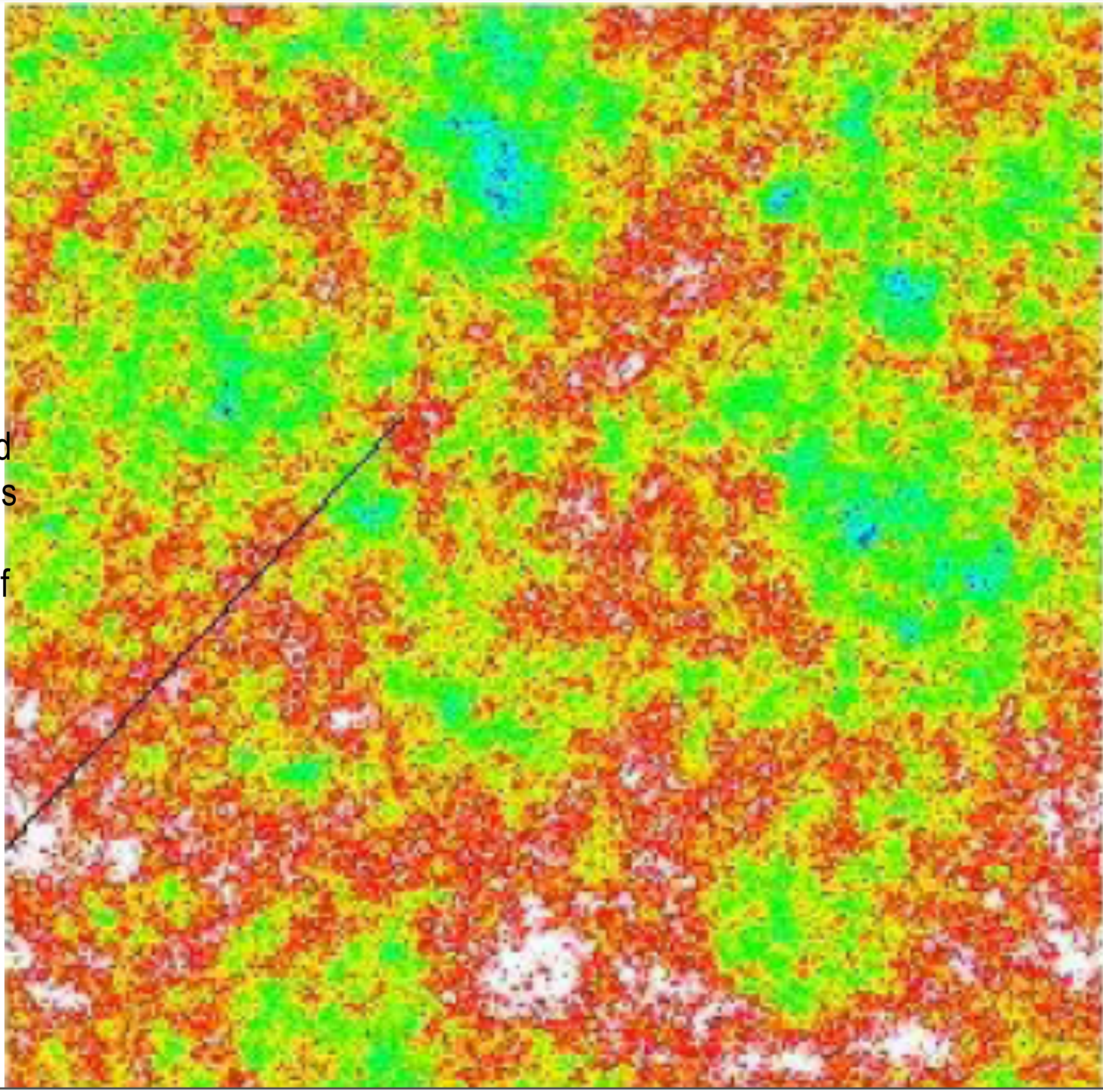
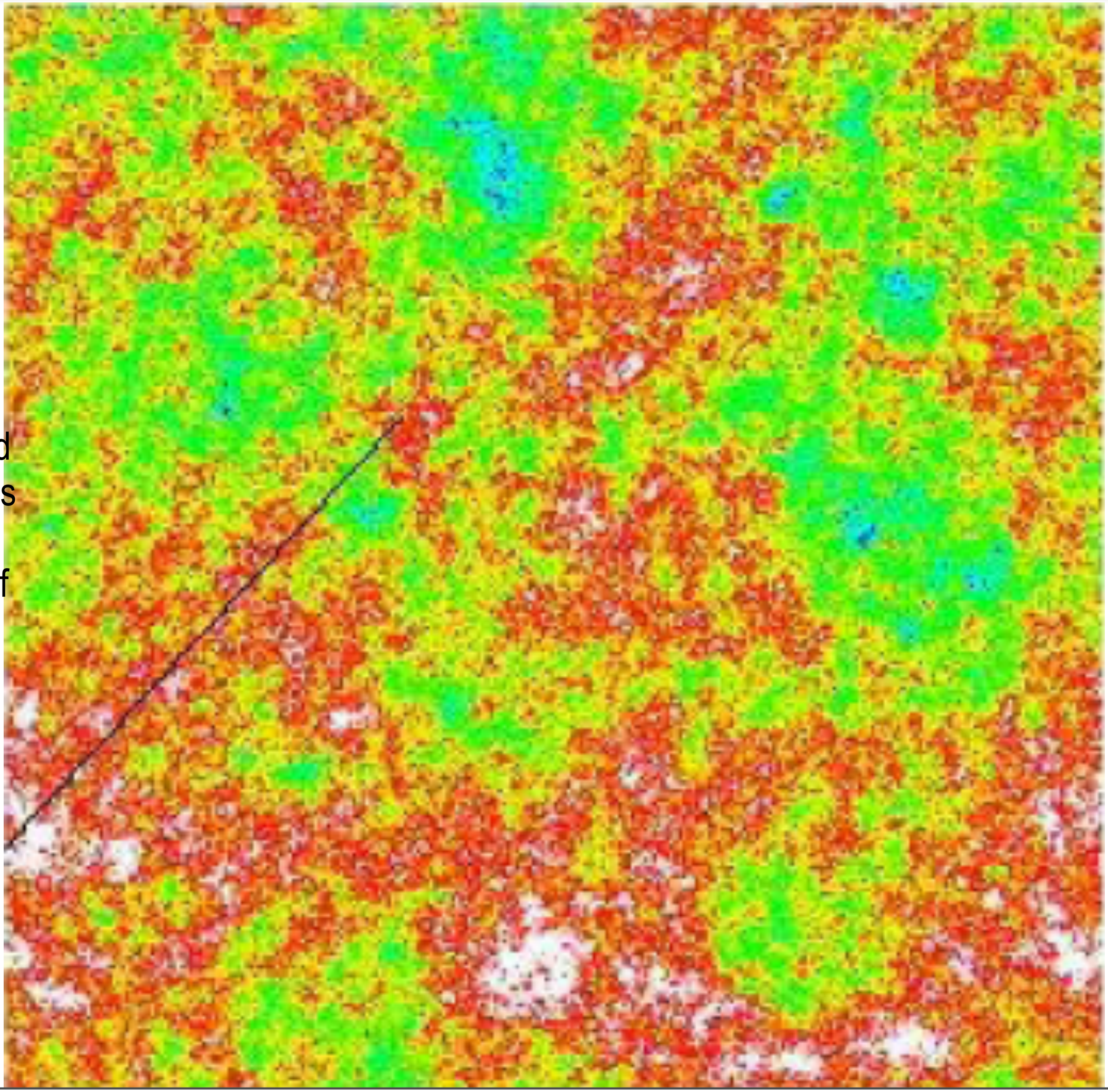
fluctuations in the **early universe "vacuum" grow** to *all* **structure**

scalar field fluctuations in the vacuum of the ultra-early Universe



fluctuations in the **early universe "vacuum" grow** to *all* **structure**

scalar field fluctuations in the vacuum of the ultra-early Universe



evolve from early U vacuum potential and vacuum noise

fluctuations in the **early universe "vacuum" grow** to *all* **structure**

400 Mpc

ΛCDM

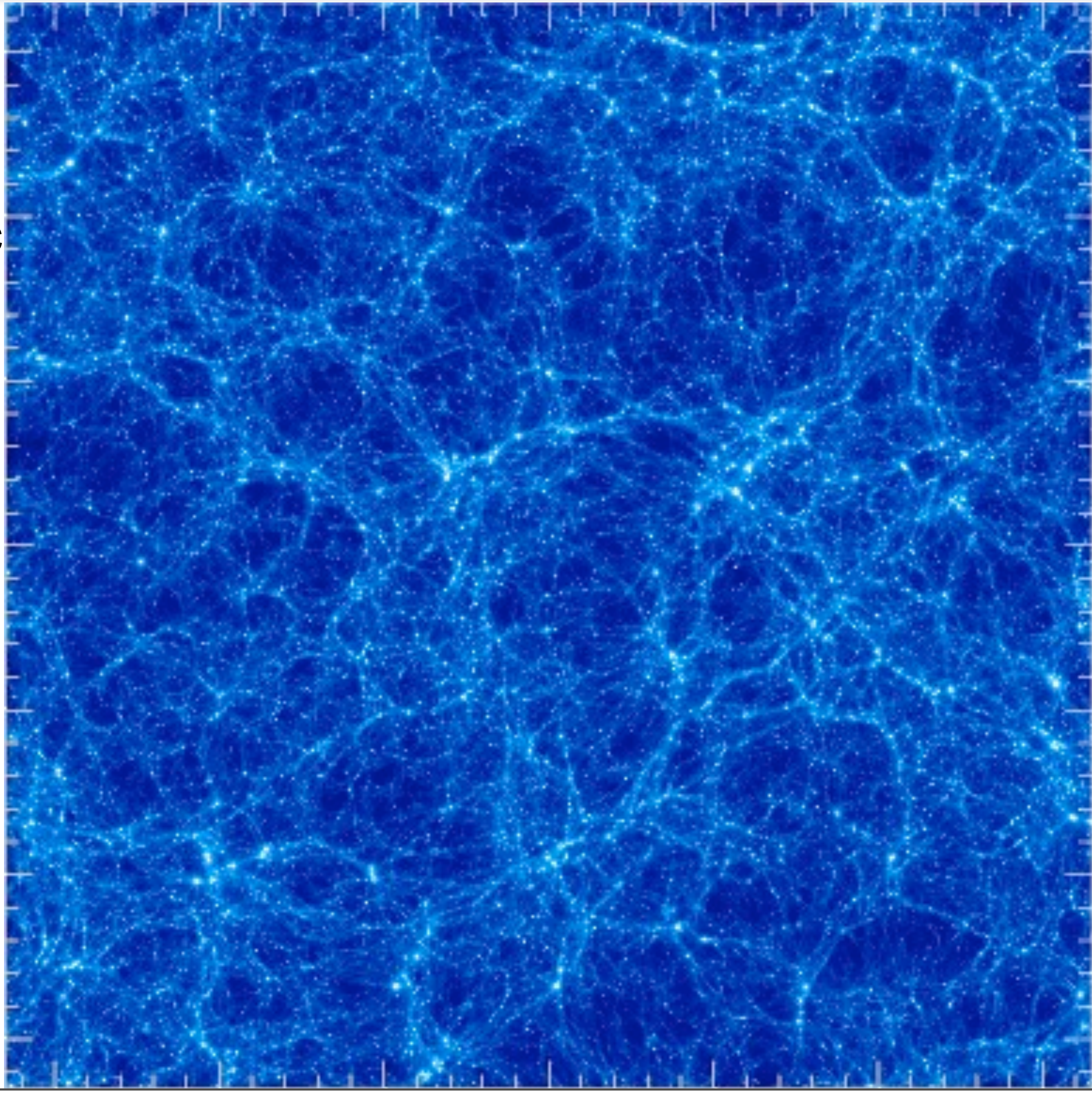
WMAP5

gas density

Gadget-3

SF+ SN E+ winds +CRs

512^3



all this can

evolve from early U vacuum potential and vacuum noise

in the presence of late U vacuum potential aka dark energy

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

400 Mpc

ΛCDM

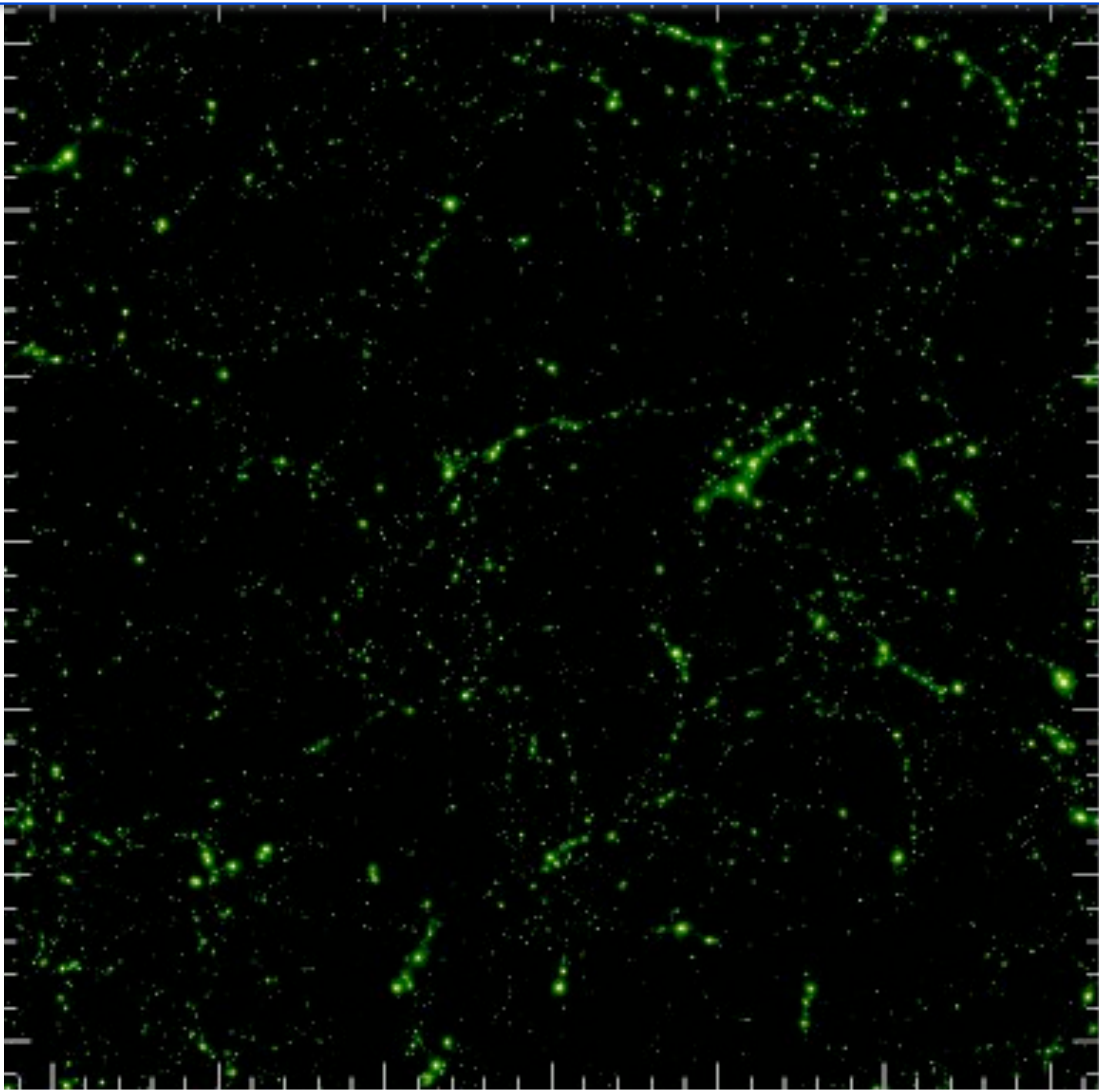
WMAP5

gas pressure

Gadget-3

SF+ SN E+ winds +CRs

512^3



entangled in the cosmic web

descending into the real astronomy

of

IGM/ISM/ICM

weather, dust storms

& turbulent times

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CIAR

the Sunyaev-Zeldovich Probes of Gas in the Cosmic Web: Overview

$\gamma + e \rightarrow \gamma + e$ Compton

$$\langle \Delta E_\gamma / E_\gamma \rangle = 4T_e/m_e c^2 - E_\gamma/m_e c^2$$

$$\langle (\Delta E_\gamma / E_\gamma)^2 \rangle = 2T_e/m_e c^2$$

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

$$y = \int n_e (T_e - T_\gamma)/m_e c^2 \, \sigma_T \, d\mathit{los} \sim \int p_e \, d\textit{line-of-sight}$$

Compton y-parameter

kinetic SZ: $\Delta T/T = \int n_e \mathbf{v}_{e||} /c \, \sigma_T \, d\mathit{los} \sim \int \mathbf{J_e} \cdot \mathbf{dr}$

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

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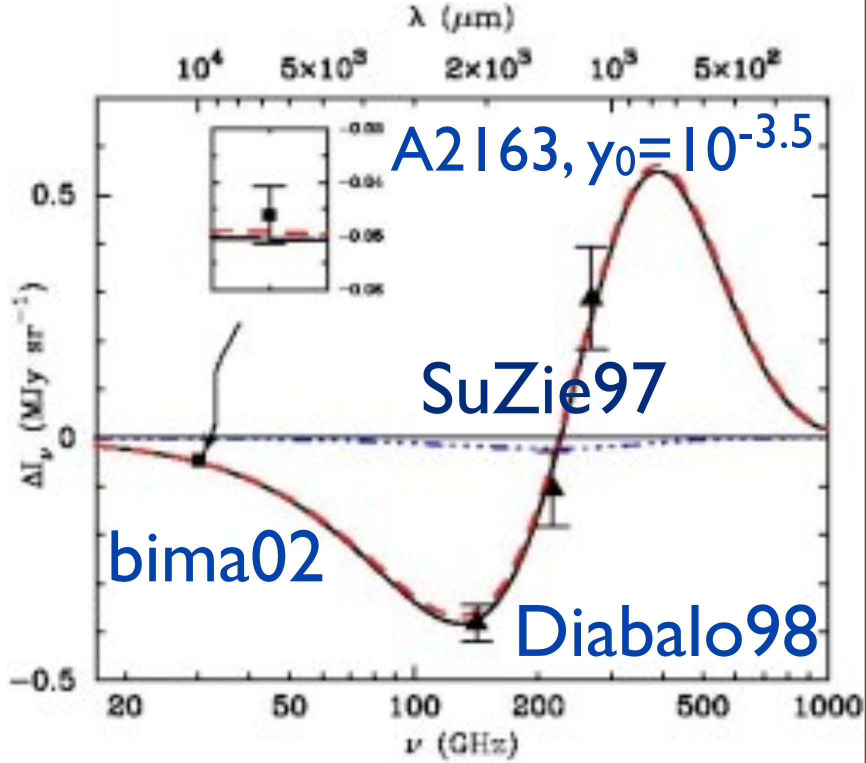
$\Delta T/T = y * (x(e^x+1)/(e^x-1)-4)$, $x = h\nu/T_\gamma$

$= -2y$ to xy, **0 @ ν=217 GHz**

$\Delta I_\nu = \Delta T/T * x^4 e^x/(e^x-1)^2$



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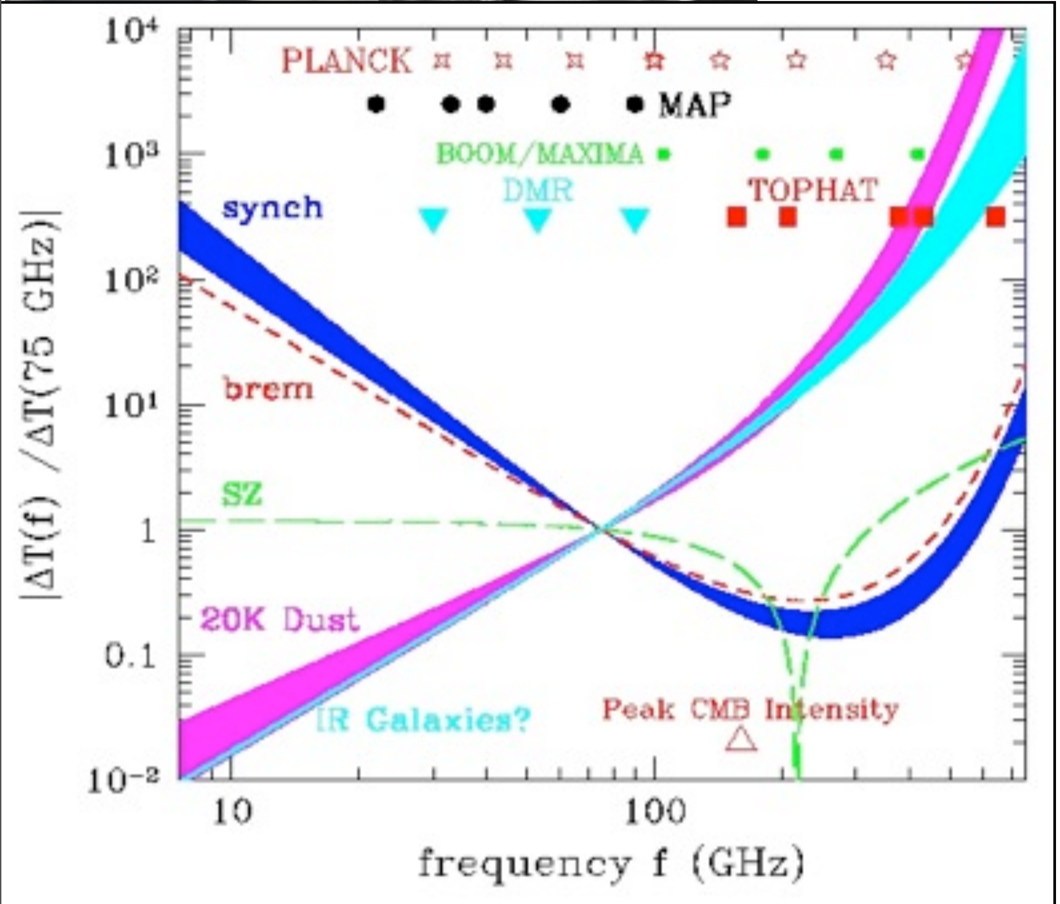

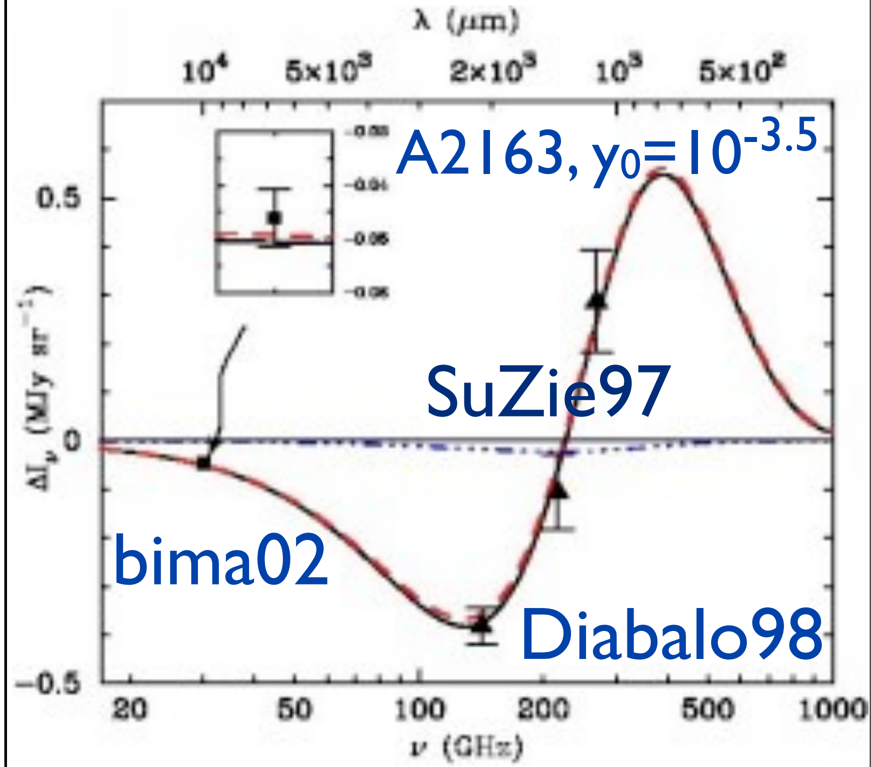

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$= -2y$ to xy, 0 @ $\nu = 217$ GHz

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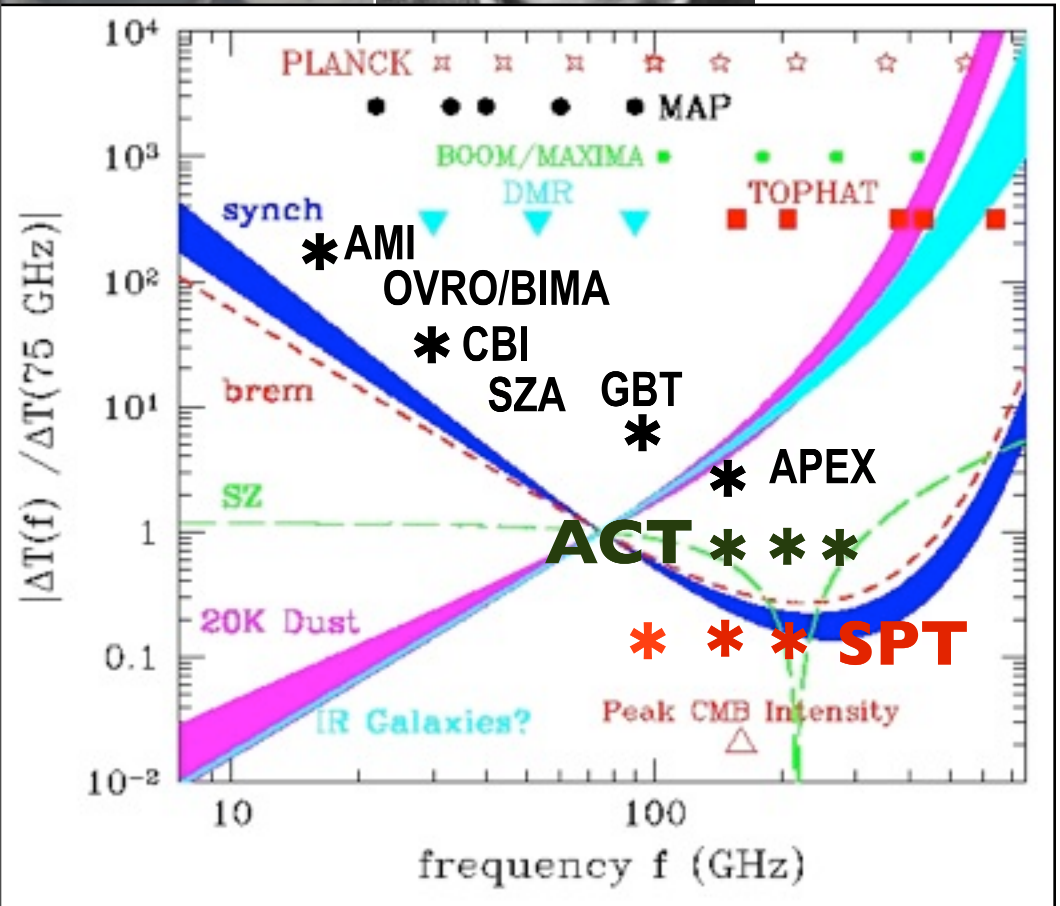
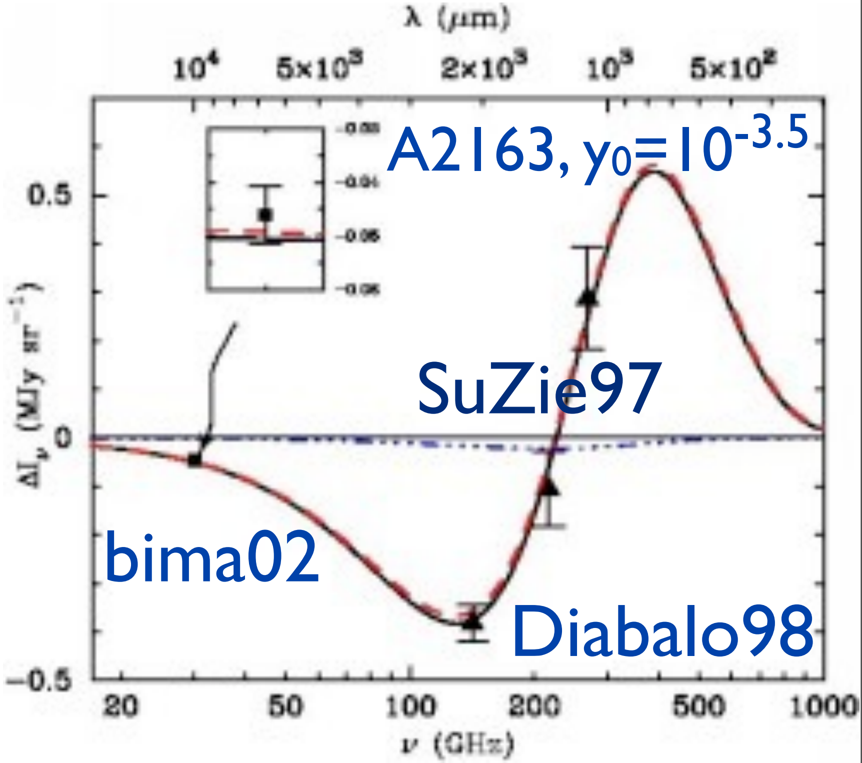
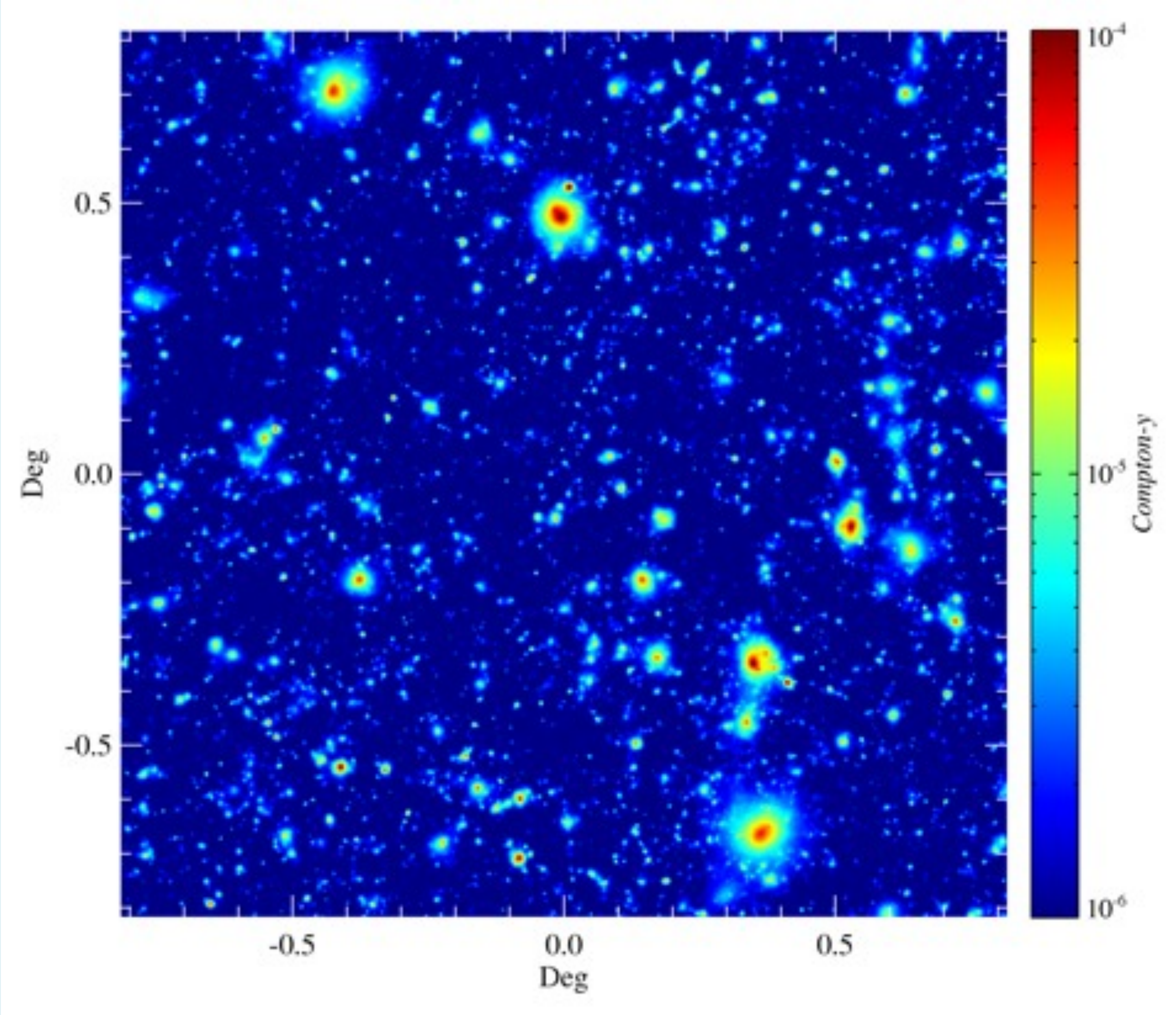




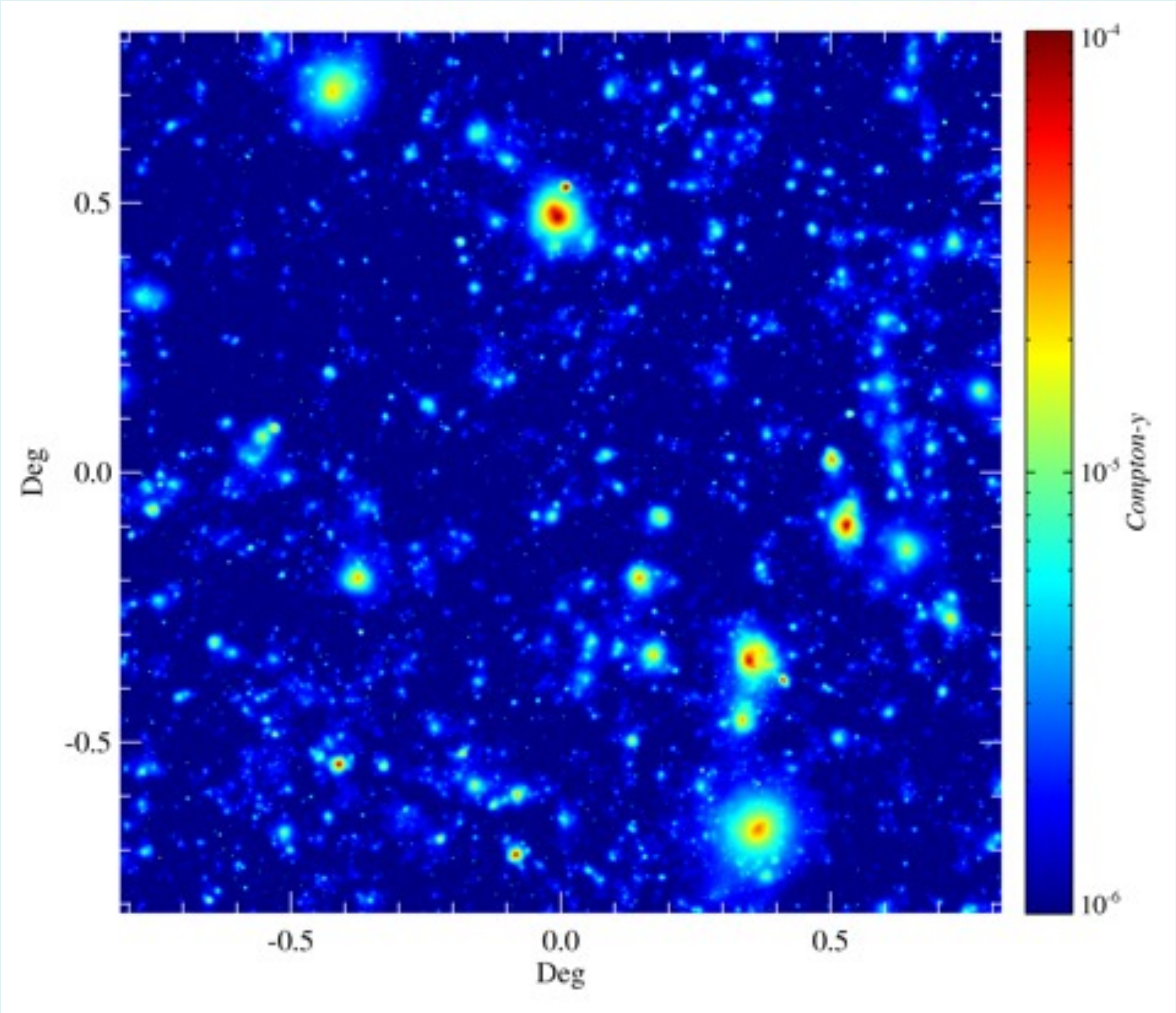
Compton-y map: "adiabatic"

= formation shock entropy from gravitational accretion only

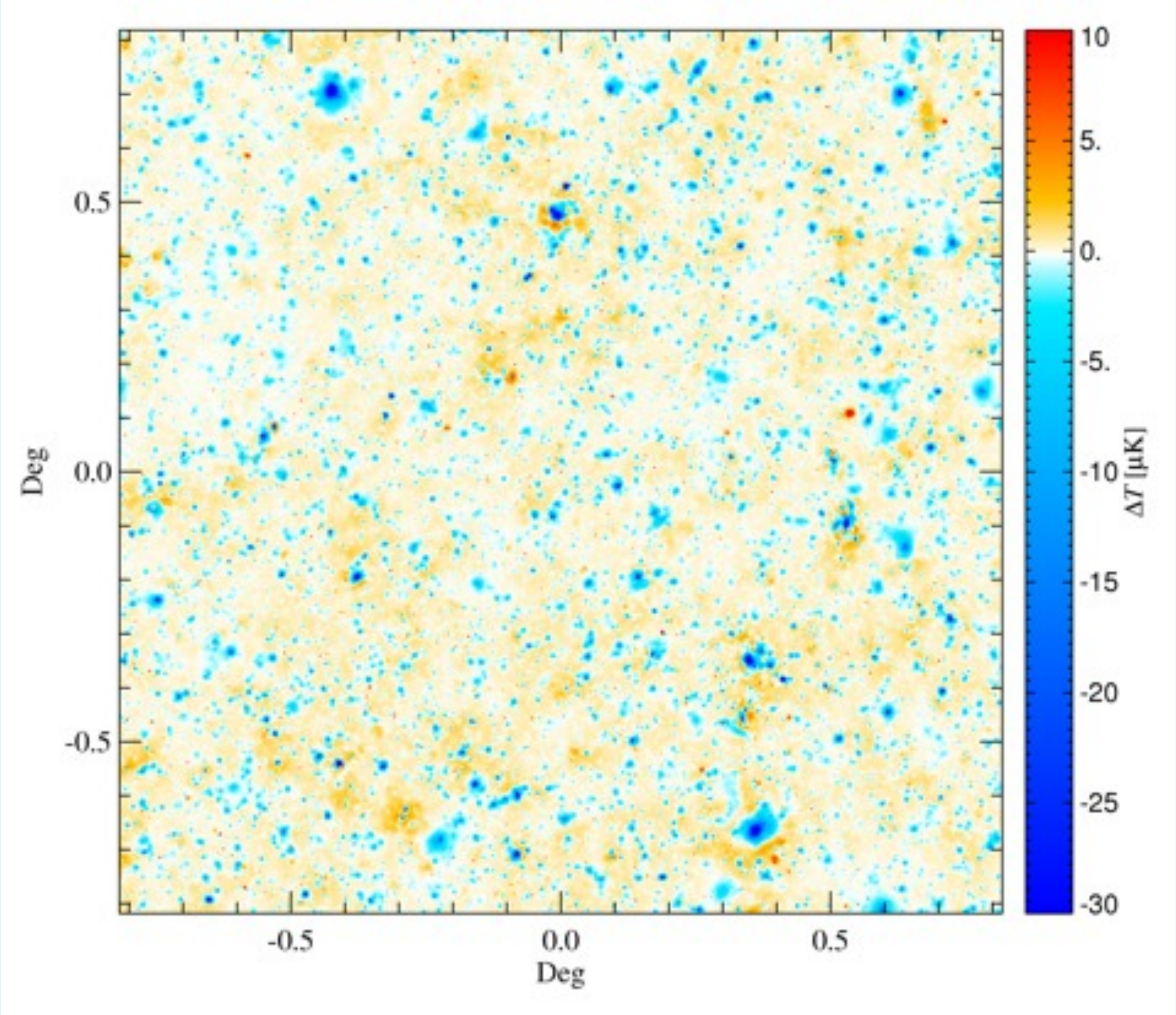


Compton-y map: Feedback

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



Adiabatic - Feedback



feedback gives "puffier" clusters, with lower core pressures

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the Sunyaev-Zeldovich Probes *of* Gas *in the* Cosmic Web

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

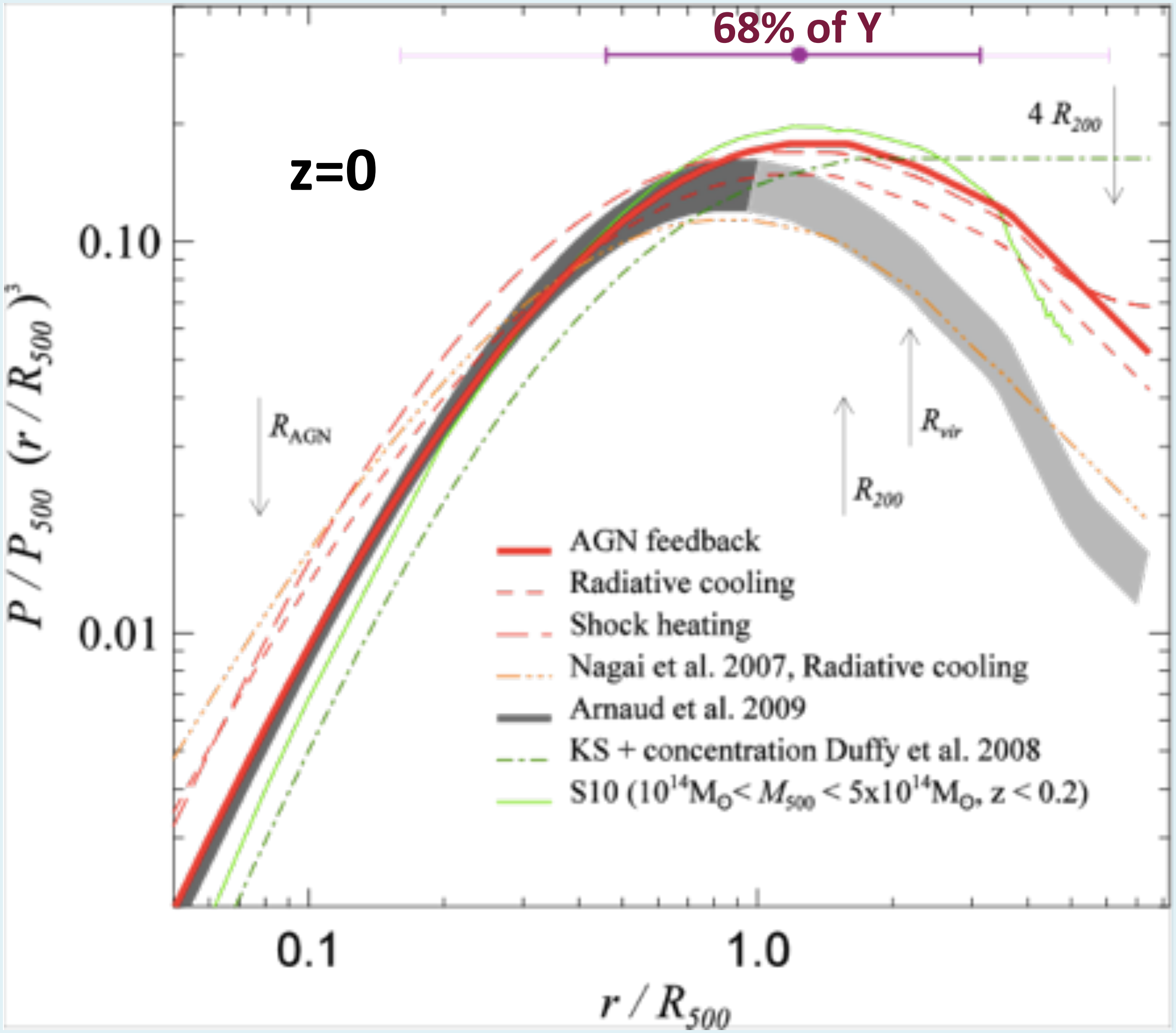
$$y = \int n_e (T_e - T_\gamma)/m_ec^2\ \sigma_T\ d\mathit{los} \sim \int p_e\ d\text{line-of-sight}$$

$$Y = \int y(\theta,\varphi)d\Omega \sim E_{th}/D_A^2 \sim (E_{grav} - 3P_{kinetic,etc}V + 3P_sV)/2\ D_A^2$$

VIRIAL THEOREM: $E_{grav} \sim GM_gM/R \sim M^{5/3}$ **dark matter dominated**

scaled Pressure profiles: $d\mathit{ln}\, E_{th}(<r)/d\mathit{ln}\, r$

Battaglia, Bond, Pfrommer, Sievers, Sijacki 10



AGN Feedback sims match Arnaud *etal* <X-ray profiles> to data-end ~r_{500} universal?

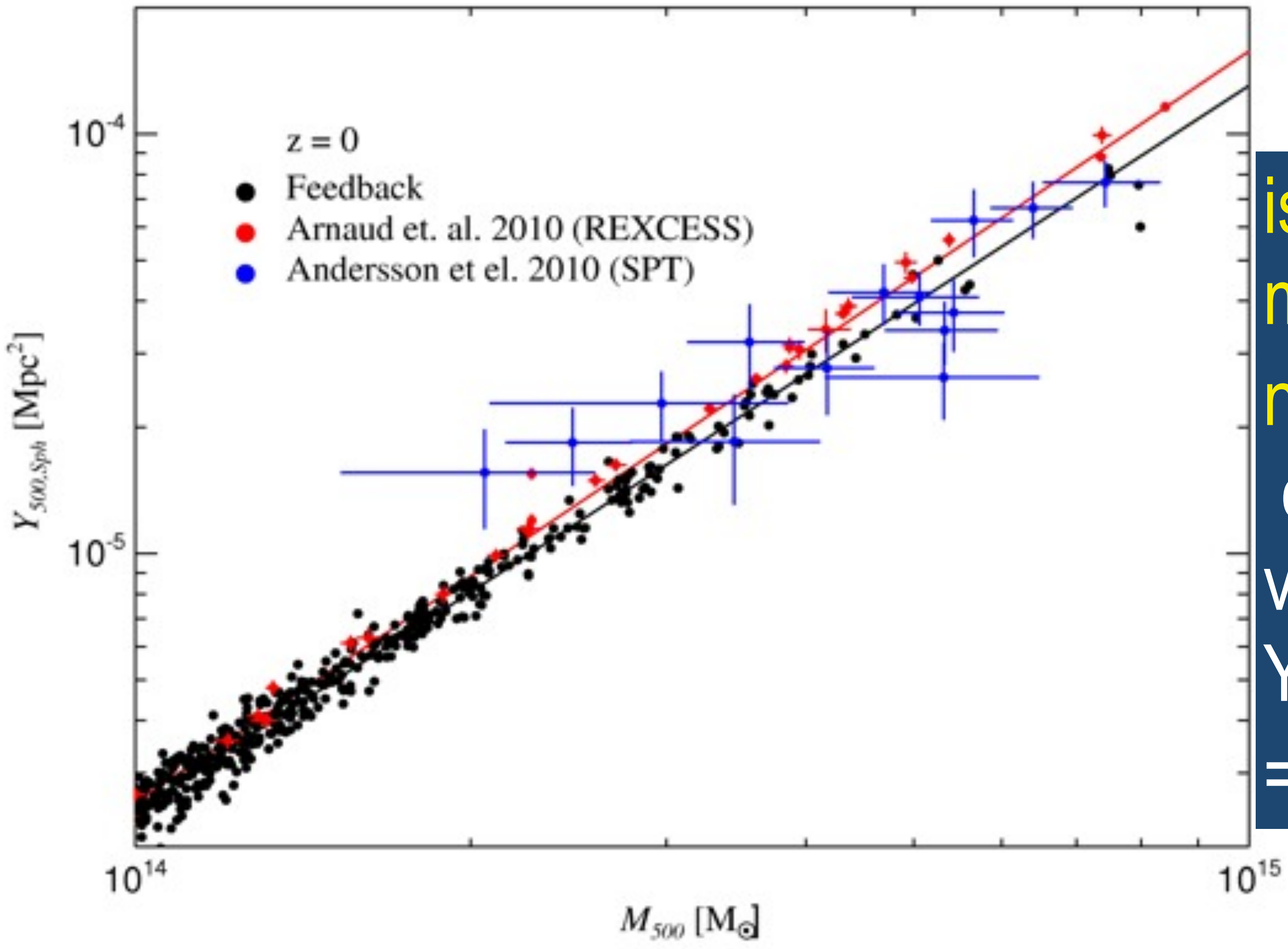
redshift, mass, ... dependent

$$\frac{P}{P_{\Delta}} = \frac{A}{\left[1+\left(\frac{x}{x_c}\right)^{\alpha}\right]^{\gamma/\alpha}}$$

$Y(<r_\Delta)$-$M(<r_\Delta)$ relation, *where*

$M(<R_\Delta)/V(<R_\Delta)=\Delta\ \rho_{crit}$, Δ=2500, **500**, 200

Battaglia, Bond, Pfrommer, Sievers 11



Planck-ESZ

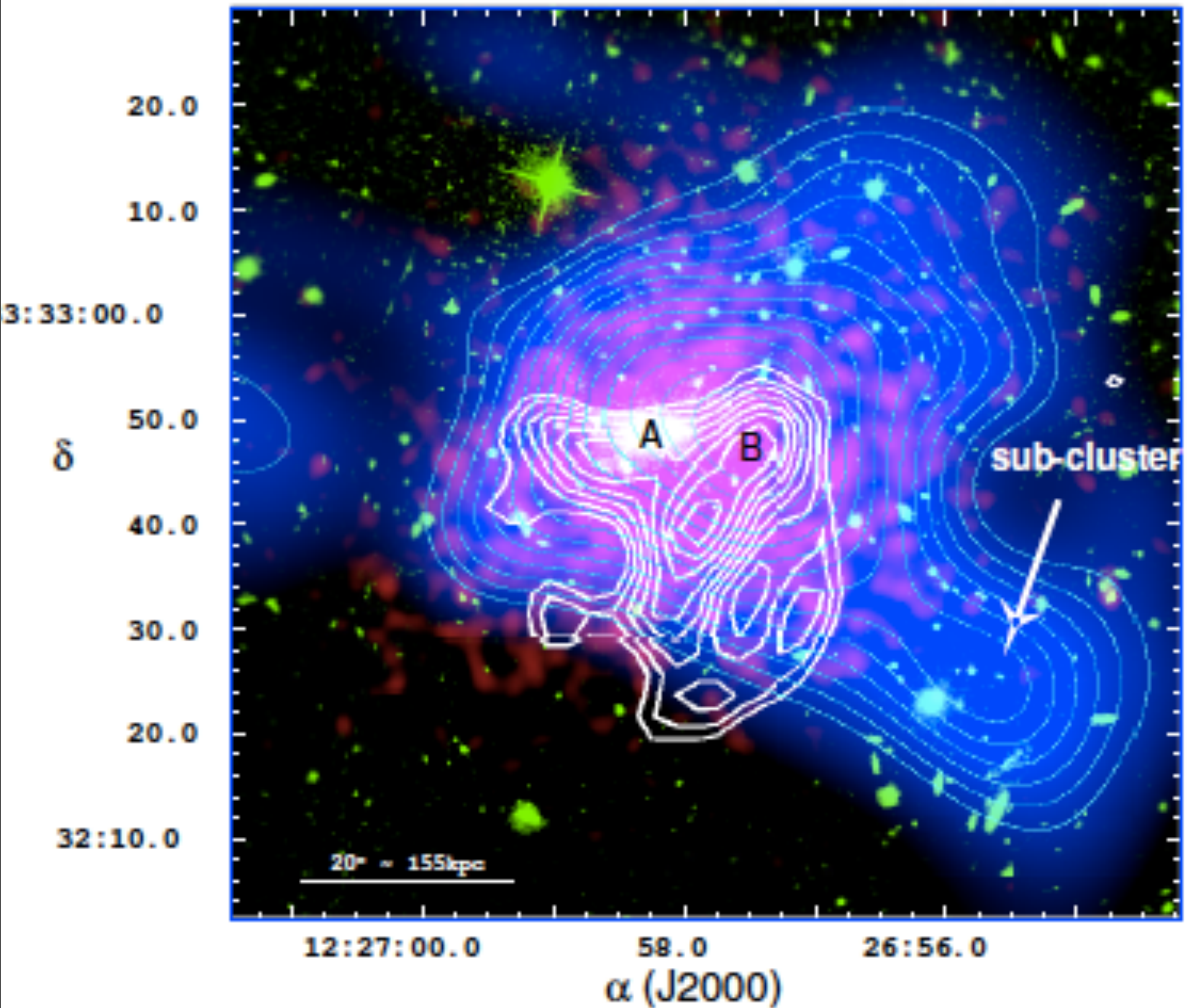
gives $\mathbf{Y_{5R500}}$

is Y_{SZ} a good mass proxy in $n_{cl}(M, z)$?

even though virial theorem $Y(e,K/U,\ldots|M)$

=> $n_{cl}(Y, z)$

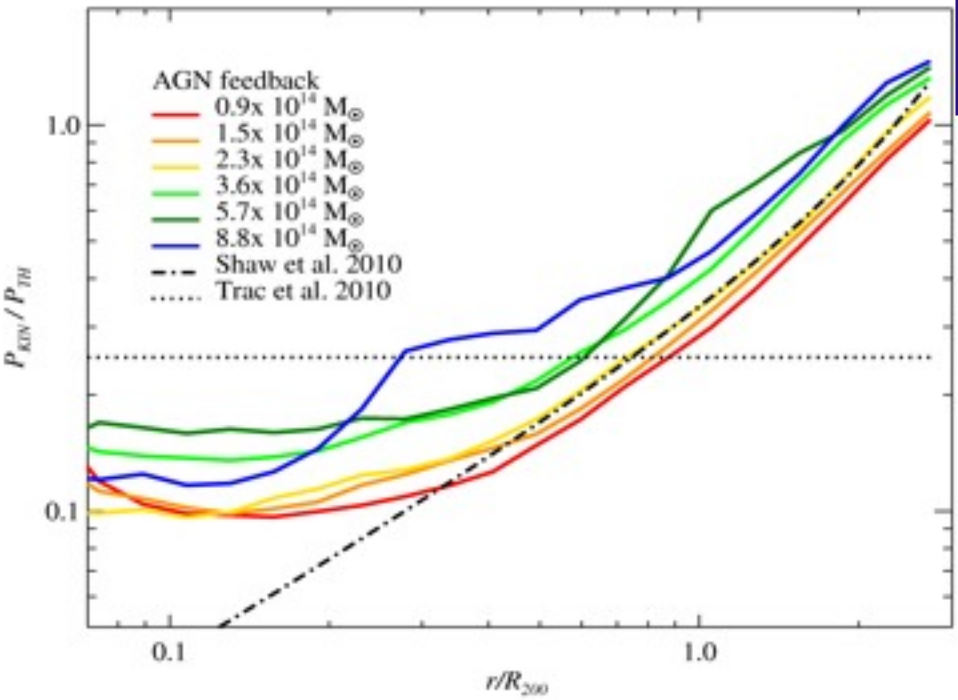
Mustang on GBT 90 GHz 64 bolometer array Imaging SZ @~10" res 4 cls 2010, ~25 Hubble CLASH cls to come Devlin, Mason, ...



CL1226 z=0.89

Red Chandra
Blue/cyan weak lens Σ
Green optical
White MUSTANG **SZ >3σ**

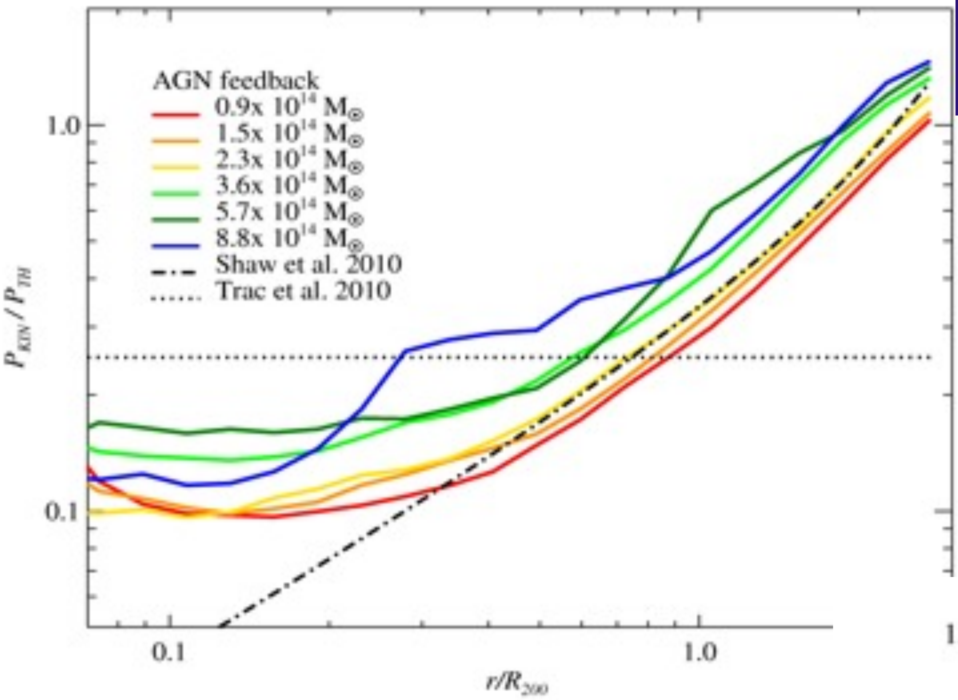
A BCG ~ X-ray peak
B Dark Matter peak
~ lobe of SZ ridge



$P_{kin} / P_{th} \sim 0.1\text{-}0.6!$

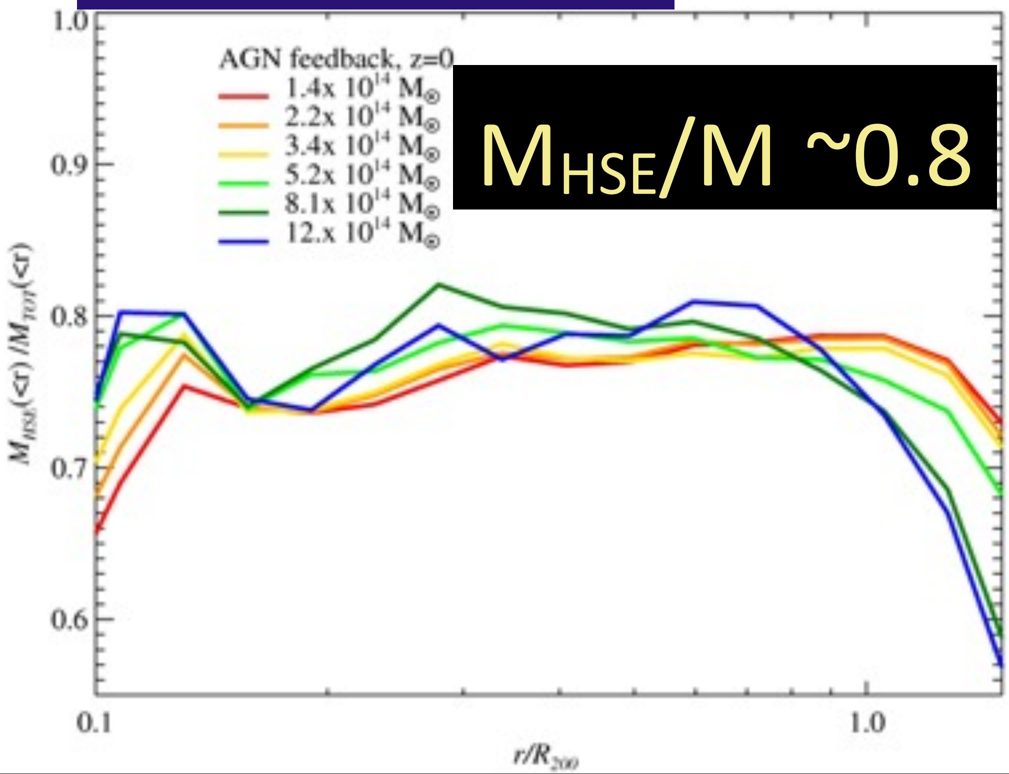
$<(\Delta v)^2>/c_s^2$
cannot be
ignored in HSE
$\nabla p_{g,tot} = \rho_g g$

Battaglia, Bond, Pfrommer, Sievers 11



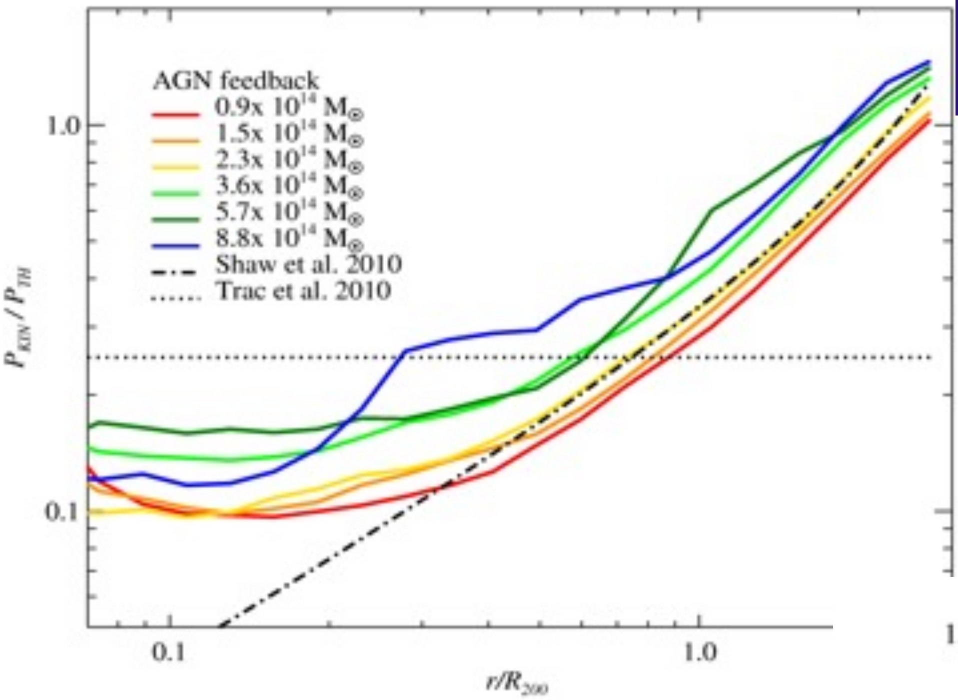
P_{kin}/P_{th}~0.1-0.6!

$\langle(\Delta v)^2\rangle/c_s^2$ cannot be ignored in HSE $\nabla p_{g,tot}=\rho_g g$



M_{HSE}/M ~0.8

Battaglia, Bond, Pfrommer, Sievers 11



P_{kin} $/P_{th}$~0.1-0.6!

$\langle(\Delta v)^2\rangle/c_s^2$
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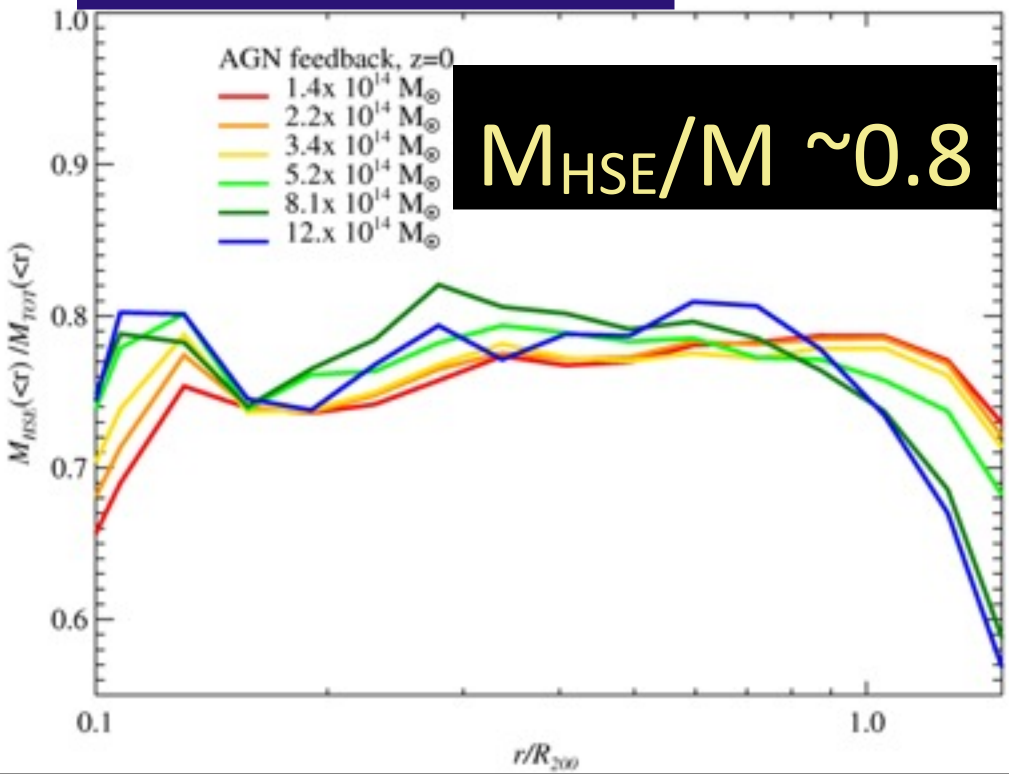


M_{HSE}/M ~0.8

Hydro Sims include all effects
(except of course for those not included).

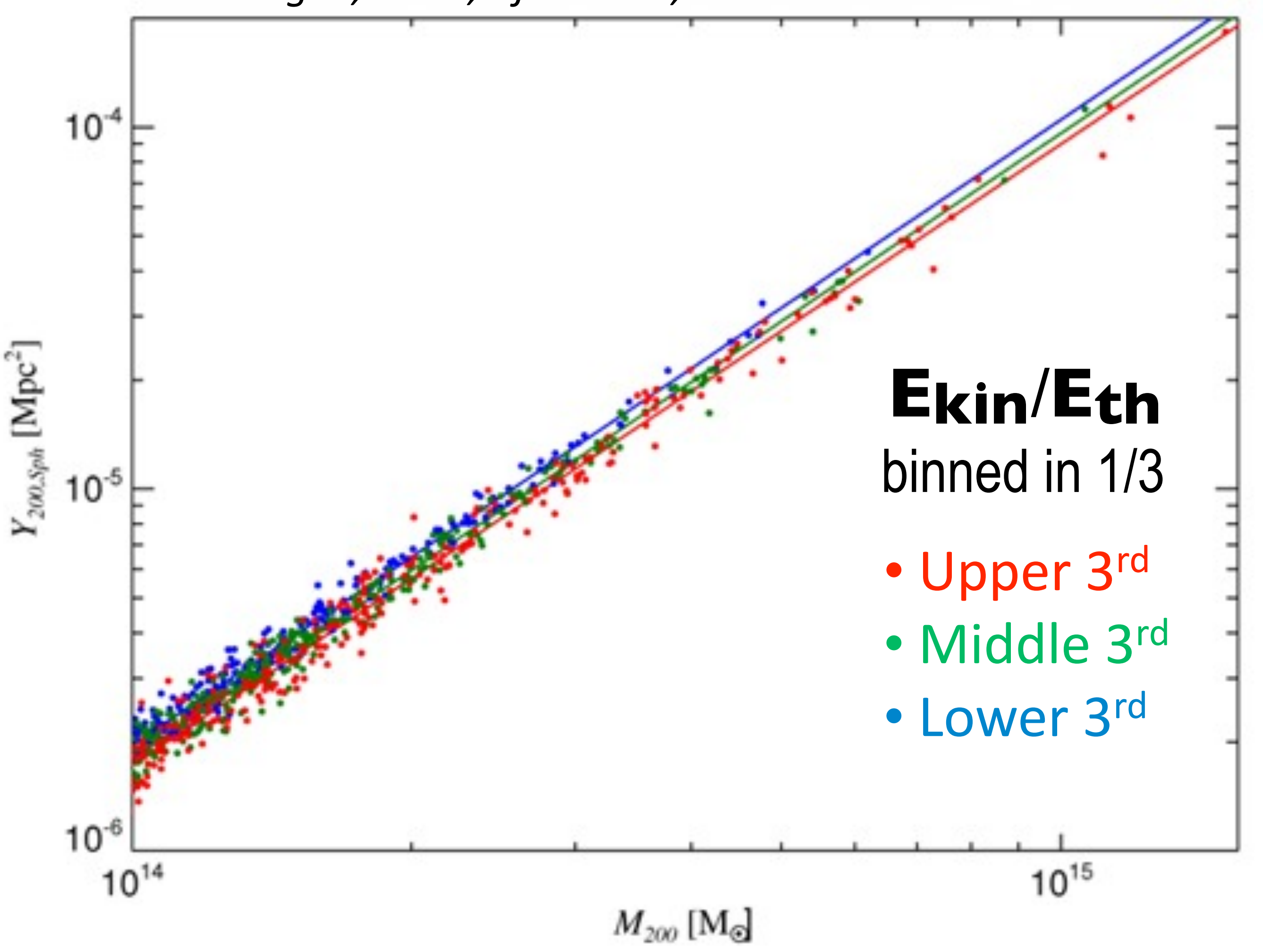
Analytic and semi-analytic treatments must be fully calibrated with sims to give a useful phenomenology.

Battaglia, Bond, Pfrommer, Sievers 11

Y(<r$_\Delta$)-M(<r$_\Delta$) relation, *where*

$M(<R_\Delta)/V(<R_\Delta)=\Delta\ \rho_{crit}$, Δ=2500, 500, 200

Battaglia, Bond, Pfrommer, Sievers 11



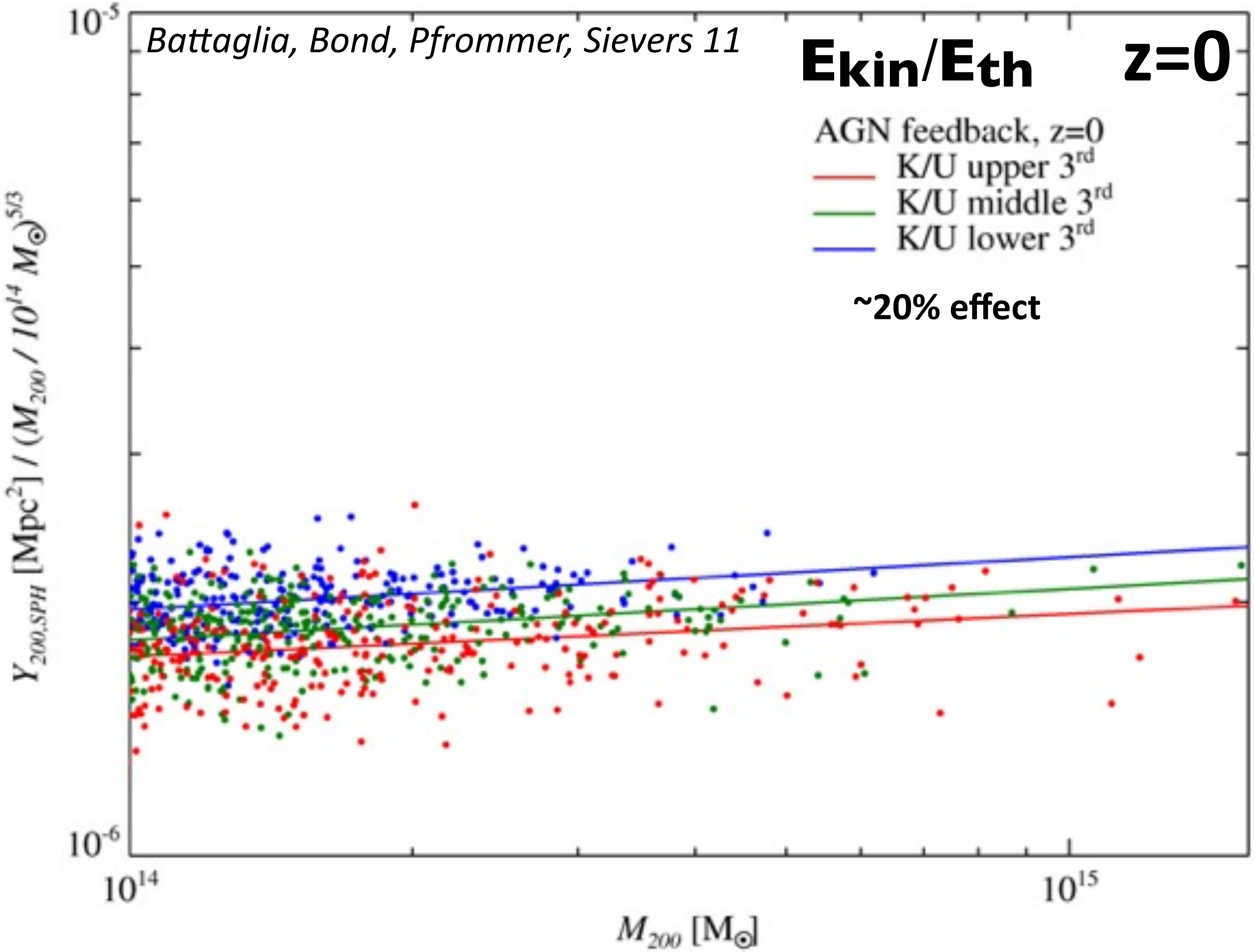
E_{kin}/E_{th}
binned in 1/3

- Upper 3rd
- Middle 3rd
- Lower 3rd

Planck-ESZ
gives **Y_{5R500}**

is Y a good mass proxy in $n_{cl}(M, z)$?
even though virial theorem
Y(e,K/U,...|M)
=> $n_{cl}(Y, z)$

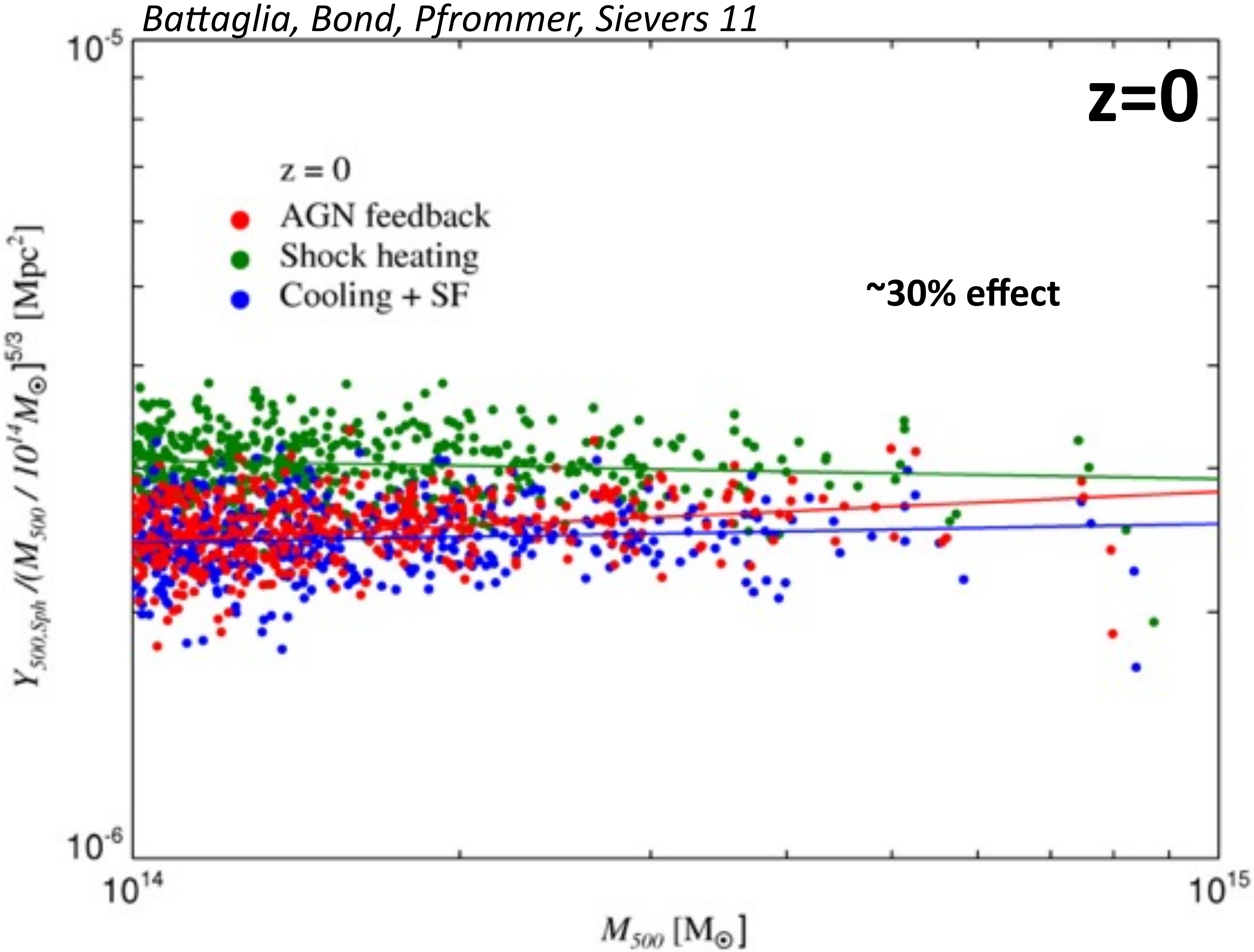
$Y/M^{5/3}$ *vs* M relation: "turbulence"



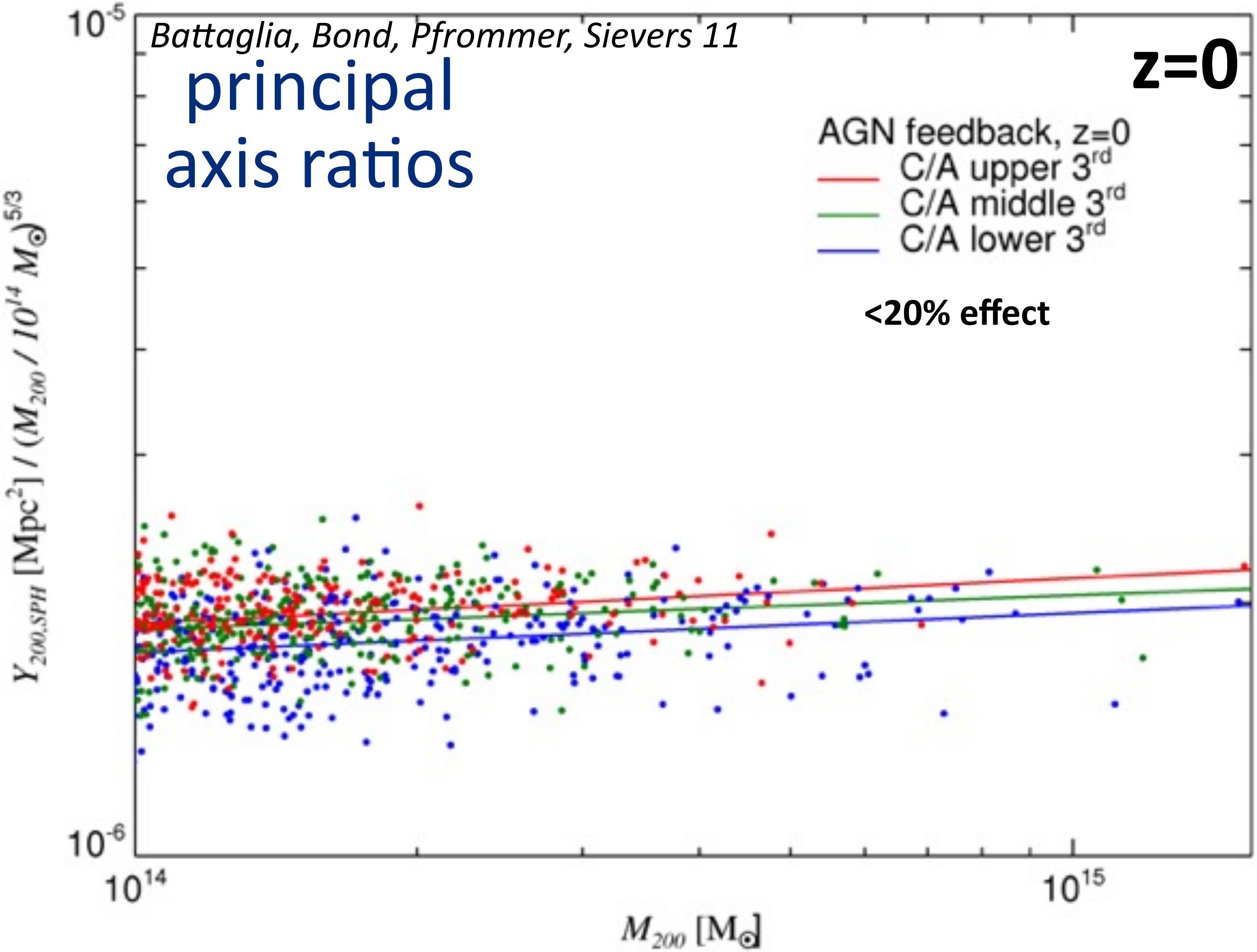
$Y/M^{5/3}$ *vs* M relation: Δ input physics

AGN feedback is better: $M^{5/3}$ scaling broken

Battaglia, Bond, Pfrommer, Sievers 11

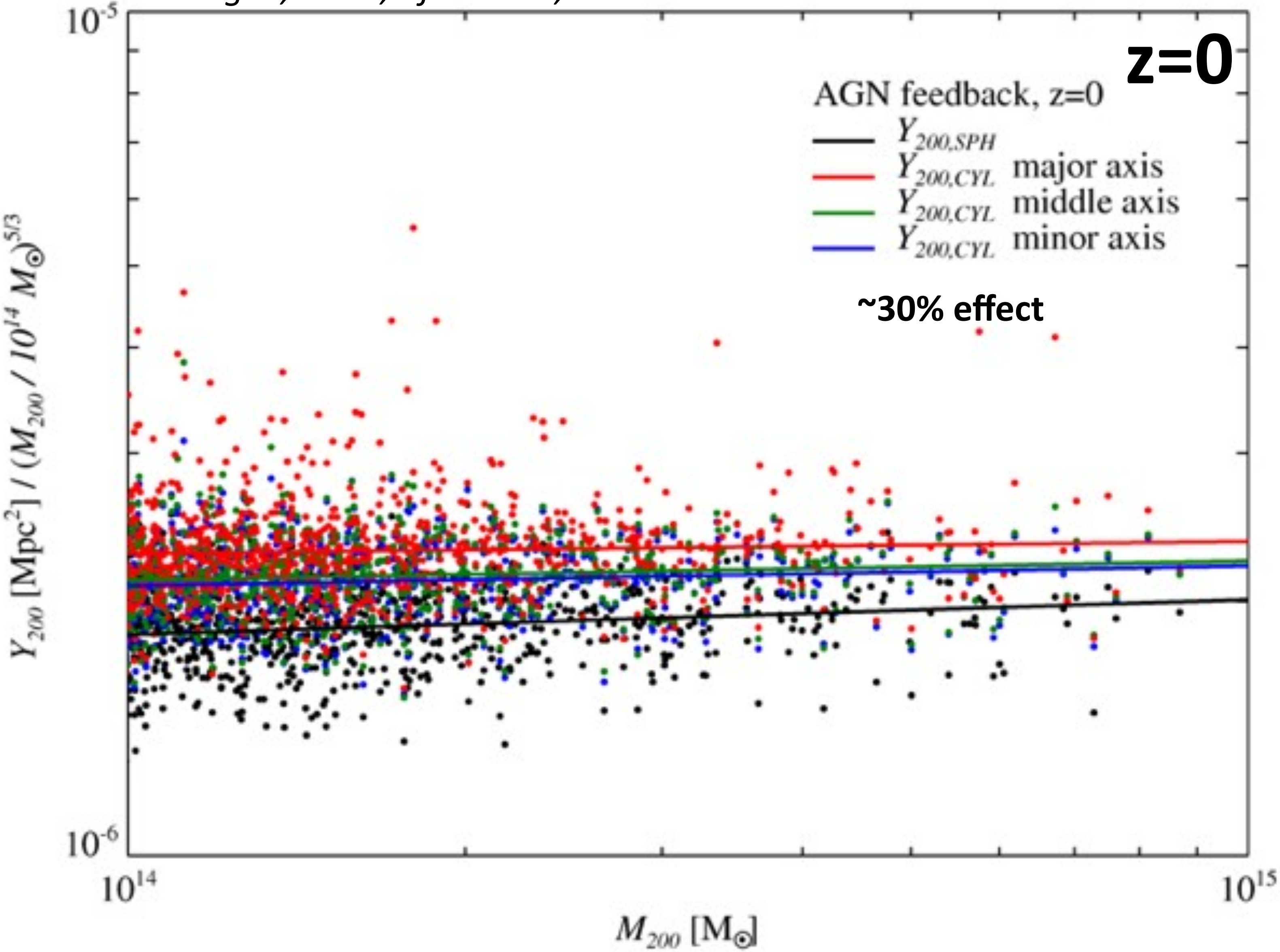


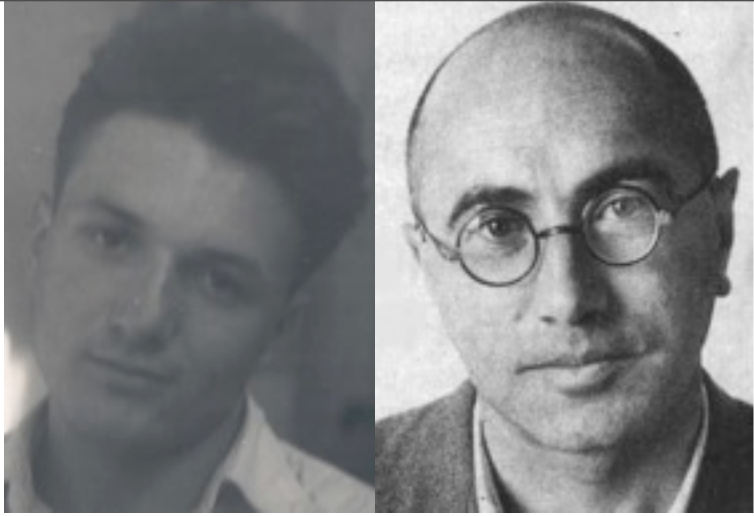
Y/M$^{5/3}$ *vs* M relation: **asymmetry**



Y_{sph} cf. Y_{cyl} *vs* M: asymmetry

Battaglia, Bond, Pfrommer, Sievers 11





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the Sunyaev-Zeldovich Probes of Gas in the Cosmic Web

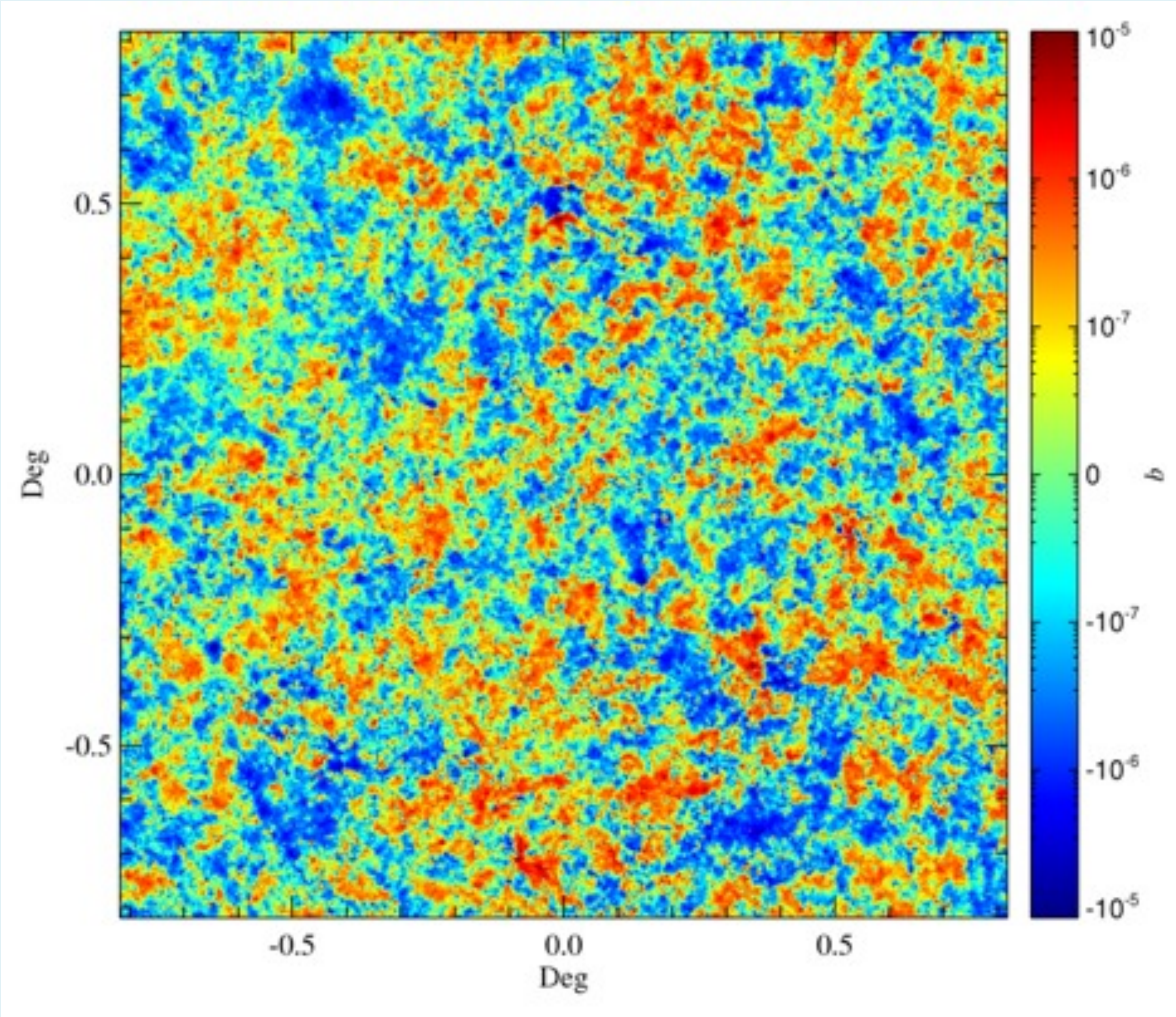
γ+e ➜ γ+e Compton

$$\textbf{kinetic SZ: } \Delta T/T = \int n_e \, \mathbf{v}_{e||} / c \, \sigma_T \, d\mathit{los} \sim \int \mathbf{J_e} \cdot \mathbf{d}\boldsymbol{r}$$

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

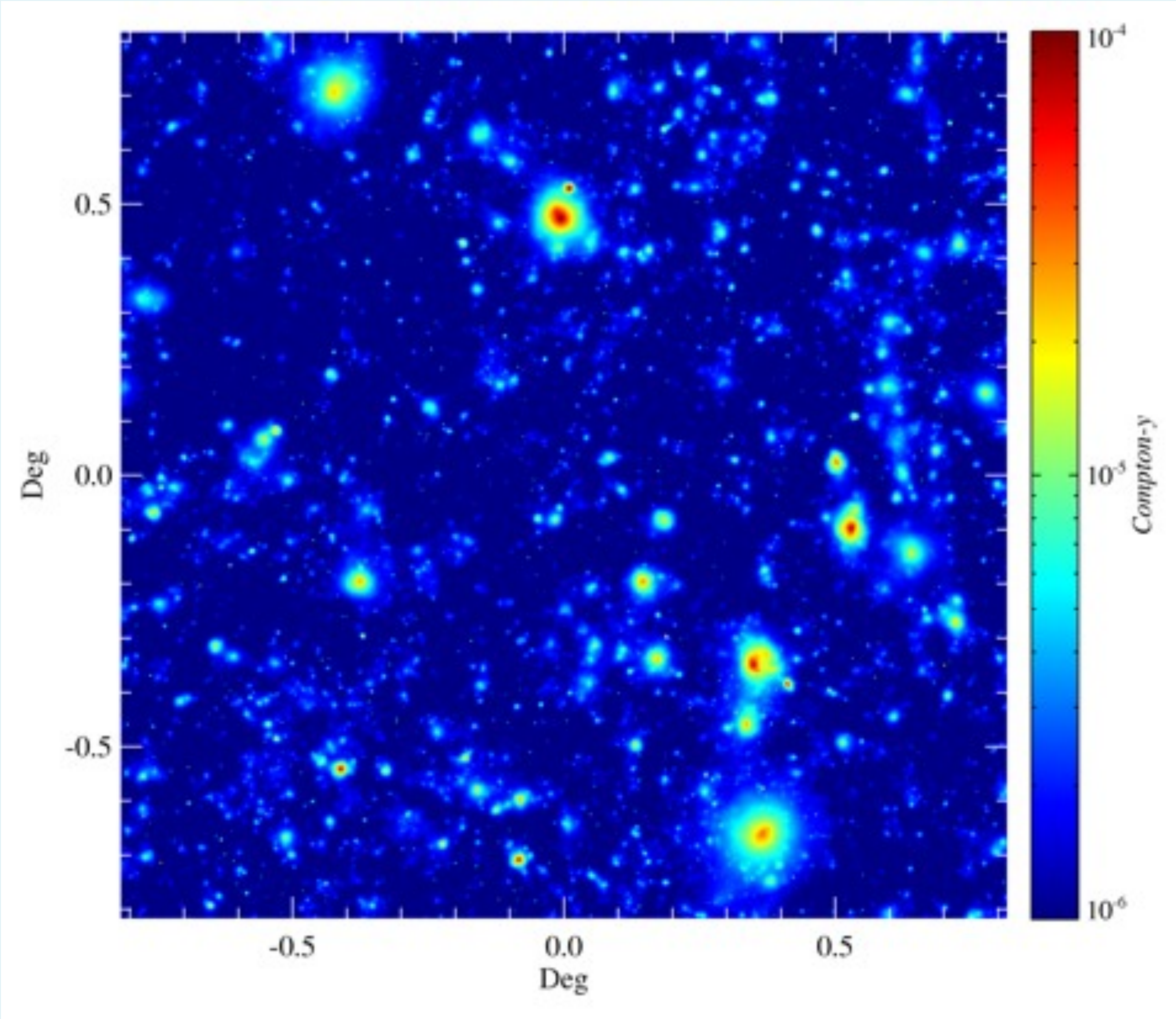
kinetic SZ map *(log)*: Feedback

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



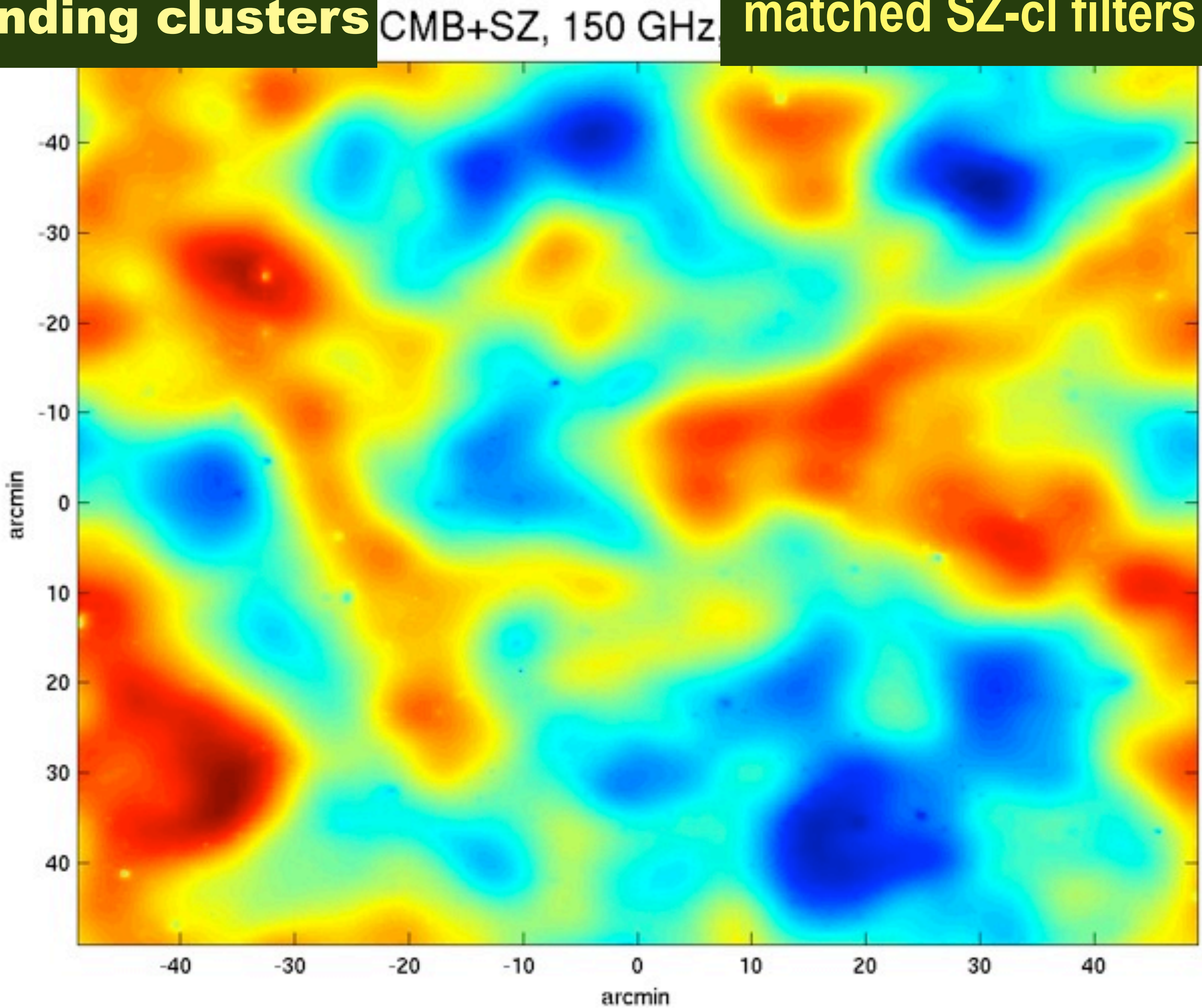
Compton-y map: Feedback

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



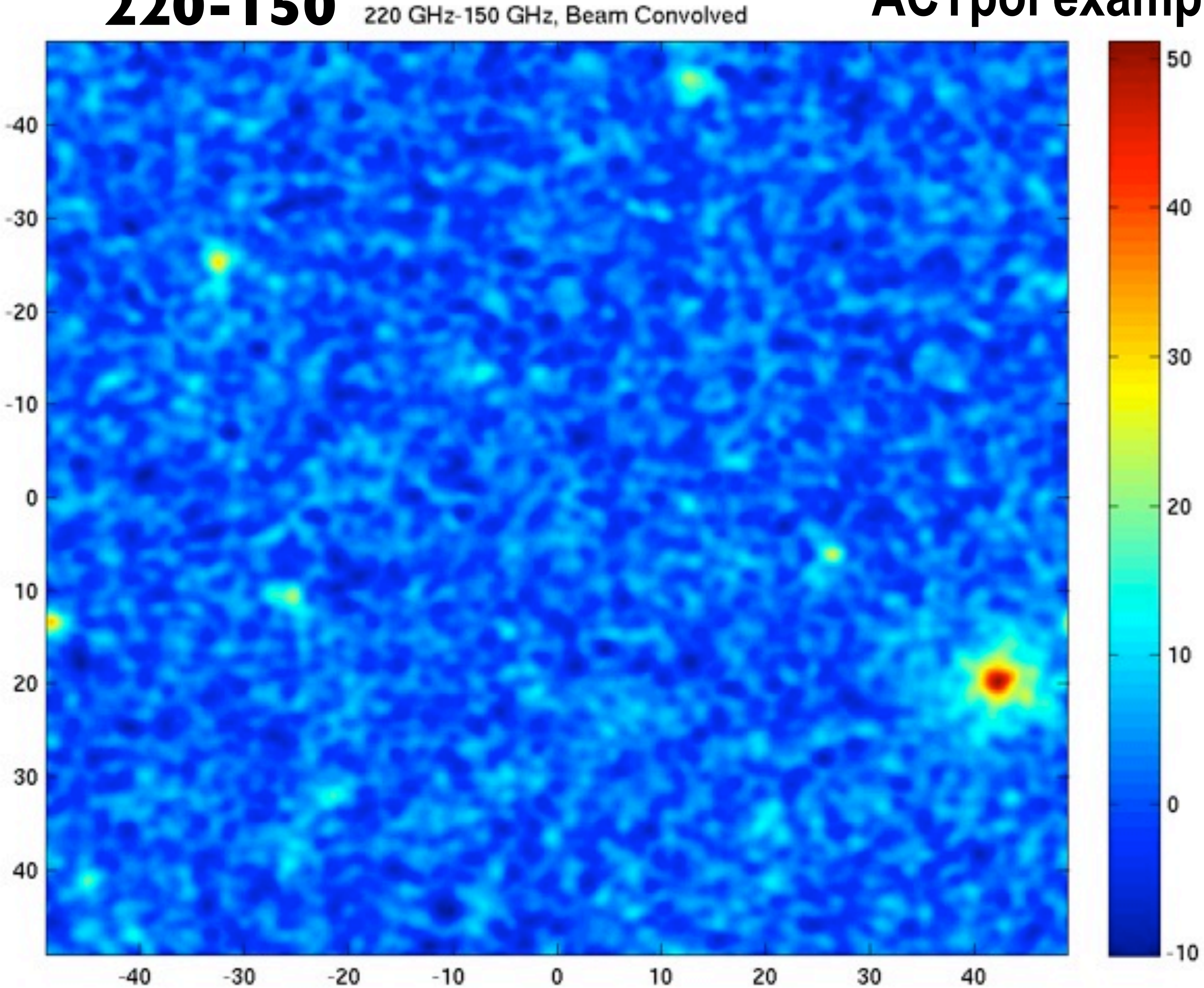
finding clusters

matched SZ-cl filters (size,ν)



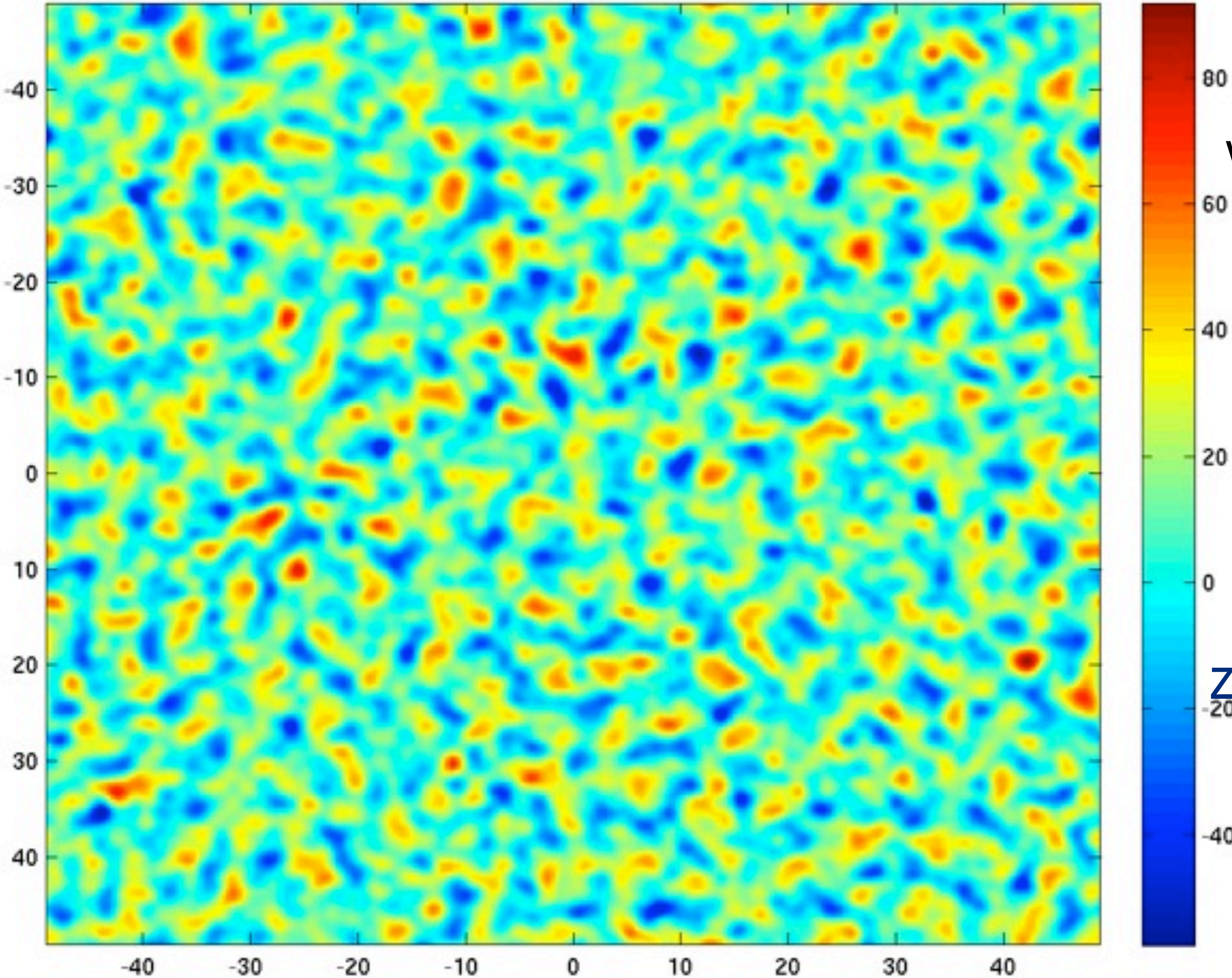
220-150

ACTpol examples



need to do **Matched SZ-Cluster Filters** using **all frequencies**

Matched Filter(ν) =f(ν)y_profile ($\theta|\theta$cl)*$(C_{signal}+C_{noise})^{-1}_{\nu\,\nu'}$

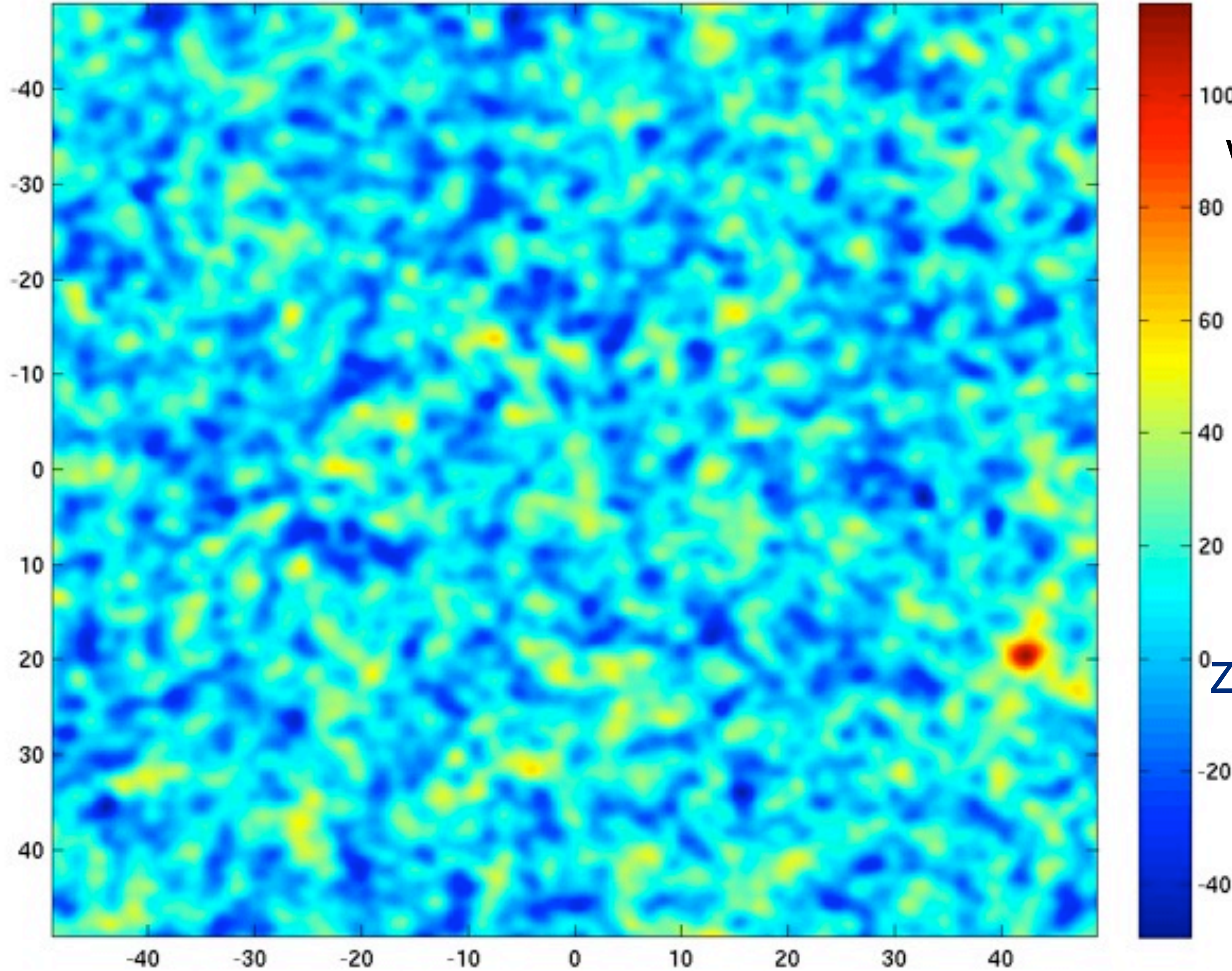


noise variance well defined hence vary **θcl** *max***S/N**

z=0 AGN hydro profile used

ACTpol-shallow ~ 4000 sq deg (20 muK-arcmin) **150** GHz only

Matched Filter(ν) =f(ν)y_profile (θ|θcl)*$(C_{signal}+C_{noise})^{-1}{}_{\nu\,\nu'}$



noise variance well defined hence vary **θcl** *max***S/N**

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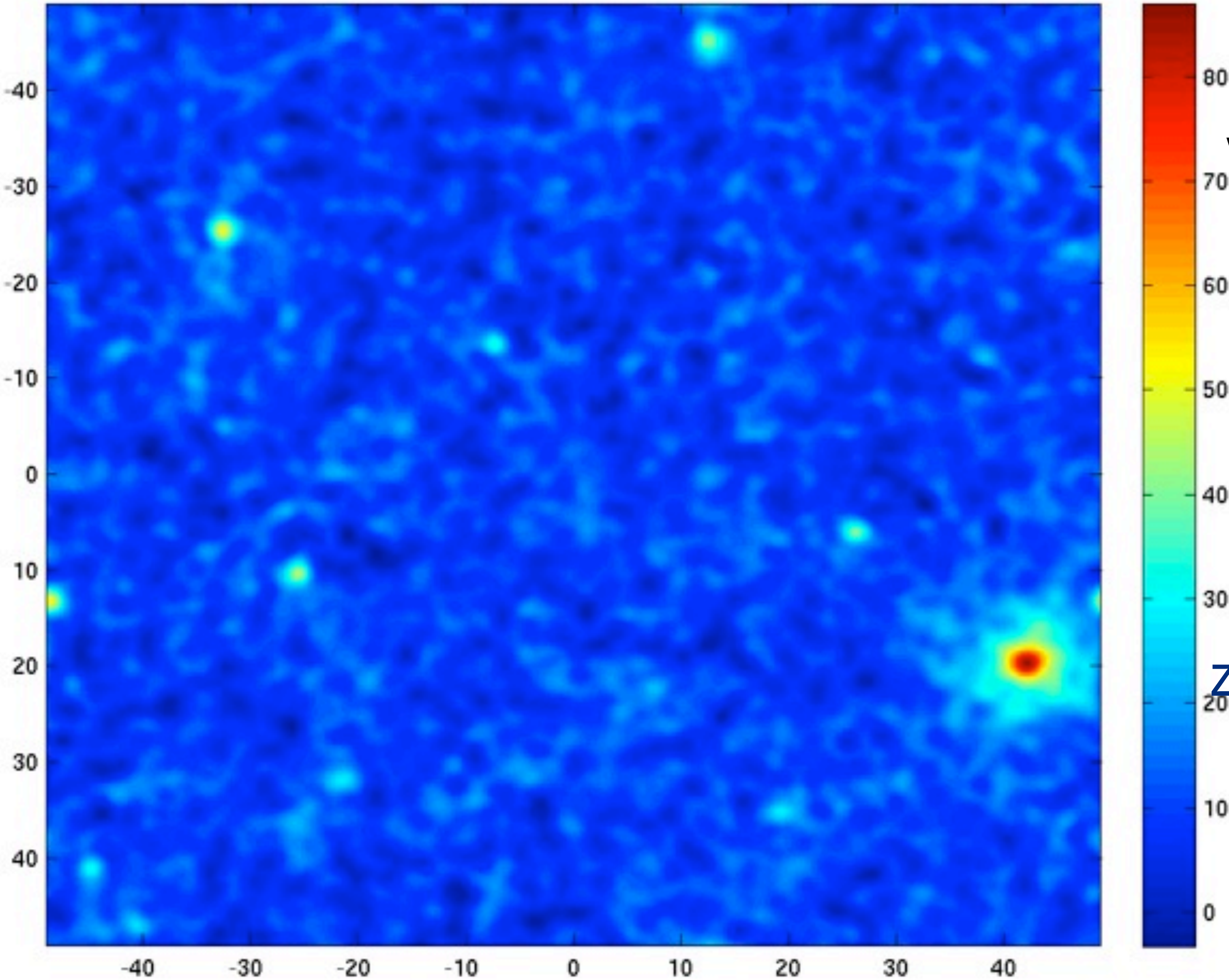
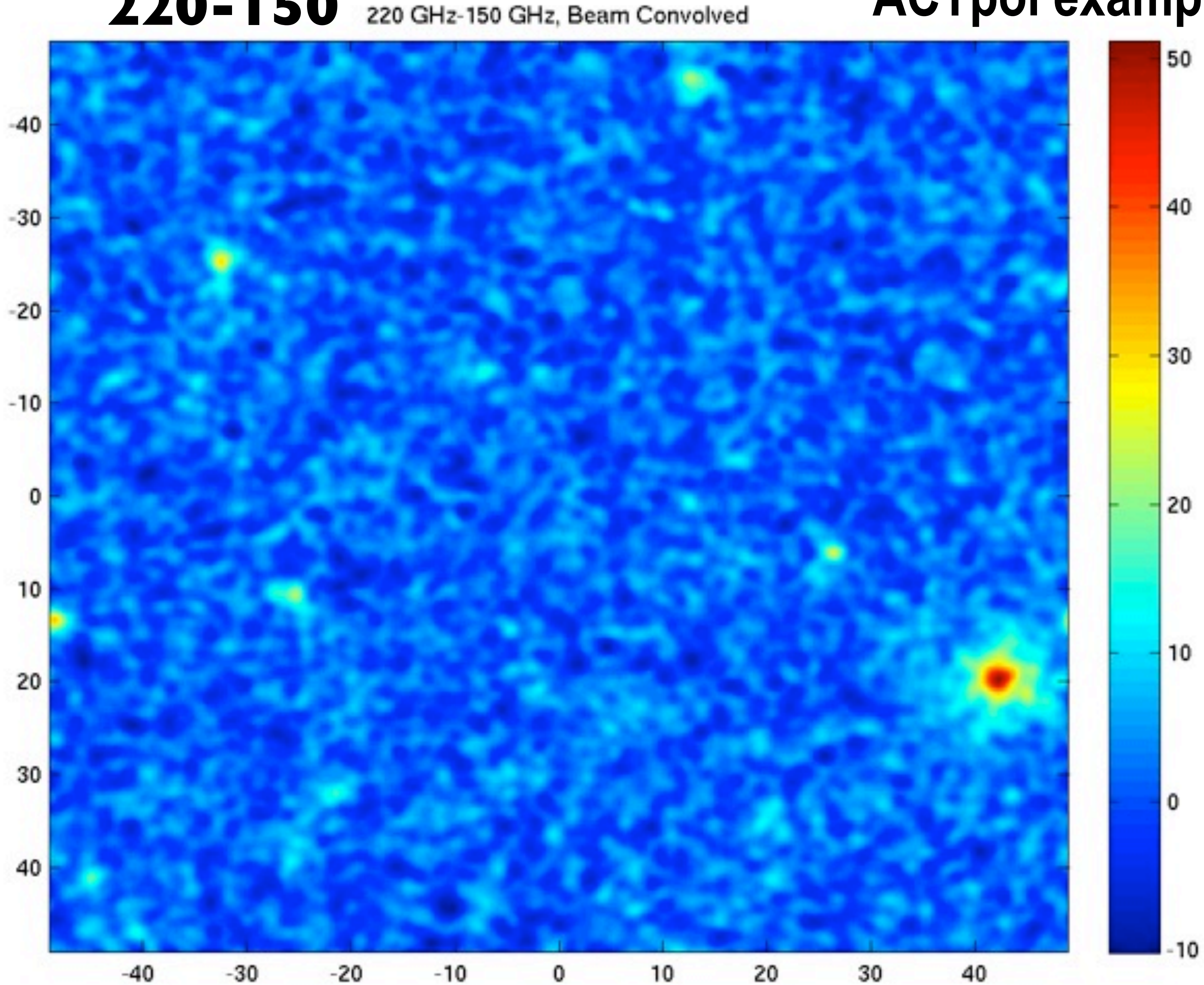


noise variance well defined hence vary **θcl** *max***S/N**

z=0 AGN hydro profile used

ACTpol-deep 150 sq deg (3.7&5.2 muK-arcmin) **150+220** GHz

220-150 ## ACTpol examples



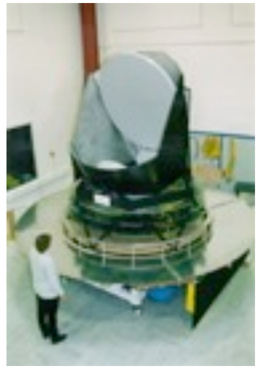
need to do **Matched SZ-Cluster Filters** using **all frequencies**

CBI pol to Apr'05 @Chile CBI2

QUaD @SP

Planck09.4

52+ bolometers
+ HEMTs @L2
9 frequencies



WMAP @L2 to 2010

2004 2006 2008 LHC 2011 Bpol @L2

2005 2007 2009

>96
OVRO /BIMA array

80s-90s
Ryle
OVRO

Acbar@SP
~1 blind

SZA@Cal

AMI

GBT

AMIBA

APEX
~400 bolos@Chile

SPT
1000 bolos
@SPole

ACT
3000 bolos
3 freqs @Chile

SCUBA2
12000 bolos
JCMT @Hawaii

SPTpol
ACTpol
ALMA
CCAT@Chile
LMT@Mexico

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

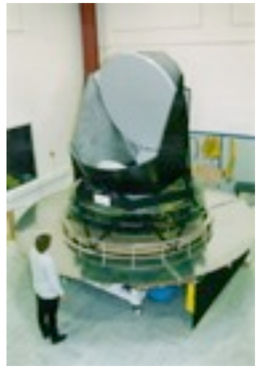
53+35 cls **(>=40)**

QUaD @SP

189 cls (>=1000)

Planck09.4

52+ bolometers
+ HEMTs @L2
9 frequencies



WMAP @L2 **to 2010**

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

2005 | 2007 | **21+26~50 (>=750)** | 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

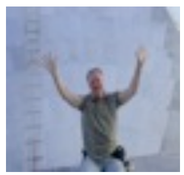
AMIBA
6 cls

APEX
~400 bolos@Chile
~25 cls

GBT
4 cls (~25 CLASH)

SPT
1000 bolos
@SPole

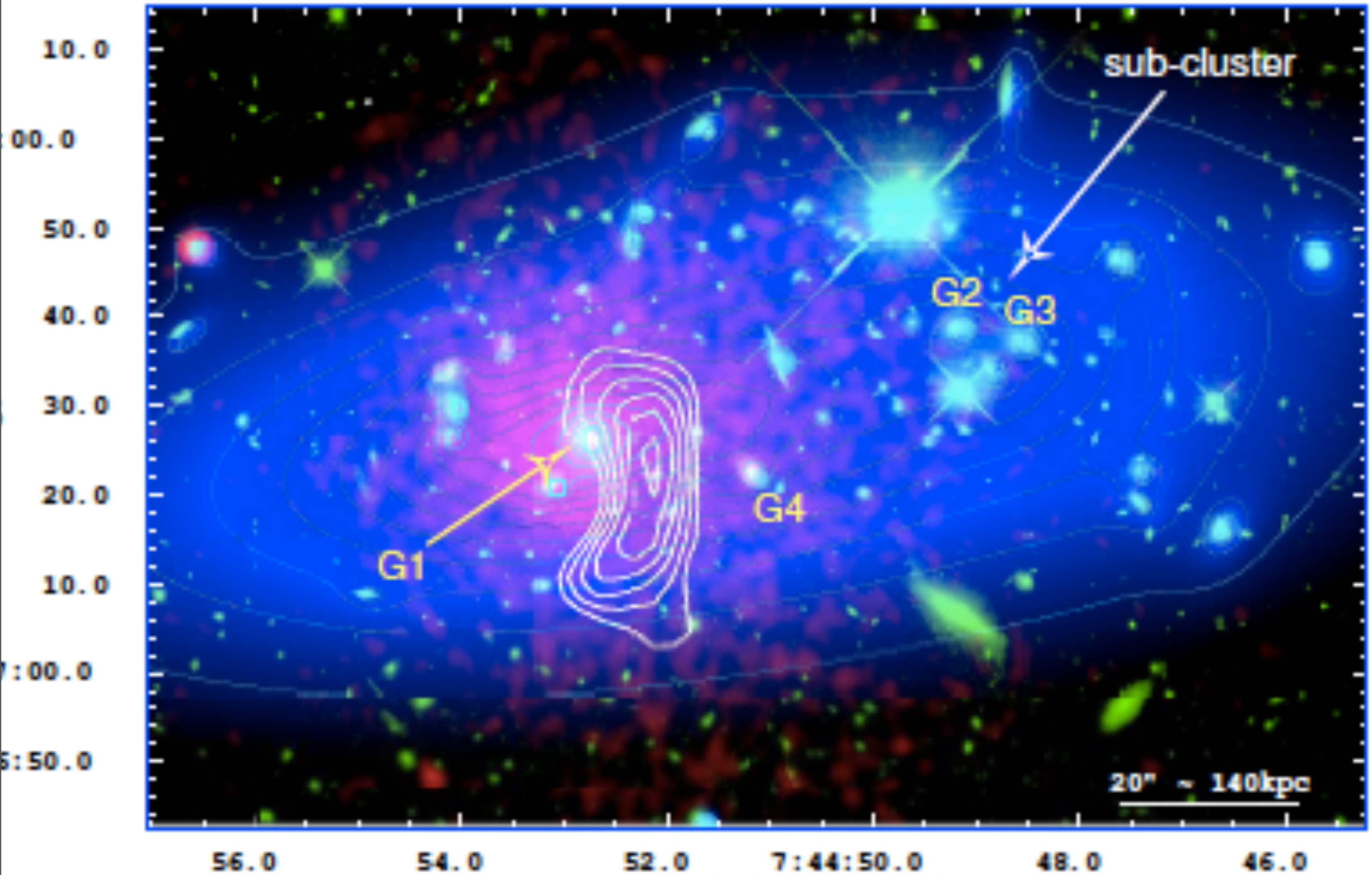
ACT **23+27~50 cls**
3000 bolos
3 freqs @Chile

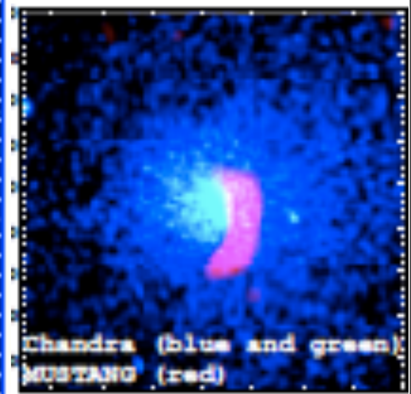


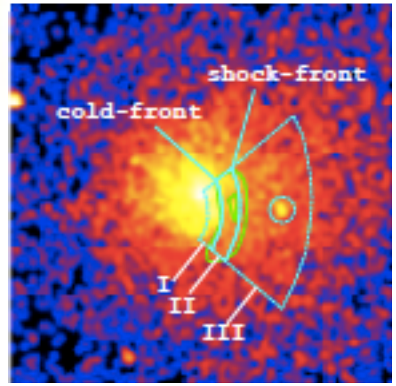
SCUBA2
12000 bolos
JCMT @Hawaii

SPTpol
ACTpol
ALMA
CCAT@Chile
LMT@Mexico

High-Res SZ with MUSTANG1

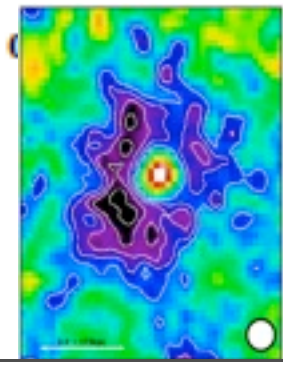






MACS0744+3927 z=0.69

weak shock near the core Korngut etal 2010

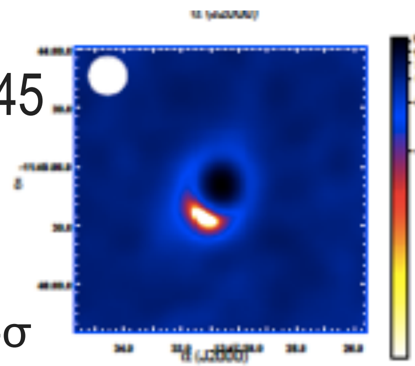


RXJ1347-1145 z=0.45

Mason etal 2010

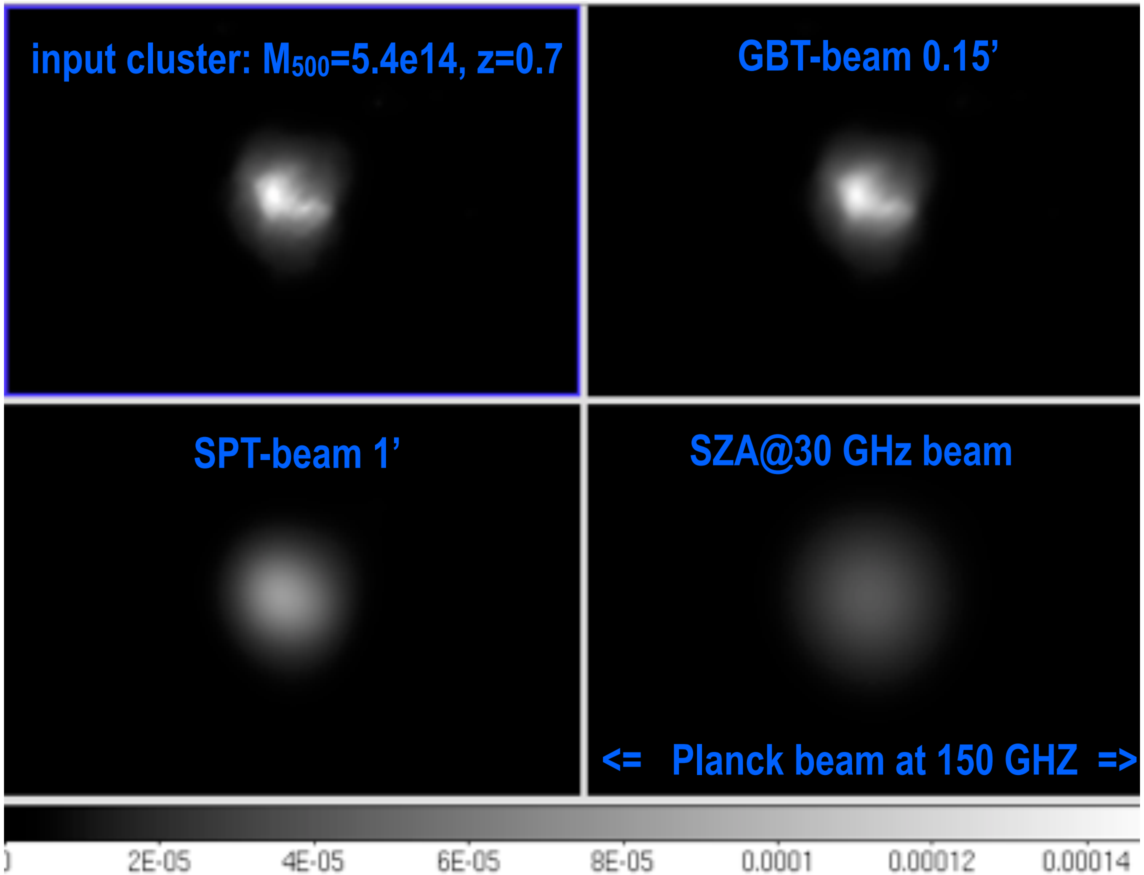
strongly shocked gas >20 keV, 14σ

2001: Nobeyama 4σ



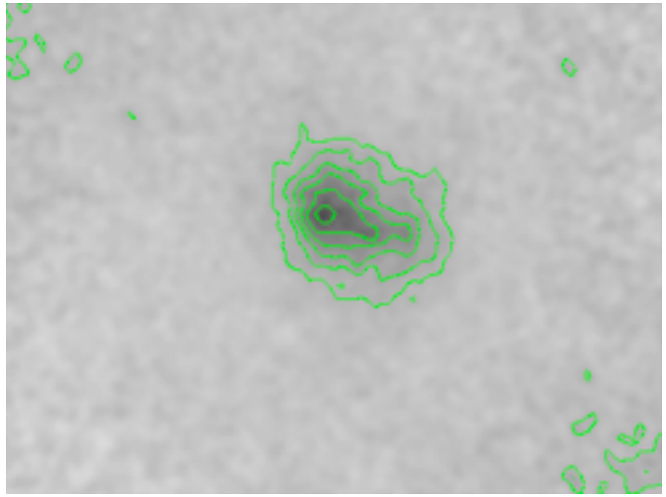
High-Res SZ future: **MUSTANG2** 100x mapping speed!

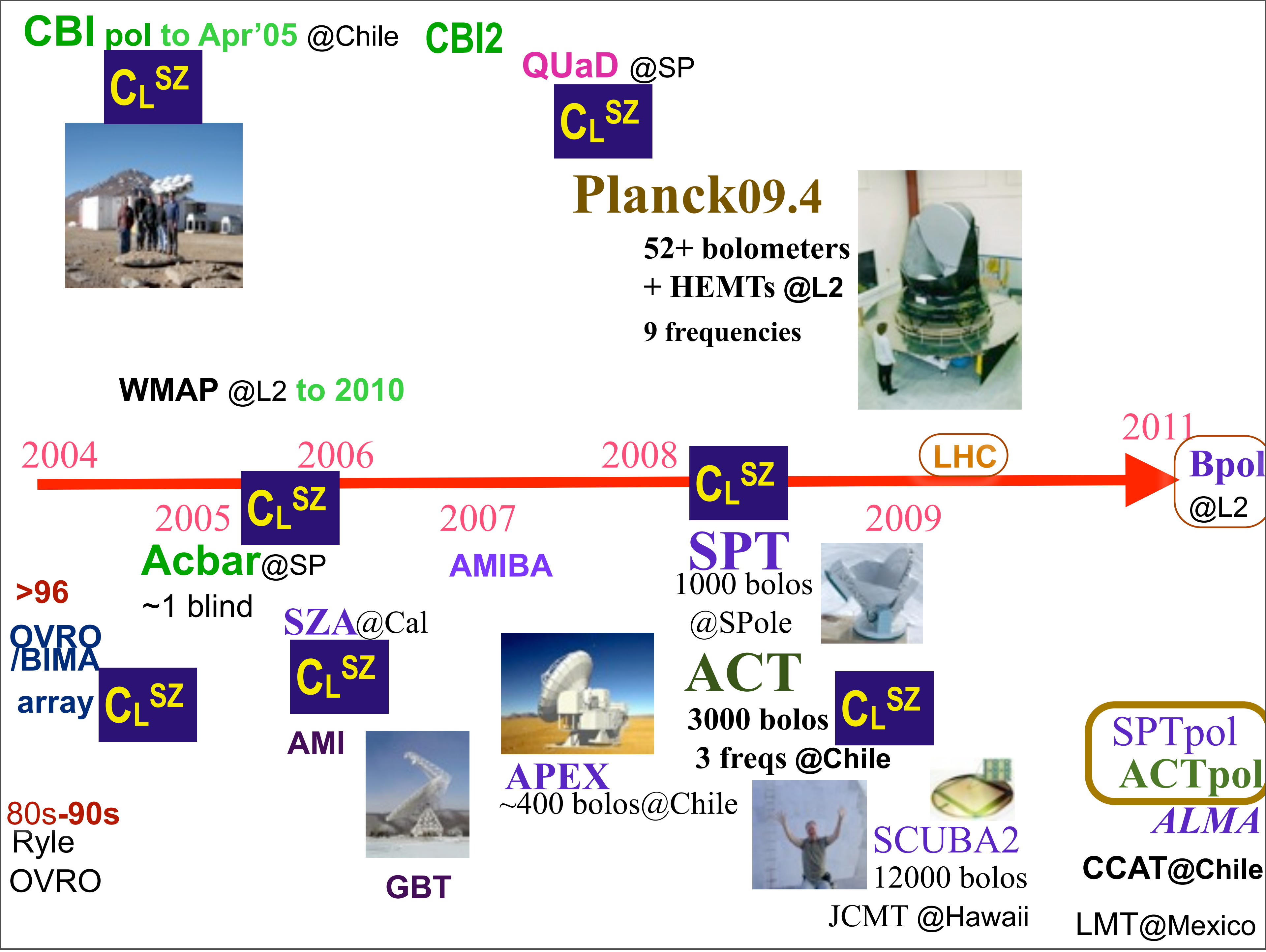
160 cf. 64 pixels, over larger area (5’ vs. 40”) Planck followup to 35σ in 1hr

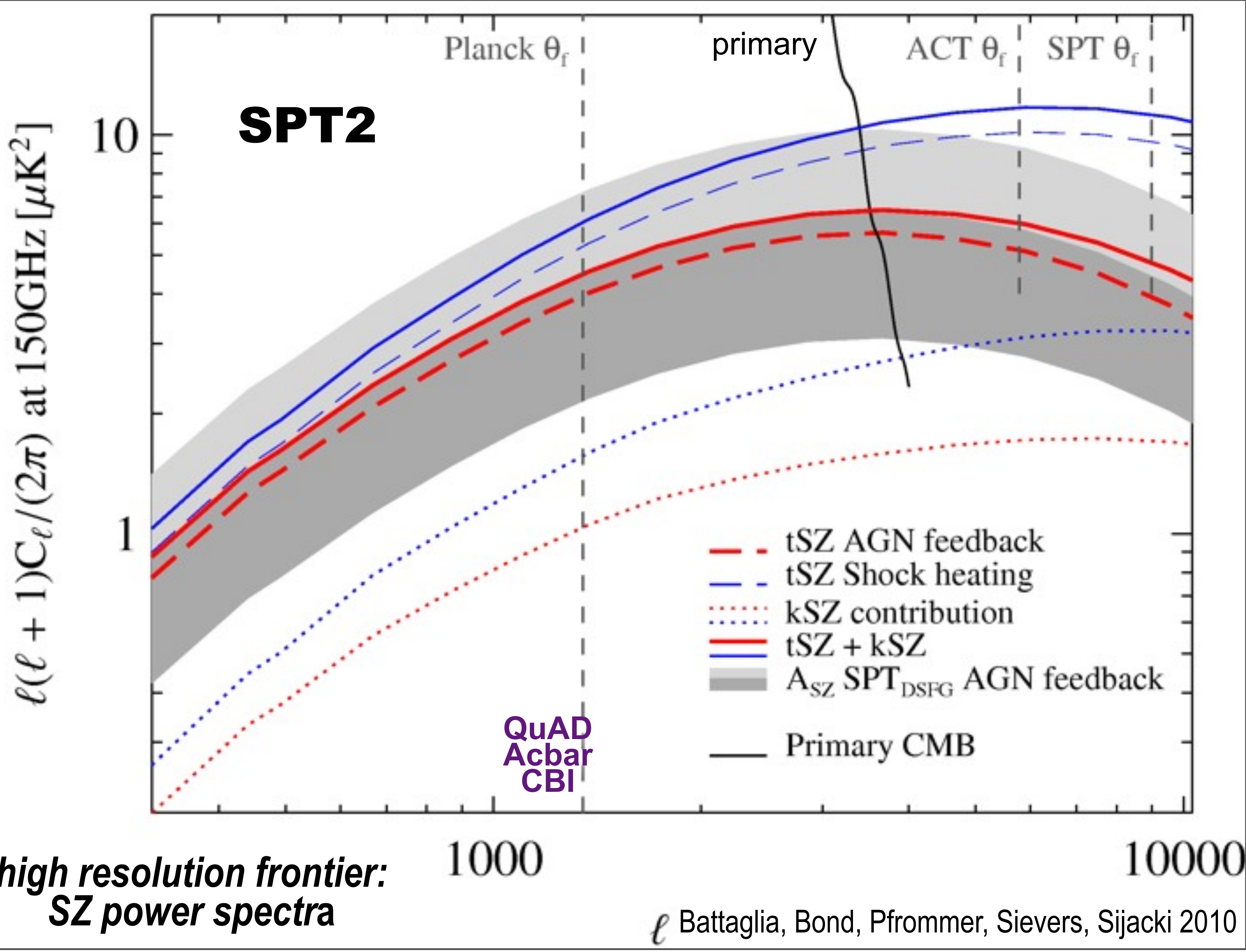


full MUSTANG2 pipeline simulation

=> Detected at 25σ in 2 hours



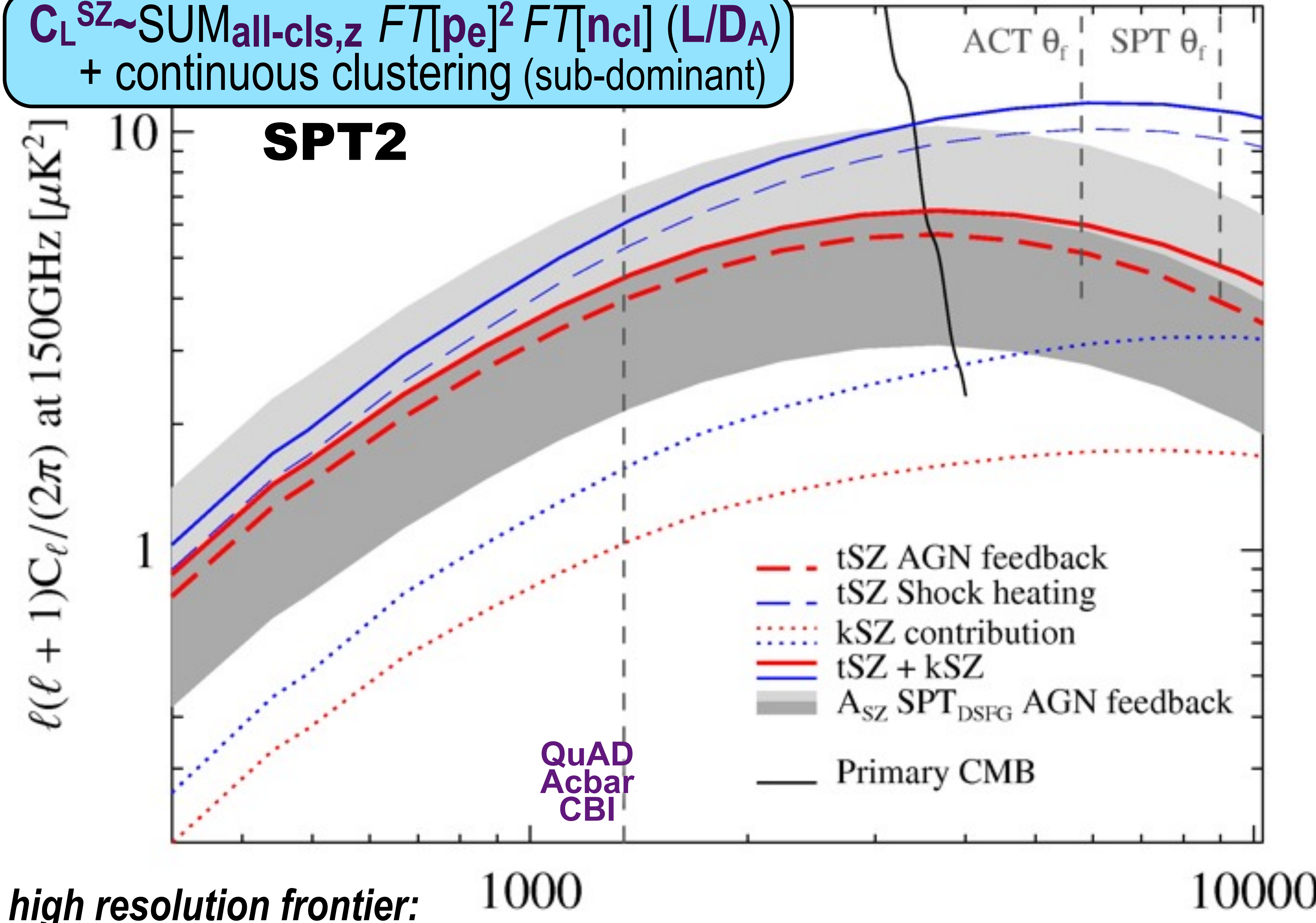

CBI pol to Apr'05 @Chile
CBI2
QUaD @SP
Planck09.4
52+ bolometers
+ HEMTs @L2
9 frequencies
WMAP @L2 to 2010
2004
2005
2006
2007
2008
2009
2011
LHC
Bpol
@L2
Acbar@SP
~1 blind
AMIBA
SPT
1000 bolos
@SPole
>96
OVRO
/BIMA
array
SZA@Cal
AMI
GBT
APEX
~400 bolos@Chile
ACT
3000 bolos
3 freqs @Chile
SCUBA2
12000 bolos
JCMT @Hawaii
SPTpol
ACTpol
ALMA
CCAT@Chile
LMT@Mexico
80s-90s
Ryle
OVRO



high resolution frontier: SZ power spectra

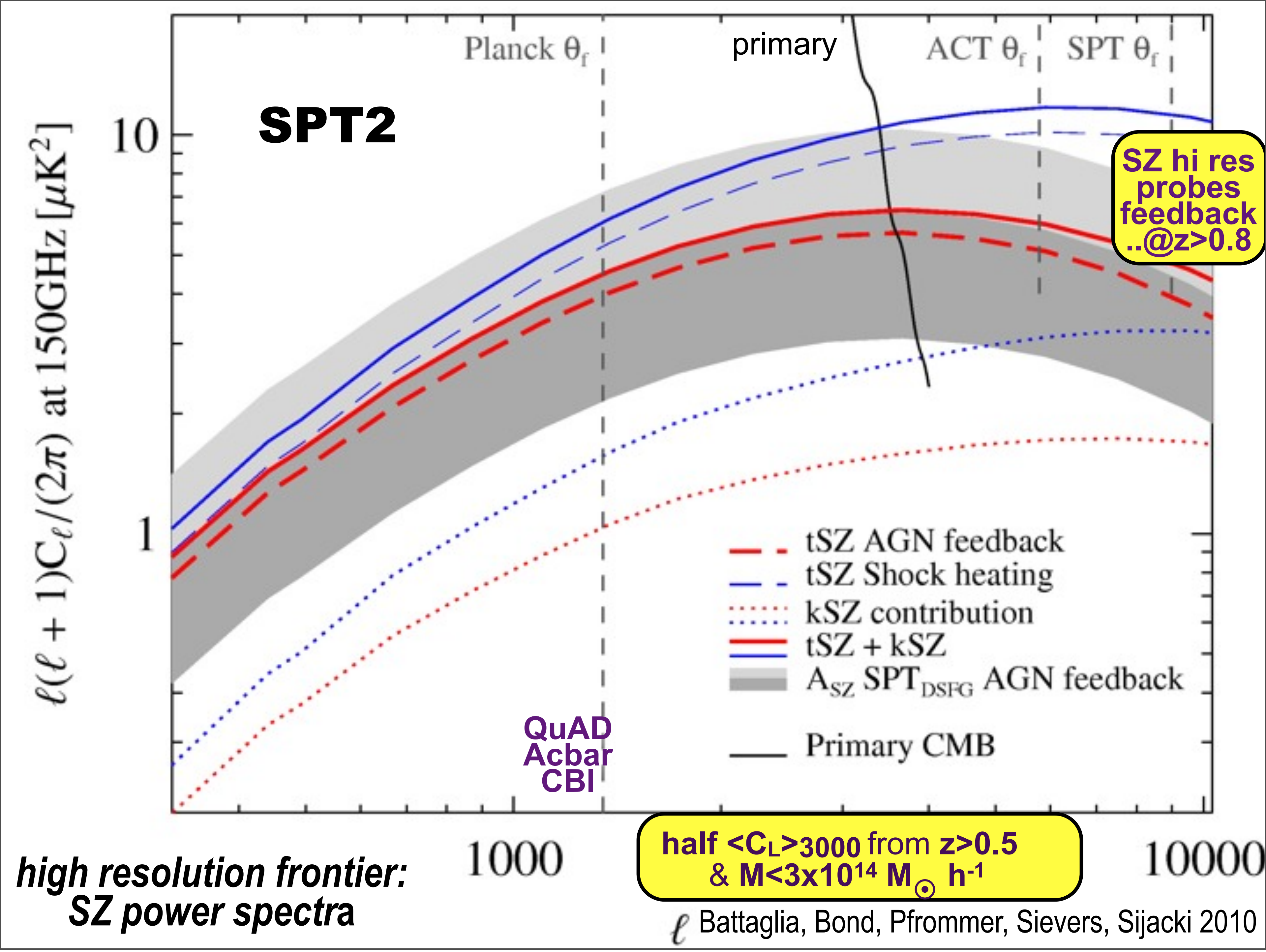
Battaglia, Bond, Pfrommer, Sievers, Sijacki 2010

$C_L^{SZ} \sim SUM_{all\text{-}cls,z}\ FT[p_e]^2\ FT[n_{cl}]\ (L/D_A)$
+ continuous clustering (sub-dominant)



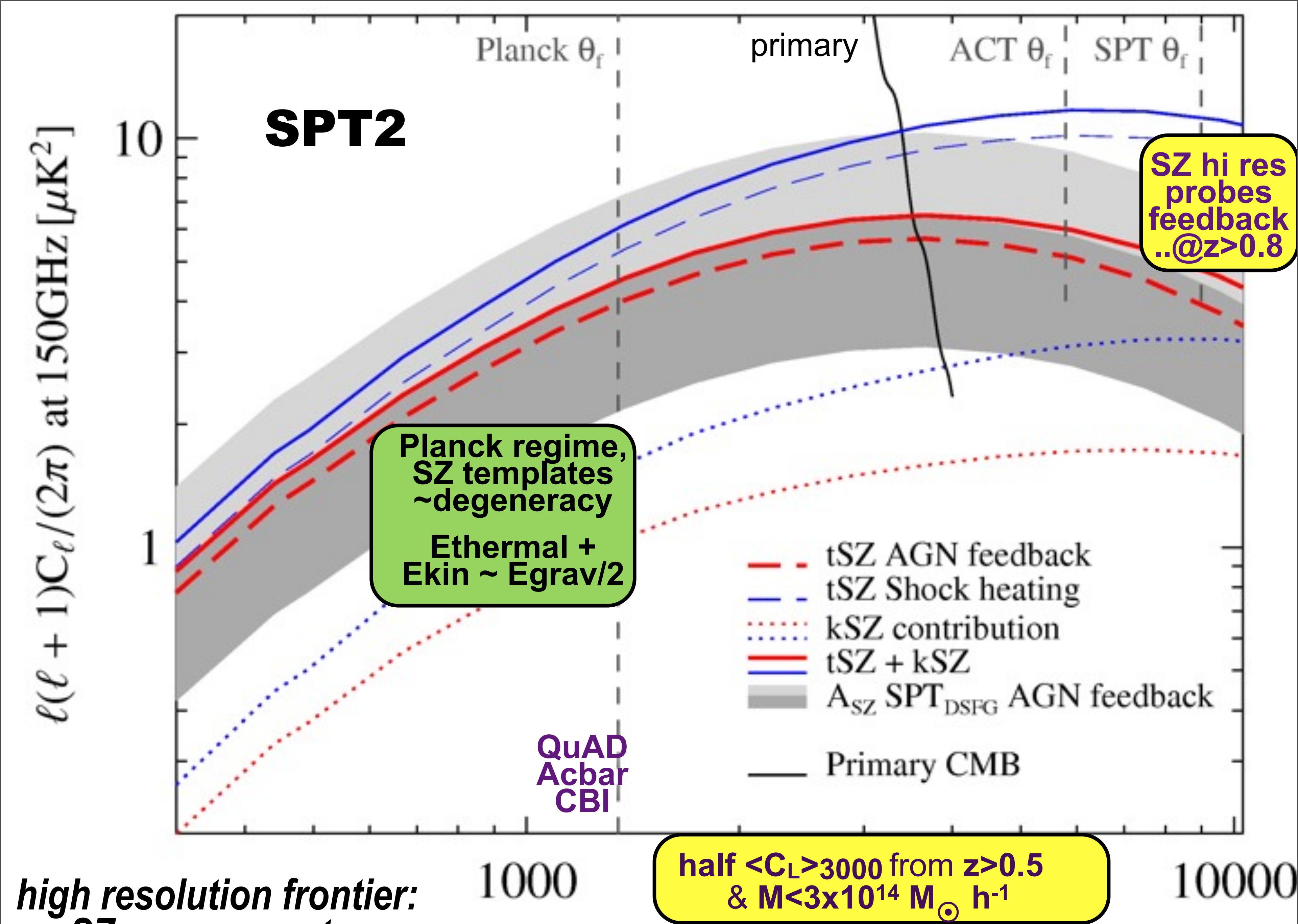
high resolution frontier: SZ power spectra

Battaglia, Bond, Pfrommer, Sievers, Sijacki 2010



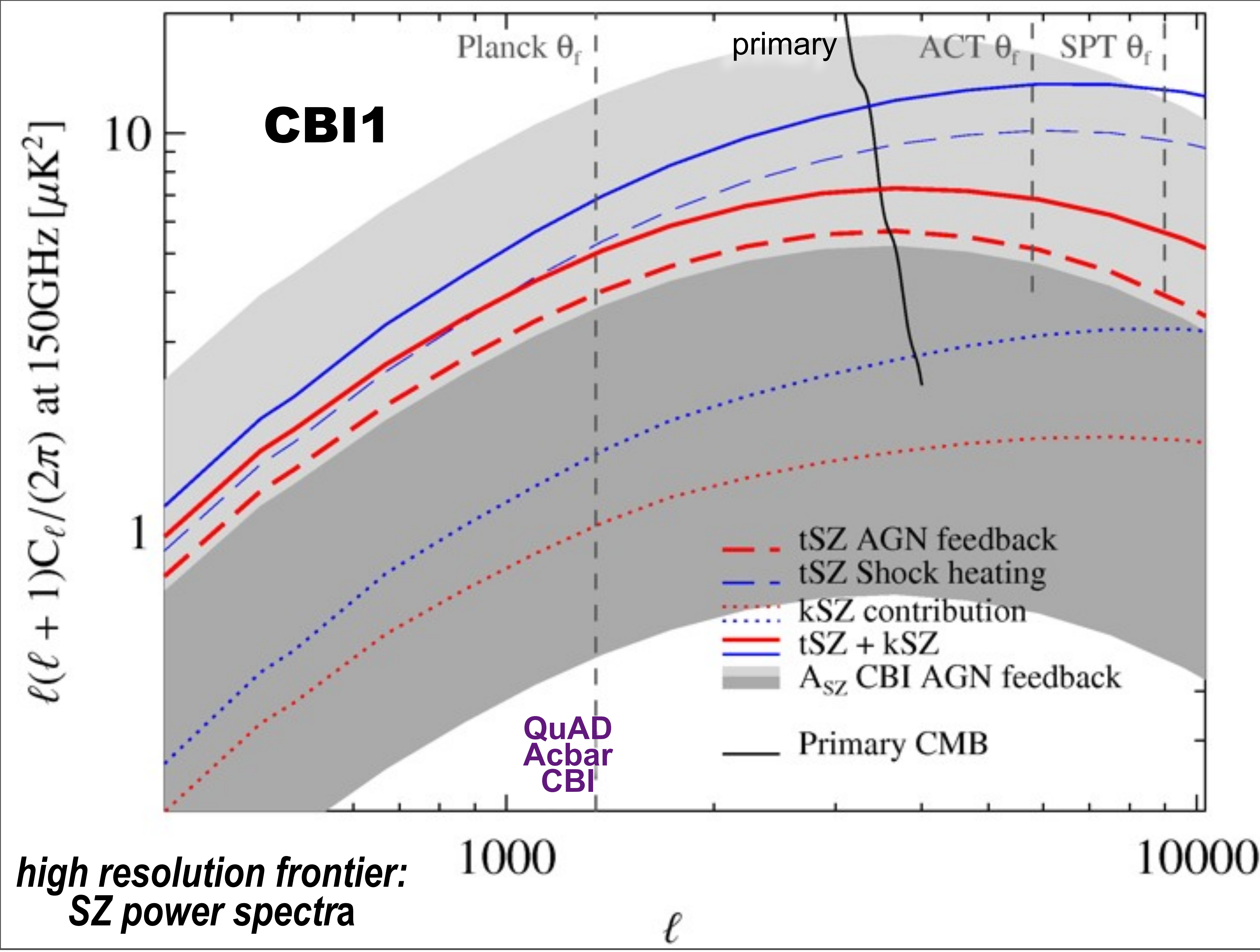
high resolution frontier:
SZ power spectra

Battaglia, Bond, Pfrommer, Sievers, Sijacki 2010

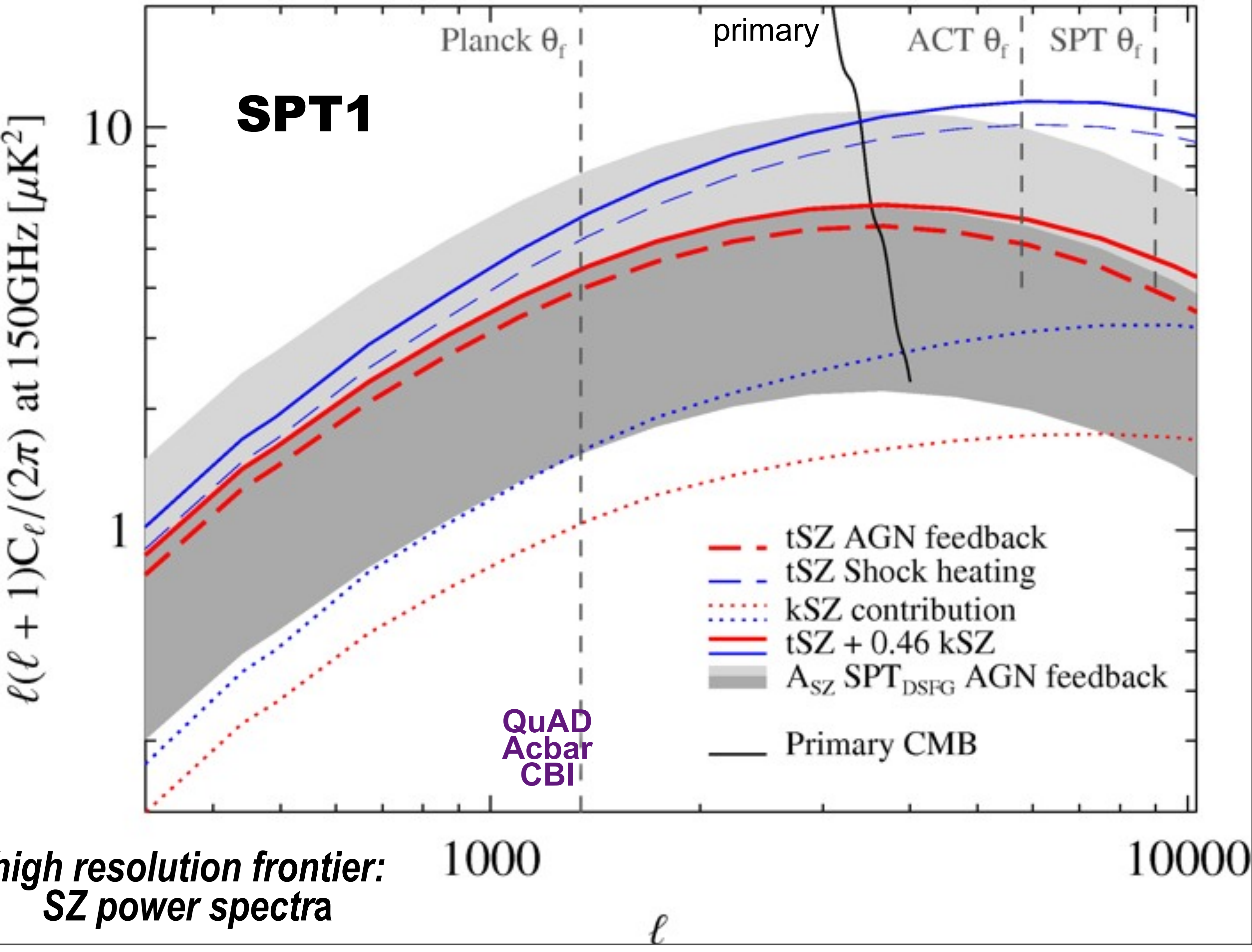


high resolution frontier: SZ power spectra

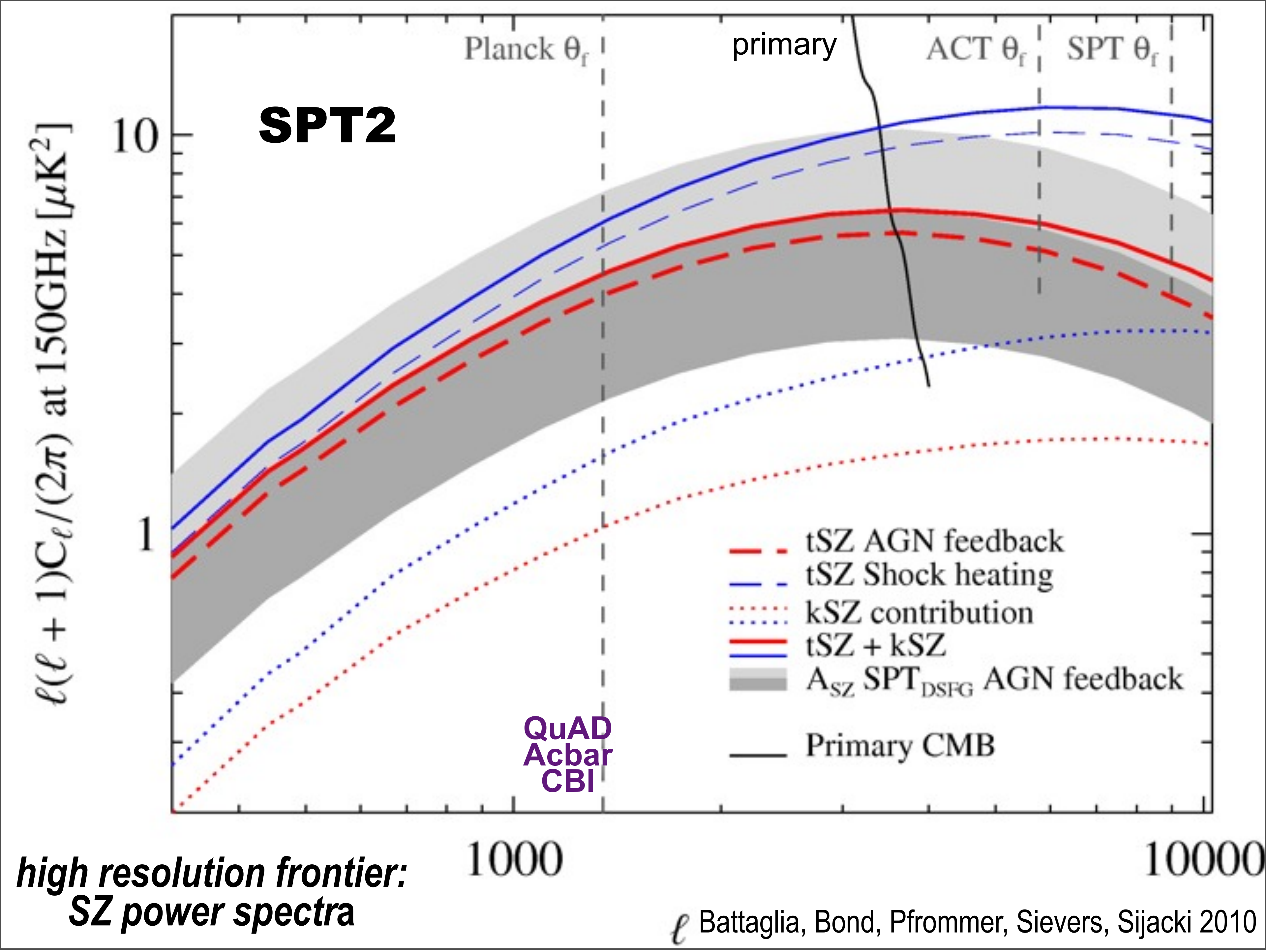
Battaglia, Bond, Pfrommer, Sievers, Sijacki 2010



high resolution frontier: SZ power spectra

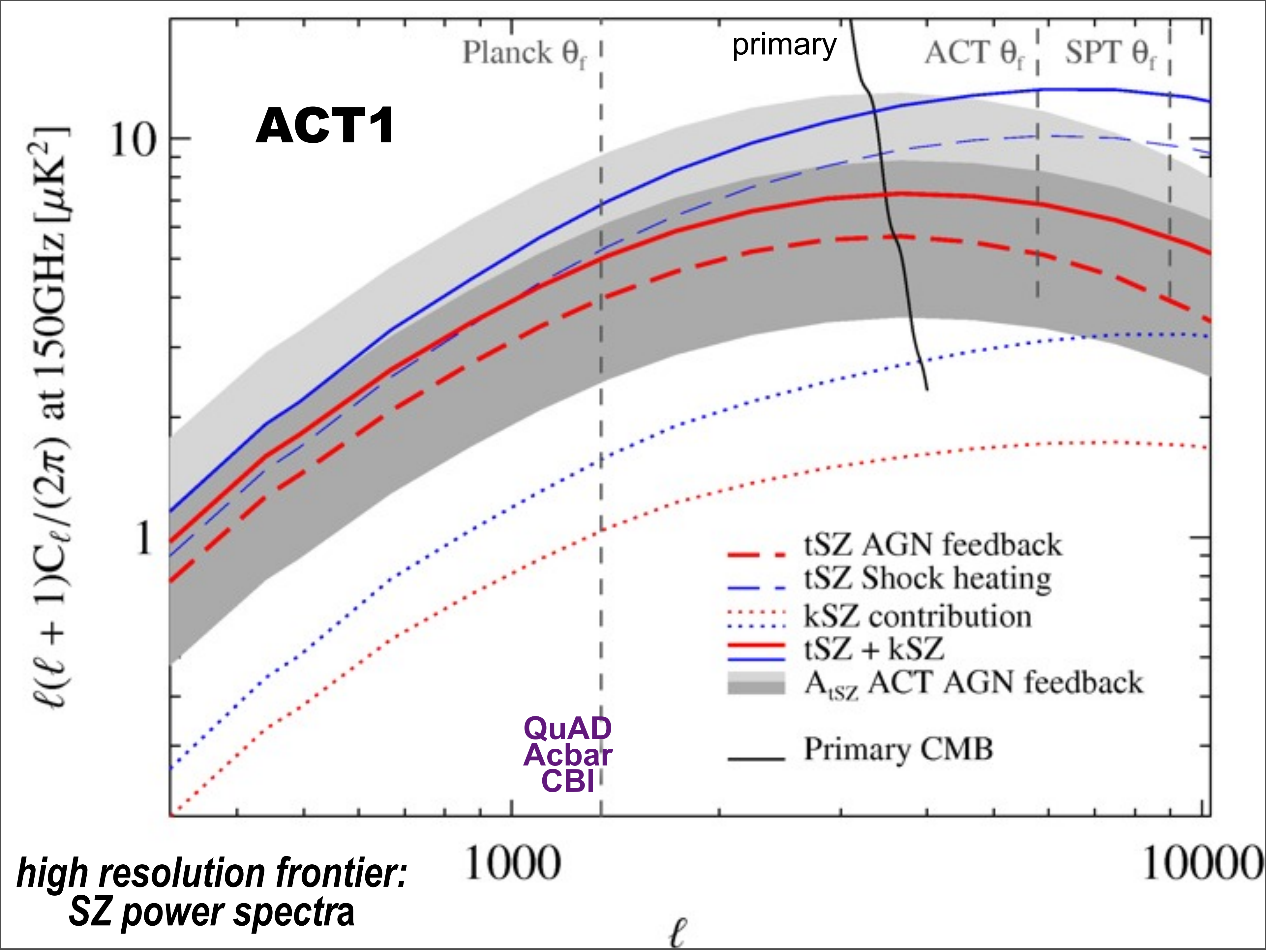


high resolution frontier: SZ power spectra

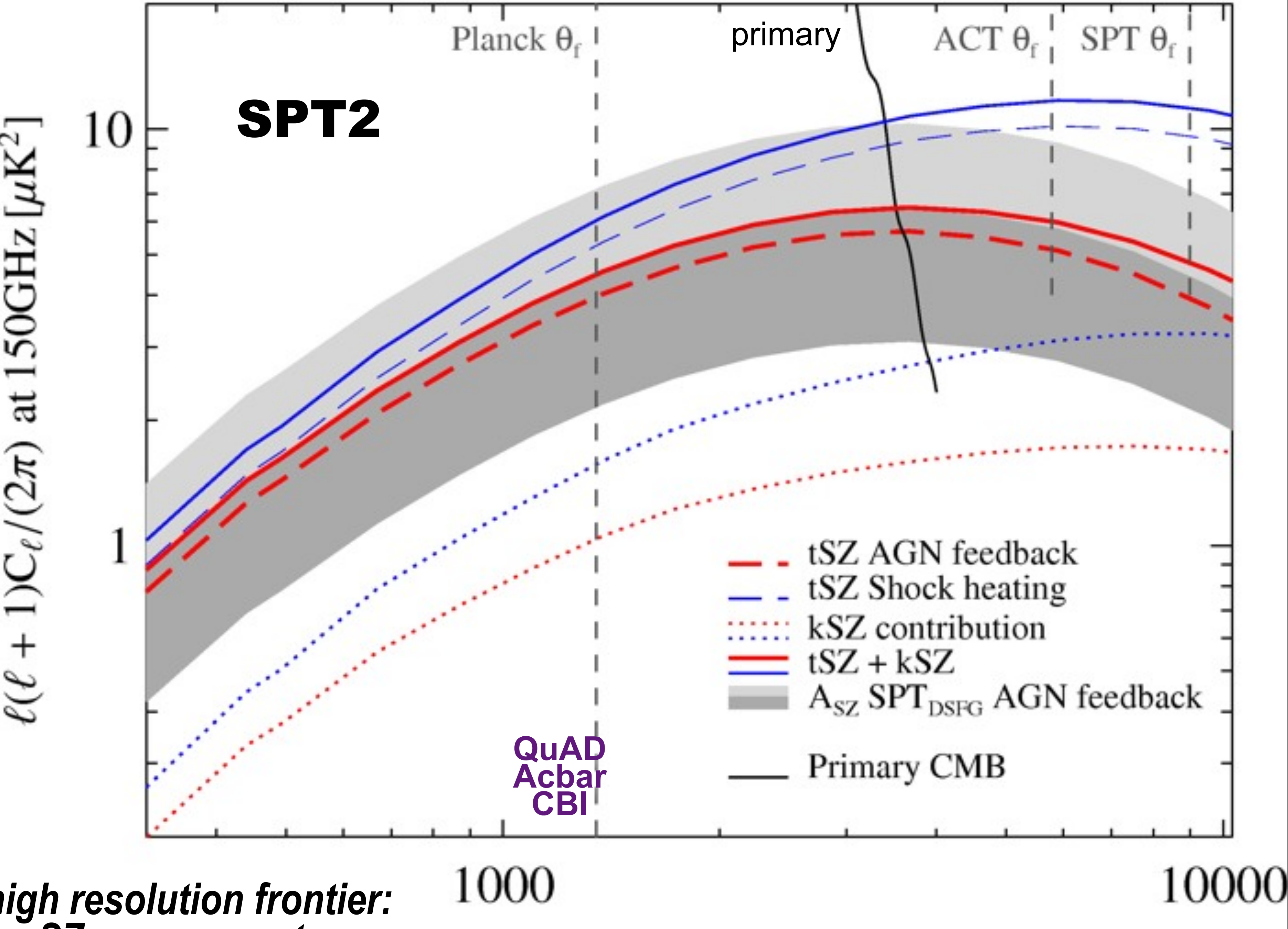


high resolution frontier: SZ power spectra

Battaglia, Bond, Pfrommer, Sievers, Sijacki 2010

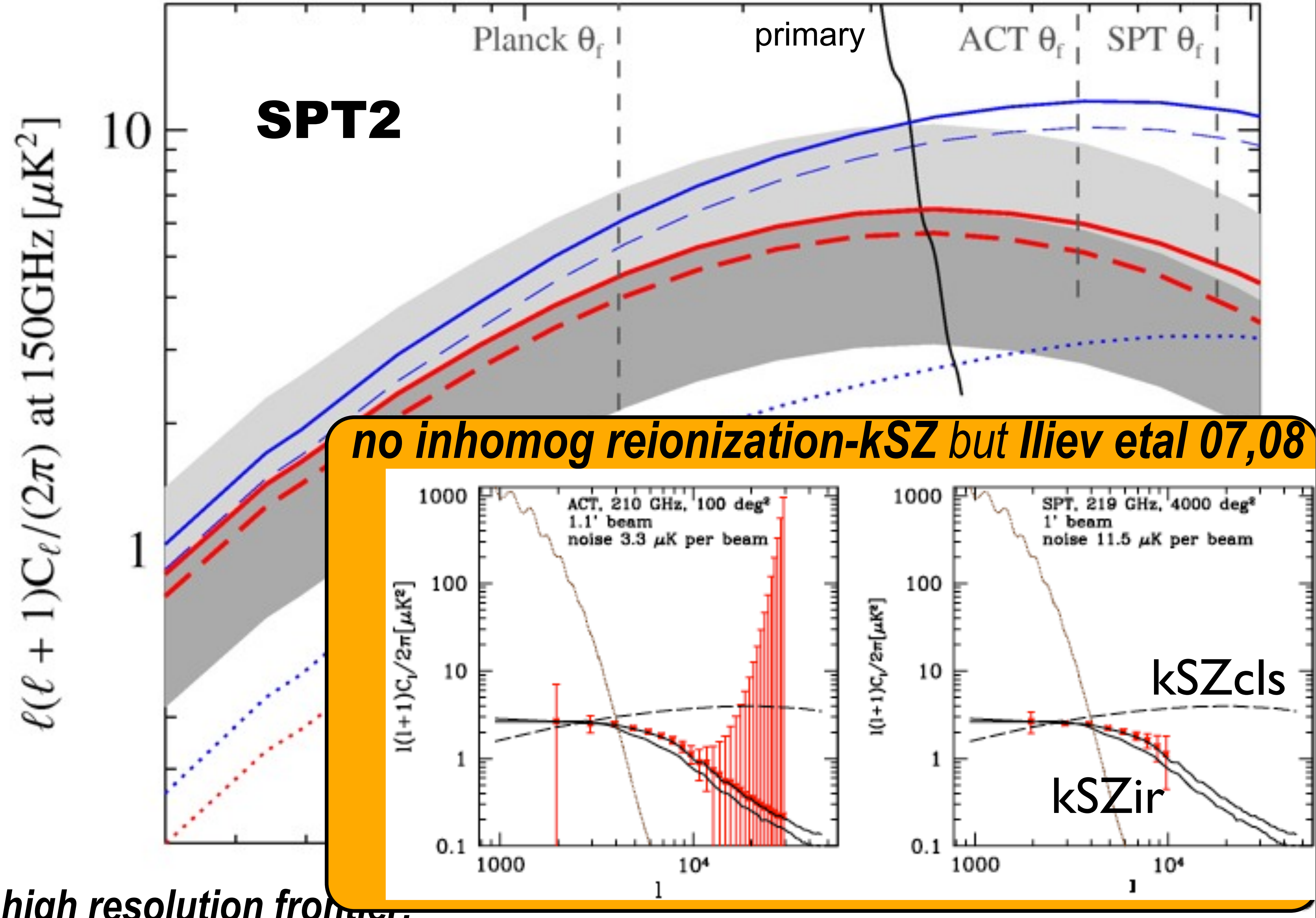


ACT1
Planck θ_f
primary
ACT θ_f
SPT θ_f
$\ell(\ell+1)C_\ell/(2\pi)$ at 150GHz $[\mu K^2]$
10
1
1000
10000
ℓ
tSZ AGN feedback
tSZ Shock heating
kSZ contribution
tSZ + kSZ
A_{tSZ} ACT AGN feedback
Primary CMB
QuAD
Acbar
CBI
high resolution frontier:
SZ power spectra



high resolution frontier: SZ power spectra

Battaglia, Bond, Pfrommer, Sievers, Sijacki 2010



high resolution frontier: SZ power spectra

Battaglia, Bond, Pfrommer, Sievers, Sijacki 2010

$$n_{cluster}(Y_{SZ}, M_{lens}, Y_X, L_X, T_X, L_{cl,opt}, R_{ich}, \ldots$$

$$|\ \text{gold-sample, thresholds})$$

$+ C_L^{SZ}$(cuts) will deliver valuable cosmic gastrophysics for sure.

Will it deliver fundamental physics e.g., the dark energy EOS, primordial non-Gaussianity??? σ_8 even?

so much for context & theory & forecasts.

on to the results: Planck, ACT, SPT, AMI, Bolocam,...