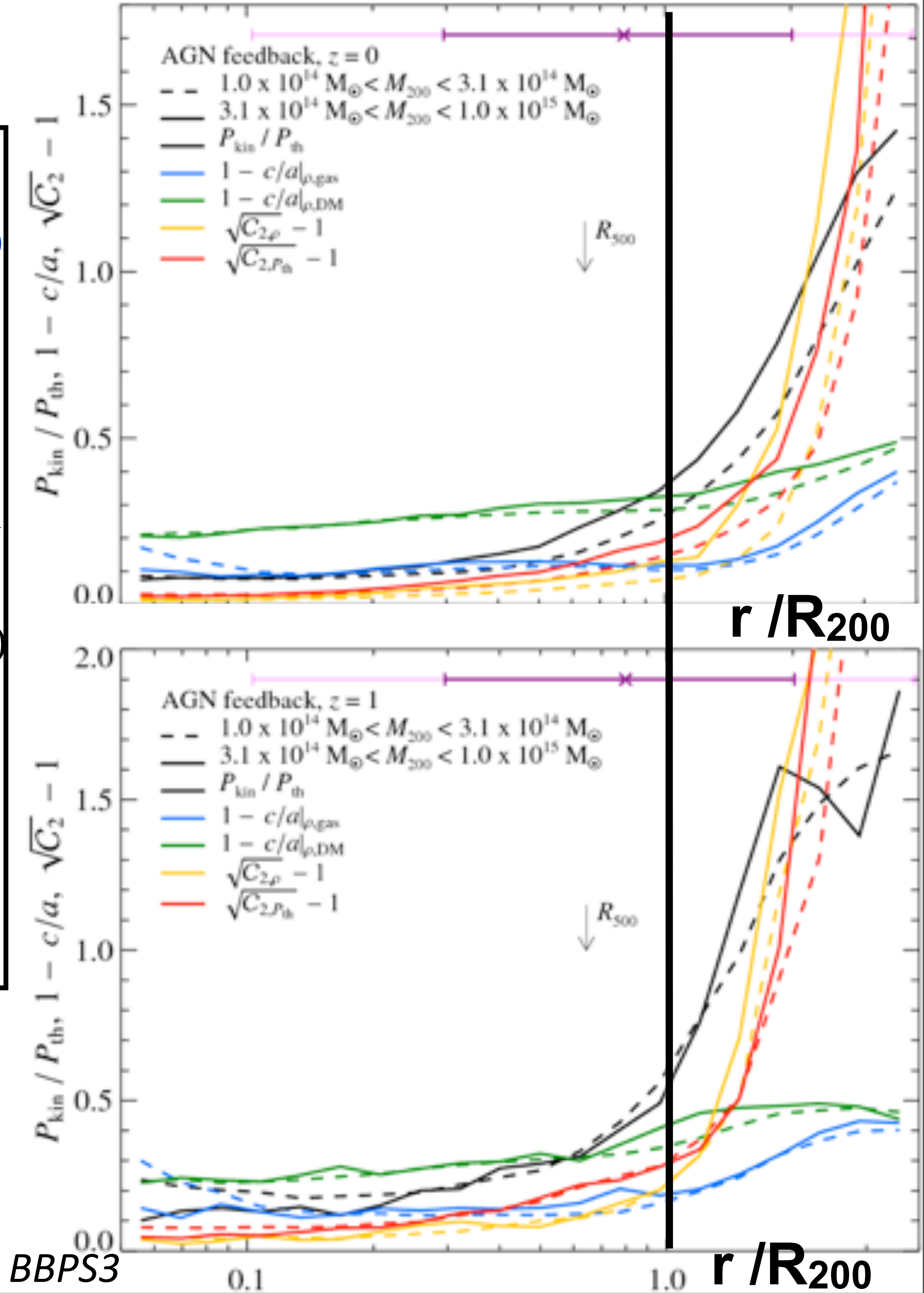
clumping of density & **pressure** (!)

$C_{p2}^{1/2}-1 = \mathrm{sqrt}[\langle p_{th}^2\rangle/\langle p_{th}\rangle^2]-1$

aka Renyi entropy of order 2

not small @ < $\mathbf{R_{500}}$

huge @ < $\mathbf{R_{200}}$ < $\mathbf{R_{vir}}$ < $\mathbf{R_{SZboundary}}$



CBI pol to Apr'05 @Chile **CBI2**

53+35 cls **(>=40)**

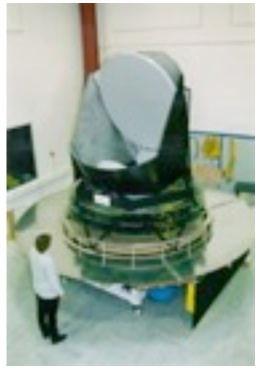
thermal SZ clusters

QUaD @SP

230 cls => 1227

Planck09.4

52+ bolometers
+ HEMTs @L2
9 frequencies



WMAP @L2 **to 2010**

2004 2006 2008 **LHC** 2011 **Bpol** @L2

2005 2007 224 (=> **747)** 2009

>96
OVRO /BIMA array
38 cls

80s-90s
Ryle
OVRO

Acbar@SP
~1 blind

SZA@Cal
3 cls (z>1), x?

AMI
7+1 cls >=50+25

GBT Mustang
4 cls (~25 CLASH)

AMIBA
6 cls

APEX
~400 bolos@Chile
~25 cls

SPT
1000 bolos
@SPole

ACT **23+68~91 cls**
3000 bolos
3 freqs @Chile

SCUBA2
12000 bolos
JCMT @Hawaii

SPTpol
ACTpol
ALMA
CCAT@Chile
LMT@Mexico

CBI **pol to Apr'05** @Chile **CBI2**

53+35 cls **(>=40)**

thermal SZ clusters

QUaD @SP

230 cls => 1227

Planck09.4

Planck PSZ, cnts, ymap

861 confirmed, 178 by Planck + 683 known, **most z<.4,**

many ~ $10^{15}M_{sun}$ *0.<z<0.8*

52+ bolometers
+ HEMTs @L2
9 frequencies

WMAP @L2 **to 2010**

2004 2006

2005 2007

Reichardt+12, Benson@ESLAB13
***100 cl cosmology*, 400 with S/N > 5**
now, 747 summer 2013 *2500 deg²*

224 (=> **747**)

SPT
1000 bolos
@SPole

Menanteau+12, Hasselfield+12
ACT Celestial Equator cls, 68 (49+19 in SDSS, half z>.5, 1 z~1.1 $10^{15}M_{sun}$
502 sq deg =>*91* in *952 deg², 0.1<z<1.3*

100% purity for S/N>5. 60% > 4.5

No significant evidence of SZ/BCG offset
M_{SZ}-N_{200} weak correlation, large scatter

Acbar@SP
~1 blind

AMIBA
6 cls

>96

OVRO /BIMA array
38 cls

SZA@Cal
3 cls (z>1), x?

ACT
23+68~91 cls
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~400 bolos@Chile
~25 cls

80s-90s
Ryle
OVRO

GBT Mustang
4 cls (~25 CLASH)

SCUBA2
12000 bolos
JCMT @Hawaii

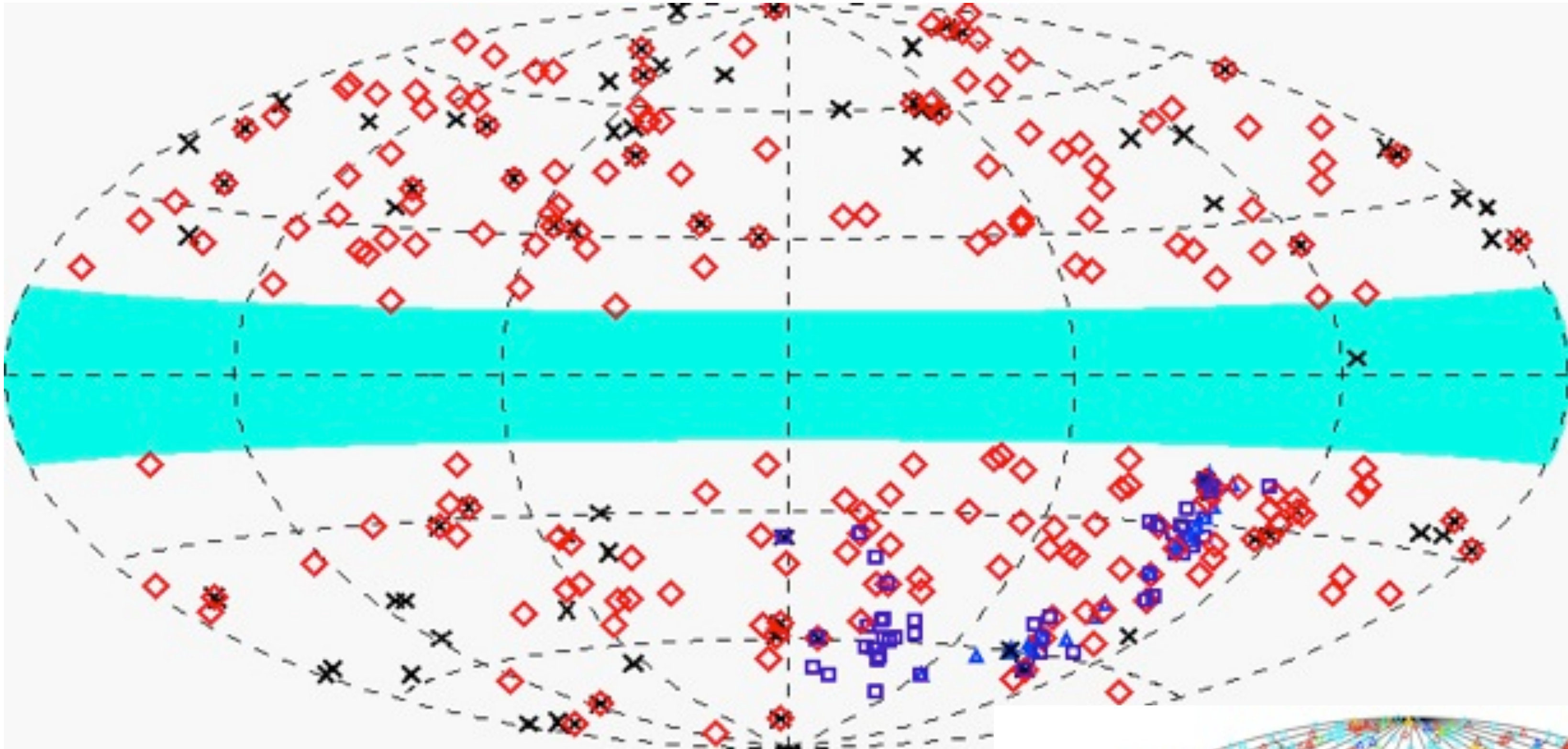
SPTpol
ACTpol
ALMA
CCAT@Chile
LMT@Mexico

Friday, 26 April, 13

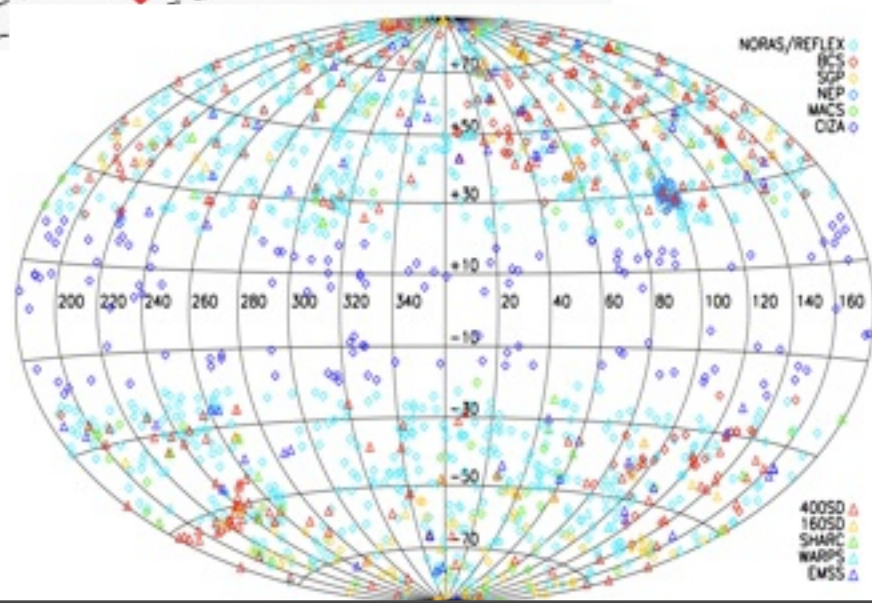
thermal SZ clusters

Planck ESZ + prior-SZ*: 189 => 200 clusters*

plus compilation of first generation SZ clusters *(Douspis et 11)*

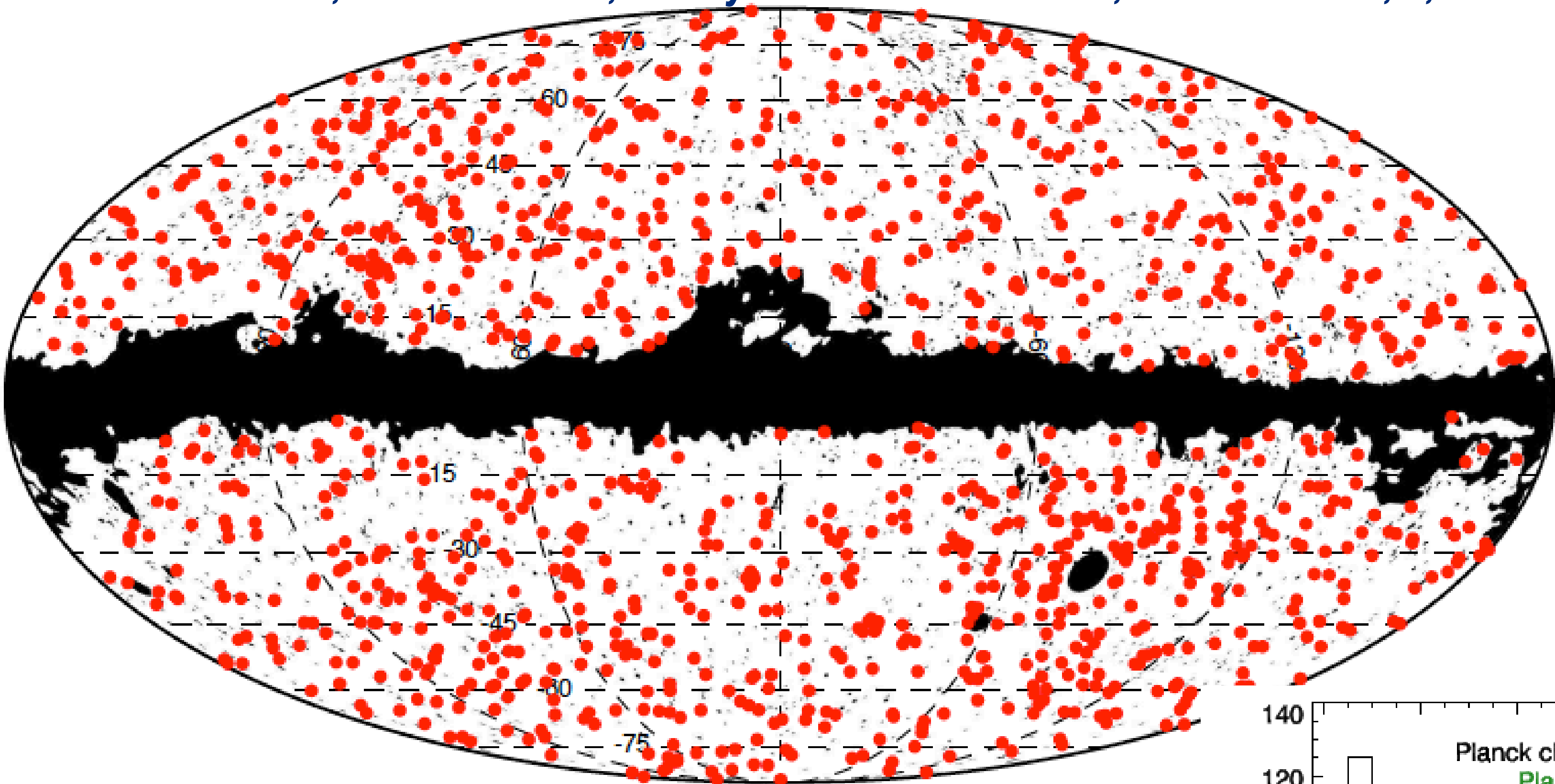


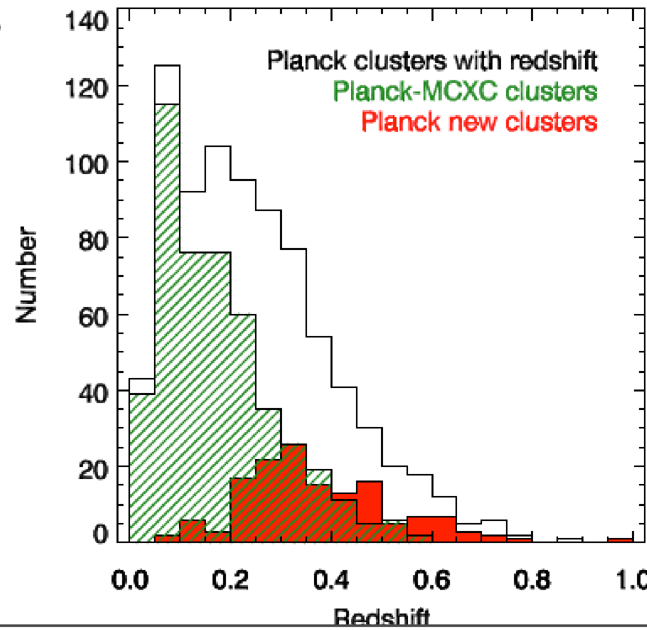
All-sky distribution of MCXC clusters ~1600 *(Piffaretti et 10)*



thermal SZ clusters

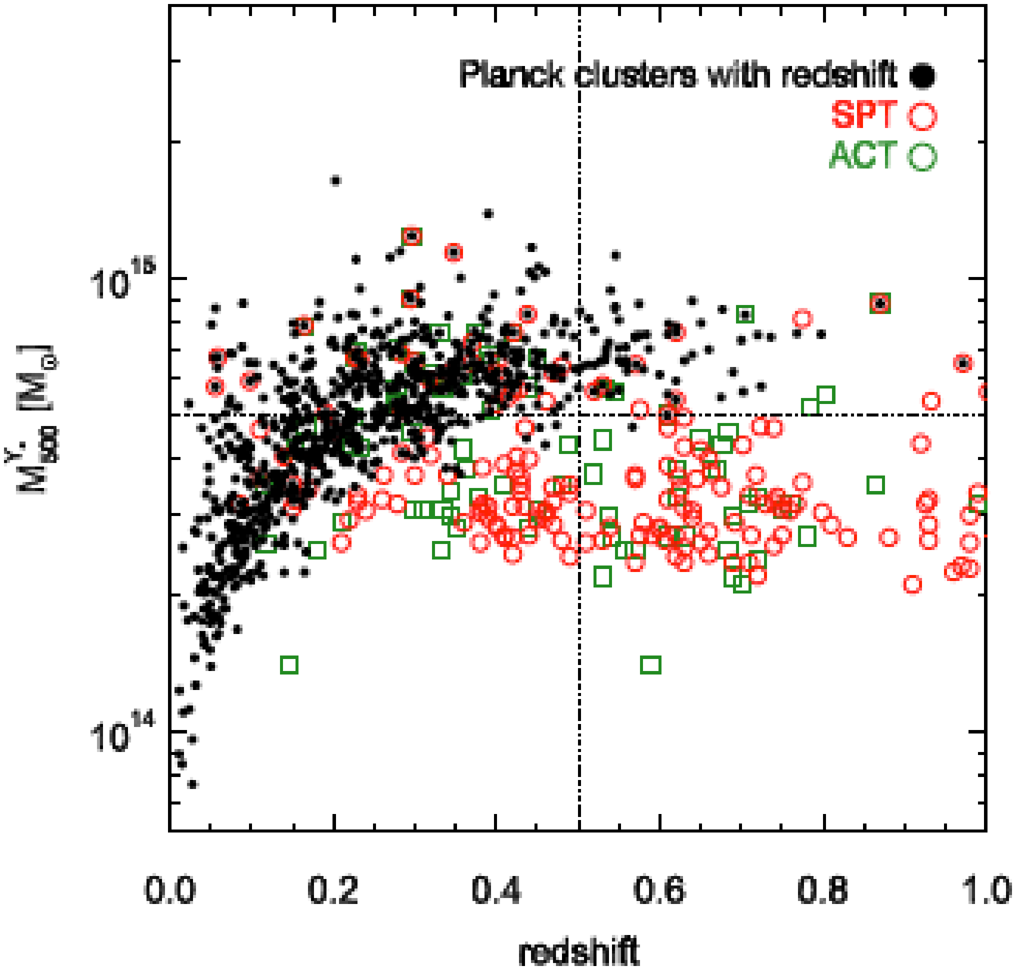
PSZ: 1227 clusters, 861 confirmed, 178 by Planck + 683 known, rest in class 1, 2, 3



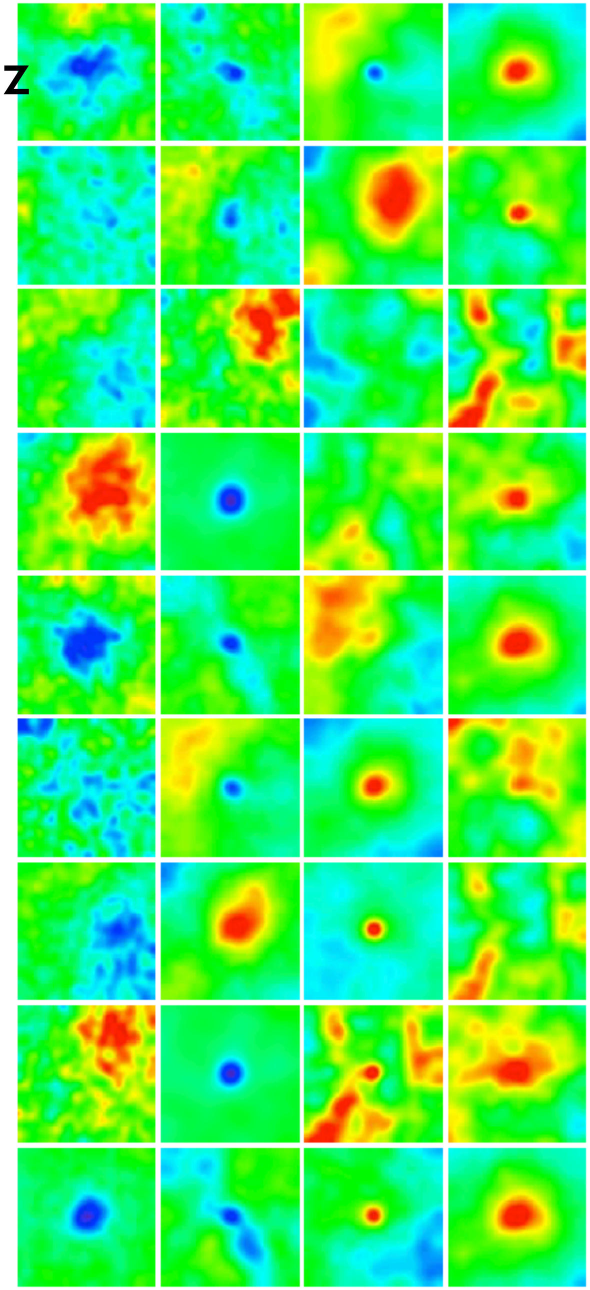


thermal SZ clusters

Planck selects massive clusters at lower z than ACT/SPT



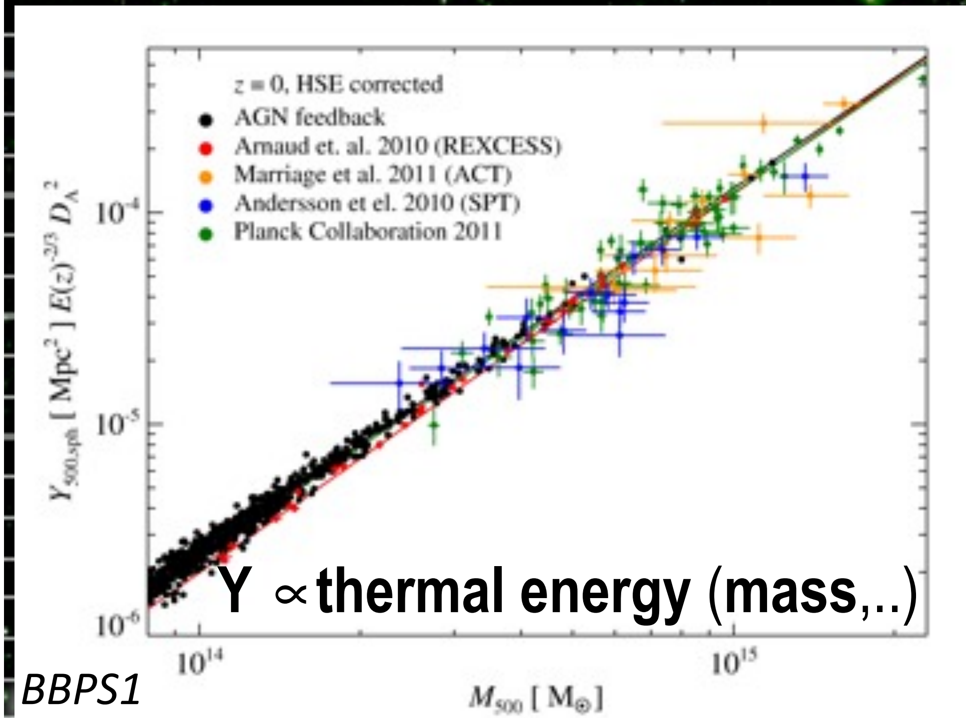
stacked: known-cls C1 C2 C3



pressure intermittency *in the cosmic web, in cluster-group concentrations probed by* **tSZ**

Secondary Anisotropies
(tSZ, kSZ, WL, reion, CIB; hydro)

Planck2013 1227 clusters, SPT 224 =>747cls, ACT 91 cls



Y $\propto$ thermal energy (mass,..)

BBPS1

to get **cosmological parameters** from

$n_{cl}(Y(M),z)$ &

$C_L^{tSZ,kSZ}$

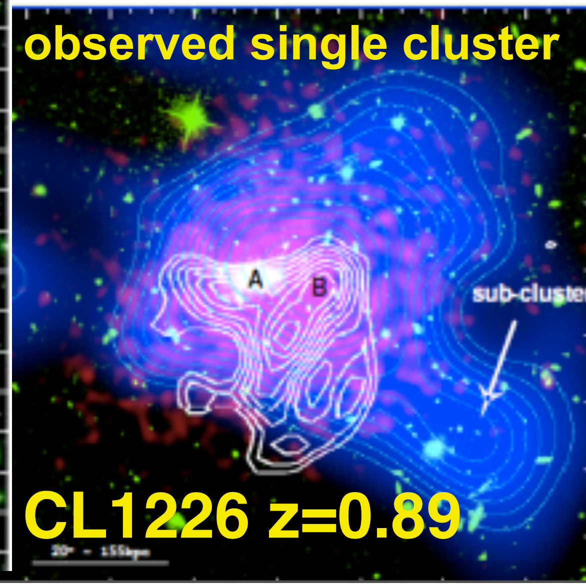
cluster complexity =>
requires **full "mocking" simulations**

BBPS2

$p_e(x,t)$

ACT's el Gordo z=0.87
$2\times10^{15} M_{sun}$, T_X=14.5kev

observed single cluster



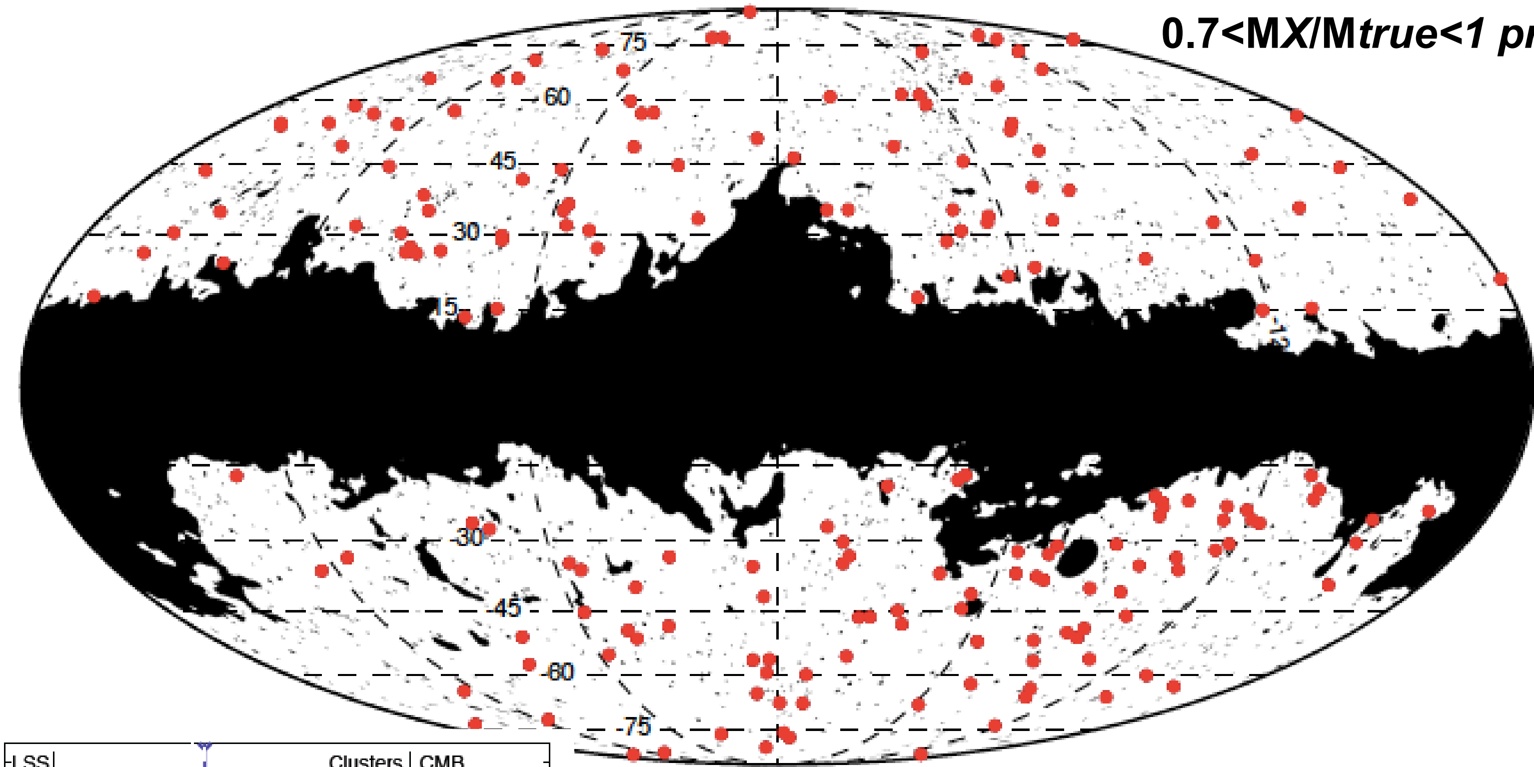
CL1226 z=0.89

thermal SZ clusters

PSZ: 189 cls for cosmology constraints.

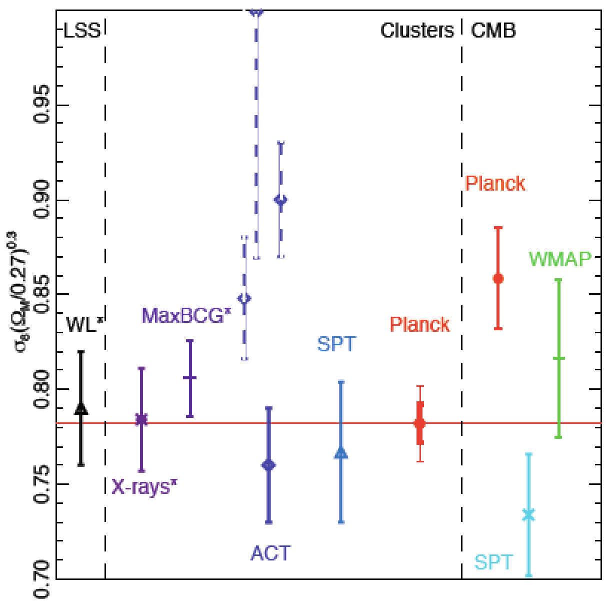
σ_8=0.77±0.02 Ω_m=0.29±0.02 *cf. primary* **σ_8=0.826±0.012**

0.7<MX/Mtrue<1 prior; 0.8 default



Cosmic Parameters
from

$n_{cl}(M,z)$



ACT12 Hasselfield+12 15 carefully chosen cls

optical dynamical information used *(i.e., not X-ray)*

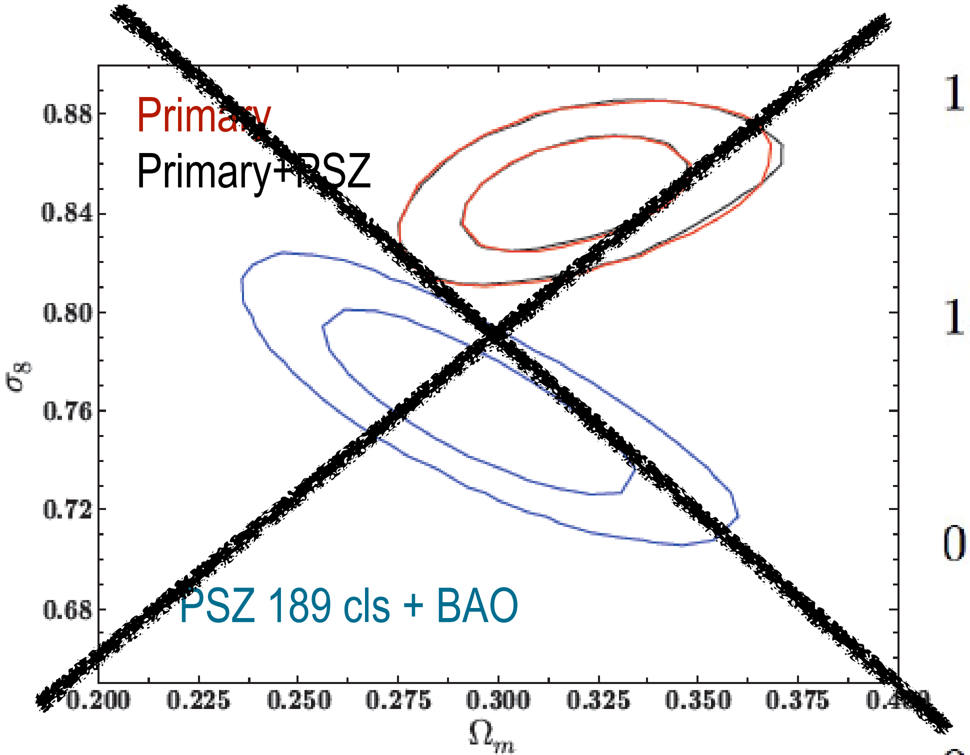
σ_8=0.829±0.024 Ω_m=0.292±0.025 WMAP7+ACT(cls)

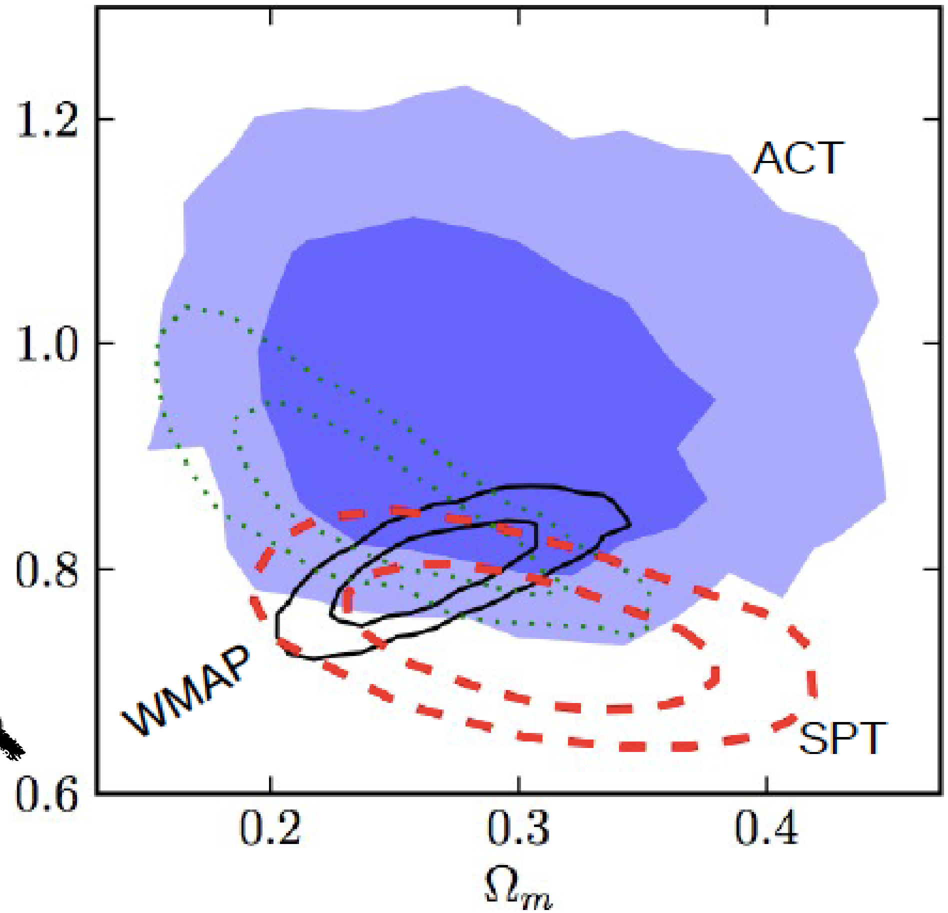
cf. ACT10 9 confirmed clusters (Sehgal+10) using cluster abundances => mass calibration still too uncertain (e.g. σ_8=0.82±0.05 to 0.85±0.12). *attempt at Dark Energy equation of state, but little leverage*

SPT similar results with ~20 clusters Benson+12

thermal SZ clusters

SPT Reichardt+12 different approach cf. ACT Hasselfield+12
X-ray mass proxy cf. dynamical mass proxy (lower bound for σ8, Ωm)
multi-scale S/N likelihood cf. Profile Based Amplitude Analysis single filter 5.9' not matched θ_{500} corrected
ACT and SPT at most mild tension (ACT SZ scaling priors - very broad, would that we knew them better)





Planck2013 XX

X bias b: 0.7<(M*X*/M*true*)$_{500}$<1 *prior; 0.8 default*

ACT Hasselfield+12

optical **velocity dispersion bias**
β^{dyn}: (M*dyn*/M*true*)$_{500}$ =1.0±0.15 *prior;*
***1.0 default pushes to 1.1*±0.12**

thermal SZ clusters

SPT Reichardt+12 different approach cf. ACT Hasselfield+12
X-ray mass proxy cf. dynamical mass proxy (lower bound for σ8, Ωm)
multi-scale S/N likelihood cf. Profile Based Amplitude Analysis single filter 5.9' not matched θ_{500} corrected
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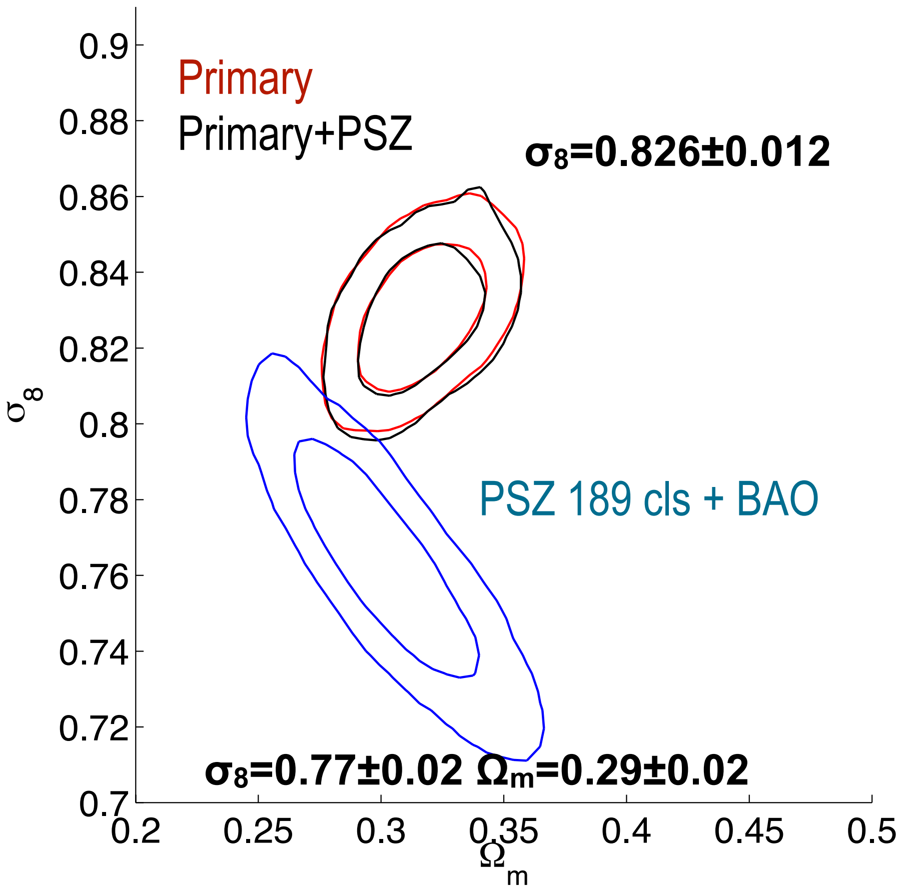
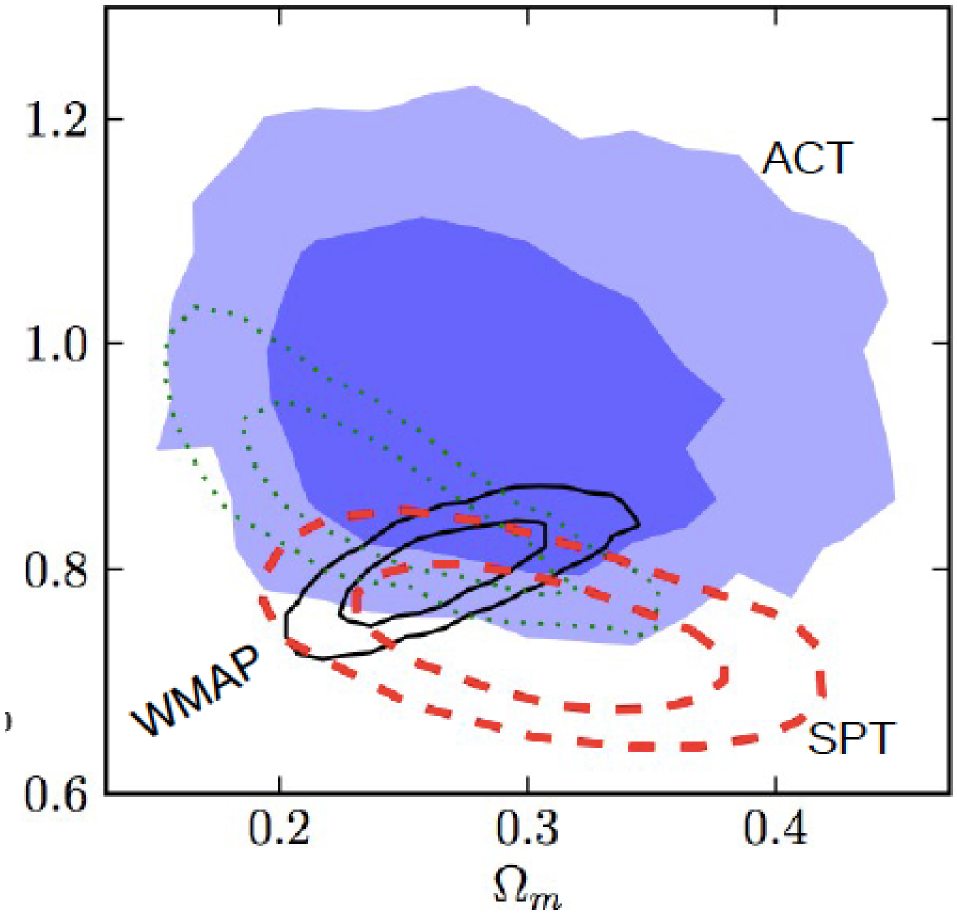




Planck2013 XX

ACT Hasselfield+12

$0.7<(MX/Mtrue)_{500}<1$ *prior; 0.8 default*

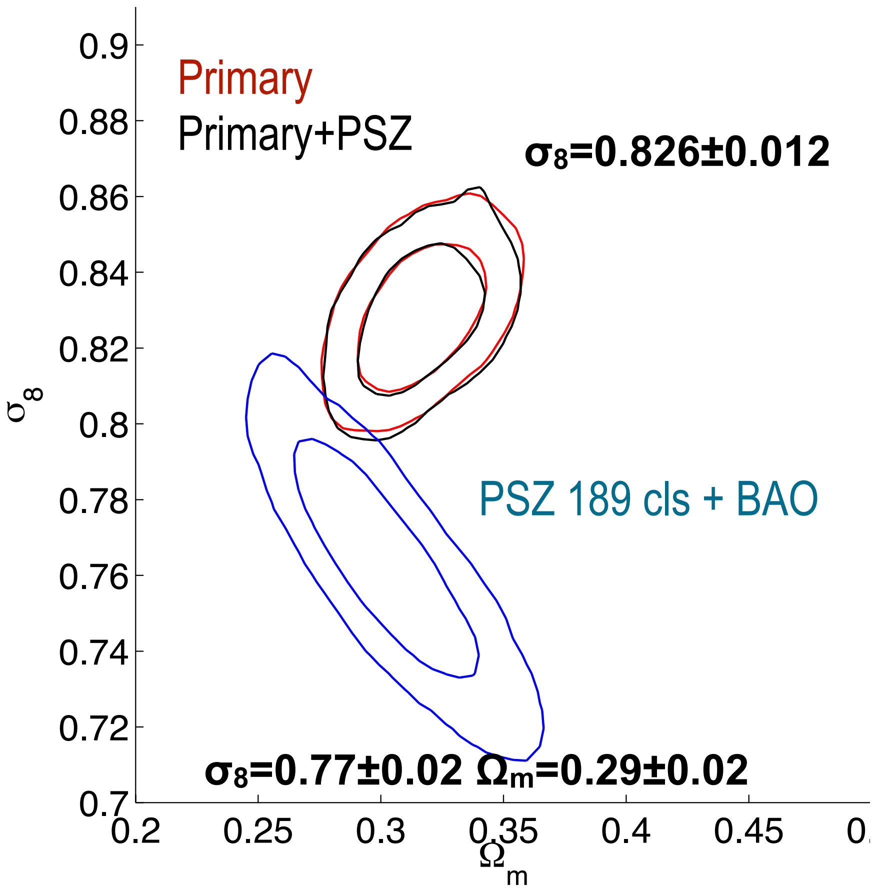
optical **velocity dispersion bias**
β^{dyn}: $(Mdyn/Mtrue)_{500}$=1.0±0.15 *prior;*
***1.0 default pushes to 1.1*±0.12**

thermal SZ clusters

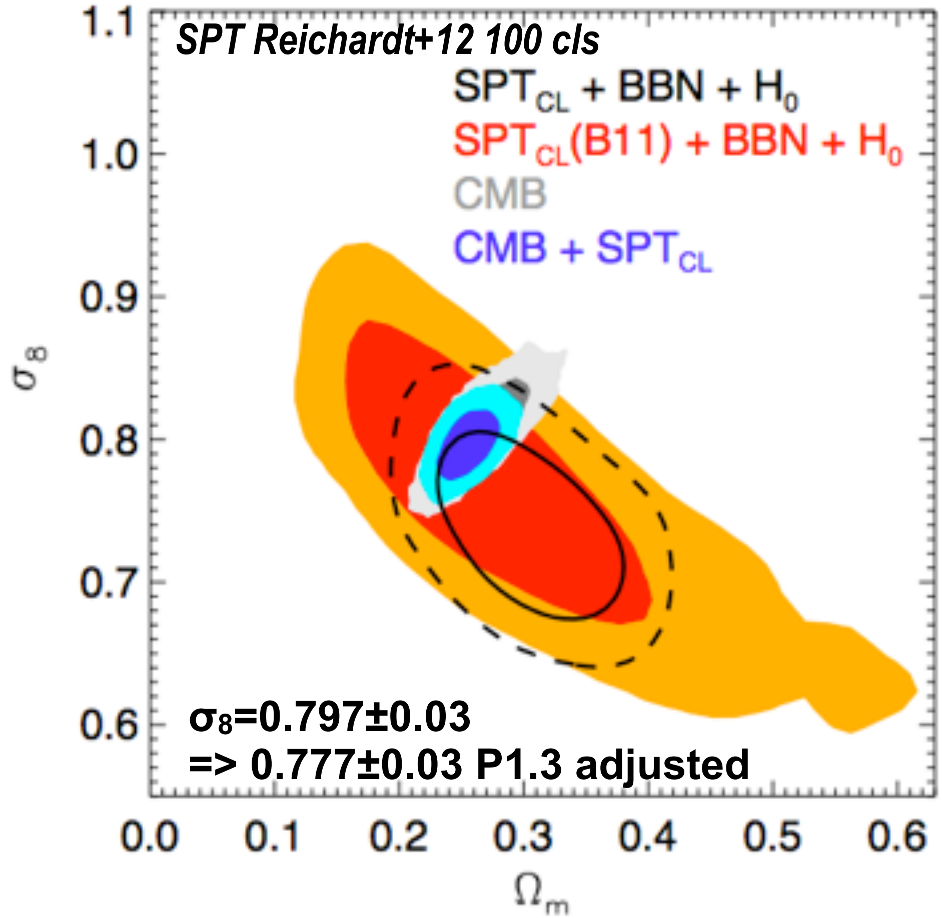
Benson@ESLAB13: SPT has 440 clusters with measured redshifts and SPT S/N > 4.0 full 2500 sq deg catalog in summer 2013

Weak Lensing Mass Calibration

M500(Yx) = (1.02 +/- 0.08) M500(WL) **M500(SPT) = (1.00 +/- 0.08) M500(WL)**



Planck2013 XX



9 Scaling Relation Parameters

0.7<(MX/Mtrue)$_{500}$<1 prior; 0.8 default

thermal SZ clusters

SPT Reichardt+12 different approach cf. ACT Hasselfield+12
X-ray mass proxy cf. dynamical mass proxy (lower bound for σ8, Ωm)
multi-scale S/N likelihood cf. Profile Based Amplitude Analysis single filter 5.9' not matched θ_{500} corrected
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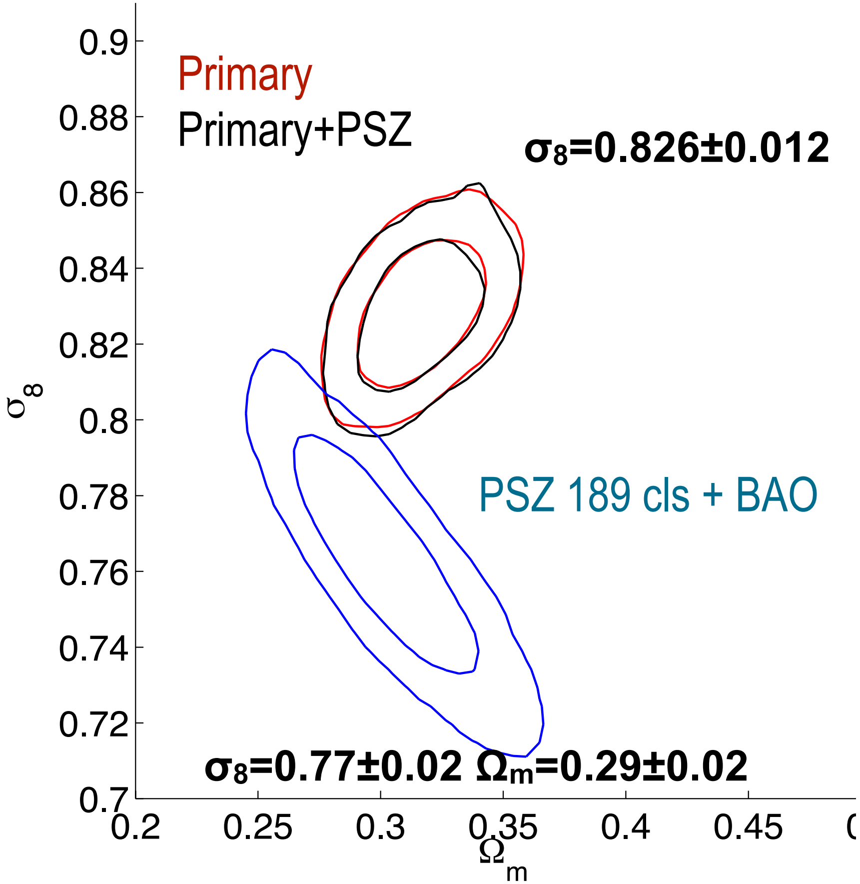
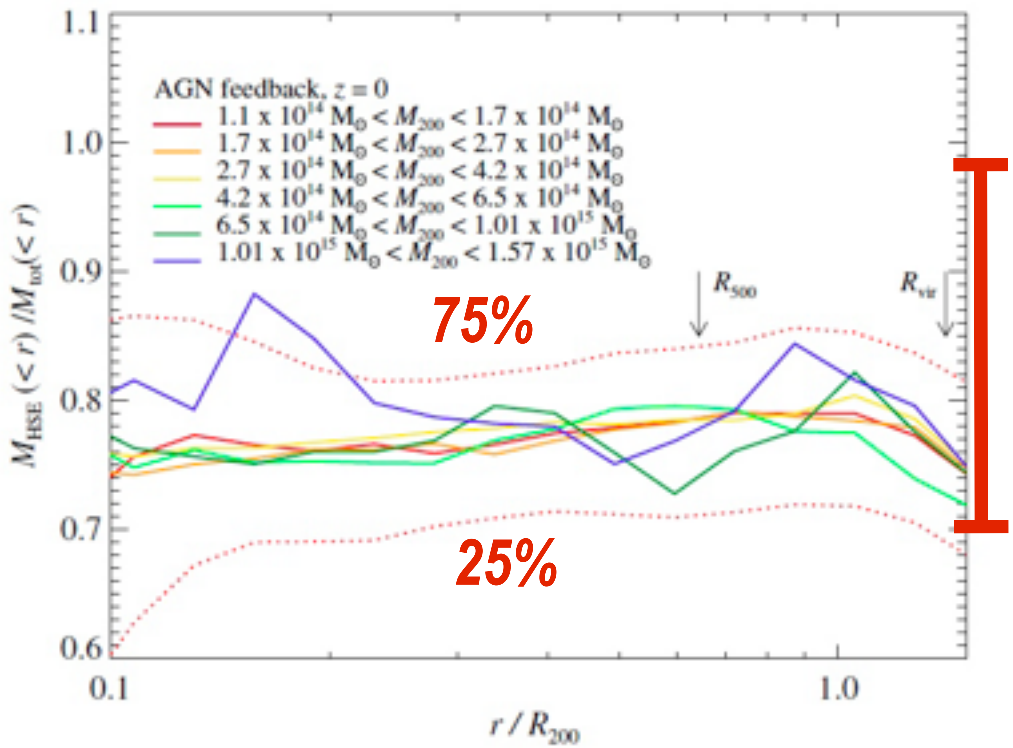


Planck2013 XX

0.7<(MX/Mtrue)$_{500}$<1 ***TOP HAT HARD prior; 0.8 default***

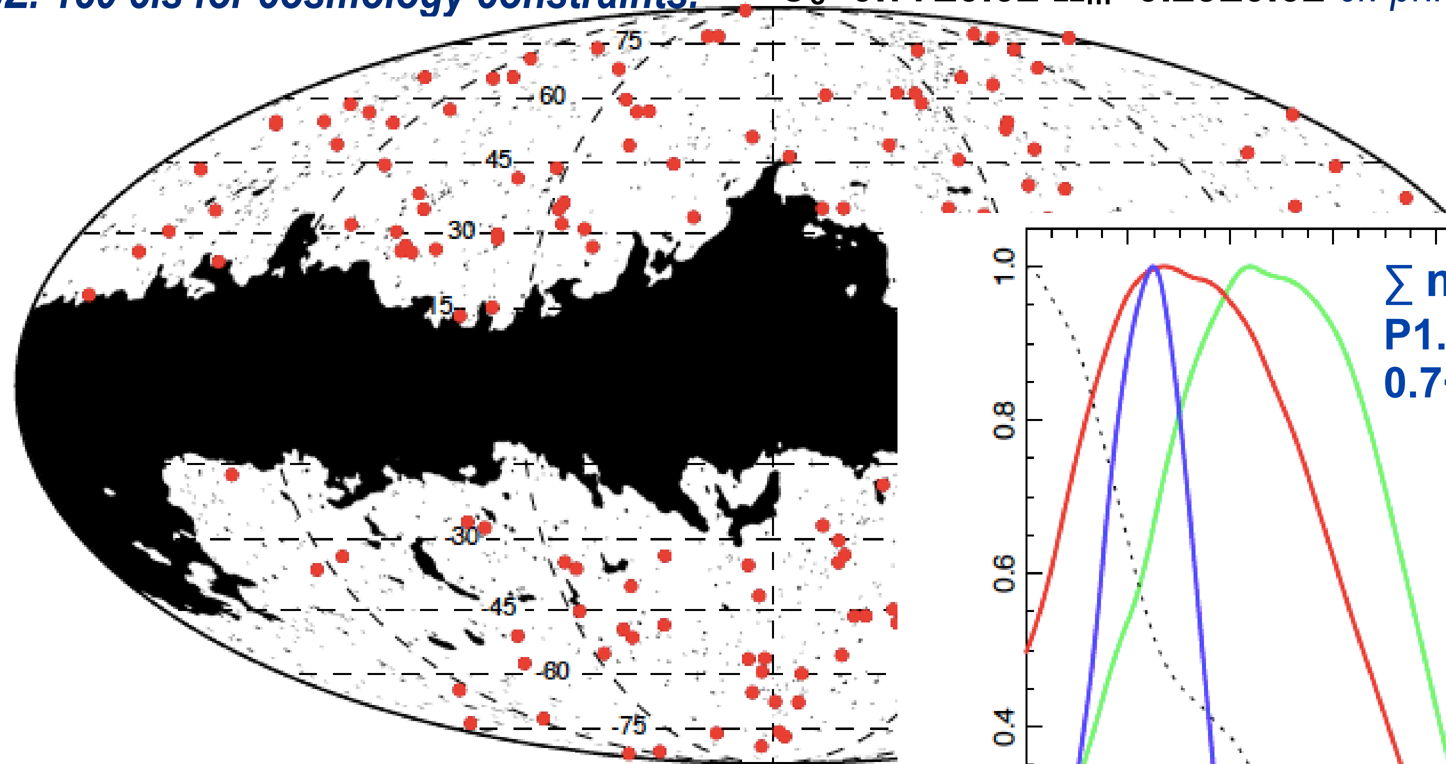
HSE X Bias b



***best theory can do blindly on bX**: not the distribution to use because of sample selection and sub-sample processing*

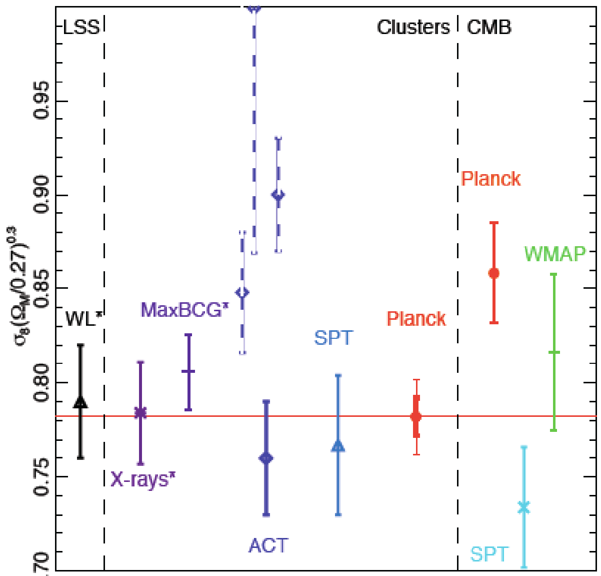
thermal SZ clusters

PSZ: 189 cls for cosmology constraints.



thermal SZ clusters

σ_8=0.77±0.02 Ω_m=0.29±0.02 *cf. primary* **σ_8=0.826±0.012**



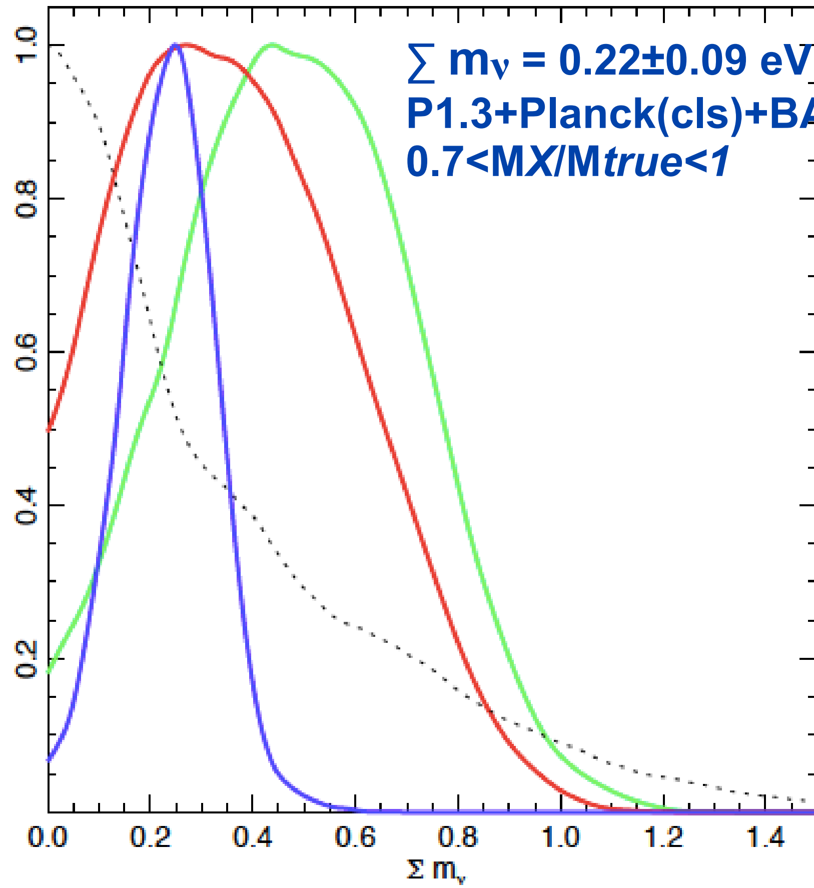


Fig. 12. Cosmological constraints when including neutrino masses $\sum m_\nu$ from: *Planck* CMB data alone (black dotted line); *Planck* CMB + SZ with $1-b$ in [0.7, 1] (red); *Planck* CMB + SZ + BAO with $1-b$ in [0.7, 1] (blue); and *Planck* CMB + SZ with $1-b = 0.8$ (green).

CBI pol to Apr'05 @Chile

CBI2

C_L^{SZ}

tSZ power spectrum

QUaD @SP

C_L^{SZ}

Planck09.4

52+ bolometers
+ HEMTs @L2
9 frequencies

Planck1.3 matched filter all-sky
y-map => C_L^{tSZ}
observed clusters seen,
cosmological parameters agree
with those from counts!
low L tail from extended nearby cls

WMAP @L2 to 2010

2004 — 2005 — 2006 — 2007 — 2008 — 2009 — 2011

C_L^{SZ}

LHC

Bpol
@L2

Acbar@SP
~1 blind

>96
OVRO /BIMA array

C_L^{SZ}

SZA@Cal

C_L^{SZ}

AMI

GBT Mustang

AMIBA

APEX
~400 bolos@Chile

C_L^{SZ}

SPT
1000 bolos
@SPole

ACT
3000 bolos
3 freqs @Chile

C_L^{SZ}

SCUBA2
12000 bolos
JCMT @Hawaii

C_L^{SZ}

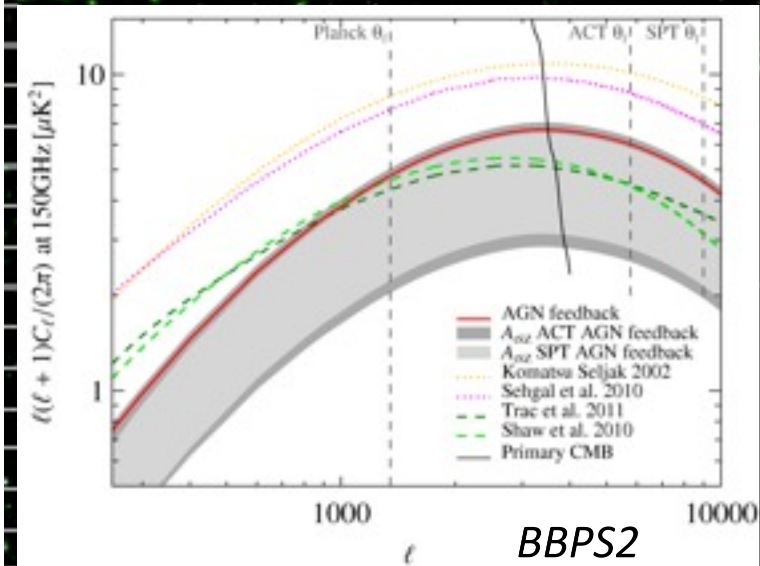
SPTpol
ACTpol
ALMA
CCAT@Chile
LMT@Mexico

80s-90s
Ryle
OVRO

pressure intermittency *in the cosmic web, in cluster-group concentrations probed by* **tSZ**

Secondary Anisotropies
(tSZ, kSZ, WL, reion, CIB; hydro)

Planck2013 1227 clusters, SPT 224 =>747cls, ACT 91 cls



to get **cosmological parameters** from

$n_{cl}(Y(M),z)$ &

$C_L^{tSZ,kSZ}$

cluster complexity => requires **full "mocking" simulations**

Planck regime, *Δphysics* SZ templates ~degeneracy

Ethermal + Ekin~Egrav/2

half $\langle C_L \rangle_{3000}$ from **z>0.5 & $M<3\times10^{14}\ M_\odot\ h^{-1}$**

σ_8^{SZ}

σ_8

mild tension

BBPS2

$p_e(x,t)$

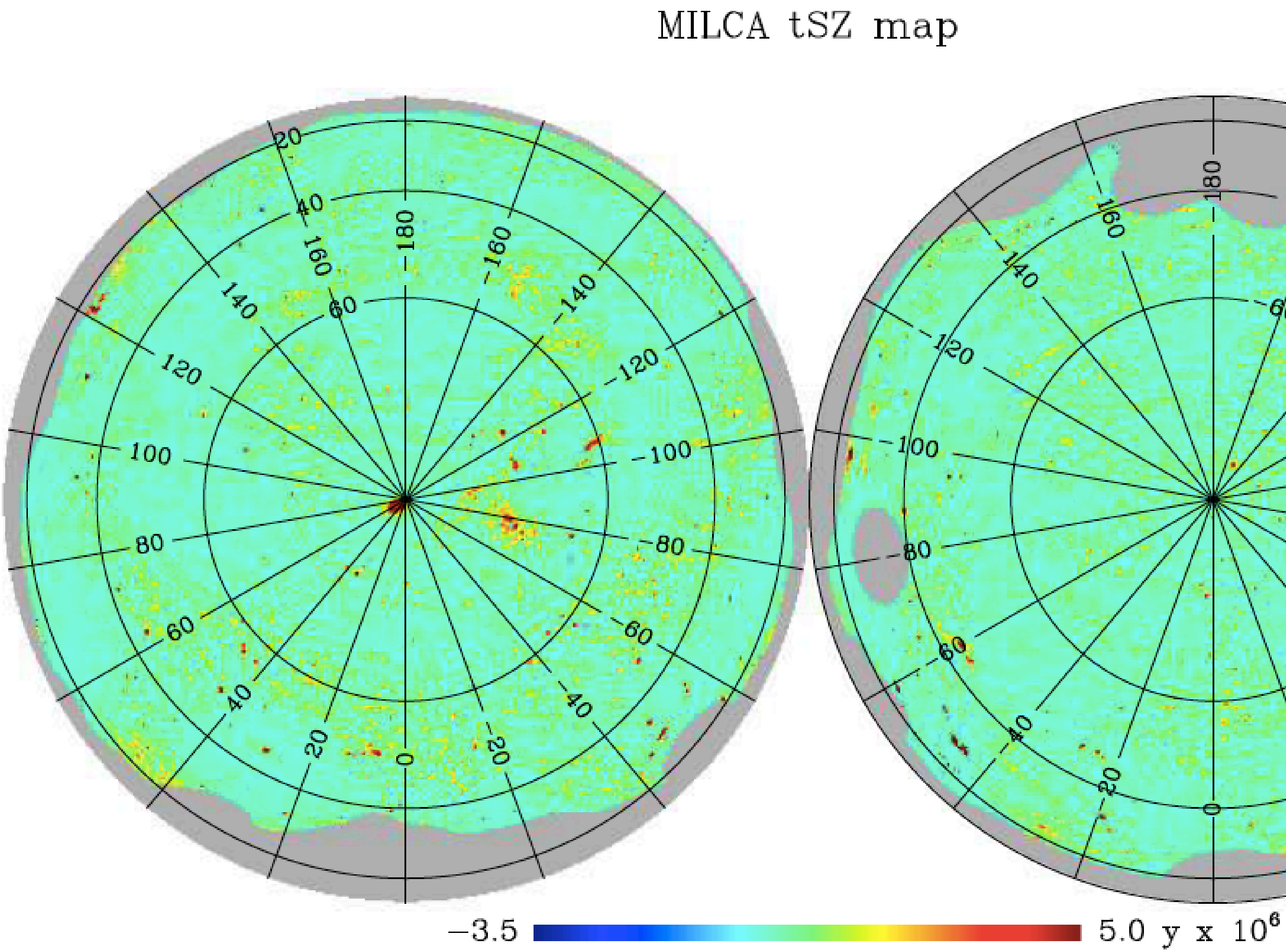
ACT's el Gordo z=0.87

$2\times10^{15} M_{sun}$, T_X=14.5kev

observed single cluster

CL1226 z=0.89

SZ power spectrum from ymaps Planck2013 XXI

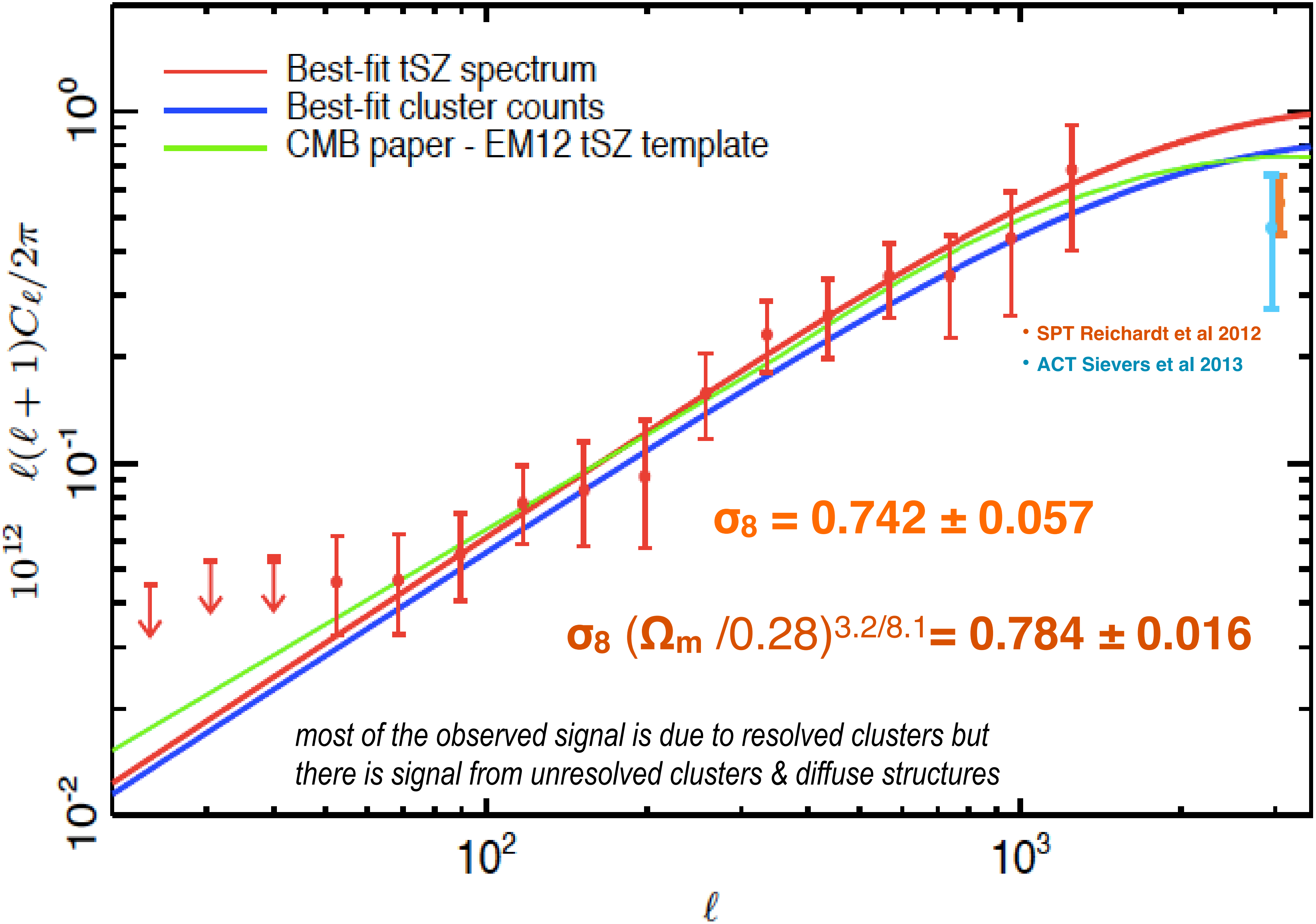


Adapted component separation algorithms: NILC & MILCA on all HFI channels 100-857 GHz @ 10' res

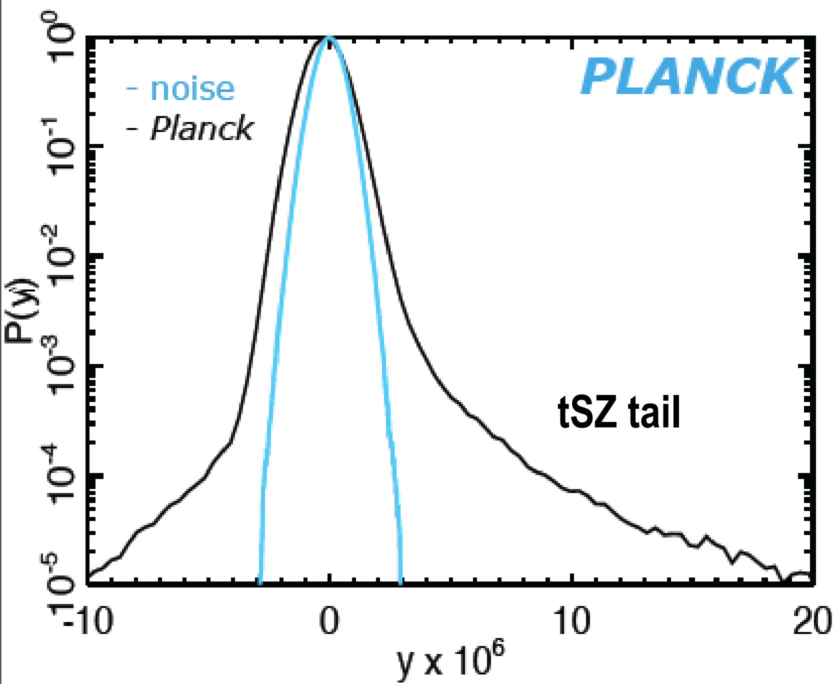
SEXtractor + MMF and MHW + SEXtractor detected clusters number & flux consistent with PSZ catalogue

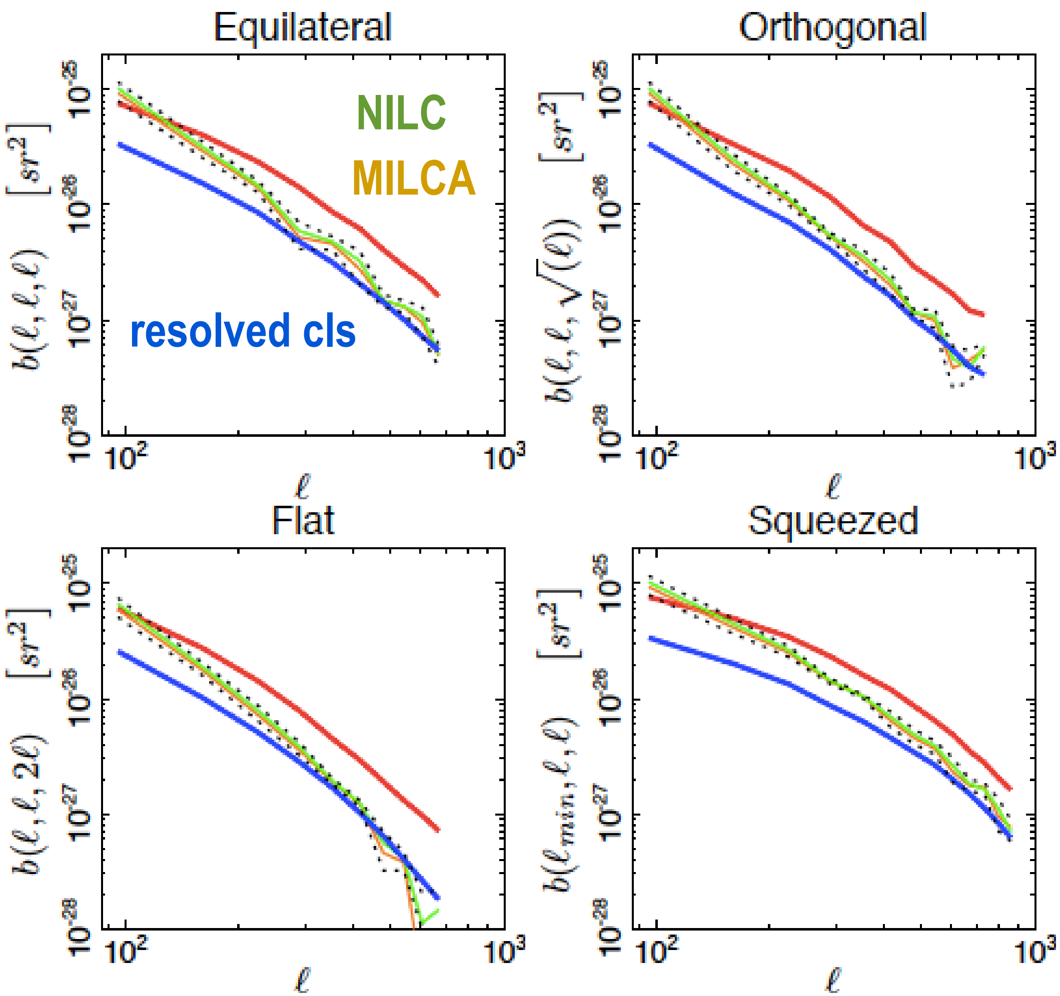
tSZ + clustered CIB + Point sources

SZ power spectrum from ymaps are consistent with cluster counts cosmology Planck2013 XXI



SZ 1pt PDF and 3 point (bispectrum) from ymaps are consistent Planck2013 XXI



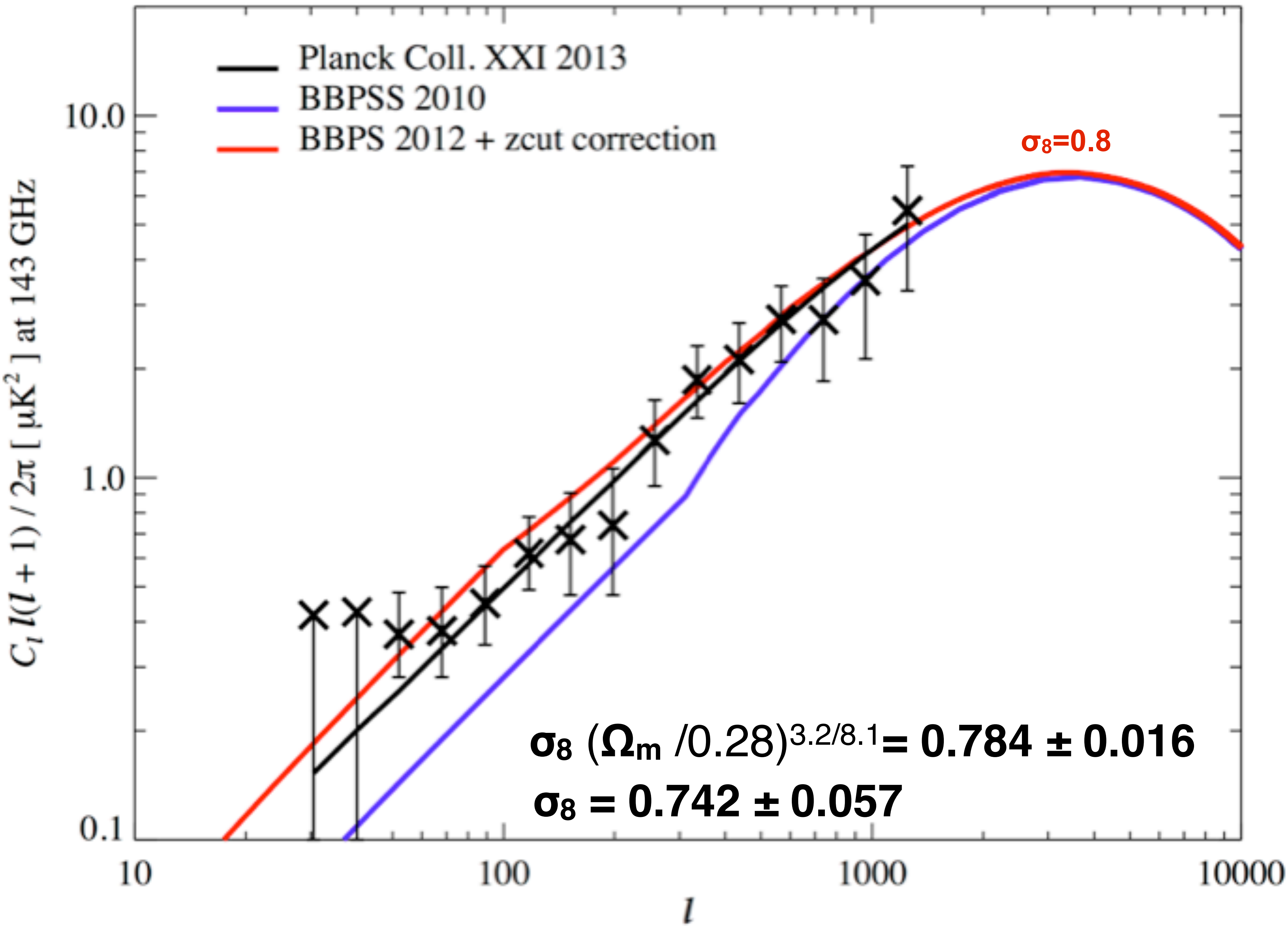


bispectrum amplitude scales as σ_8^{10-12}

=> $\sigma_8 \sim 0.74 \pm 0.04$

SZ power spectrum from ymaps

thermal SZ clusters

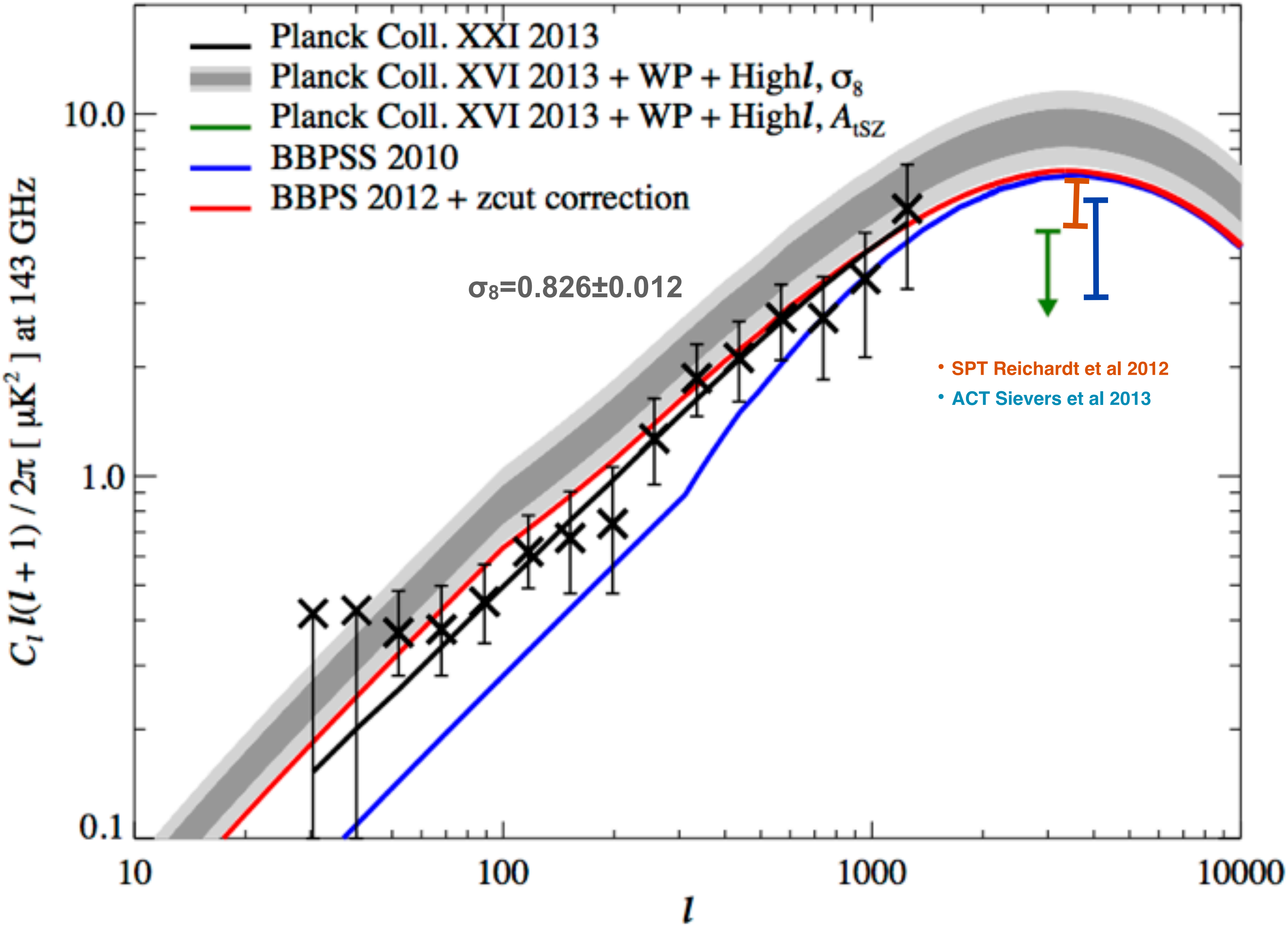


$\sigma_8\ (\Omega_m/0.28)^{3.2/8.1} = 0.784 \pm 0.016$

$\sigma_8 = 0.742 \pm 0.057$

SZ power spectrum from ymaps

thermal SZ clusters



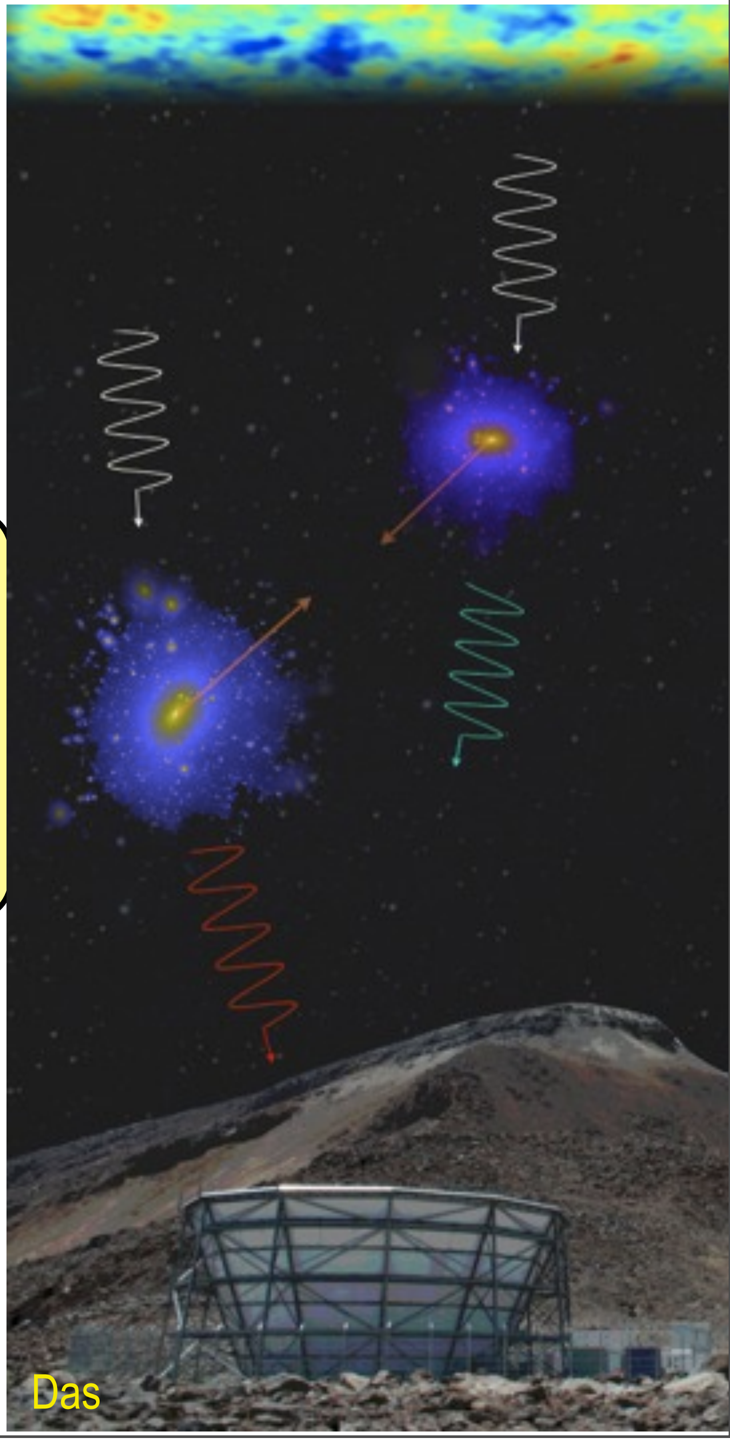
kinetic SZ:

$$\Delta T/T = \int n_e\, \mathbf{v}_{e||} /c\, \sigma_T\, dlos$$

$$\sim \int J_e \cdot dr$$

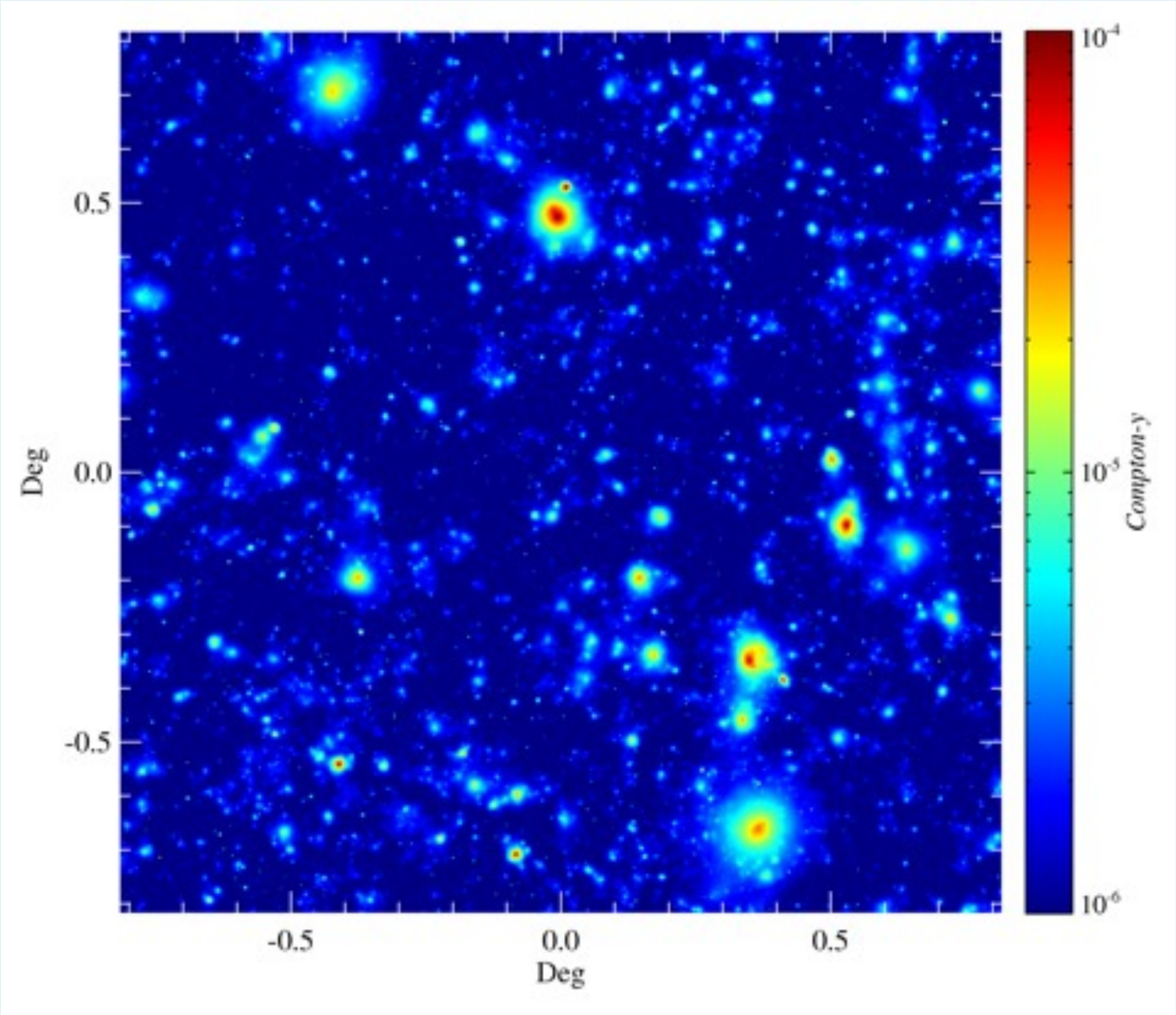
spectrally degenerate with primary anisotropies

$$\int \mathbf{kSZ}(\theta,\varphi)\mathbf{d}\Omega \sim \mathbf{M}_{\mathbf{gas}}\mathbf{V}_{\mathbf{bulk}} / D_A^2$$



Compton-y map: Feedback

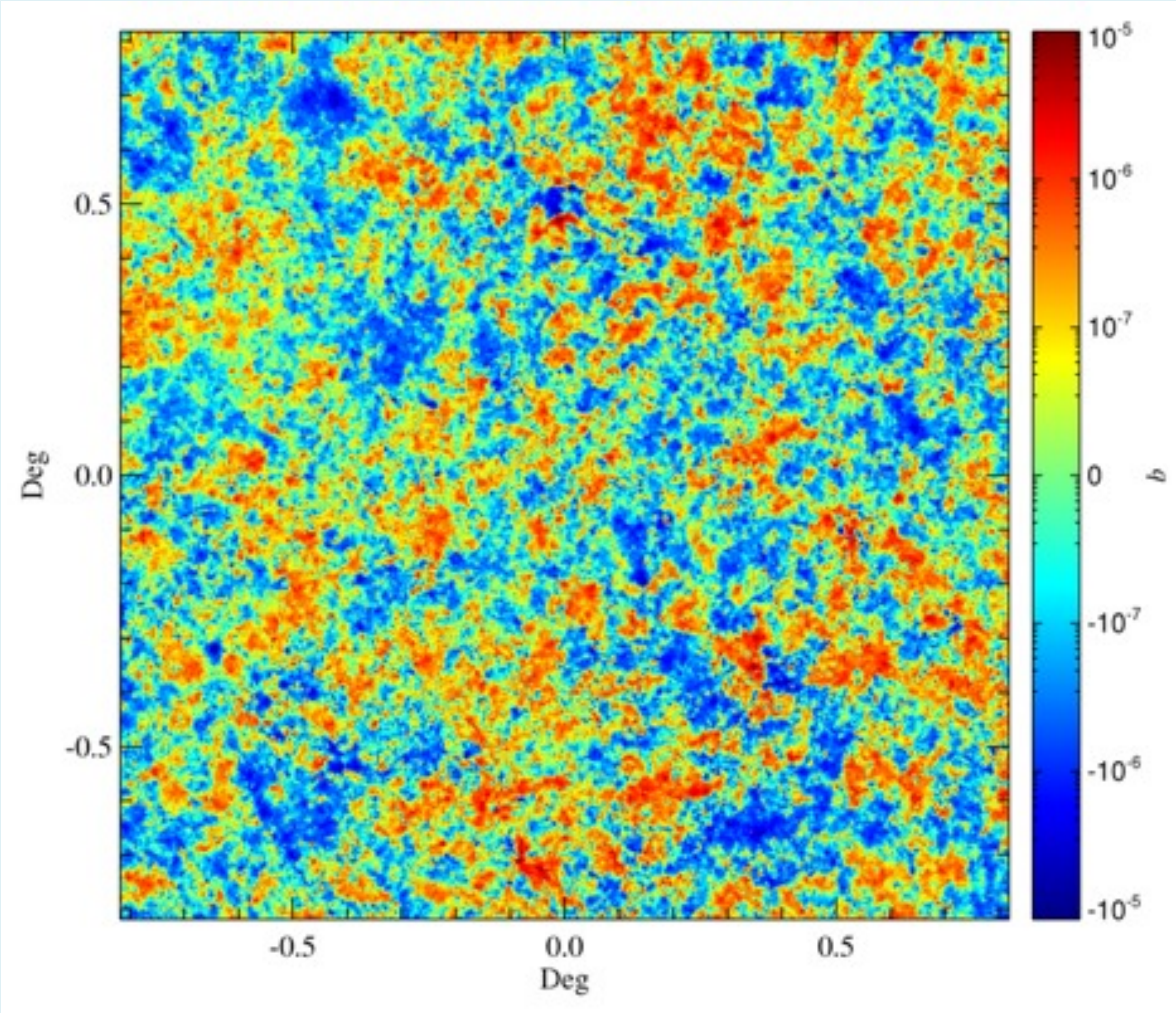
= AGN or Starburst E-feedback + radiative cool + SN energy + wind + (CR)



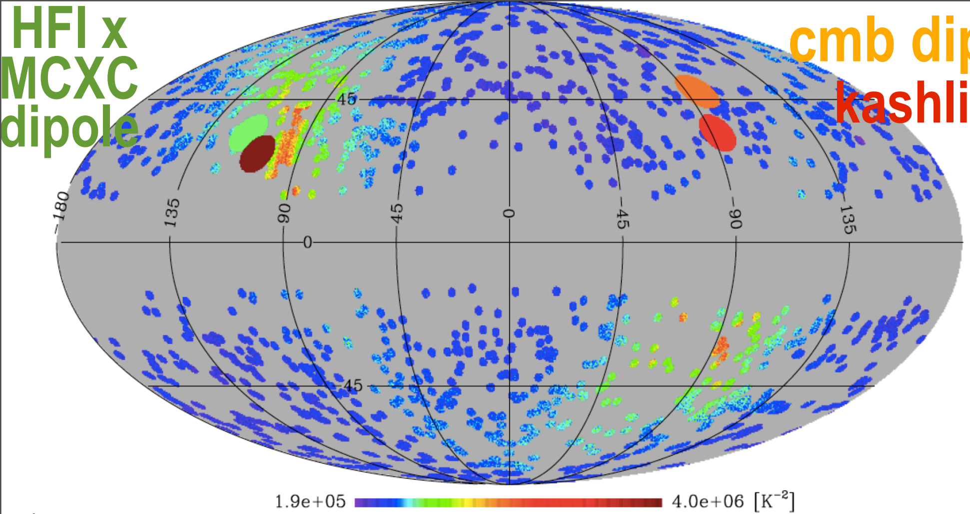
BBPS1,2,3,4,5

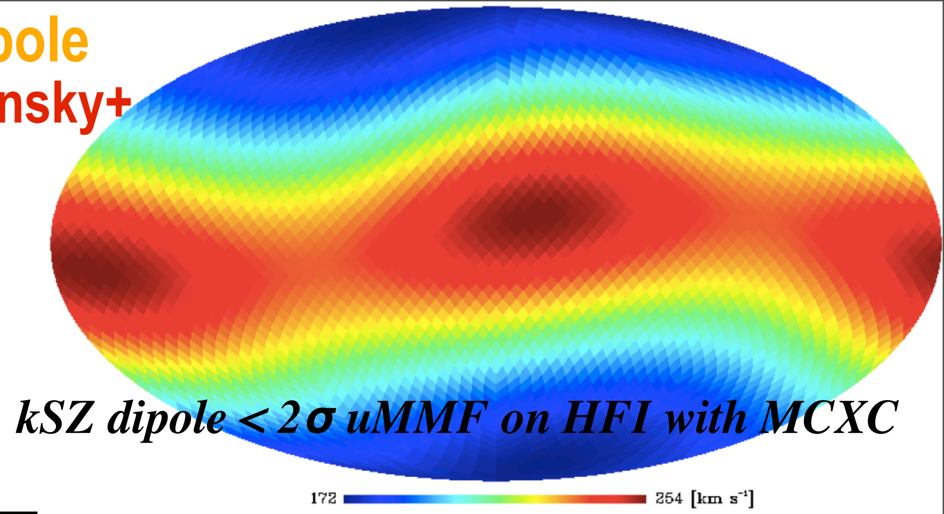
kinetic SZ map *(log)*: Feedback

= AGN or Starburst E-feedback + radiative cool + SN energy + wind + (CR)



BBPS1,2,3,4,5





kinetic SZ:

$$\Delta T/T = \int n_e \, v_{e||} / c \, \sigma_T \, dlos$$

$$\sim \int J_{e,||} \, dr$$

spectrally degenerate with primary anisotropies

$$\int kSZ(\theta,\varphi) d\Omega \sim M_{gas} V_{bulk} / D_A^2$$

ACT x BOSS direct detection of the kSZ effect:

Hand+ 2012 arXiv/1203.4219 $\langle \Delta T \, n_{gal} \rangle$ using 7,500 brightest of 27291 luminous BOSS galaxies 220 sq deg overlap with ACT equatorial strip 3x110 sq deg 2008-10 data. <z>~0.5.

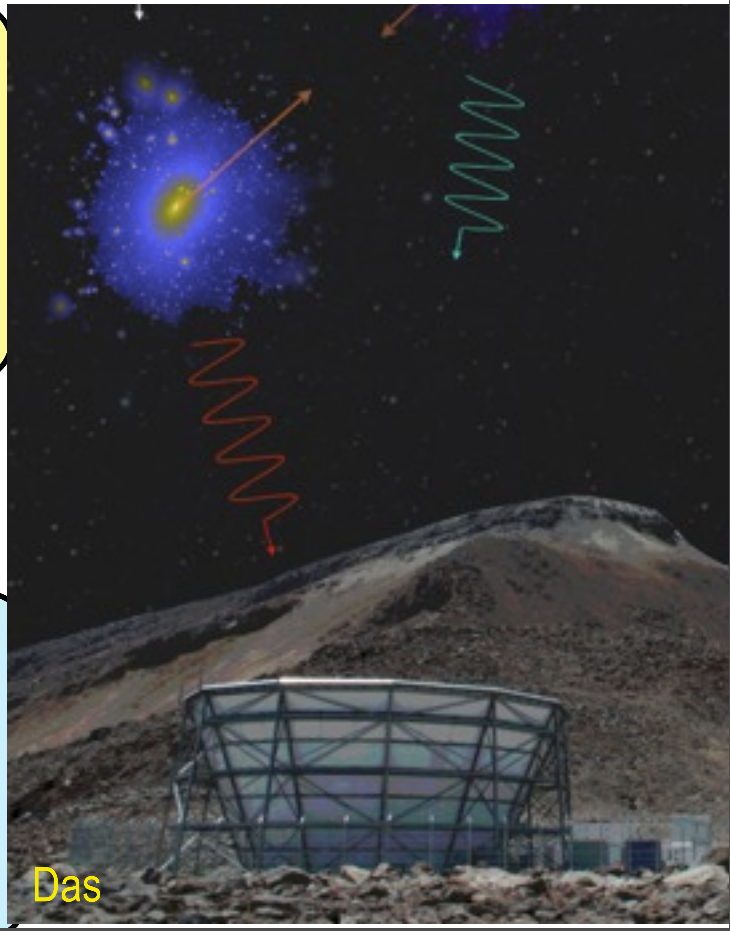
Planck13 X MCXC 1750 X-rays cls

Meta Catalogue of X-ray detected Clusters made for Planck

<z>~0.18, <v_radial> = 72 +- 60 km/s monopole

blind search < 254 km/s 95% CL

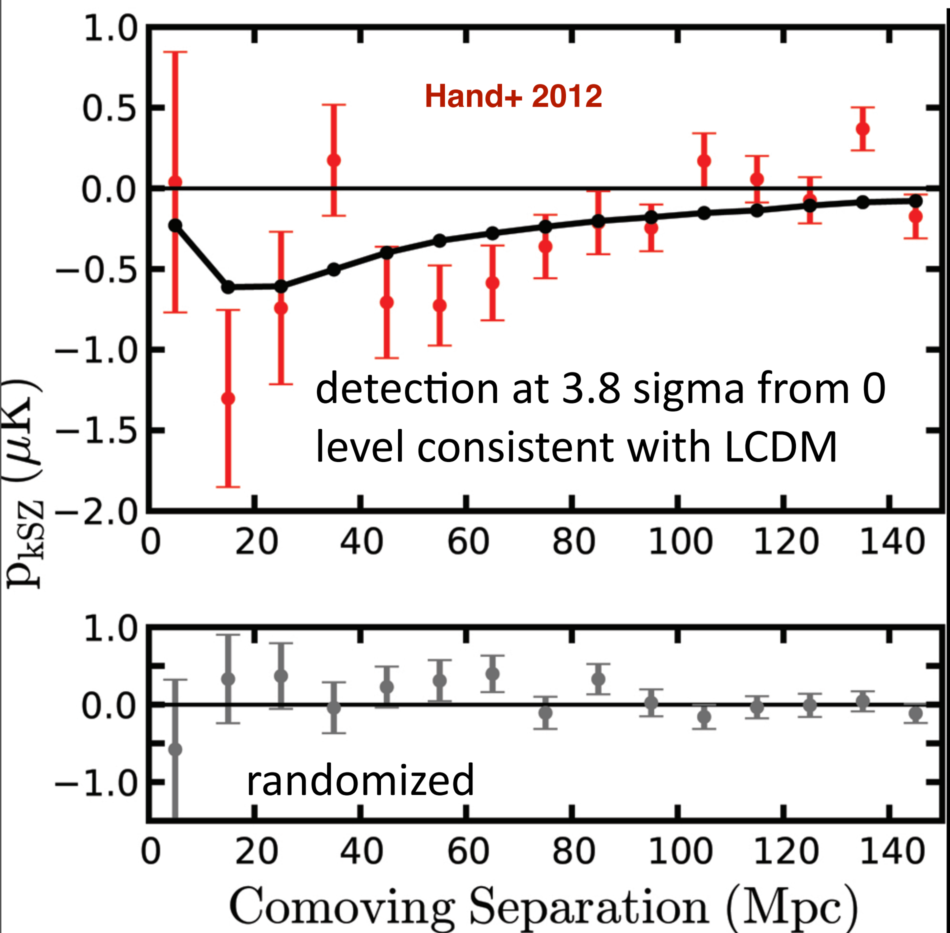
no super-bulk flow *aka the* ***Dark Flow*** *~1000 km/s*



kinetic SZ map *(log)*: Feedback

= AGN or Starburst E-feedback + radiative cool + SN energy + wind + (CR)

pair-wise velocities (momenta) statistic from ACT x Opt-Cls/Gps ~BOSS bright galaxies



$$\tilde{p}_{\rm pair}(r) = \frac{\sum_{i<j}(\mathbf{p}_i \cdot \hat{\mathbf{r}}_i - \mathbf{p}_j \cdot \hat{\mathbf{r}}_j)c_{ij}}{\sum_{i<j} c_{ij}^2}$$

$$c_{ij} \equiv \hat{\mathbf{r}}_{ij} \cdot \frac{\hat{\mathbf{r}}_i + \hat{\mathbf{r}}_j}{2} = \frac{(r_i - r_j)(1+\cos\theta)}{2\sqrt{r_i^2 + r_j^2 - 2r_i r_j \cos\theta}},$$

bulk velocity from WMAP7 x Xray-Cls

the Dark Flow

Kashlinsky, Atrio-Barandela, Kocevski & Ebeling08

3σ detection of v ~600 km/s out to z=0.3 towards (*l,b*)= (267°, 34°). 1588 X-cls total

Kashlinsky, Atrio-Barandela & Ebeling12 PhysRep

challenged by:

Keisler 09, Osborne+ 10, Zhang & Stebbins 11, & Mody & Hajian 12 (using Planck & Rosat cls) =>

no significant detection of kSZ signal

bulk velocity from Planck1.3 x Xray-Cls

PIP XIII ~order of mag sensitivity gain, no detection

challenged by: *Atrio-Barandela: PIP13 overestimates errors*

PUPPY and our hydro sims agree: *slower falloff than Arnaud+ X-ray UPP; although there are mass and redshift bin variations, universality is pretty good; variance in pressure profiles is wide*

pressure clumping is not small, *important for SZ- a consequence of merging history*

Universal Entropy Profile? *not as good as PUPPY. obs cf. theory needs work*

rare clusters are still consistent with std ΛCDM; *some highly non-eq, bullet el Gordo ++*

σ_8^{SZ} vs σ_8 tension from P1.3, ACT&SPT CL, P1.3 SPT ncl; ACT ncl ok **broad scaling bias priors**

Σm_ν ~0.2 ev a possibility; mass bias ~1.45 needed; and/or X-ray selection bias

Use physical observables rather than funneling through halo Mass

i.e., not $n_{cluster}(M_{halo}|z)$ but

$n_{cluster}(Y_{SZ}, M_{lens}, Y_X, L_X, T_X, \sigma_v^2, L_{cl,opt}, Rich, \ldots \mid z$, gold-sample, thresholds)

$+ C_L^{SZ}$(cuts) $+\xi_{cc}(r|n_{cl})$ $+f_{gas}$

biases in gas fraction estimation => variance large => not robust

these all deliver valuable cosmic gastrophysics.

Can they deliver fundamental physics: dark energy EOS?? σ_8 even? primordial non-Gaussianity??? X cf. opt, sphericalize?? but nice ymap stats C_L^{SZ} PDF, 3pt, counts, X cf. opt, ..

complex systems => theory/obs dispersion/systematics assessment is critical => mock sims for robust measures

kSZ detected,** but **dark flow constrained

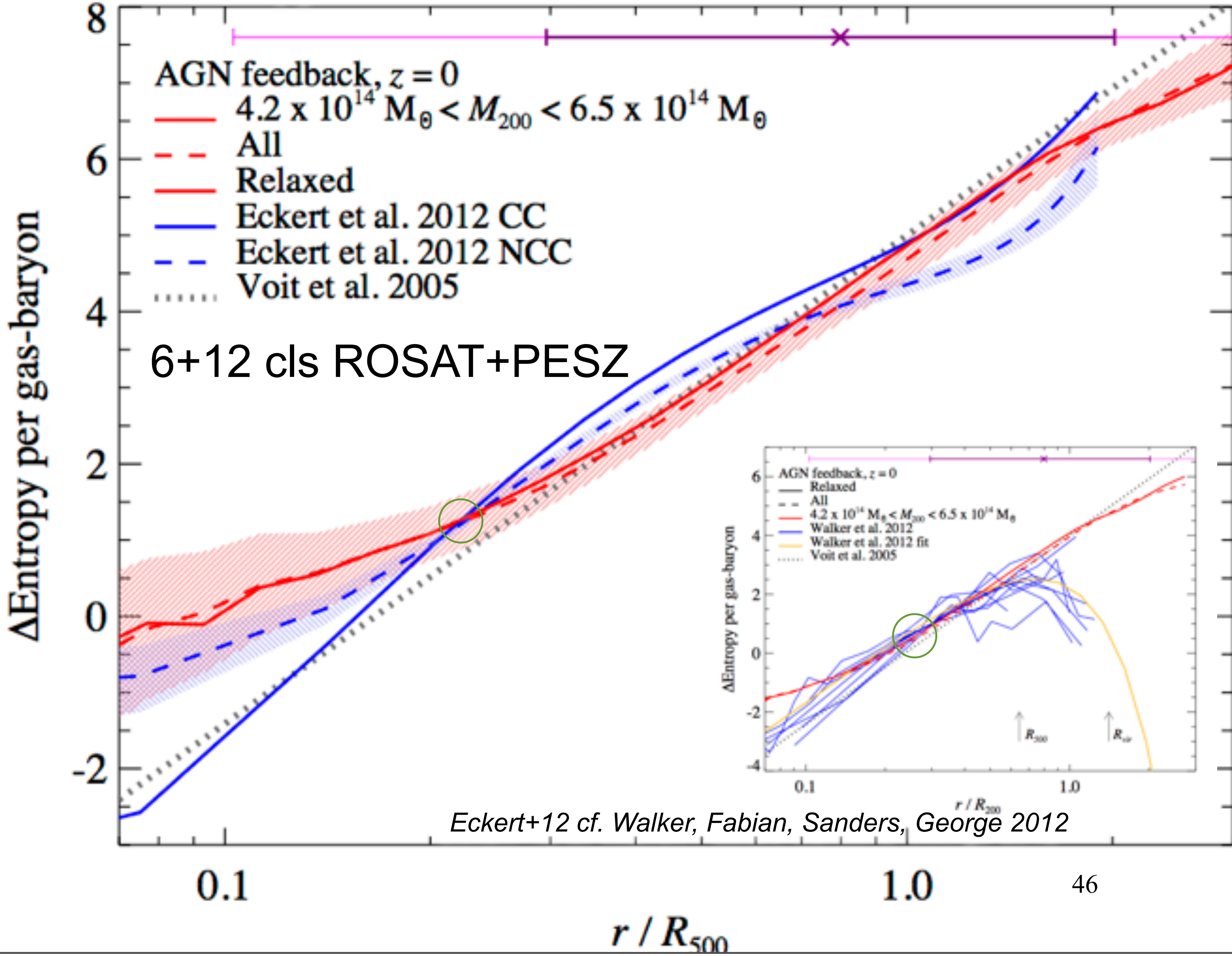
END

the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.

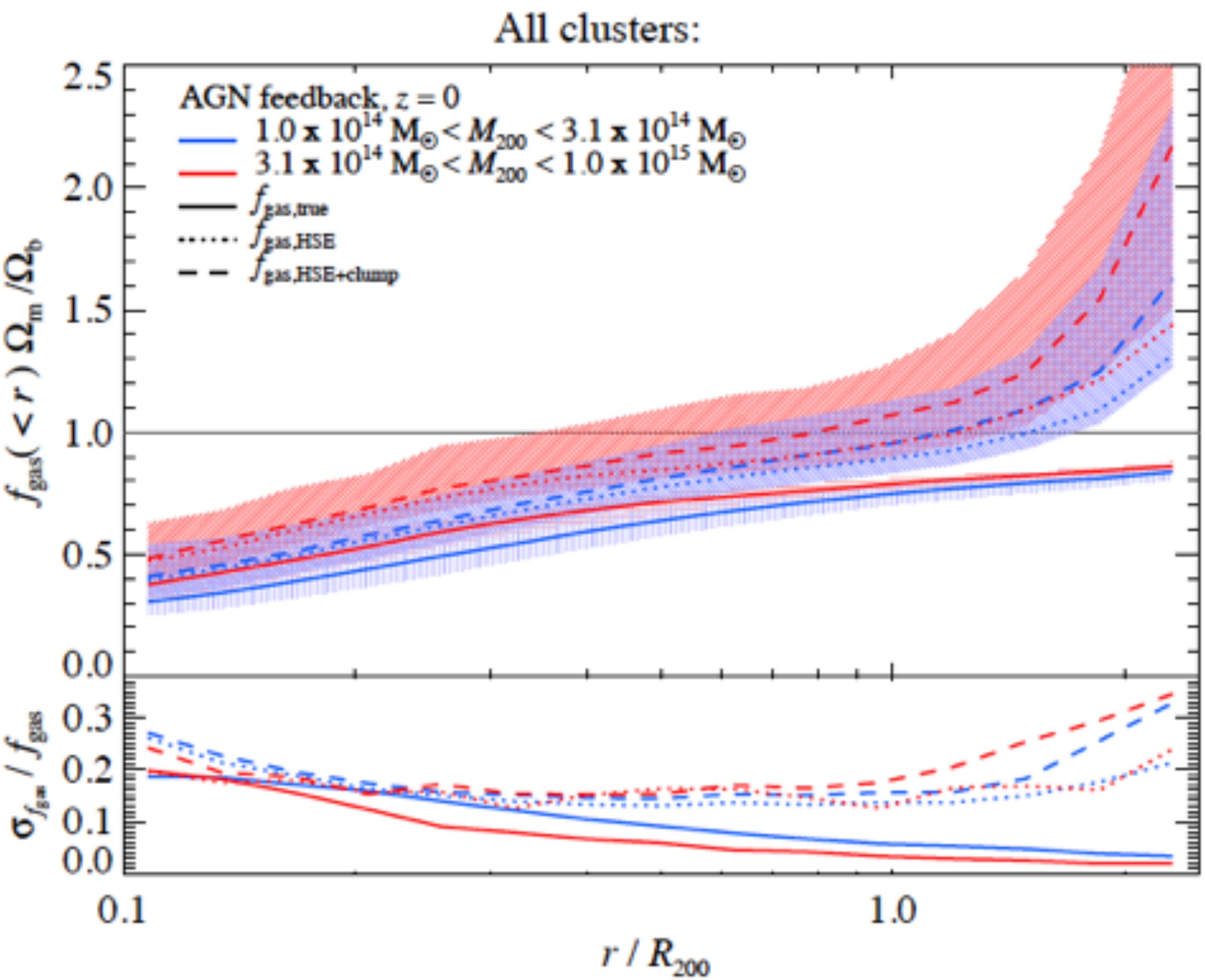
Bond since 1993, Canada since 2001, 1st CSA pre-launch contract 2002-09, post-launch 2010-11, 2011-15

Universal Entropy Profile? *sort of, but inference from observations is difficult*

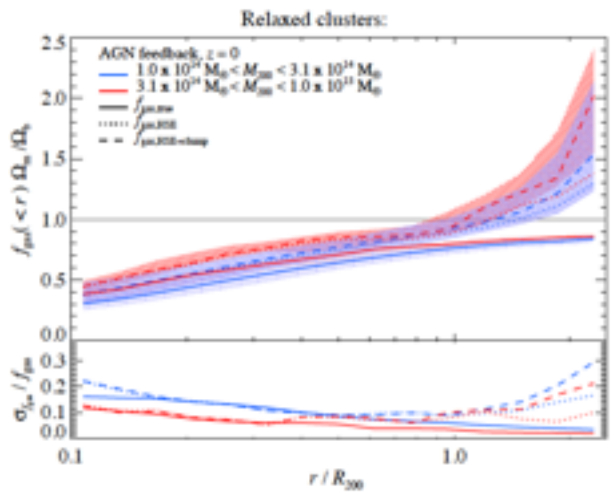


Eckert+12 cf. Walker, Fabian, Sanders, George 2012

biases in gas fraction estimation in clusters



relaxed = third lowest in K/U



bbps3 sims cf.

growing collection of *Suzaku* clusters, consisting of PKS0745-191 (George et al. 2009), Abell 1795 (Bautz et al. 2009), Abell 2204 (Reiprich et al. 2009), Abell 1413 (Hoshino et al. 2010), Abell 1689 (Kawaharada et al. 2010), Abell 2142 (Akamatsu et al. 2011), Perseus (Simionescu et al. 2011), a fossil group RX J1159+5531 (Humphrey et al. 2012), Abell 2029 (Walker et al. 2012), and Hydra A (Sato et al. 2012).

SZ observations of age in 2010-2011
2011 PEP
Planck early results XII: Cluster Sunyaev-Zeldovich optical scaling relations SDMW@cifar13
Planck Early Results XI: Calibration of the local galaxy cluster Sunyaev-Zeldovich scaling relations
Planck Early Results. X. Statistical analysis of Sunyaev-Zeldovich scaling relations for X-ray galaxy clusters
Planck early results. IX. XMM-Newton follow-up for validation of Planck cluster candidates
Planck Early Results VIII: The all-sky Early Sunyaev-Zeldovich cluster sample 189+ cls
Planck Early Results. VII. The Early Release Compact Source Catalog
2010-11 ACT
The Atacama Cosmology Telescope: Detection of Sunyaev-Zel'dovich Decrement in Groups and Clusters Associated with Luminous Red Galaxies
The Atacama Cosmology Telescope: Sunyaev Zel'dovich Selected Galaxy Clusters at 148 GHz in the 2008 Survey
The Atacama Cosmology Telescope: Cosmology from Galaxy Clusters Detected via the Sunyaev-Zel'dovich Effect
The Atacama Cosmology Telescope: Physical Properties and Purity of a Galaxy Cluster Sample Selected via the Sunyaev-Zel'dovich Effect
The Atacama Cosmology Telescope (ACT): Beam Profiles and First SZ Cluster Maps
The Cosmic Background Imager 2 Taylor+
2013 Combined CBI, SZA, BIMA, and OVRO analysis of the thermal Sunyaev-Zel'dovich Effect in A1689 Alison+ B@cifar13
< *2011* Subdegree Sunyaev-Zel'dovich Signal from Multifrequency BOOMERanG observations
< *2011* High resolution CMB power spectrum from the complete ACBAR data set
2010-12 *also many SPT cluster papers*
2010-13 Battaglia, Bond, Pfrommer, Sievers: theory & hydro sims with feedback
Simulations of the Sunyaev-Zel'dovich Power Spectrum with AGN Feedback BBPSS B@cifar13
Exploring the magnetized cosmic web through low frequency radio emission BBPS
2013 On the Cluster Physics of Sunyaev-Zel'dovich and X-ray Surveys IV: Density and Pressure Clumping due to Infalling Substructures BBPS3 B@cifar13
2013 On the Cluster Physics of Sunyaev-Zel'dovich Surveys III: Information Theoretic View of Clusters and their Non-equilibrium Entropies BBPS5 B@cifar13

< *2011* Galaxy Cluster Astrophysics and Cosmology: Questions and Opportunities for the Coming Decade *white paper*
2010-12 MUSTANG2 on GBT proposals *Planck cluster followup to 35σ in 1 hr @10” B@cifar13*
2013 CCAT sims

Burst of papers in 2012 Planck, ACT, SPT, theory

Planck Early Results XXVI: Detection with Planck and confirmation by XMM-Newton of PLCK G266.6-27.3, an exceptionally X-ray luminous and massive galaxy cluster at z~1
Planck Intermediate Results. I. Further validation of new Planck clusters with XMM-Newton
Planck Intermediate Results II: Comparison of Sunyaev-Zeldovich measurements from Planck and from the Arcminute Microkelvin Imager for 11 galaxy clusters
Planck intermediate results. III. The relation between galaxy cluster mass and Sunyaev-Zeldovich signal
Planck Intermediate Results. IV. The XMM-Newton validation programme for new Planck galaxy clusters
Planck intermediate results. VI: The dynamical structure of PLCKG214.6+37.0, a Planck discovered triple system of galaxy clusters
Planck Intermediate Results. V. Pressure profiles of galaxy clusters from the Sunyaev-Zeldovich effect PUPPY
Planck intermediate results. X. Physics of the hot gas in the Coma cluster PUPPY
Planck intermediate results. VIII. Filaments between interacting clusters
Planck Intermediate Results. XI: The gas content of dark matter halos: the Sunyaev-Zeldovich-stellar mass relation for locally brightest galaxies
The Atacama Cosmology Telescope: High-Resolution Sunyaev-Zel'dovich Array Observations of ACT SZE-selected Clusters from the Equatorial Strip
The Atacama Cosmology Telescope: ACT-CL J0102-4915 "El Gordo," a Massive Merging Cluster at Redshift 0.87
The Atacama Cosmology Telescope: Dynamical Masses and Scaling Relations for a Sample of Massive Sunyaev-Zel'dovich Effect Selected Galaxy Clusters
Evidence of Galaxy Cluster Motions with the Kinematic Sunyaev-Zel'dovich Effect
The Atacama Cosmology Telescope: A Measurement of the Thermal Sunyaev-Zel'dovich Effect Using the Skewness of the CMB Temperature Distribution
The Atacama Cosmology Telescope: Relation Between Galaxy Cluster Optical Richness and Sunyaev-Zel'dovich Effect
Subaru weak-lensing measurement of a z = 0.81 cluster discovered by the Atacama Cosmology Telescope Survey
The Atacama Cosmology Telescope: Physical Properties of Sunyaev-Zel'dovich Effect Clusters on the Celestial Equator
The Atacama Cosmology Telescope: the stellar content of galaxy clusters selected using the Sunyaev-Zel'dovich effect
The Atacama Cosmology Telescope: Sunyaev-Zel'dovich Selected Galaxy Clusters at 148 GHz from Three Seasons of Data

On the Cluster Physics of Sunyaev-Zel'dovich and X-ray Surveys III: Measurement Biases and Cosmological Evolution of Gas and Stellar Mass Fractions BBPS3
On the Cluster Physics of Sunyaev-Zel'dovich Surveys II: Deconstructing the Thermal SZ Power Spectrum BBPS2
On the Cluster Physics of Sunyaev-Zel'dovich Surveys I: The Influence of Feedback, Non-thermal Pressure and Cluster Shapes on Y-M Scaling Relations BBPS1

Burst of papers in 2013 Planck

Planck Intermediate Results. XIII. Constraints on peculiar velocities

Planck 2013 results. XXI. Cosmology with the all-sky Planck Compton parameter y-map

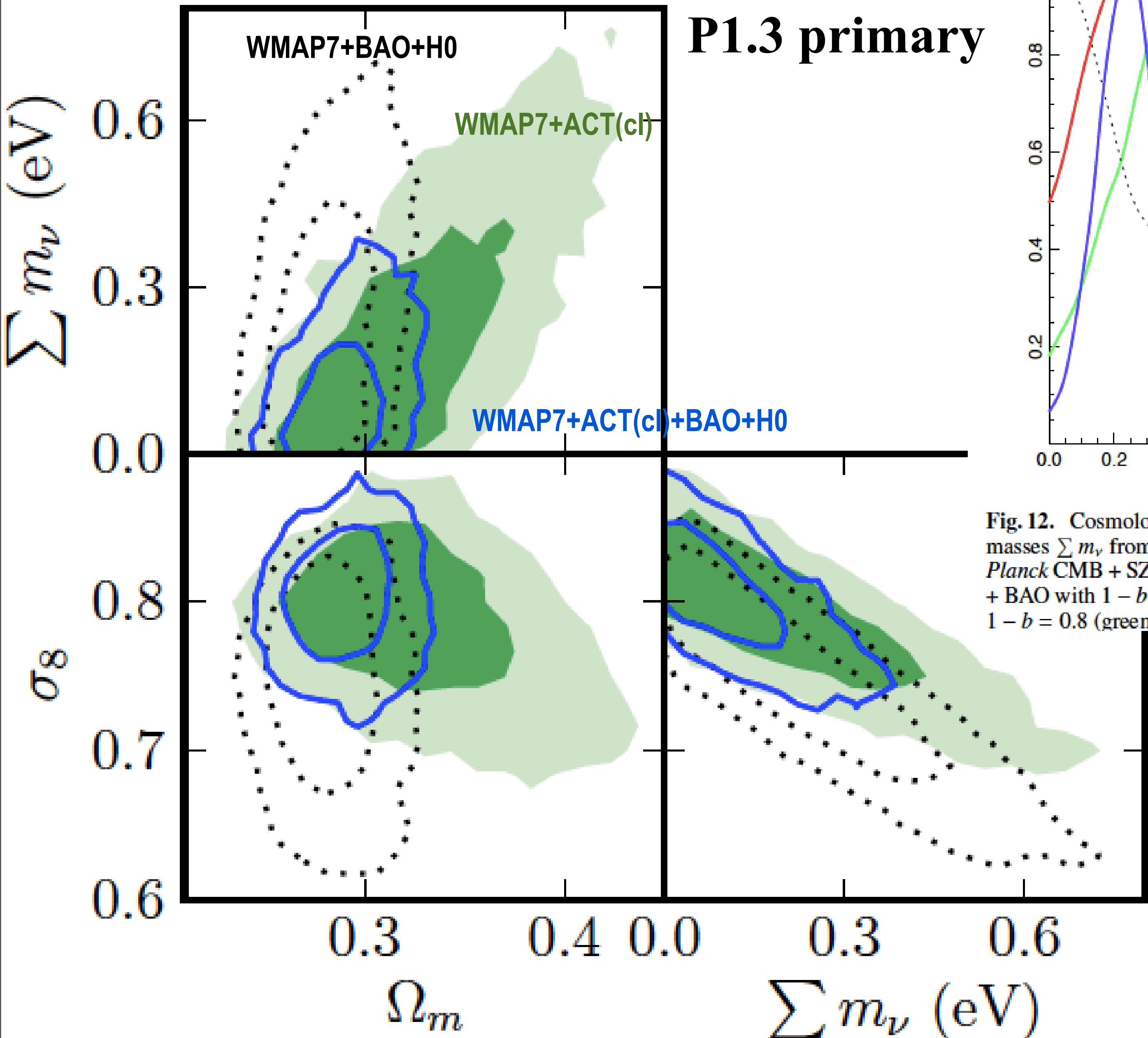
Planck 2013 results. XX. Cosmology from Sunyaev–Zeldovich cluster counts

Planck 2013 results. XXIX. Planck catalogue of Sunyaev–Zeldovich sources

thermal SZ clusters

$\Sigma m_\nu < 0.230$ ev

P1.3 primary



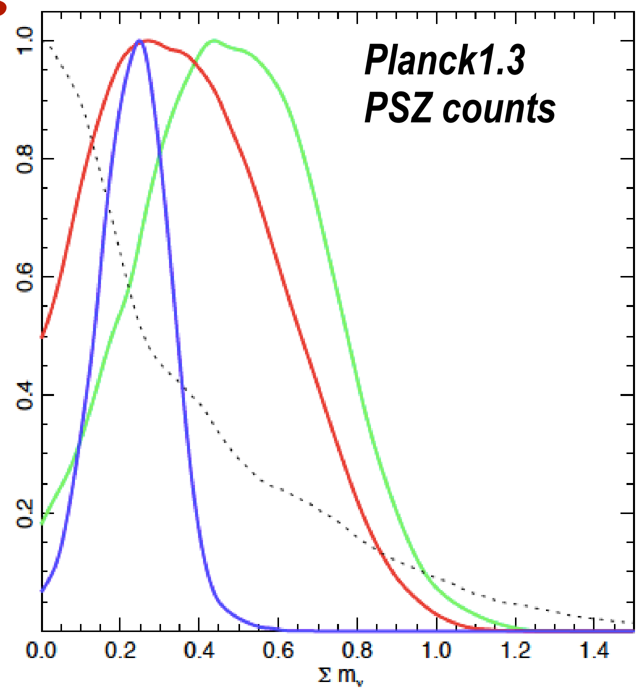


Fig. 12. Cosmological constraints when including neutrino masses $\sum m_\nu$ from: *Planck* CMB data alone (black dotted line); *Planck* CMB + SZ with $1-b$ in [0.7, 1] (red); *Planck* CMB + SZ + BAO with $1-b$ in [0.7, 1] (blue); and *Planck* CMB + SZ with $1-b = 0.8$ (green).

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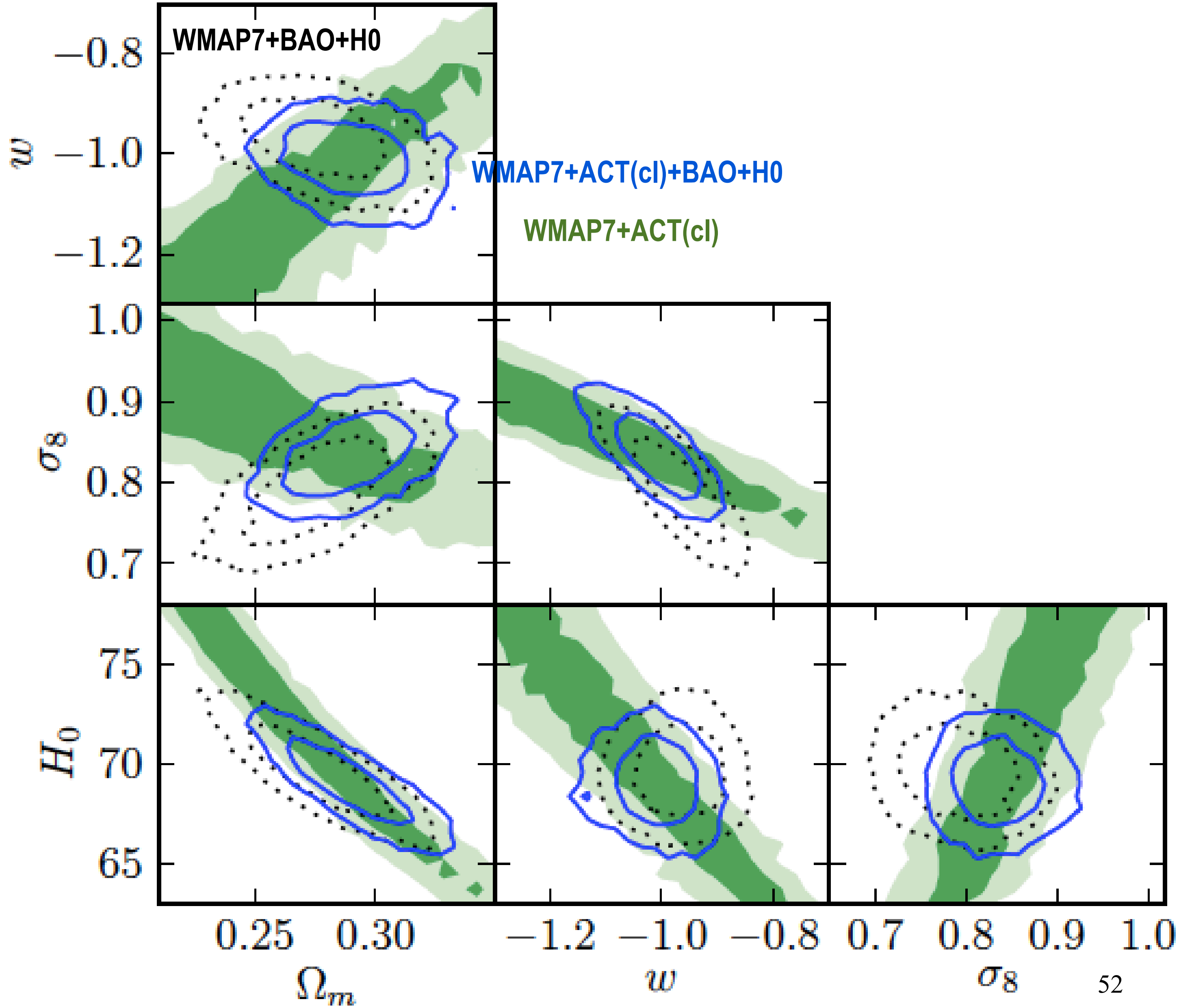
thermal SZ clusters



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