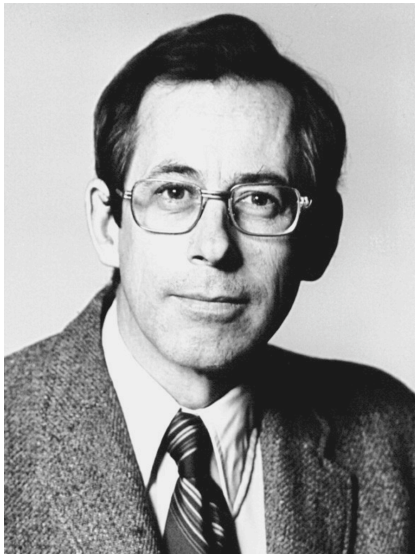



CITA ICAT Canadian Institute for Theoretical Astrophysics L'institut canadien d'astrophysique theorique

Dick Bond

CIAR

the Power in Sunyaev & Zeldovich, then & now



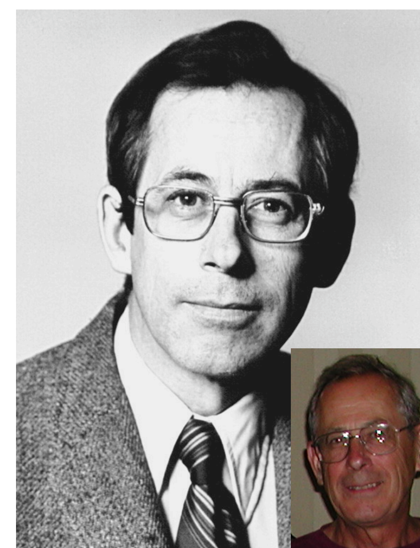
Canadian Institute for Theoretical Astrophysics
L'institut canadien d'astrophysique theorique

Dick Bond

CIAR

the Power in Sunyaev & Zeldovich, then & now

Peebles, Page, Partridge, *Finding the Big Bang,* *Apr09 CUP*



CITA ICAT Canadian Institute for Theoretical Astrophysics L'institut canadien d'astrophysique theorique

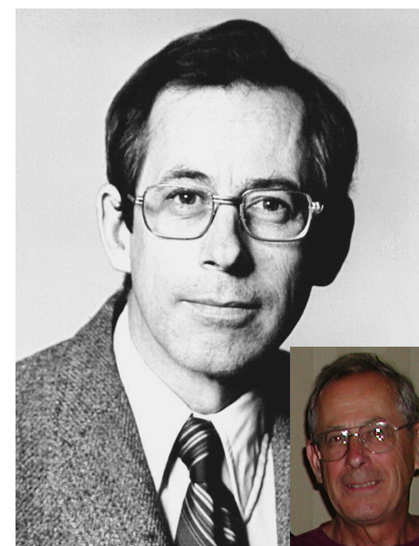
Dick Bond

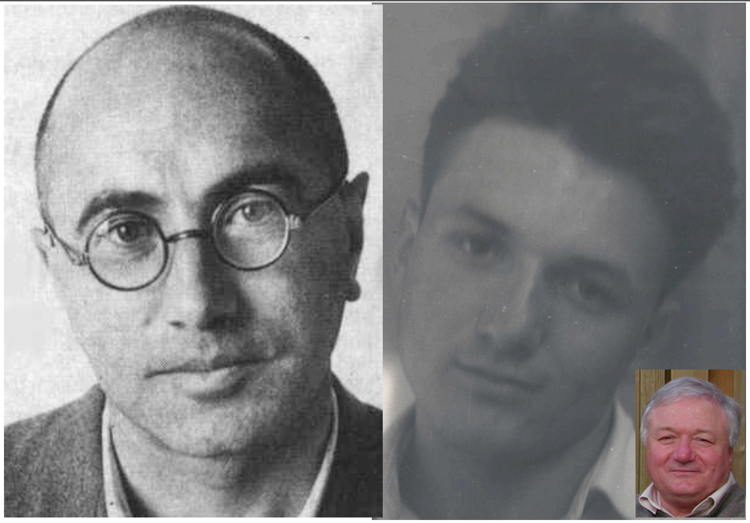
CIAR

the Power in Sunyaev & Zeldovich, then & now

Peebles, Page, Partridge, *Finding the Big Bang,* *Apr09 CUP*

*(Linear) primary CMB anisotropies are strongly damped by photon-baryon shear viscosity at high L > 1000, where **secondary anisotropies from the weakly and strongly nonlinear cosmic web dominate.** In order of dominance: **thermal Sunyaev-Zeldovich effect** (Compton scattering of CMB off hot gas, unique frequency signature), **CMB weak lensing** (smooths out peaks and troughs, no frequency signature), **kinetic Sunyaev-Zeldovich** effect (Thomson scattering of CMB off moving ionized gas, at high and low redshift), & more. **Extragalactic radio** (synchrotron) and **infrared sources** (dust emission) are important (frequency signatures, complex). Galactic foregrounds strongest at low L.*



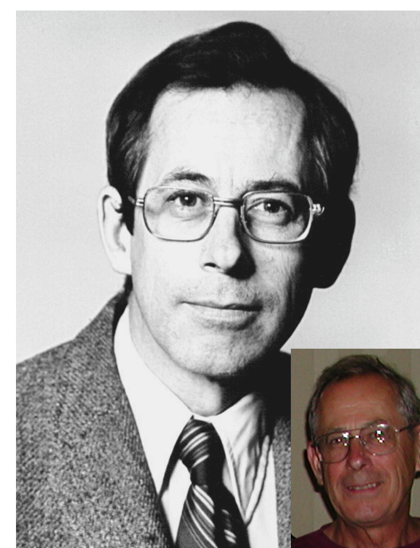


CITA ICAT Canadian Institute for Theoretical Astrophysics L'institut canadien d'astrophysique theorique

Dick Bond CIAR

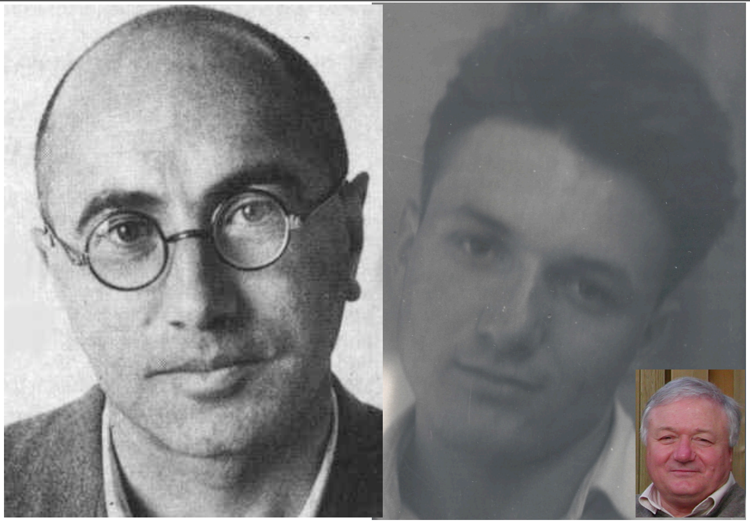
the Power in Sunyaev & Zeldovich, then & now

Peebles, Page, Partridge, *Finding the Big Bang*, *Apr09 CUP*



(Linear) primary CMB anisotropies *are strongly damped by photon-baryon shear viscosity at high L > 1000, where* ***secondary anisotropies from the weakly and strongly nonlinear cosmic web dominate.*** *In order of dominance:* ***thermal Sunyaev-Zeldovich effect*** *(Compton scattering of CMB off hot gas, unique frequency signature),* ***CMB weak lensing*** *(smooths out peaks and troughs, no frequency signature),* ***kinetic Sunyaev-Zeldovich*** *effect (Thomson scattering of CMB off moving ionized gas, at high and low redshift), & more.* ***Extragalactic radio*** *(synchrotron) and* ***infrared sources*** *(dust emission) are important (frequency signatures, complex). Galactic foregrounds strongest at low L.*

To get n_s, m_ν etc., from cosmic parameter estimation of the primary CMB anisotropy power, the statistics of secondary power must be fully incorporated ⇒ need to know accurately.



CITA ICAT Canadian Institute for Theoretical Astrophysics L'institut canadien d'astrophysique theorique

Dick Bond

CIAR

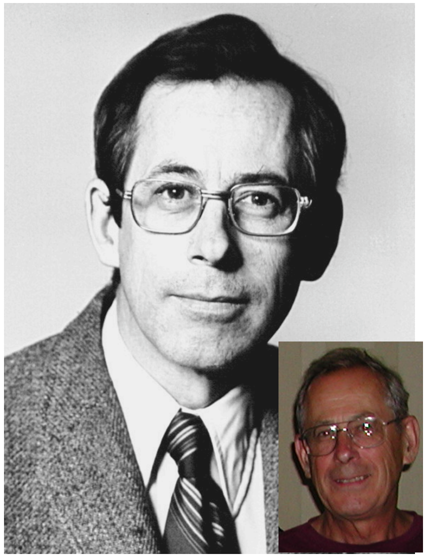
the Power in Sunyaev & Zeldovich, then & now

(Linear) primary CMB anisotropies *are strongly damped by photon-baryon shear viscosity at high L > 1000, where* ***secondary anisotropies from the weakly and strongly nonlinear cosmic web dominate.*** *In order of dominance:* ***thermal Sunyaev-Zeldovich effect*** *(Compton scattering of CMB off hot gas, unique frequency signature),* ***CMB weak lensing*** *(smooths out peaks and troughs, no frequency signature),* ***kinetic Sunyaev-Zeldovich*** *effect (Thomson scattering of CMB off moving ionized gas, at high and low redshift), & more.* ***Extragalactic radio*** *(synchrotron) and* ***infrared sources*** *(dust emission) are important (frequency signatures, complex). Galactic foregrounds strongest at low L.*

To get n_s, m_ν etc., from cosmic parameter estimation of the primary CMB anisotropy power, the statistics of secondary power must be fully incorporated ⇒ need to know accurately.

2ndary signals are also cosmic-info-loaded: density **power spectra** in gas and dark matter. **Dark energy equation of state** from **large SZ cluster samples** (measures their thermal energy, related by virial equation to DM+gas gravitational energy) (& **CMB weak lensing**).

Peebles, Page, Partridge, *Finding the Big Bang,* *Apr09 CUP*



CITA ICAT Canadian Institute for Theoretical Astrophysics L'institut canadien d'astrophysique theorique

Dick Bond

CIAR

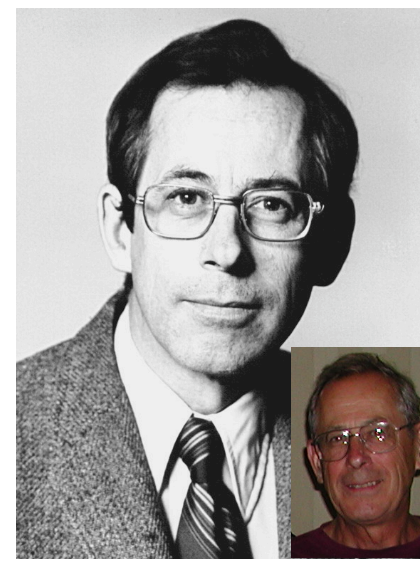
the Power in Sunyaev & Zeldovich, then & now

Peebles, Page, Partridge, *Finding the Big Bang*, *Apr09 CUP*

(Linear) primary CMB anisotropies are strongly damped by photon-baryon shear viscosity at high L > 1000, where secondary anisotropies from the weakly and strongly nonlinear cosmic web dominate. In order of dominance: thermal Sunyaev-Zeldovich effect (Compton scattering of CMB off hot gas, unique frequency signature), CMB weak lensing (smooths out peaks and troughs, no frequency signature), kinetic Sunyaev-Zeldovich effect (Thomson scattering of CMB off moving ionized gas, at high and low redshift), & more. Extragalactic radio (synchrotron) and infrared sources (dust emission) are important (frequency signatures, complex). Galactic foregrounds strongest at low L.

To get n_s, m_ν etc., from cosmic parameter estimation of the primary CMB anisotropy power, the statistics of secondary power must be fully incorporated $\Rightarrow$ need to know accurately.

2ndary signals are also cosmic-info-loaded: density **power spectra** in gas and dark matter. **Dark energy equation of state** from large SZ cluster samples (measures their thermal energy, related by virial equation to DM+gas gravitational energy) (& CMB weak lensing).



the expts: **CBI, ACBAR to L~2500+, BIMA ~6000, Quad to 2000+, Planck ~ 2000, SZA ~ 4000, APEX, ACT & SPT to ~10000, eventually SPTpol and ACTpol.** + *high res follow-ups GBT, SZI, ALMA, CCAT, ...*

first dedicated CMB conference, exptalists + theorists, primary+secondary $\Delta T/T$

DELTA T OVER TEA WORKSHOP

1-2 May, 1987
Toronto, Canada

Sponsored by
The Canadian Institute for Theoretical Astrophysics and
The Canadian Institute for Advanced Research

Topics

Present and Future Experiments of Cosmic Microwave Background Anisotropies and Their Theoretical Interpretation on very small ($< 1'$), *small* ($1' - 1^o$), *intermediate* ($1^o - 10^o$) *and large* ($> 10^o +$ *multipole angular scales*

Contact: Dick Bond
CITA, McLennan Labs, University of Toronto
60 St George St., Toronto, Ontario, Canada, M5S 1A1
Phone (416) 978 6879 or 6874
Bitnet BOND@UTORPHYS

Organizers: J.R. Bond (CITA), D.T. Wilkinson (Princeton)

Delta T over Tea Workshop Participants

Bennett, Chuck, Goddard
Birkinshaw, Marc, Harvard *
Bond, Dick, CITA
Boughn, Steve, Haverford
Boynton, Paul, University of Washington
Cannizzo, John, McMaster
Carlberg, Ray, York
Cheng, Ed, MIT
Couchman, Hugh, CITA
Cottingham, David, Princeton
Daly, Ruth, Boston U
Davies, Rod, Jodrell Bank
Davis, Marc, Berkeley
Dragovan, Marc, Bell Labs
Dyer, Charles, U of Toronto
Efstathiou, George, Cambridge
Fitchett, Mike, CITA
Fomalent, Ed, NRAO
Gorski, Chris, Berkeley
Gulkis, Sam, Caltech
Gush, Herb, UBC
Halpern, Marc, UBC
Ip, Peter, U of Toronto
Juszkiewics, Roman, Berkeley
Henriksen, Dick, Queens
Kaiser, Nick, Cambridge
Kellerman, K, NRAO
Kronberg, Phil, Toronto
Lang, Andrew, Berkeley
Lasenby, Anthony, Cambridge
Lawrence, Charles, Caltech
Lee, Hyung-Mok, CITA
Legg, Tom, Herzberg Institute, Ottawa
Little, Blaine, Toronto
Lubin, Phil, Santa Barbara
Matarrese, Sabino, Padova
Mather, John, Goddard
Meyer, Steve, MIT
Meyers, Steve, Caltech
Moseley, Harvey, Goddard
Nelson, Lorne, CITA
Noriega-Crespo, Alberto, CITA
Occhionero, F., Rome *
Ostriker, Jerry, Princeton
Page, Lyman, MIT
Partridge, Bruce, Haverford
Peterson, J.B., Princeton
Radford, Simon, IRAM, France
Readhead, Tony, Caltech
Richards, Paul, Berkeley
Salopek, Dave, Toronto
Sargent, Wal, Caltech *
Schaeffer, Bob, Goddard
Silk, Joe, Berkeley
Silverberg, Bob, Goddard
Stebbins, Albert, Fermilab
Suto, Yasushi, Berkeley
Timby, Peter, Princeton
Tremaine, Scott, CITA
Timusk, Tom, McMaster
Unruh, Bill, UBC
Vishniac, Ethan, U. Texas Austin
Vittorio, Niccolo, Rome
Wilkinson, Dave, Princeton
Webster, Rachel, Toronto

Dave Wilkinson

Wilkinson Microwave Anisotropy Probe

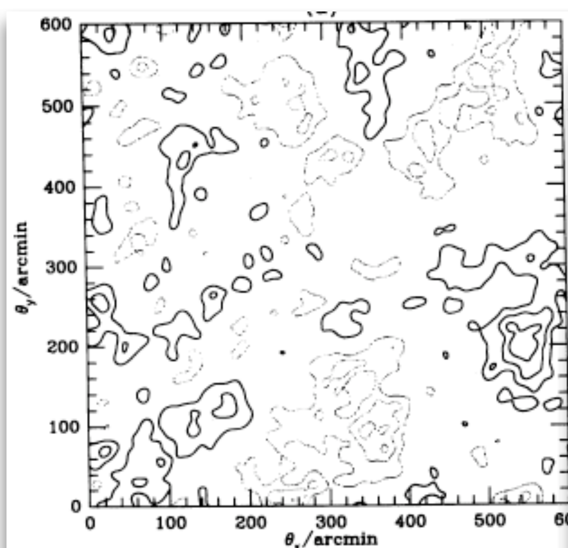

WMAP
launch
2001.6
Text
Dave Wilkinson
Rashid Sunyaev

Delta T over Tea Toronto May 1987: first dedicated CMB conference, exptalists+theorists, primary+secondary ΔT/T

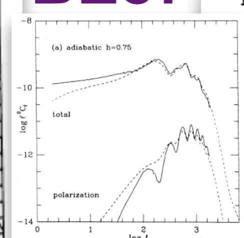
Primary Cosmic Microwave Background Radiation ~ a statistically isotropic all-sky GRF on the 2-sphere $C_L = \langle|\Delta T(LM)|^2\rangle$ *with target* C_L *shapes*

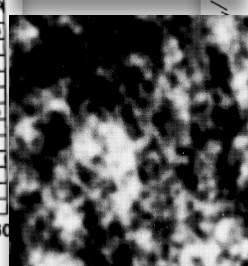
A tentative list of topics organized according to angular scale, with theory and observation intertwined, is:

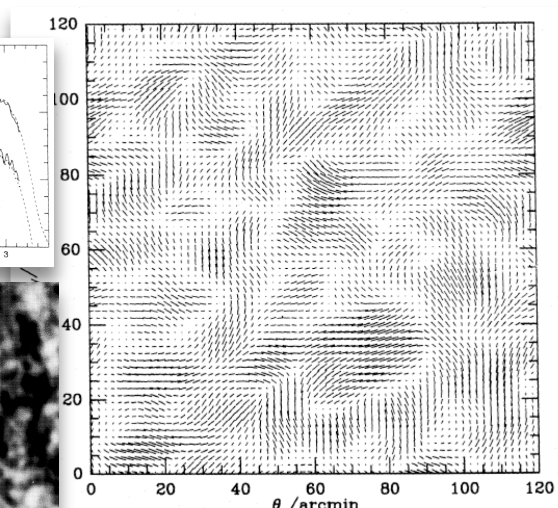
- very small angle anisotropies - VLA results, secondary fluctuations via the Sunyaev-Zeldovich effect, primeval dust emission, and radio sources
- small angle anisotropies - current results, optimal measuring strategies, statistical methods for small signals in larger noise, which universes can we rule out, the reheating issue, future detectors and techniques, CMB map statistics, polarization
- intermediate and large angle anisotropies - $5^o - 10^o$ results, future experiments at $\sim 1^o$, COBE and other large angle analyses, theoretical $C(\theta)'s$ and their angular power spectra, Sachs-Wolfe effect in open Universes, the isocurvature CDM and baryon stories, $\Delta T/T$ from gravitational waves, the cosmic string story.



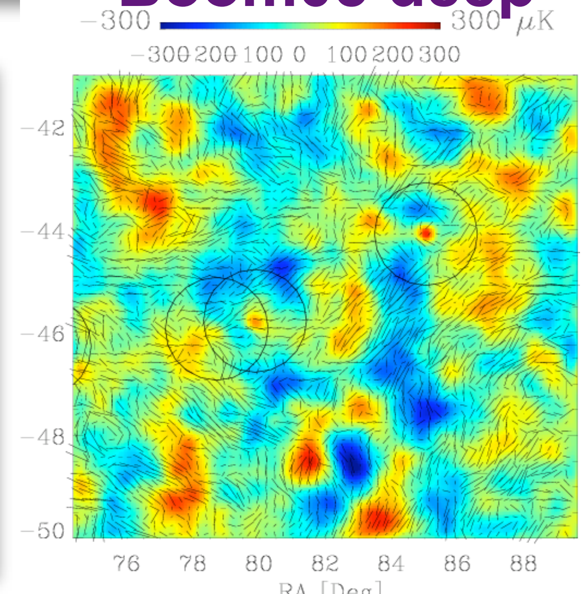
BE87



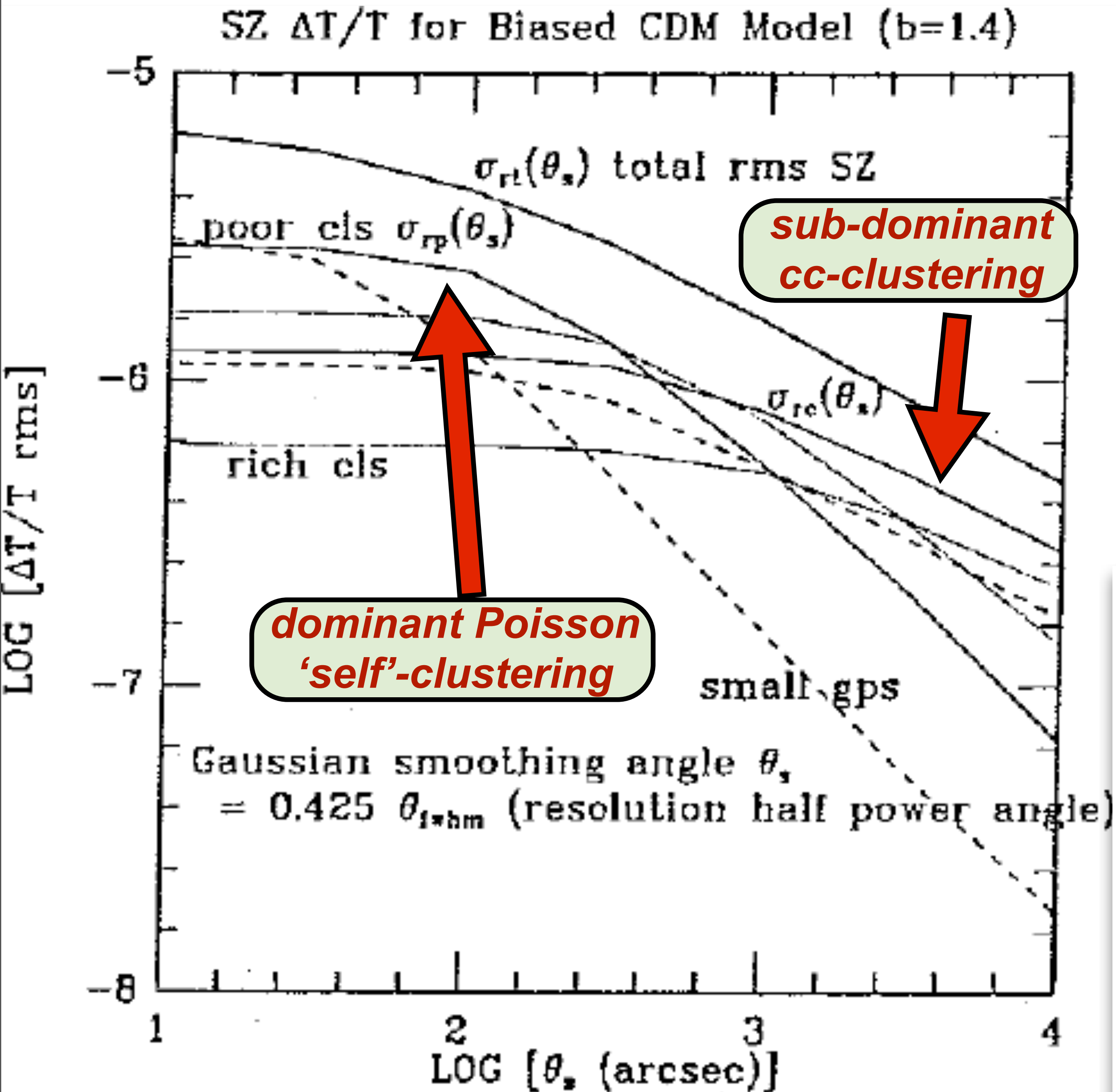




Boom05 deep



ambient/blank-field tSZ effect from clusters and groups B86-87

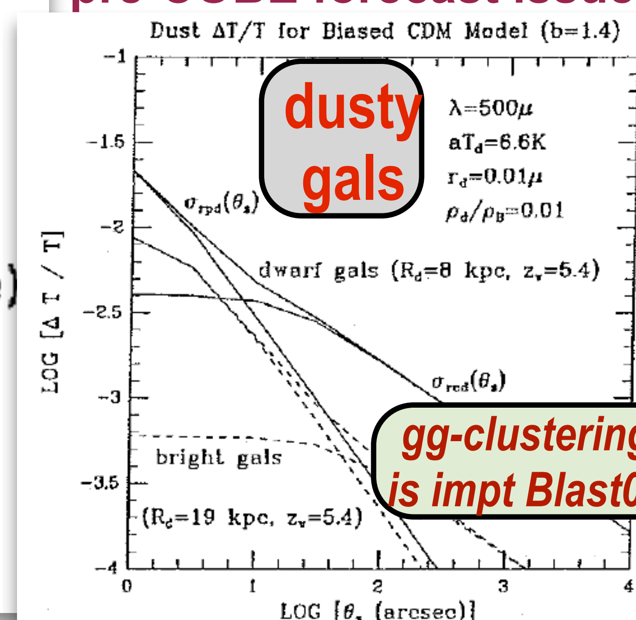


bond@ ΔT/Tea87: "clustered shots" (bbks86-peaks for halos) with pressure profiles - *via binding energy (not mass) but beta-profiles with core scaling and old X-ray beta's*

BUT spherical collapse - *too many cls* **& non-dynamical masses** - *high M's too low*

⇒ peak patches BM91-96

+ effect of energy injection/ explosions on LSS- a big pre-COBE forecast issue



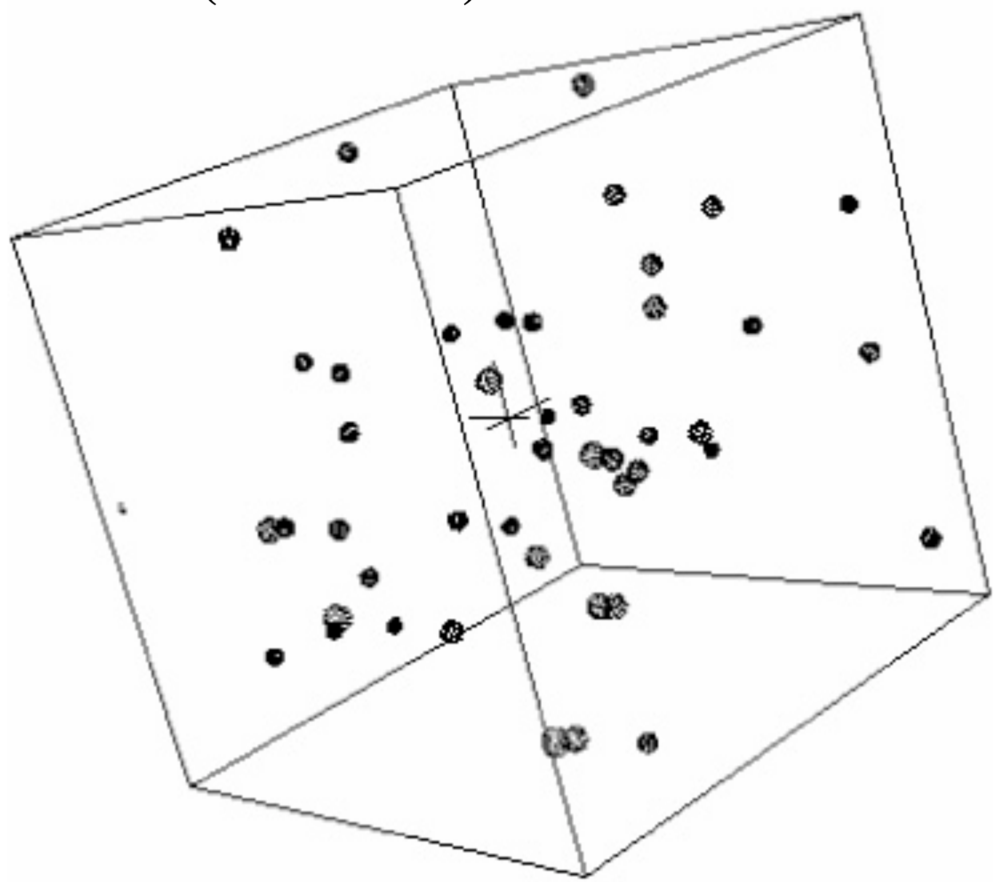
Cluster Peak Patches in Final State Space

(Eulerian)

peak patches BM91-96

importance of tidal fields - virial mass from homogeneous ellipsoid dynamics

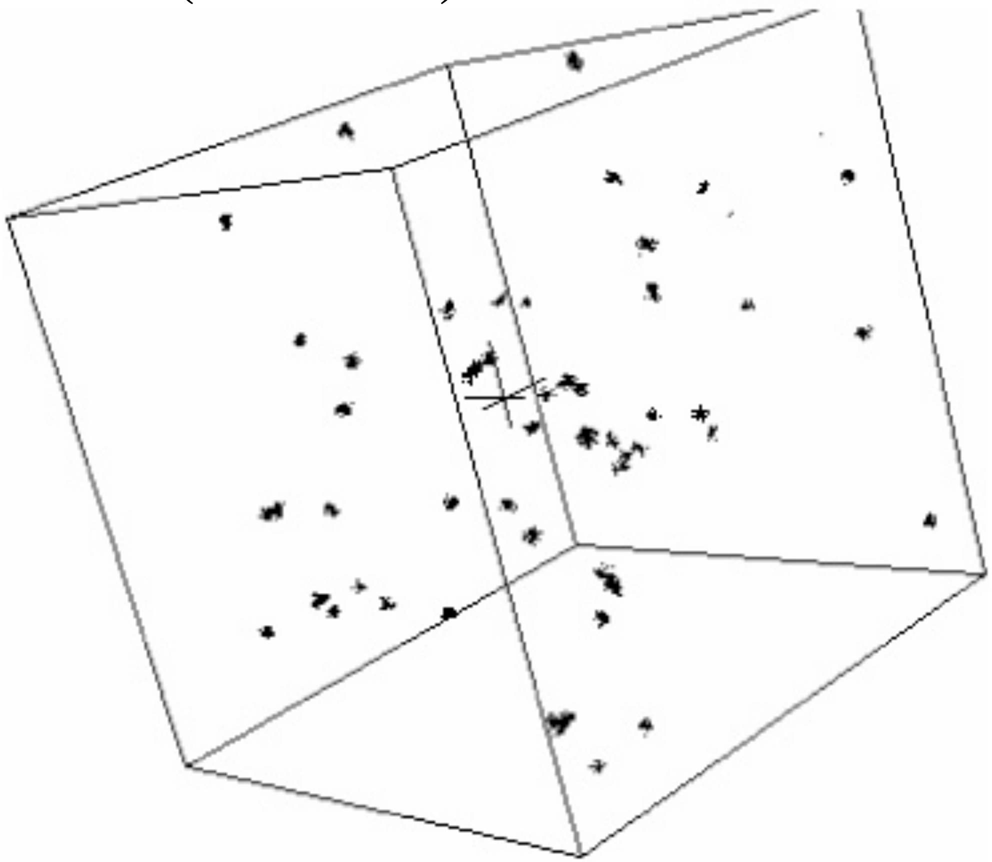
accurate cluster positions, masses, binding energies, clustering



(400 Mpc)^3 simulation

N-body groups in Final State Space

(Eulerian)

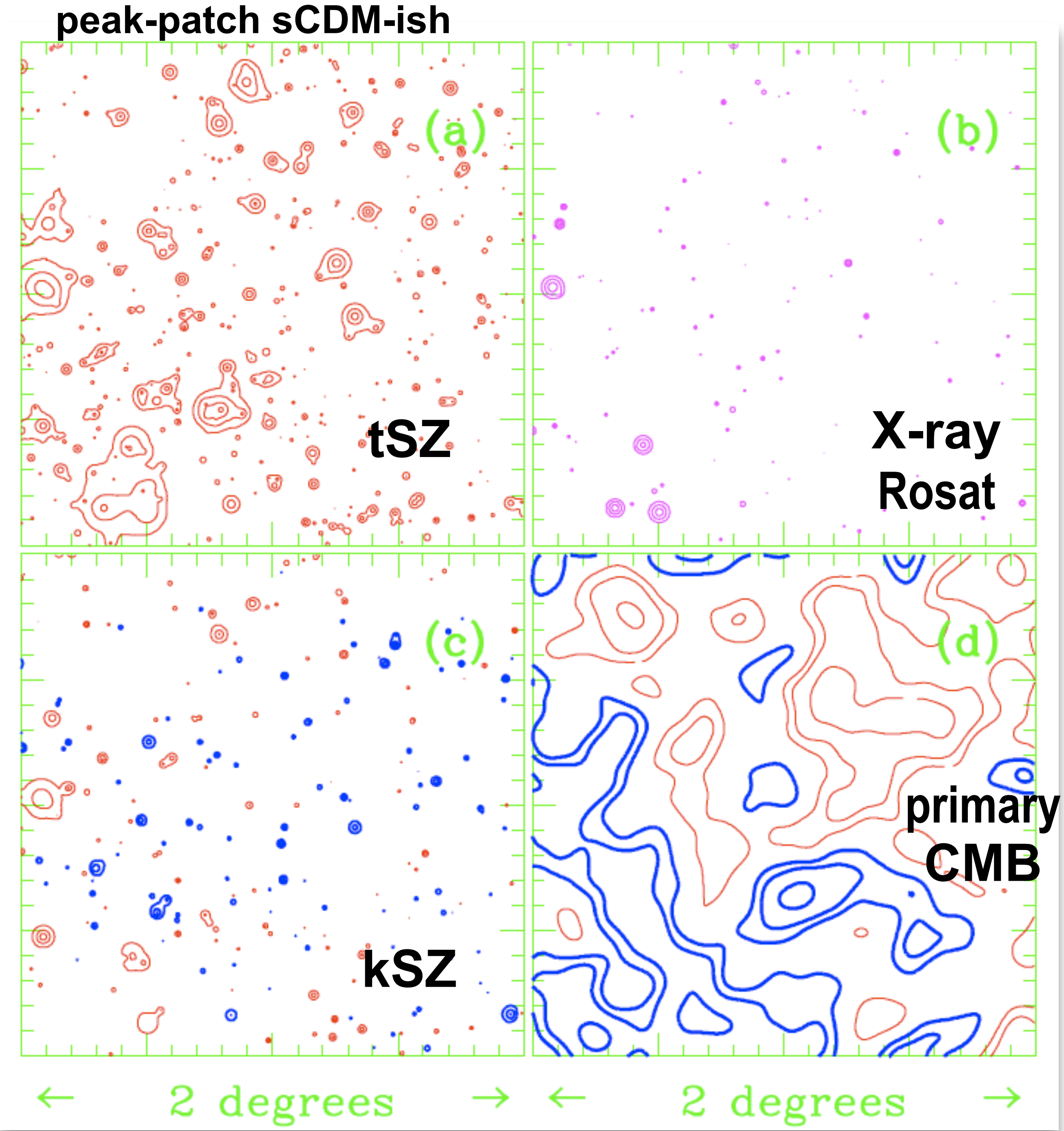


$(400\ \text{Mpc})^3$ simulation

peak patches BM91-96

importance of tidal fields - virial mass from homogeneous ellipsoid dynamics

accurate cluster positions, masses, binding energies, clustering



peak patches
BM91-96

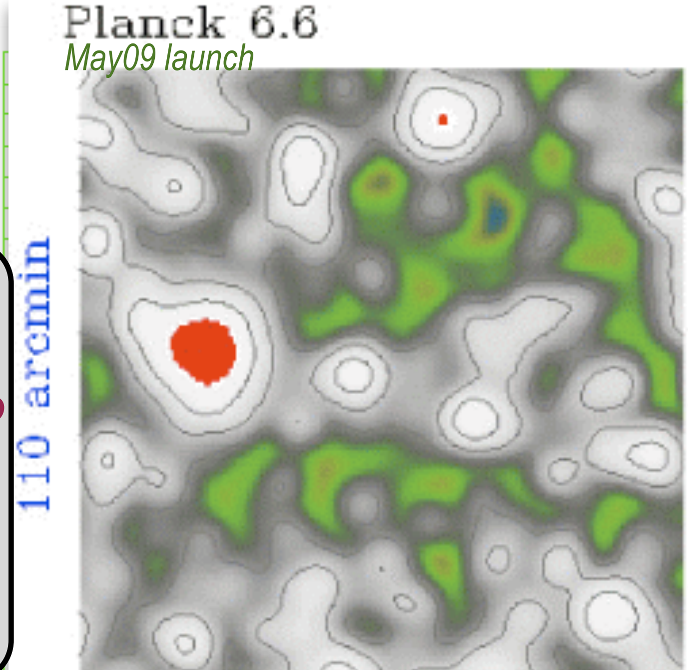
importance of tidal fields - virial mass from homogeneous ellipsoid dynamics

accurate cluster positions, masses, binding energies, clustering

BUT pressure still painted on *a la* spherical beta-profile with core scaling and old X-ray beta's

peak-patch sCDM-ish

vintage 93-96 forecast of what CBI would be - became 13 elements, no 15 GHz. but NVSS, OVRO, GBT (ATCA), .. thrown at source contamination issue



peak-patch ΛCDM > 10K smeared cls @lowish z

from Planck

Figure 16: $2^\circ \times 2^\circ$ maps for a $\sigma_8 = 0.7$ CDM model that could be probed by the Cosmic Background Imager (CBI) being built by Caltech: an 8 small-dish interferometer to map scales from $\sim 2'$–$20'$, with optimal sensitivity $\gtrsim 5'$, using HEMTs to cover frequencies 30–40 GHz, with a 15 GHz channel to help to remove contamination. (a) Shows the SZ effect for 30 GHz, with contours $-5 \times 10^{-6} C_{SZ} \times 2^{n-1}$; (b) the associated ROSAT map (0.1–2.4 keV), with contours $10^{-14} C_X \times 2^{n-1}$ erg cm^{-2} s^{-1}, so the minimum contour level is similar to the ROSAT 5σ sensitivity for long exposure pointed observations; (c) the Thomson scattering anisotropy induced by the bulk motion of the clusters, with contours now $\pm 1.25 \times 10^{-6} C_V \times 2^{n-1}$, $C_V \approx 1.2$; (d) primary anisotropies, with contour levels at $\pm 10^{-5} \times 2^{n-1}$. Negative contours are light and dotted. The C_{SZ}, C_X and C_V are order-unity correction factors.

the quest for primordial non-Gaussianity within the primary CMB requires exquisite foreground removal, whether inflation-induced or cosmic-string-induced, ...

the TBD of Planck vintage 98: signal separation

striping

dust

synchrotron

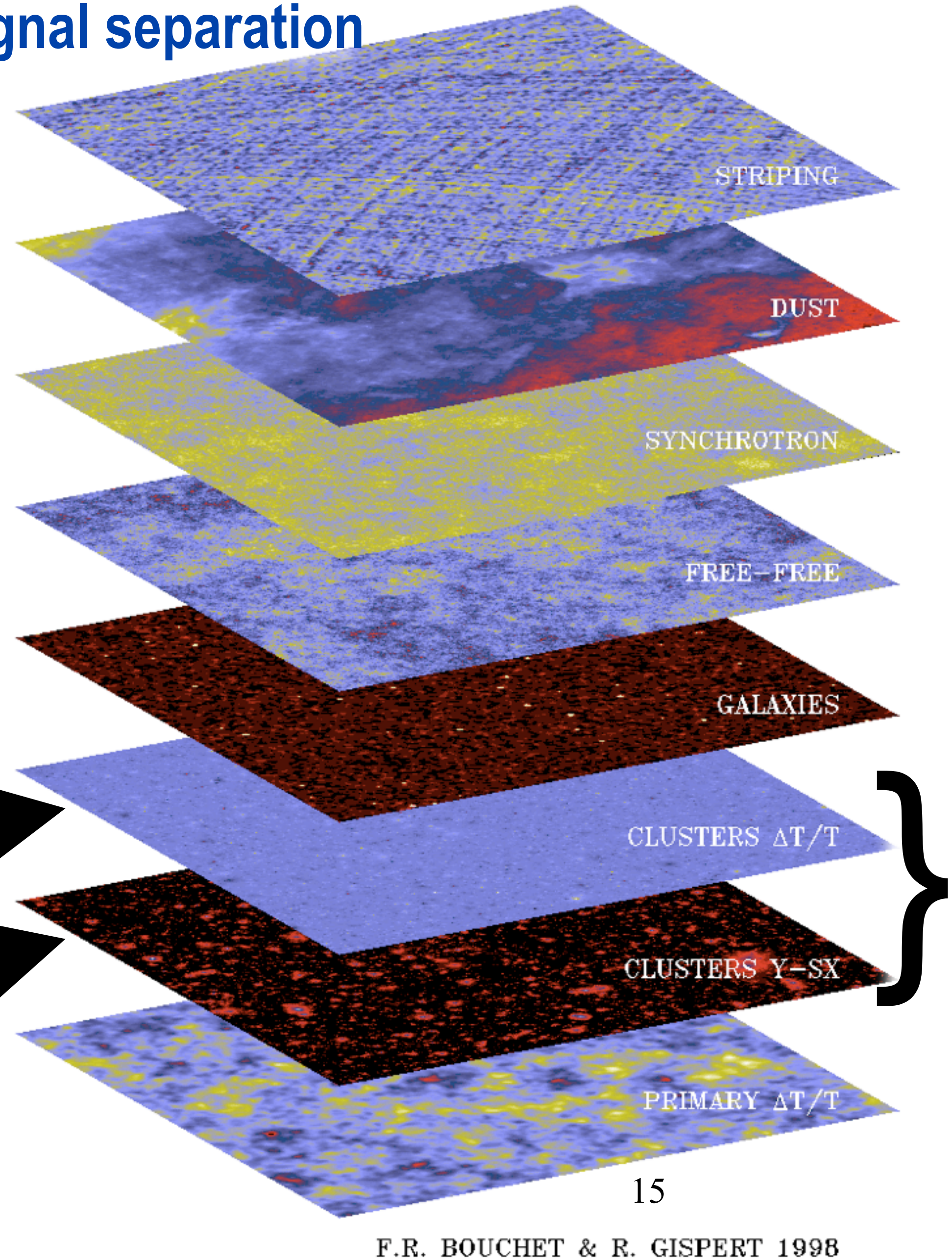
bremsstrahlung

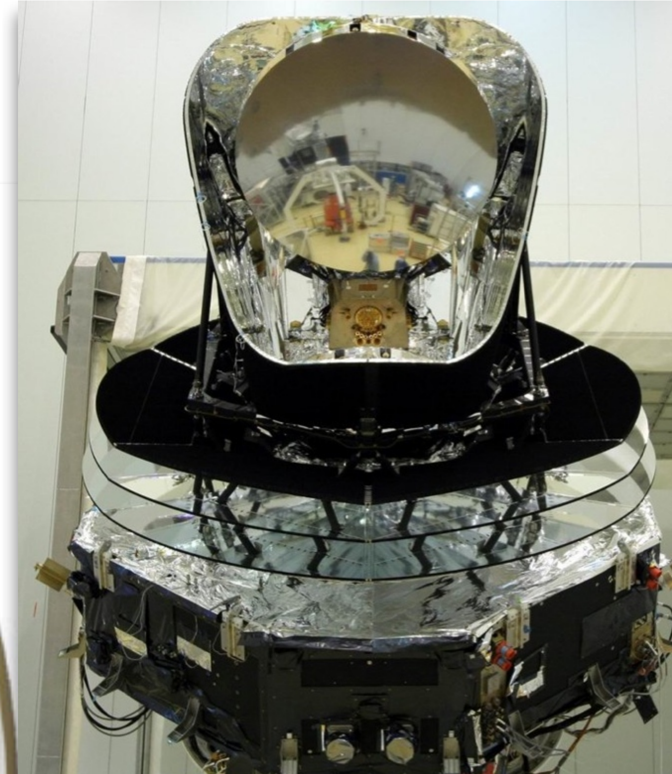
dusty galaxies

kinetic SZ

thermal SZ

PRIMARY





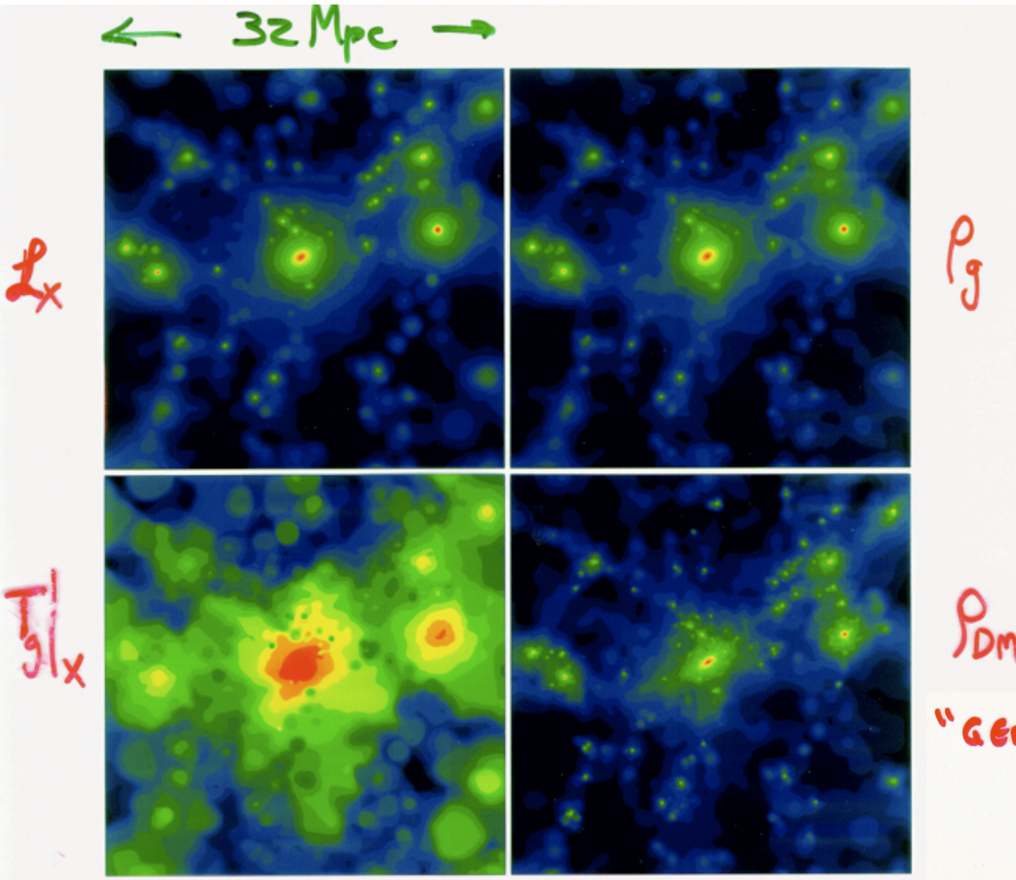
Planck and Herschel split ~1/2hr after launch

Trip to L2: ~ 30 days from May xx launch

- *Decontamination & Cool-down ~ 45 days*
- *Detectors at 100mK at L2 around Canada Day July 1*
- *CPV (Checkout & Performance Verification) to early Aug*

- *Two sky surveys finished 2010.7*
- *Early Release Compact Source Catalog 2011.1*
- *Four sky surveys finished 2011.7*
- *Public release of 1yr data, papers 2012.7*

SB adiabatic cluster test *then*: ITP9



Contoured images of the projected X-ray luminosity (top left), gas density (top right), X-ray weighted Temperature (bottom left) and dark matter density (bottom right) for a large cluster at redshift zero in a CDM simulation with $H_0 = 50\,kms^{-1}$, $\Omega_b = 0.1$, $\sigma_8 = 0.65$ and $\Gamma = 0.25$, performed by Bond & Wadsley as part of the cluster code comparison of Frenk *et al.* (1997). Each figure panel is 32 Mpc across. The cluster at the centre contains $10^{15}\,M_{sun}$ and has a total X-ray luminosity of $2 \times 10^{45}\,ergs^{-1}$, integrated out to $r_{200} = 2.7\,Mpc$. The peak temperature is $10^8\,K$.

ITP '95 CLUSTER COMPARISON τCDM

$\Omega_B = 0.1, \sigma_8 = .65, \Gamma = .25$

FINAL STATE

$M_d = 10^{15} M_\odot$

$L_x(< r_{200} = 2.7\,\mathrm{Mpc}) = 2 \times 10^{45}\,\mathrm{erg/s}$

$T_{gas}|_{max} = 10^8\,\mathrm{K}$

"1995" ITP Cluster Comparison of Cosmological Hydro+N-body Codes

CALCULATIONS '96 SUBMITTED '98

Coordinators: Frenk + White

Group	Method	CPU	machine	storage
	+treeP^{3}M	60		50
Bond & Wadsley	SPH+P^{3}MG	119hr	DECα	100MB
Bryan & Norman	PPM+PM	200	SGI PowCh	500
Cen	TVD+PM	5312	IBM Sp2	4400
Evrard	SPH+P^{3}M	320	HP375	17
Gnedin	SLH+P^{3}M	136	SGI PowCh	90
Jenkins, Thomas & Pearce	SPH+AP^{3}M	5000	Cray-T3D	512
Owen & Villumsen	ASPH+PM	40	Cray-YMP	106
Navarro	SPH+Direct	120	Sparc10+Grape	75
Pen	MMH+MMPM	480	SGI PowCh	900
Steinmetz	SPH+Direct	28	Sparc10+Grape	22
Couchman	SPH+AP^{3}M	77	DECα	95
Yepes & Klypin	FCT+PM	350	Cray-YMP	480
Warren & Zurek DM ONLY	Tree	15360	Intel-Δ	1000

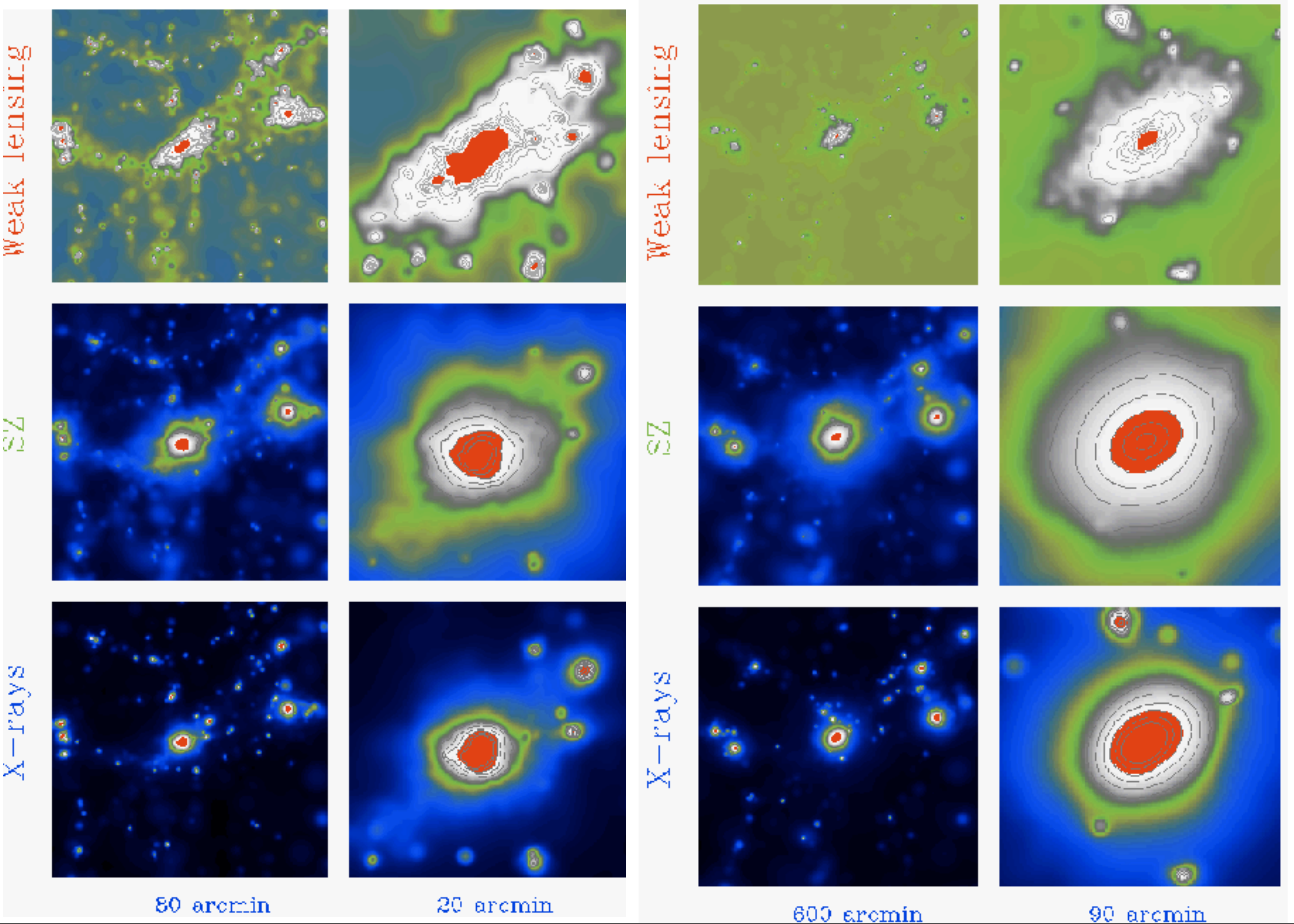
"GENERAL" AGREEMENT ON FINAL STATE.

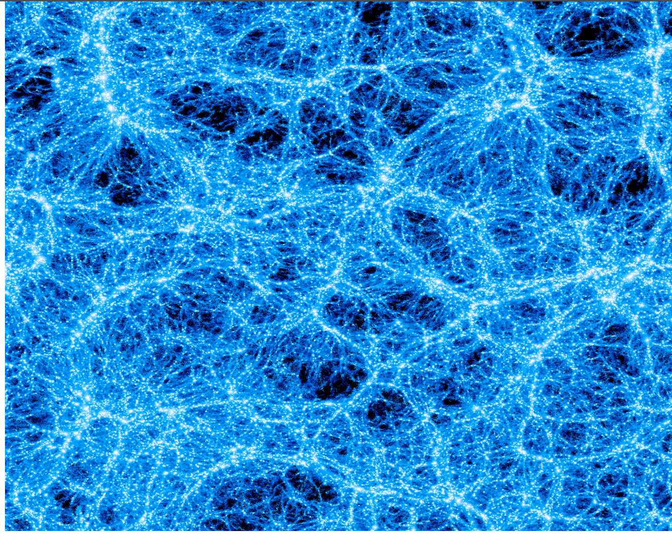
- EXCELLENT IN ρ_{DM}, ρ_{gas}
- good in T_{gas}, S_{gas}, P_{gas}, $\mathcal{L}_x$, gas fract^n

& *then:* KITP cluster workshop Jan-Apr 2011

Kravtsov, Marrone, Oh organizers

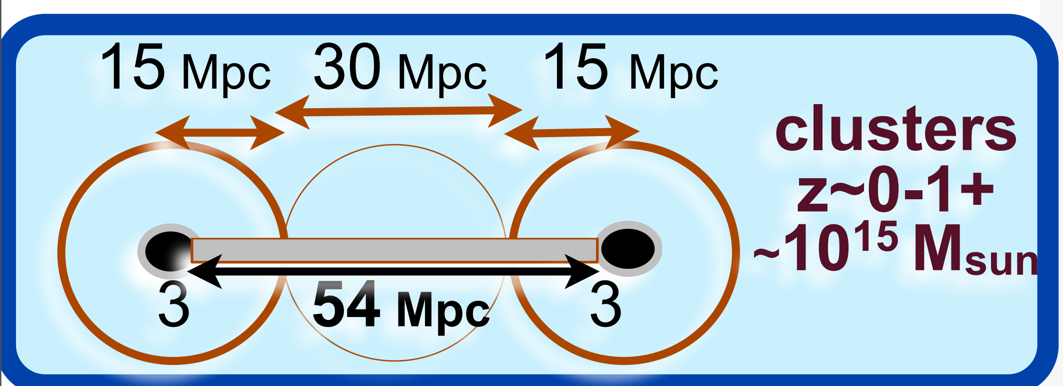
ITP95 Cluster Comparison seen in Lensing, SZ & X at z=0.5 & z~0





"Molecular" Picture of Filaments & Membranes in LSS

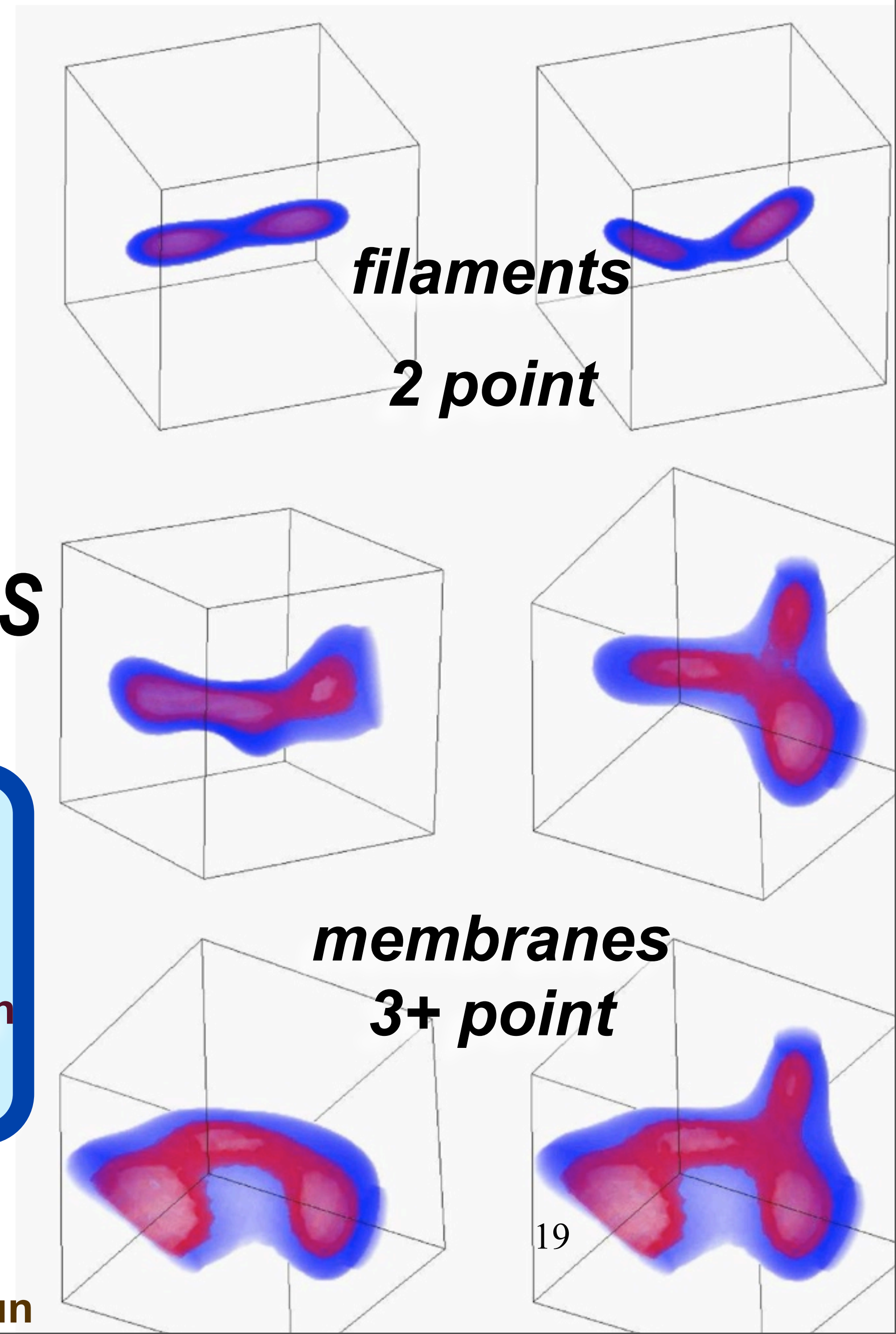
B+Kofman+Pogosyan 96-99



1 Mpc 2 Mpc 1 Mpc

3.6 Mpc

galaxies
z~2-5
~$10^{11.5}$ M_{sun}



galaxy clusters: *intermittency in cosmic random fields* of mass, pressure, X-ray & optical luminosity, tides/shear (lensing) ...

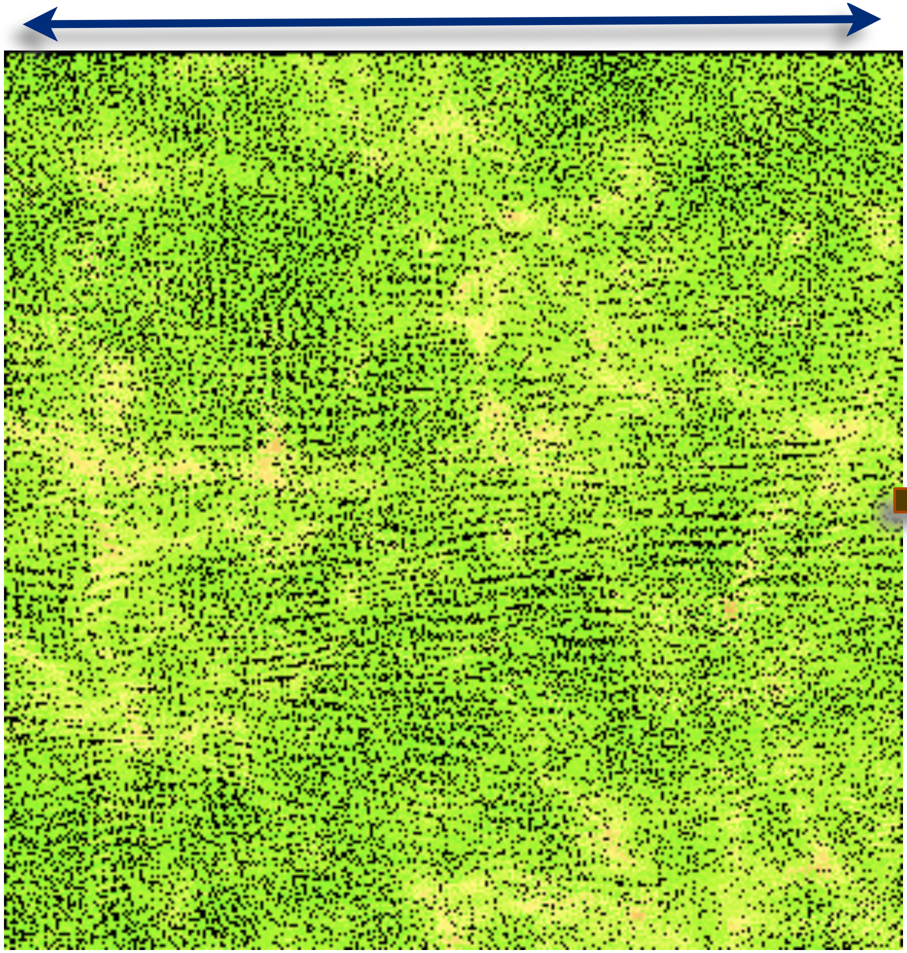
B+Kofman+Pogosyan+Wadsley 97/99

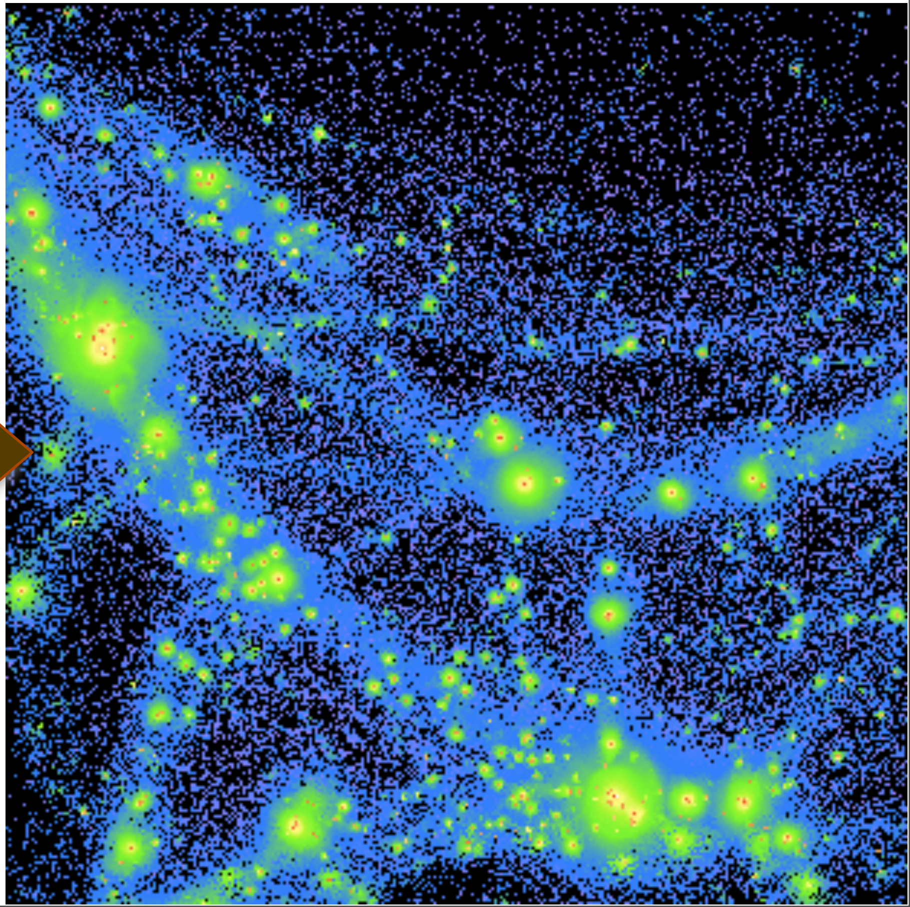
constrained supercluster treePM-SPH *sim* of ΛCDM +cooling

largest k-range of its time (>> Virgo sim)

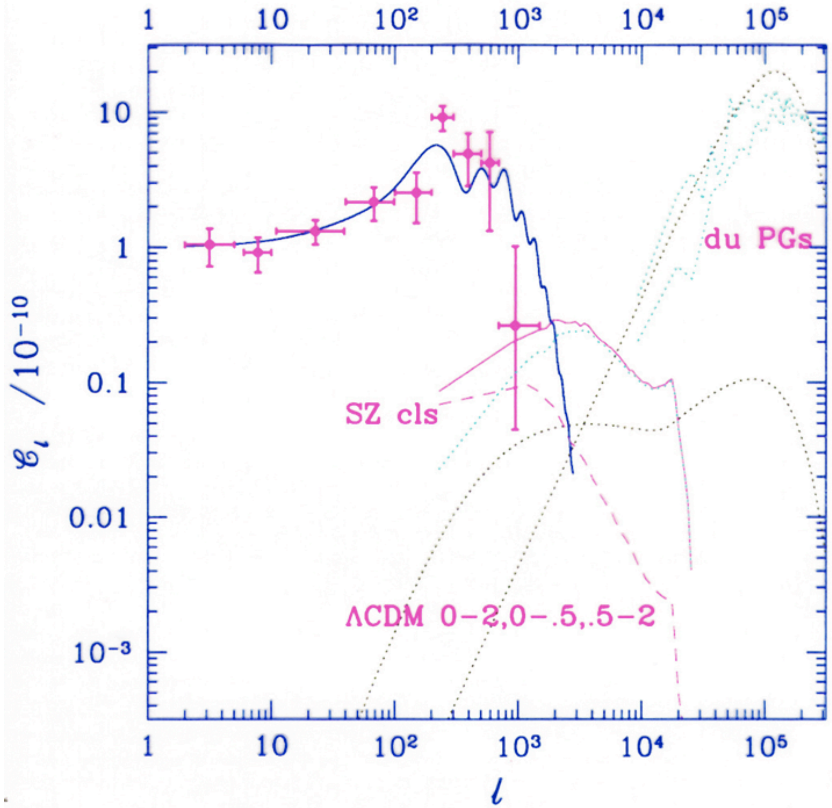
104 Mpc HighResolution +166 MedRes +266 LoRes

⟹ *Sunyaev-Zeldovich effect in supercls may give outskirts of clusters & groups, but not filaments (unless ∃ large gas E-outflows)*

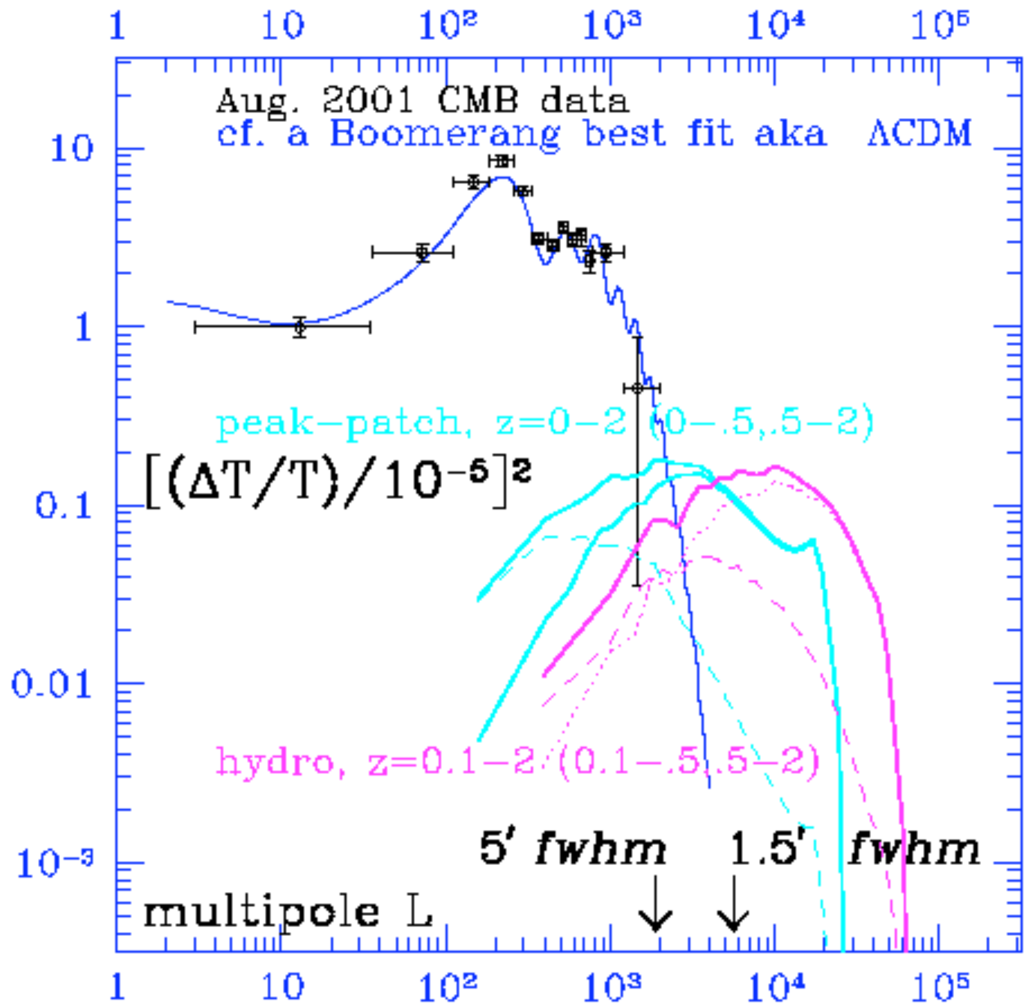


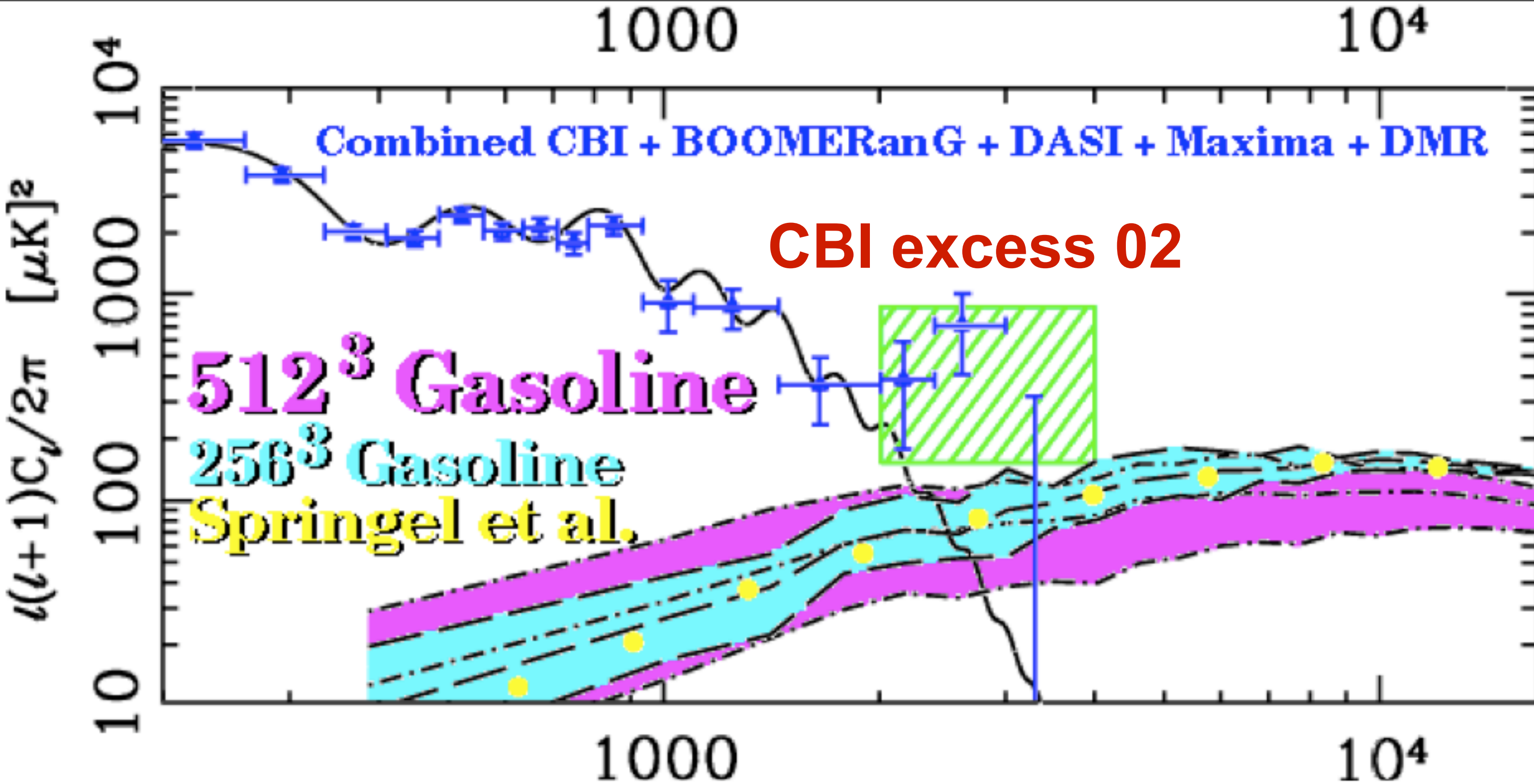


pre-Boomerang

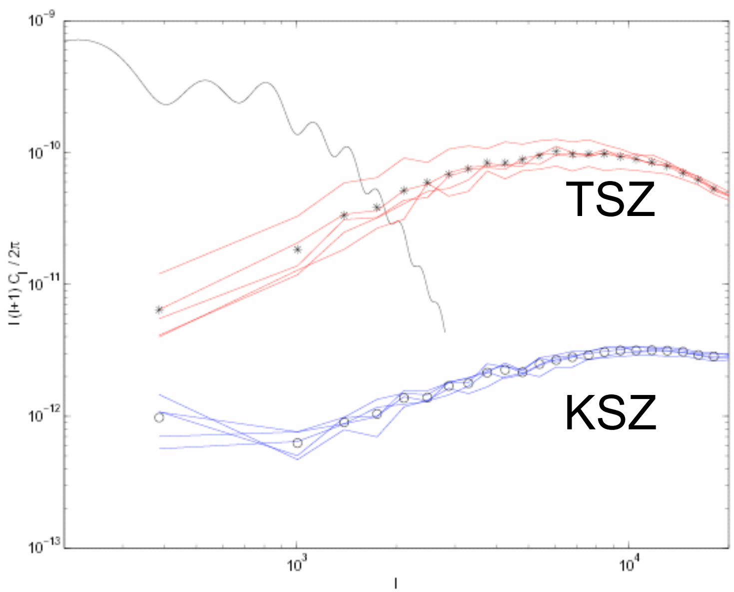


post-Boomerang

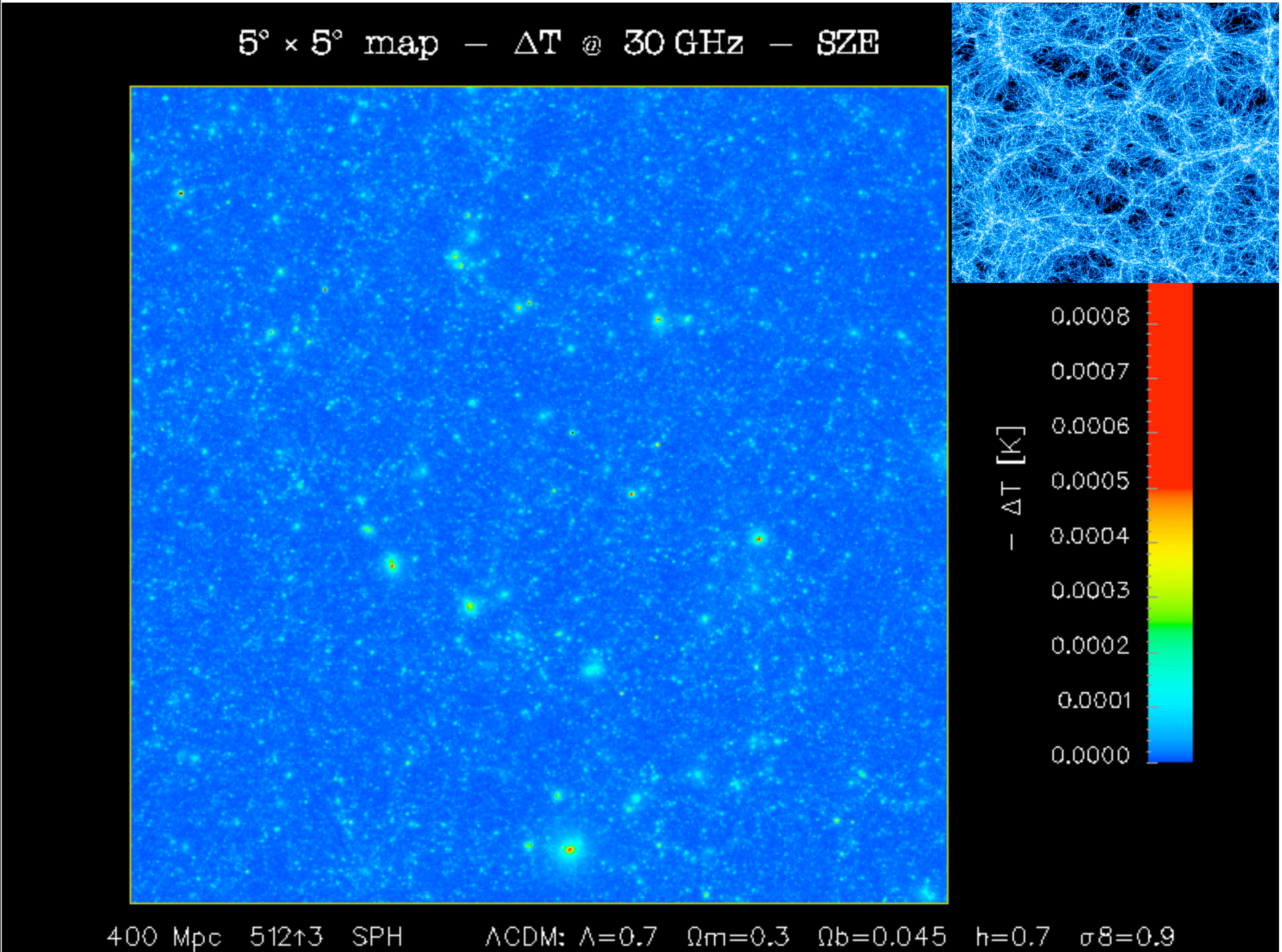




512^3 ΛCDM sim SZ power spectra for various realizations



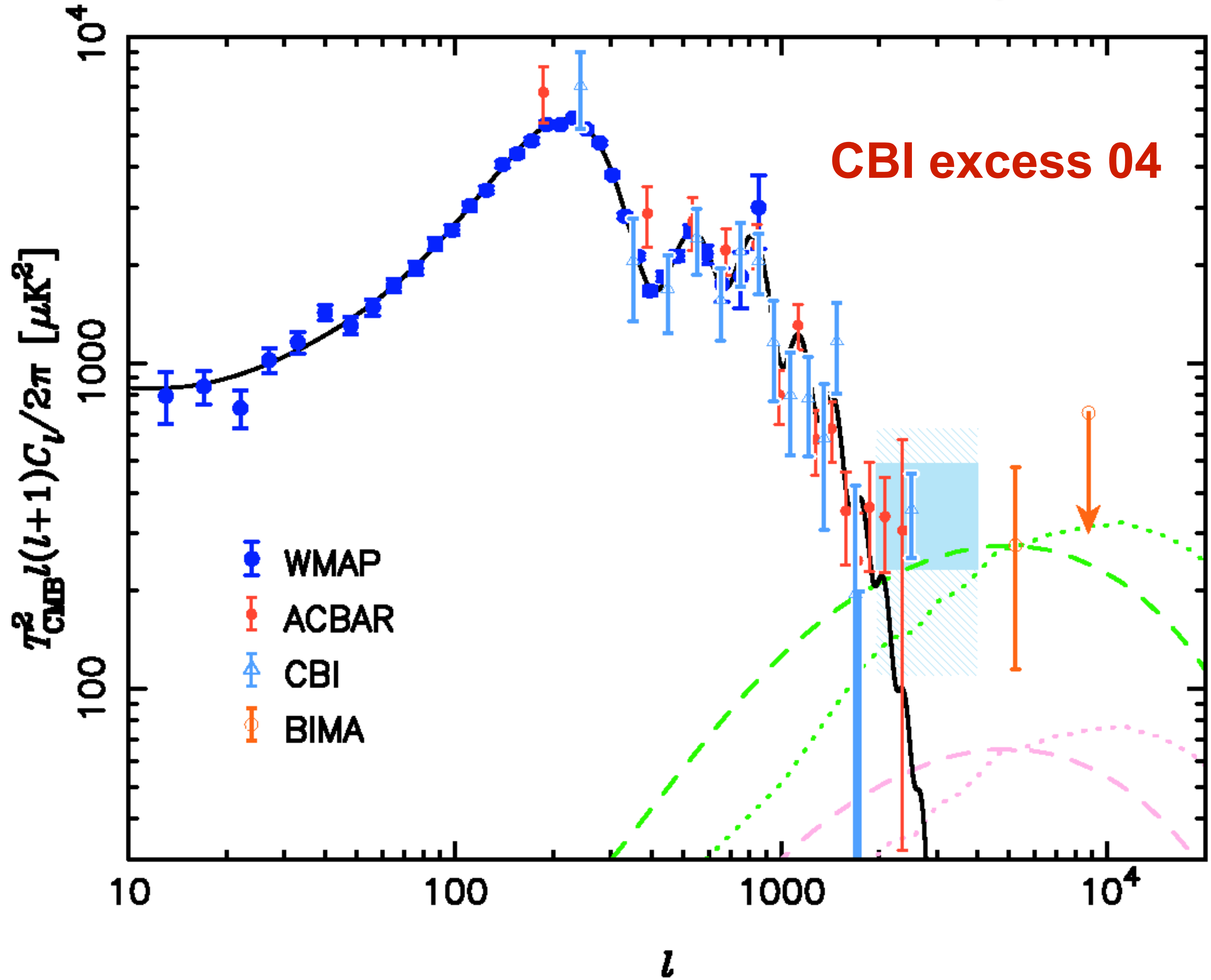
cf. Pen & Zhang 02 MMH for CBI02, smaller box, more power at low L, flatter at high L, analytic PS approximation to it, calibration for KS?



pass the CMB thru the cosmic web; CBI extra power??

512^3 LCDM tree-SPH sim tSZ maps: rotate & translate copies(z) of 400 Mpc box

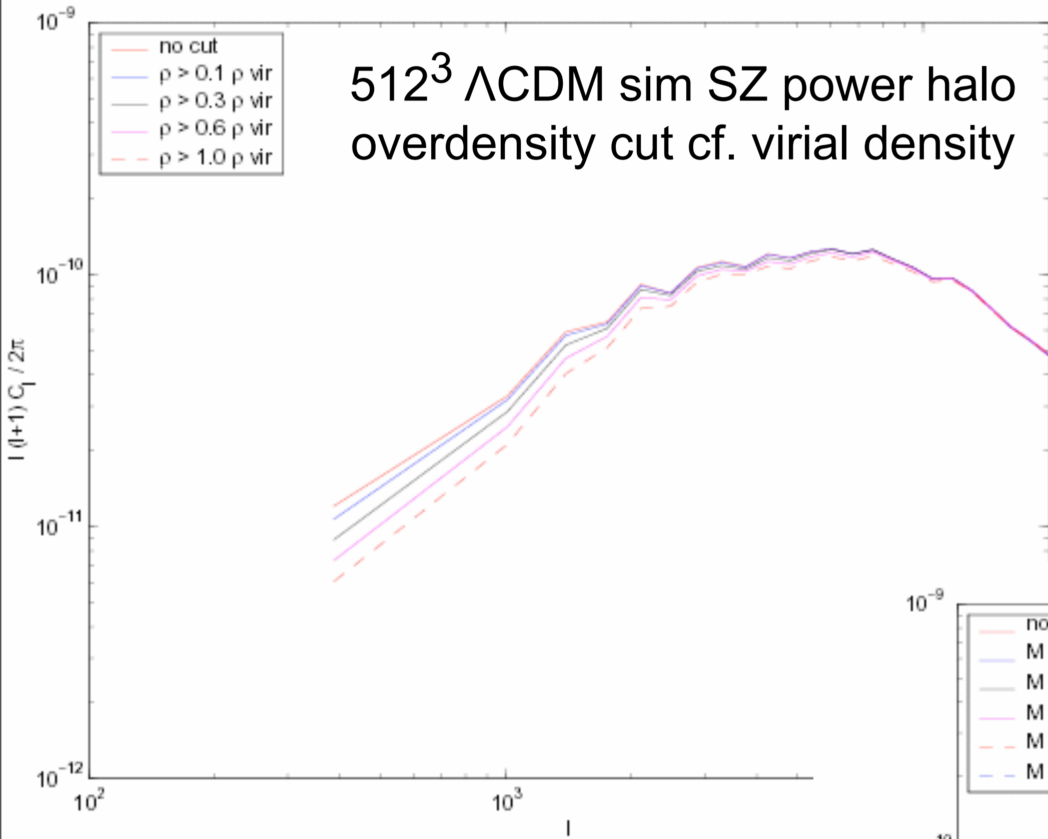
Readhead et al. 2004, ApJ 609, 498



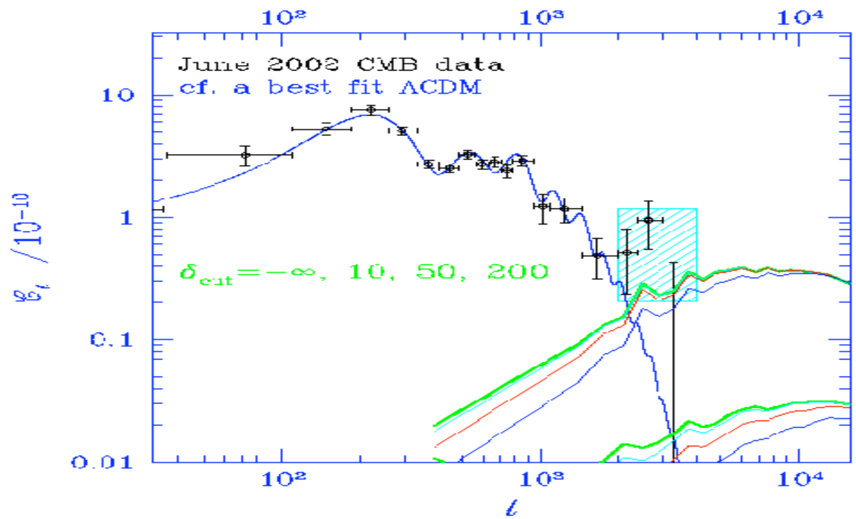
by then, Springel etal's 1st heating/cooling attempts showed no dramatic effect on SZ, but ...

What sort of objects in the cosmic web dominate the SZ effect?

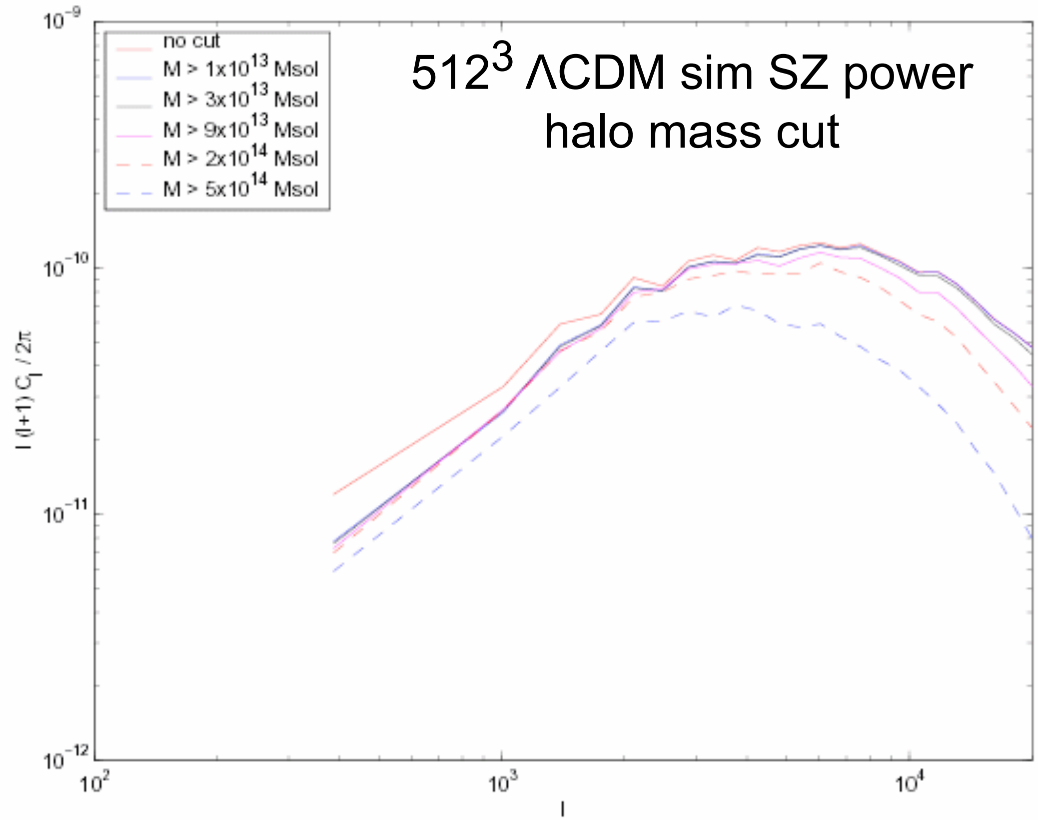
clusters and groups, with only a little from the filament outskirts, unless there has been substantial energy injection along the filaments



512³ ΛCDM sim SZ power halo overdensity cut cf. virial density
no cut
ρ > 0.1 ρ vir
ρ > 0.3 ρ vir
ρ > 0.6 ρ vir
ρ > 1.0 ρ vir
l (l+1) C_l / 2π
l



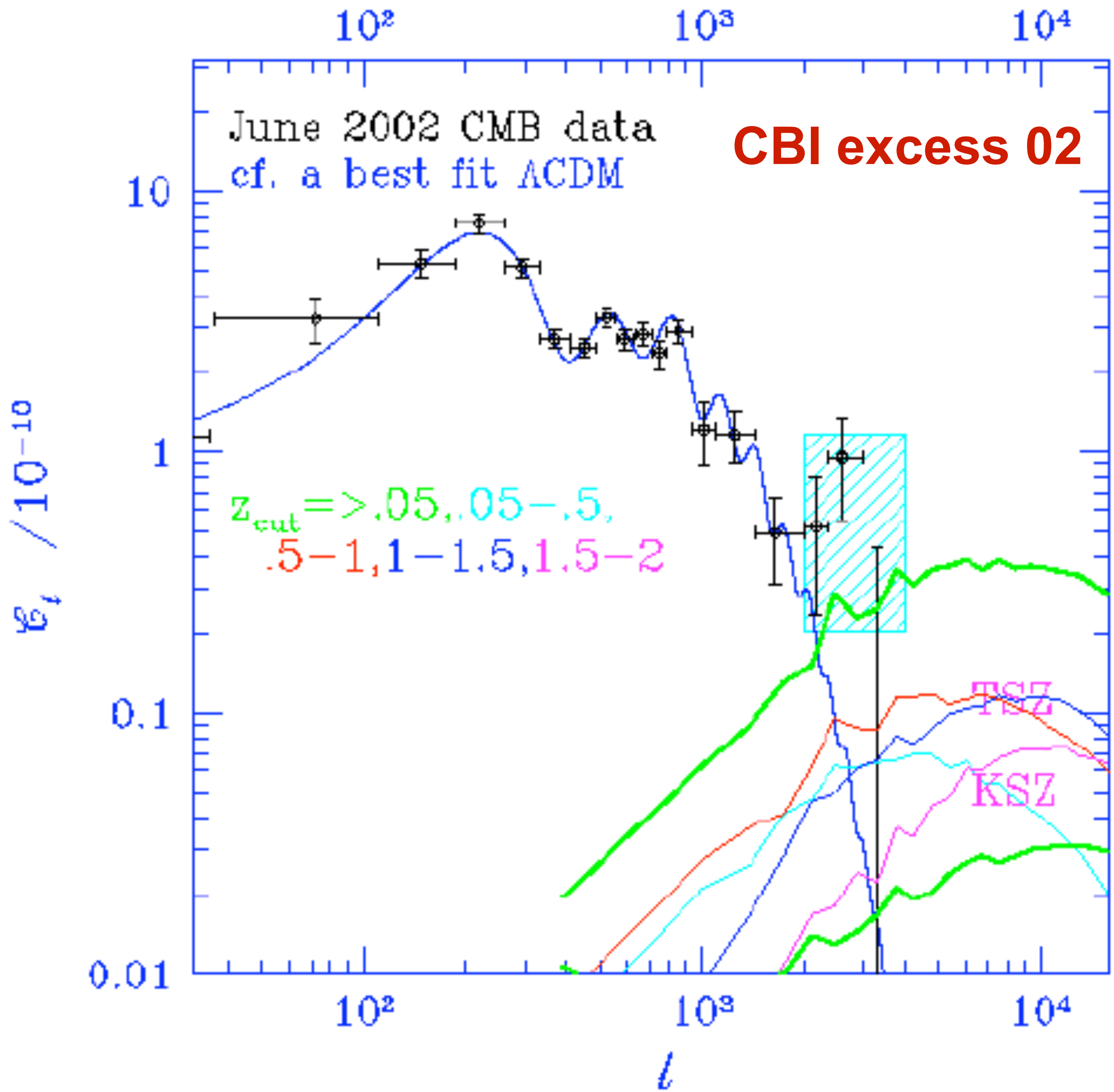
June 2002 CMB data
cf. a best fit ΛCDM
δ_cut = −∞, 10, 50, 200
ℓ



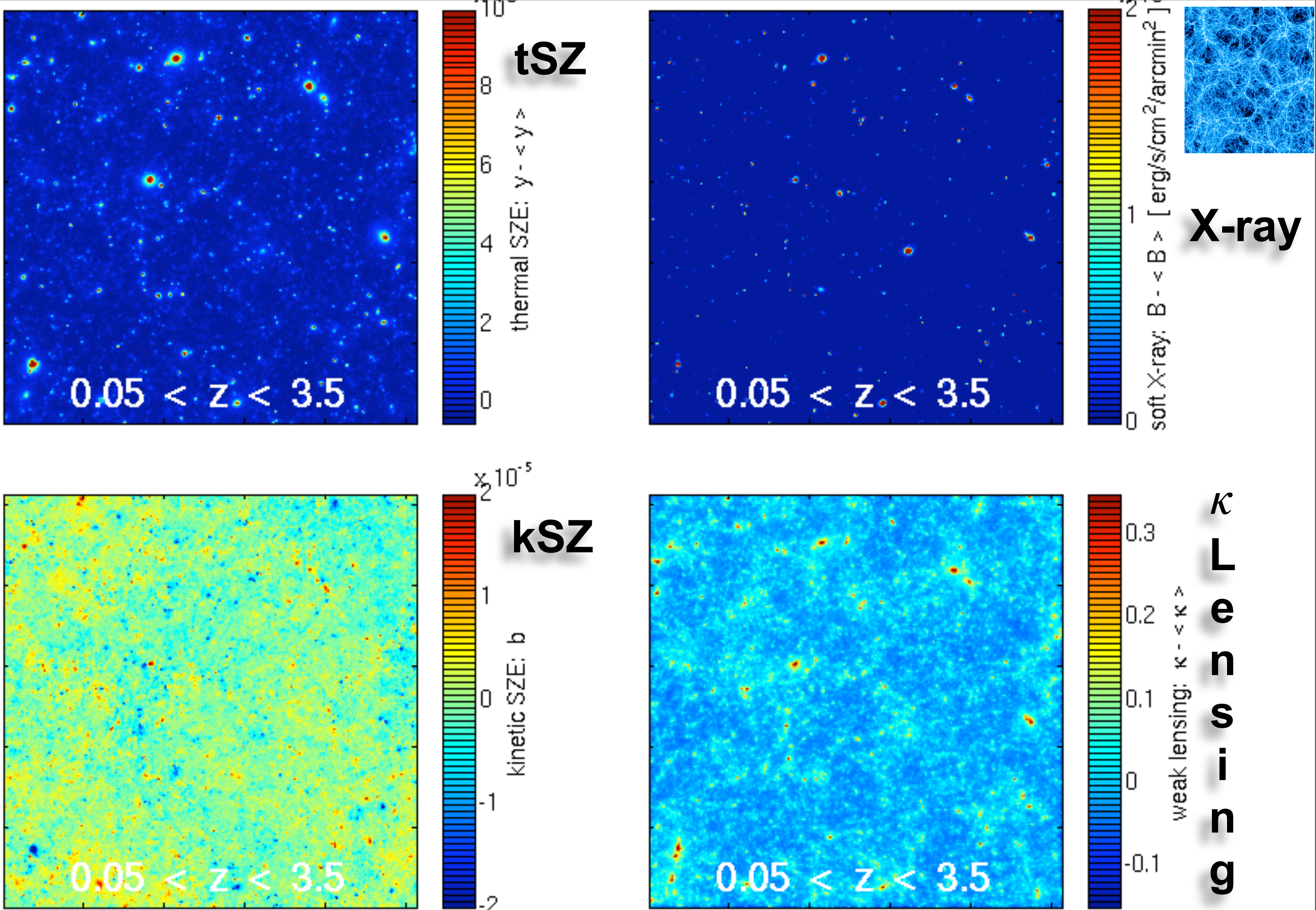
512³ ΛCDM sim SZ power halo mass cut
no cut
M > 1x10¹³ Msol
M > 3x10¹³ Msol
M > 9x10¹³ Msol
M > 2x10¹⁴ Msol
M > 5x10¹⁴ Msol
l (l+1) C_l / 2π
l

What is the redshift range that contributes to the SZ effect?

all from 0 to ~2

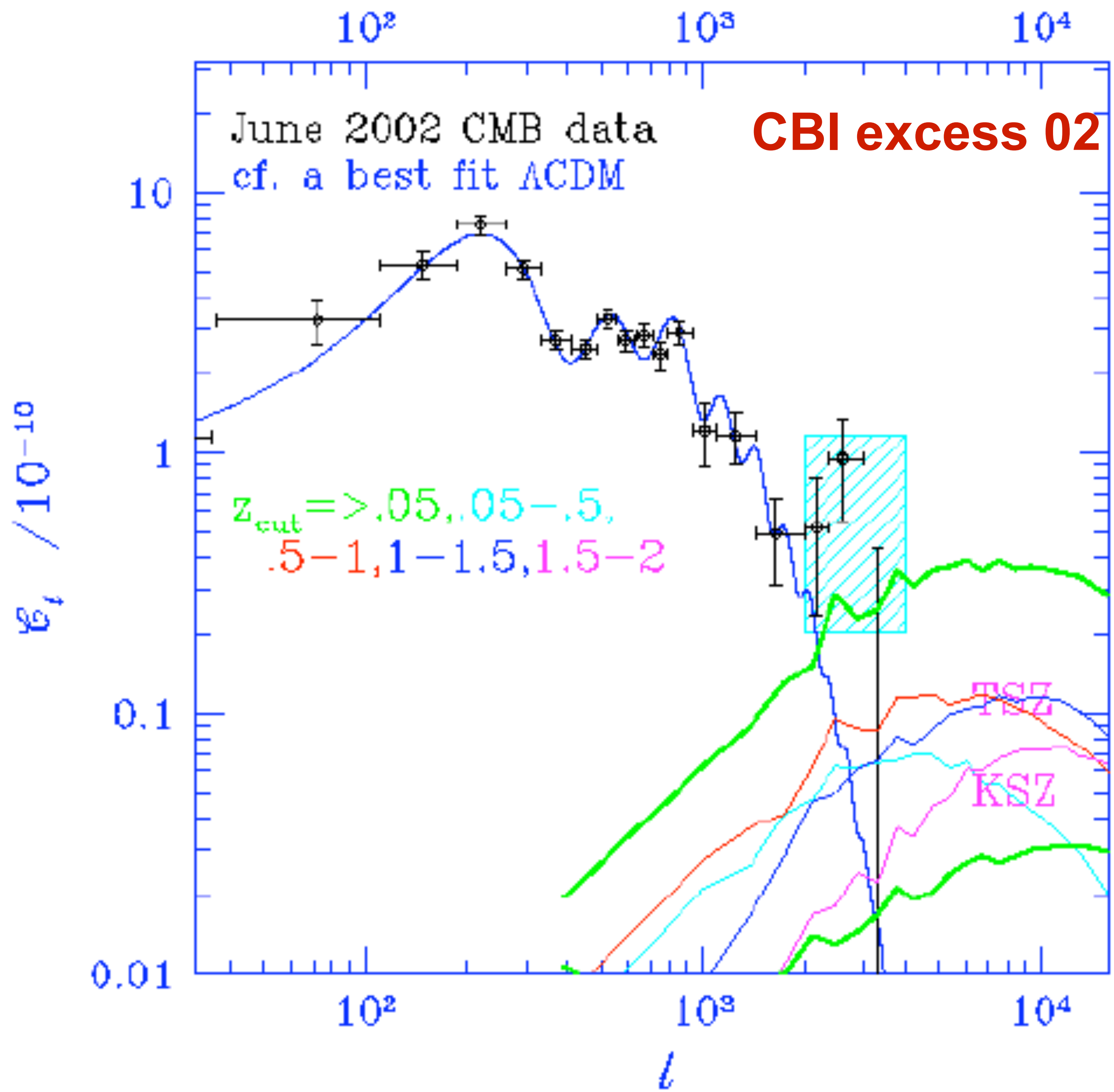


CBI excess 02
June 2002 CMB data
cf. a best fit ΛCDM
z_{cut}=>.05,.05−.5,
.5−1,1−1.5,1.5−2
TSZ
KSZ
$\mathcal{C}_\ell$ /10^{-10}
ℓ
10
1
0.1
0.01
10^2
10^3
10^4

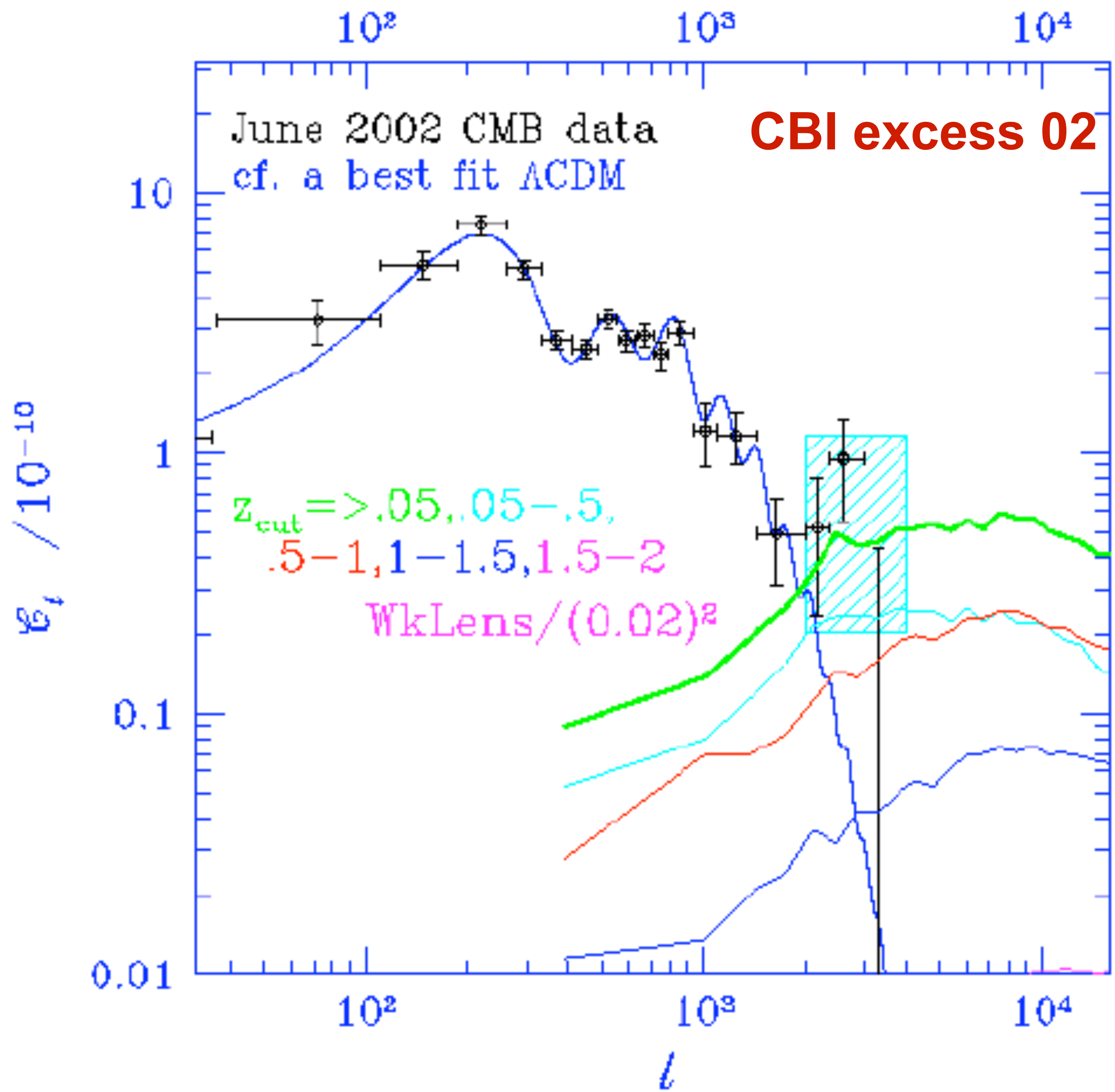


pass the CMB thru the cosmic web; CMB extra power??

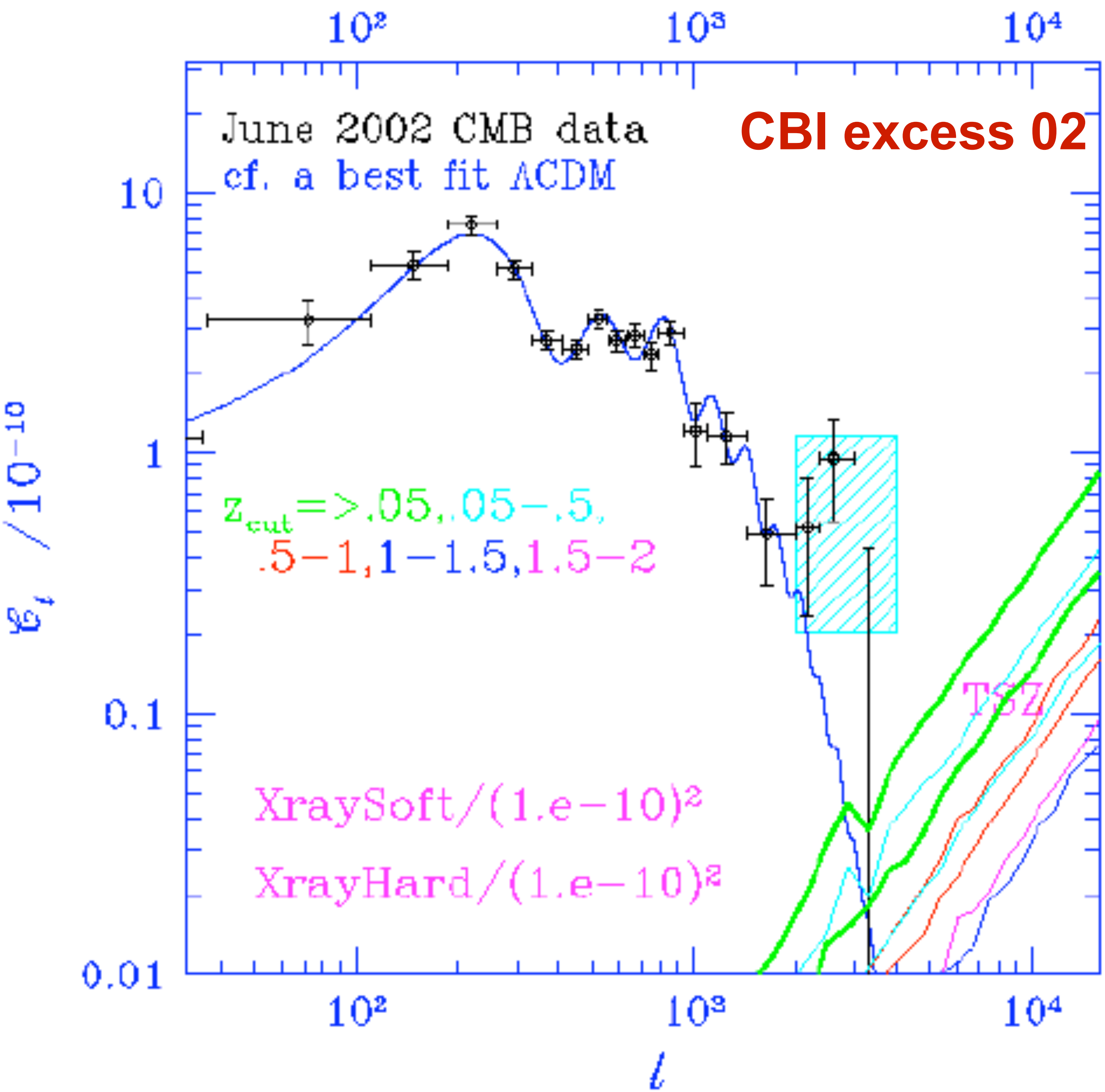
512^3 LCDM sim tSZ maps: rotate & translate copies(z) of 400 Mpc box



CBI excess 02
June 2002 CMB data
cf. a best fit ΛCDM
z_{cut}=>.05,.05−.5,
.5−1,1−1.5,1.5−2
TSZ
KSZ
$\mathcal{C}_\ell$ /10^{-10}
ℓ
10
1
0.1
0.01
10^2
10^3
10^4



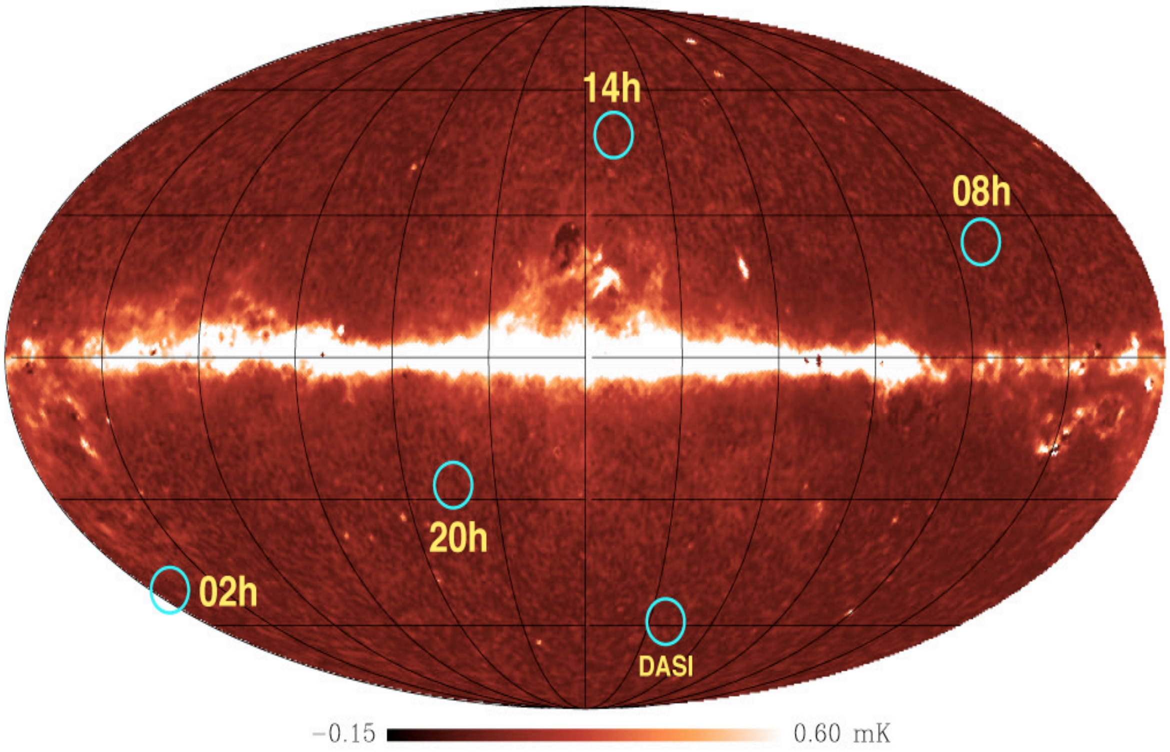
June 2002 CMB data
cf. a best fit ΛCDM
CBI excess 02
z_{cut}=>.05,.05−.5,
.5−1,1−1.5,1.5−2
WkLens/(0.02)²
10
1
0.1
0.01
10^2
10^3
10^4
$\mathcal{C}_l\ /10^{-10}$
l

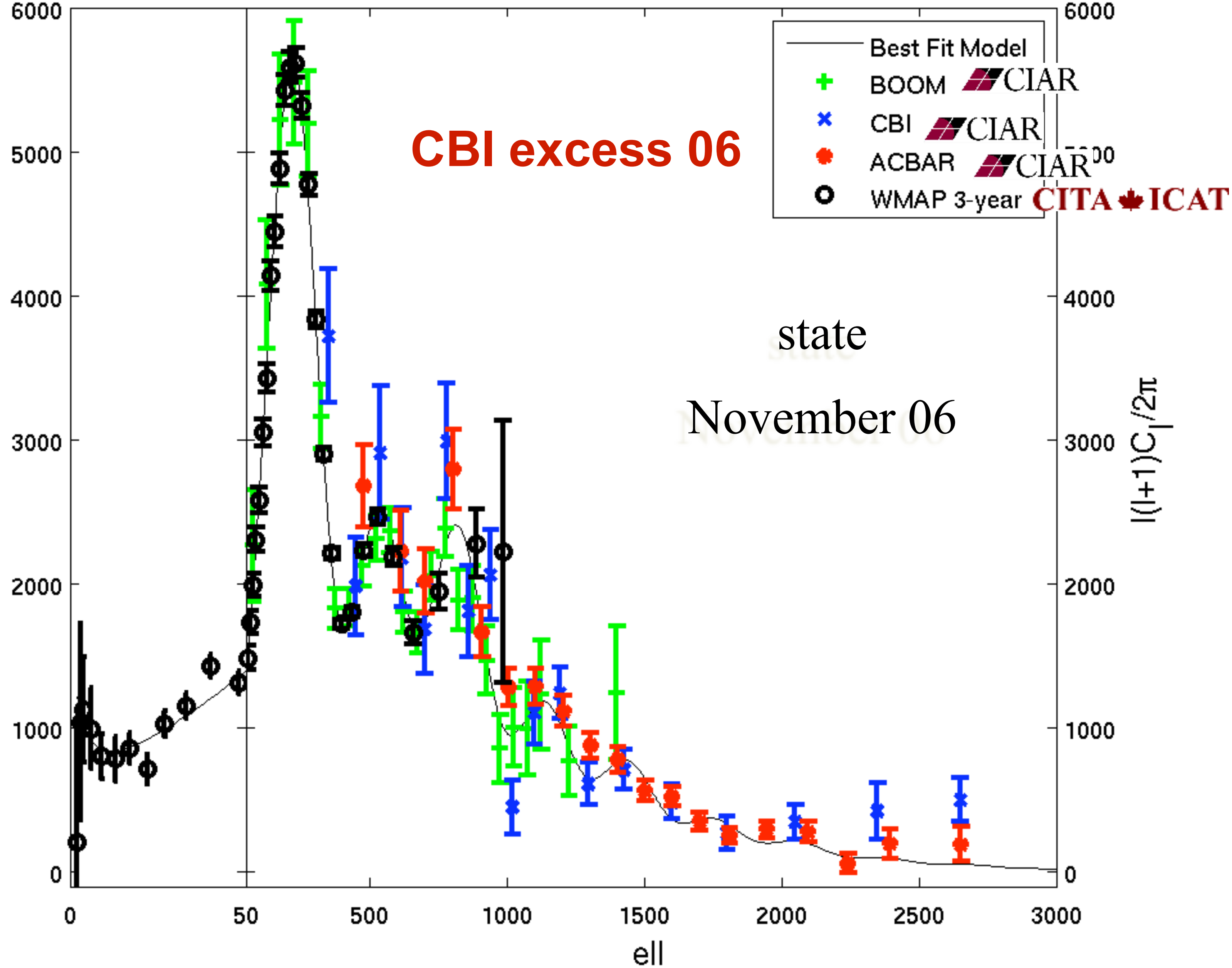


CBI excess 02
June 2002 CMB data
cf. a best fit ΛCDM
z_{cut}=>.05,.05−.5,
.5−1,1−1.5,1.5−2
TSZ
XraySoft/(1.e−10)²
XrayHard/(1.e−10)²
$\mathcal{C}_\ell$ /10^{-10}
ℓ
10
1
0.1
0.01
10²
10³
10⁴

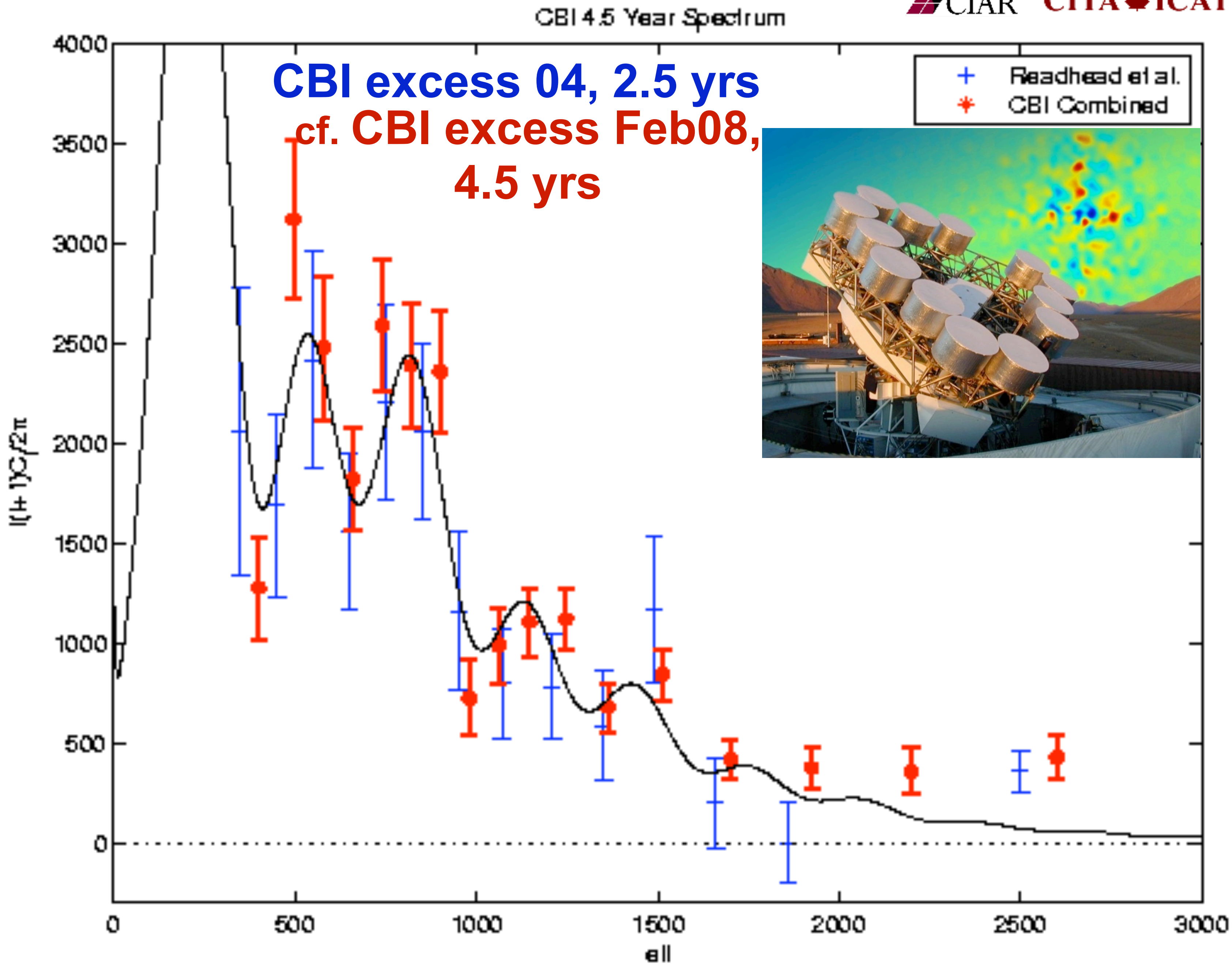
CBI has 2 distinct datasets. Partly overlap, so correlations must be done. Observing patterns differ.

- CBI observes 4 patches of sky – 3 mosaics & 1 deep strip in pol'n, 3 mosaic, 1 deep field in TT
- Pointings in each area separated by 45'. Mosaic 6x6 pointings, for 4.5^{o2}, deep strip 6x1.
- Lose 1 mode per strip to ground from pol'n, ½ from differencing in TT.
- ~5 years of data, Jan 00 – Apr 05.



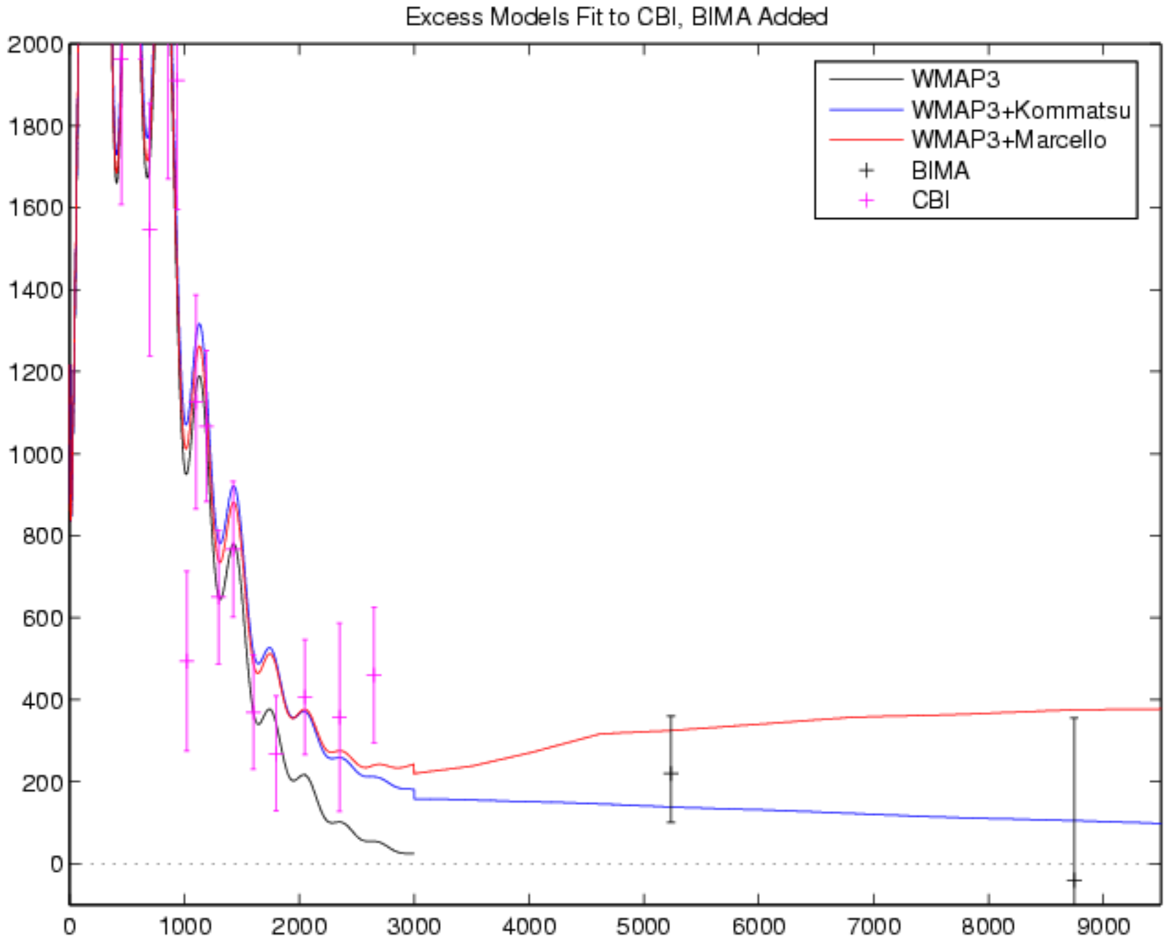


CBI excess 06
state
November 06
Best Fit Model
BOOM CIAR
CBI CIAR
ACBAR CIAR
WMAP 3-year CITA ICAT
6000
5000
4000
3000
2000
1000
0
0
50
500
1000
1500
2000
2500
3000
ell
$l(l+1)C_l/2\pi$



CBI 4.5 Year Spectrum
CBI excess 04, 2.5 yrs
cf. CBI excess Feb08, 4.5 yrs
Readhead et al.
CBI Combined
l(l+1)C_l/2π
ell
4000
3500
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
3000

Current CBI+BIMA PS



Fit CMB+Excess model

to CBItot data

Red curve SPH simulation-based template (Bond et al.), 1.03 +- 0.07 to .988 +- .05

blue curve analytic (Komatsu&Seljak, Spergel et al.06). 0.92+-0.07

Magenta points CBI w/ finer binning. Black points latest BIMA.

Models extrapolated to BIMA points – not a fit.

If CBI excess were due to unexpected source population, BIMA would see them. They don't.

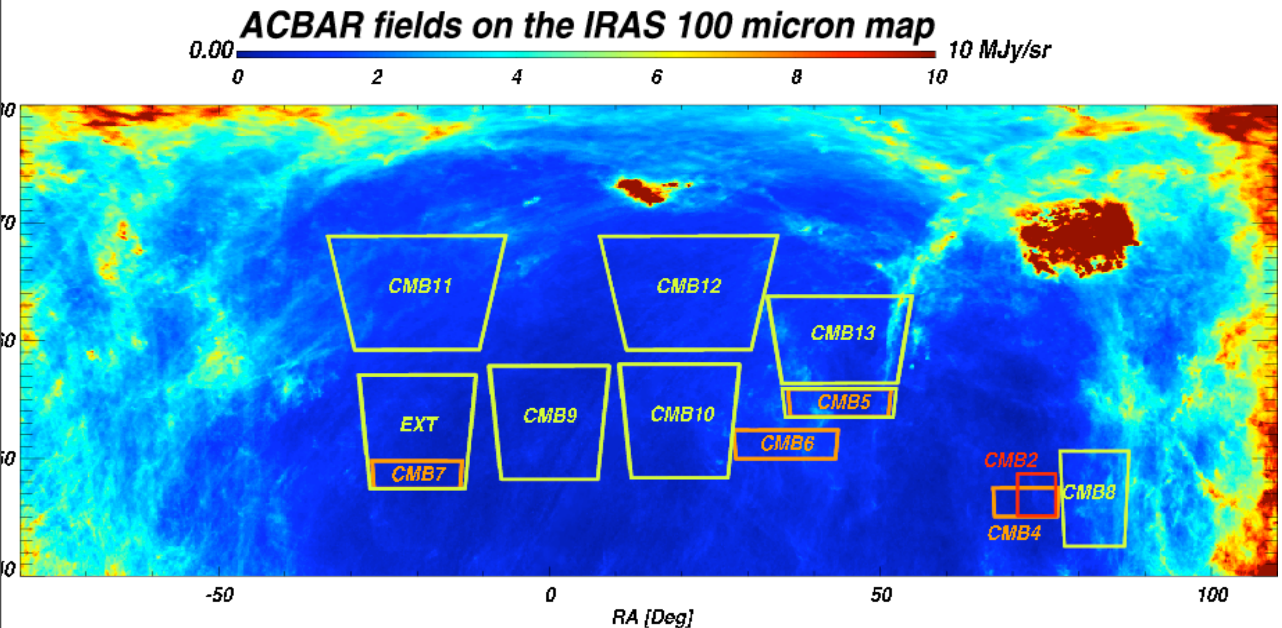
ACBAR08

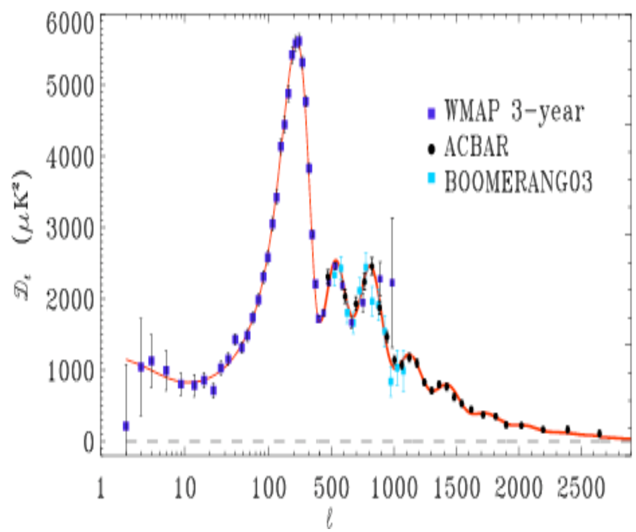
Reichardt et.al. astro-ph Thurs Jan 10

2.1 x detector-hours of ACBAR07

4.9 x sky coverage of ACBAR07 1.7% of sky

Calibration uncertainty to 2.2% from 6% via WMAP

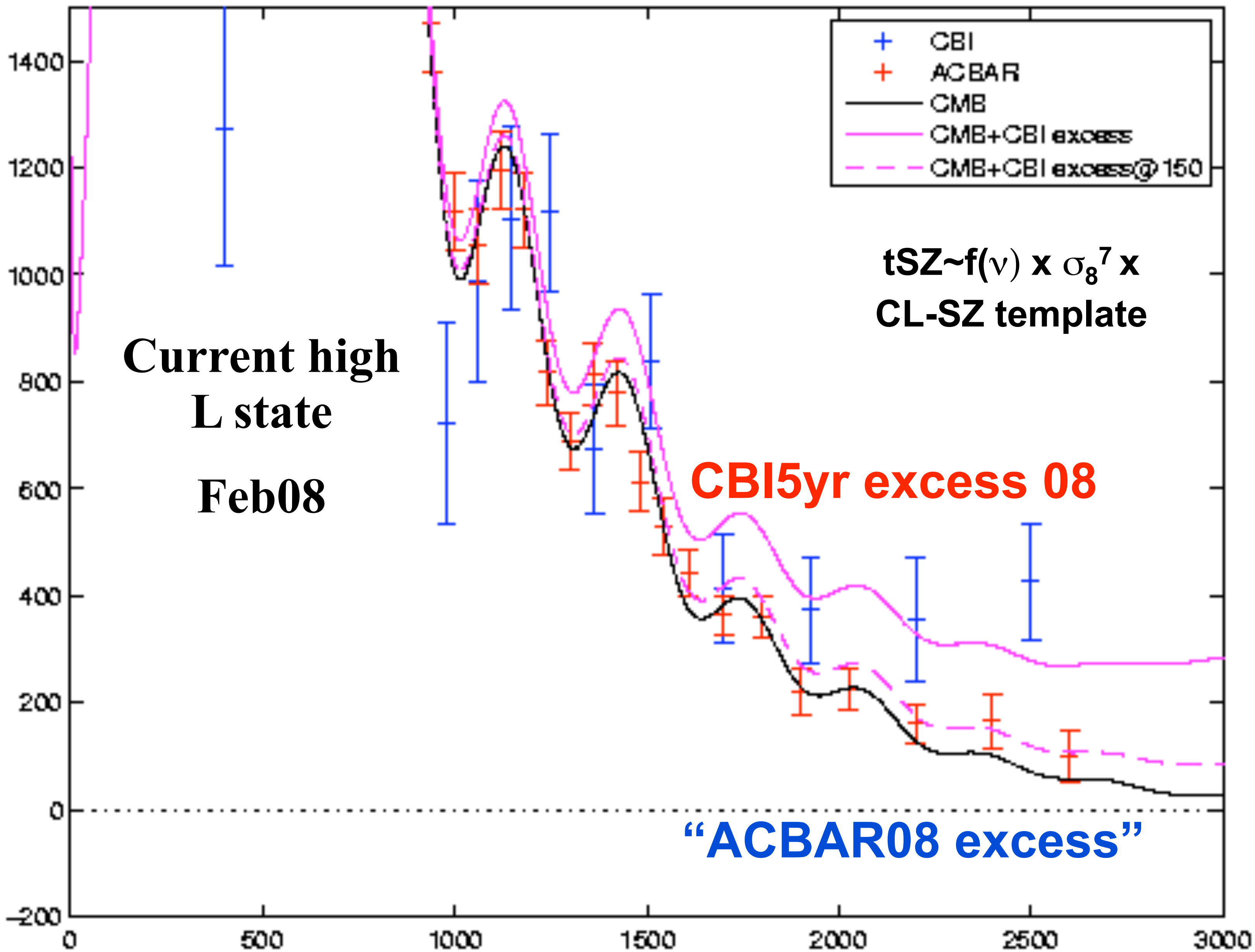




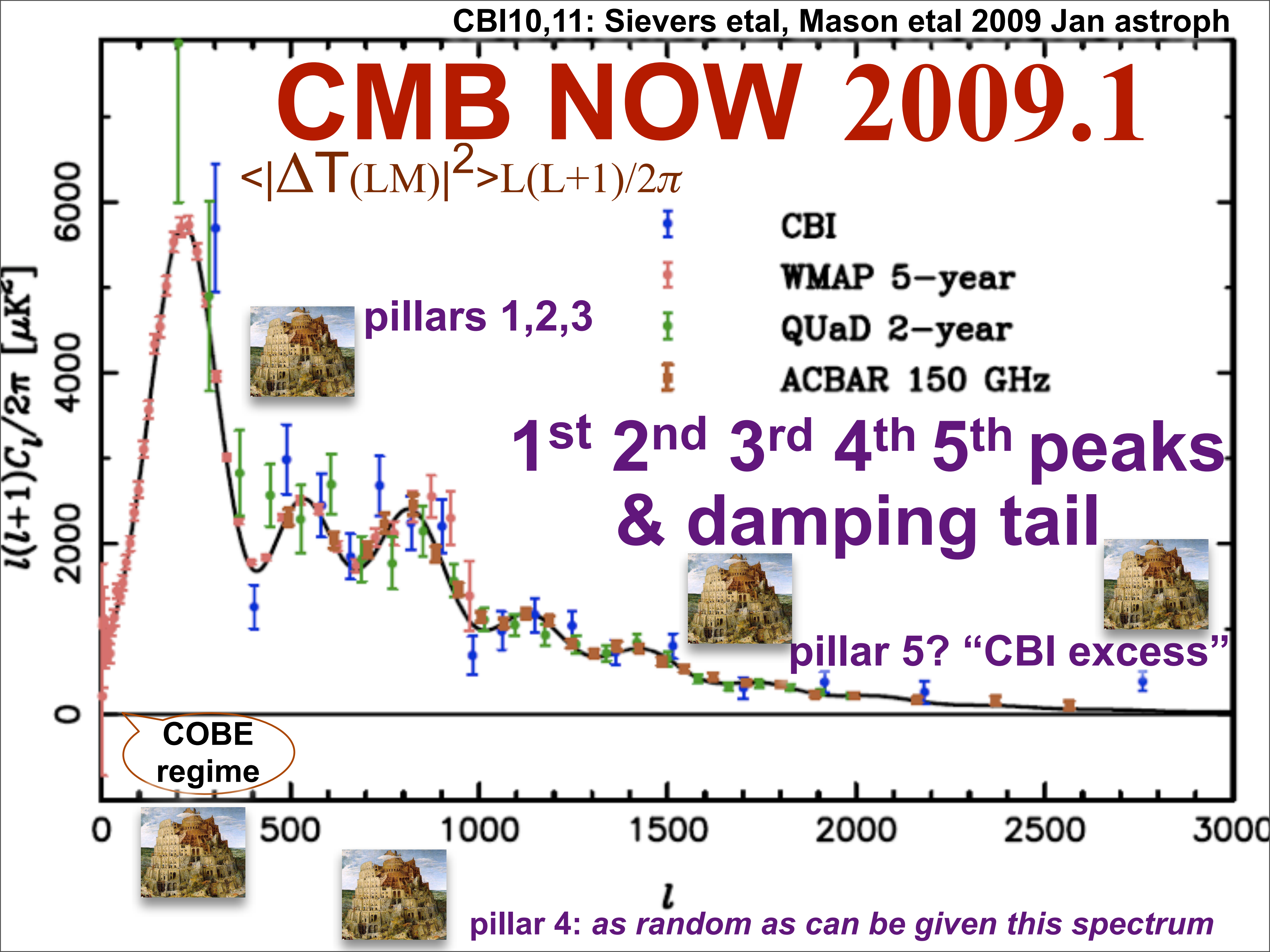
3rd & 4th & 5th peaks, brilliant damping tail

ACBAR excess > 2000, 1.7sigma consistent with CBI excess (tSZ), but could be enhanced sub-mm sources @150 GHz *(now 0.6sigma)*

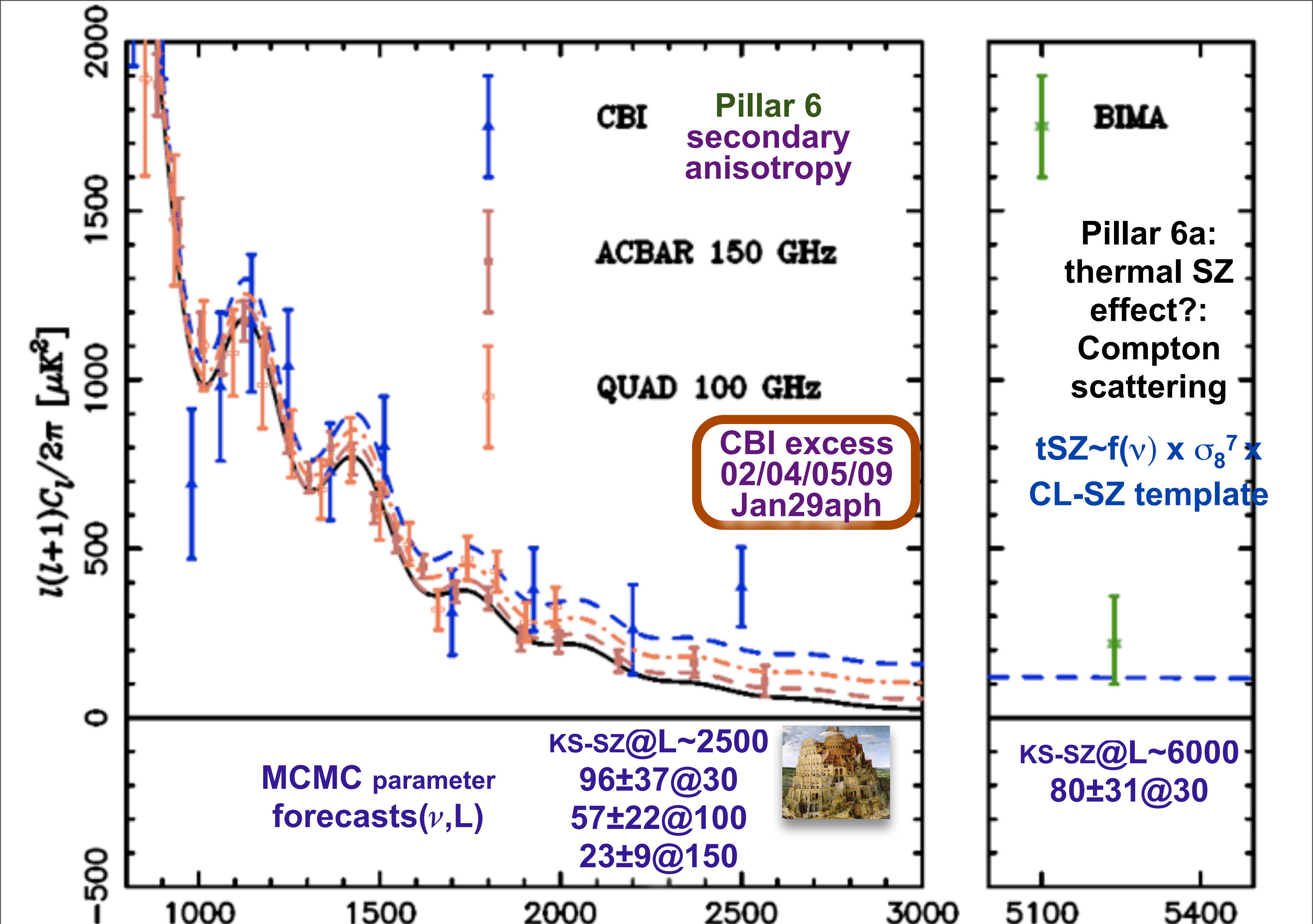
CIAR CITA ICAT



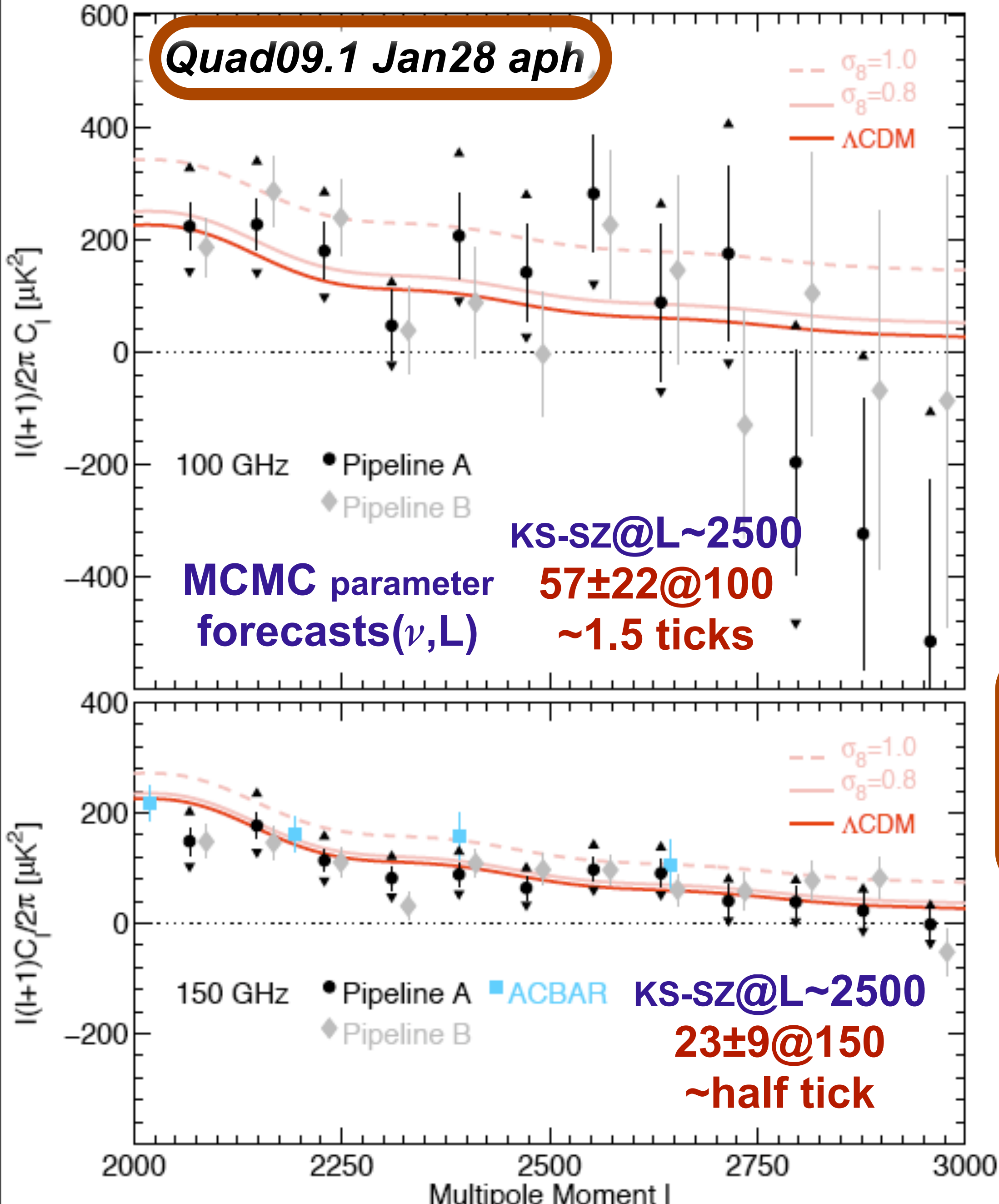
marginalization critical to get n_s & dn_s /dlnk; tSZ, radio, submm sources



CBI10,11: Sievers etal, Mason etal 2009 Jan astroph
CMB NOW 2009.1
<|ΔT(LM)|^2>L(L+1)/2π
CBI
WMAP 5-year
QUaD 2-year
ACBAR 150 GHz
pillars 1,2,3
1st 2nd 3rd 4th 5th peaks
& damping tail
pillar 5? “CBI excess”
COBE regime
pillar 4: as random as can be given this spectrum
l(l+1)C_l/2π [μK^2]
l
0
2000
4000
6000
0
500
1000
1500
2000
2500
3000



09Jan29 aph SZA@L~4066 60+65-55@30 ⇒ 34±60 cf. 92±35@30 KS-SZ@L~4000



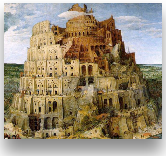
Pillar 6
secondary anisotropy

CBI excess
02/04/05/09.1

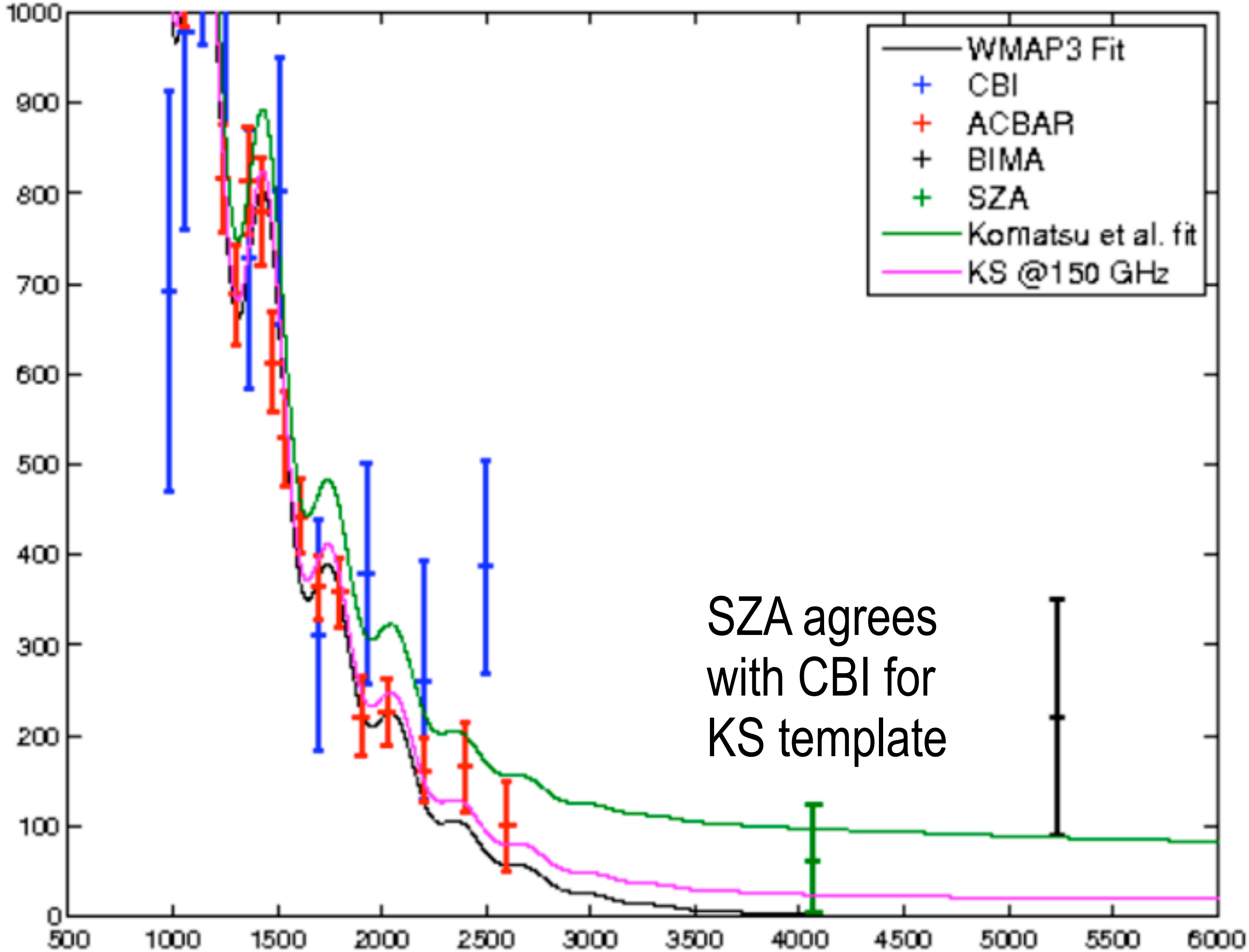
Pillar 6a: thermal SZ effect?: Compton scattering

tSZ~f(ν) x σ_8^7 x CL-SZ template

Conclude: QuAD is consistent with the SZ-frequency-scaled CBI excess



CBI+ACBAR+BIMA+SZA April 2009



CITA SZ with feedback: Battaglia, Bond, Pfrommer & Sievers 2009

Oct 2007 decided to embark on large treePM-sph sims (>700^3 gas + dark matter with cooling + SN feedback + winds + CRs)

because of core overcooling and overproduction of stars, we decided to wait for a subgrid model of AGN feedback in cluster cores, to be calibrated by extrapolating the (small mass) cluster-BH calculations of Sijacki (with Springel, Pfrommer, ...).

full Sijacki-resolution was/is ~ infeasible for single massive clusters, and certainly strongly infeasible for big-box statistically useful samples, hence subgrid.

it is just an exploratory BH model in any case.

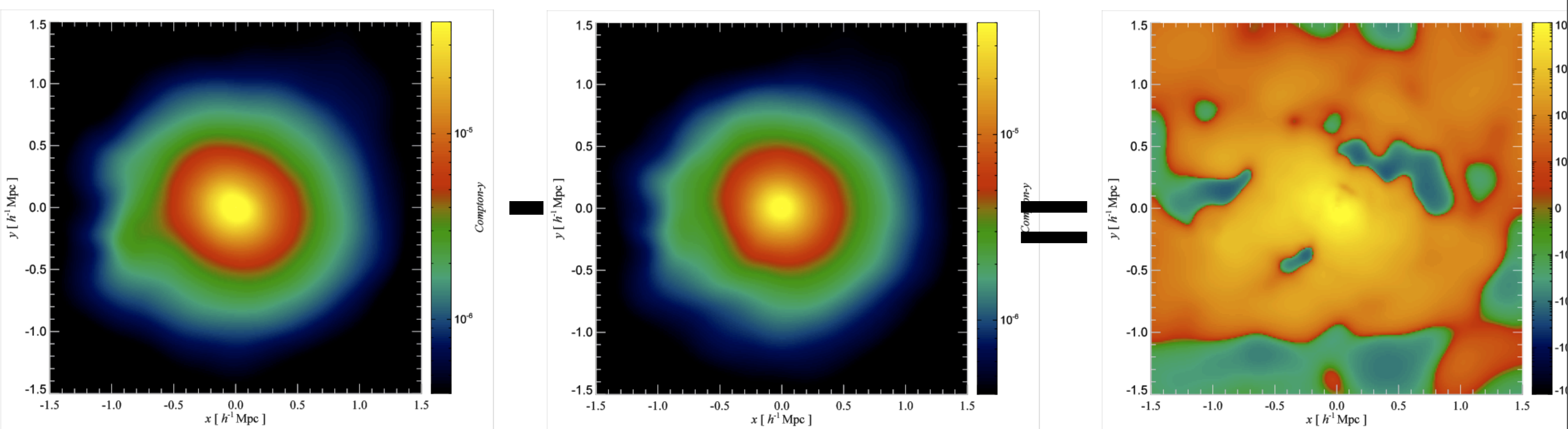
conclusion in 2009 is **silly us:** there will be no universal panacea to cure all cluster cores: episodic and cluster-history-dependent, if observables are overly sensitive to this, then we become gastrophysical weather reporters and not cosmological gold-sample miners delivering parameter purity.

with ACT (+SPT), it is now urgent to show the range of C_L^{SZ} as effects are added, plausible and implausible.

so far, adiabatic-shock heat; cool+SN E; cool + SN E + winds; cool + SN E + winds + CRs from cluster shocks

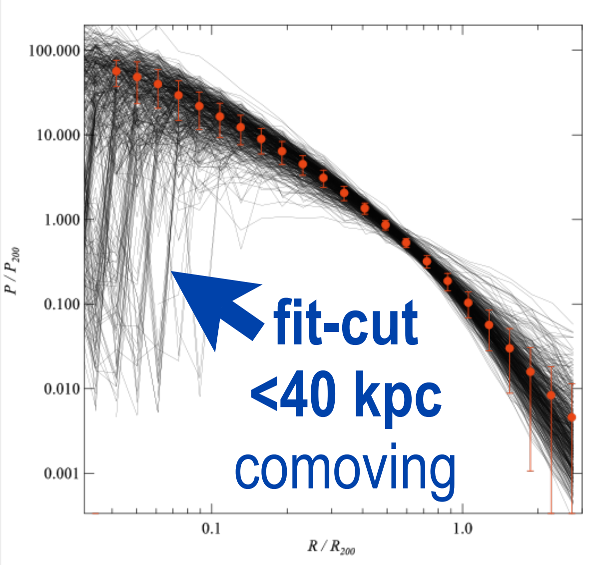
CITA SZ with feedback: Battaglia, Bond, Pfrommer & Sievers 2009

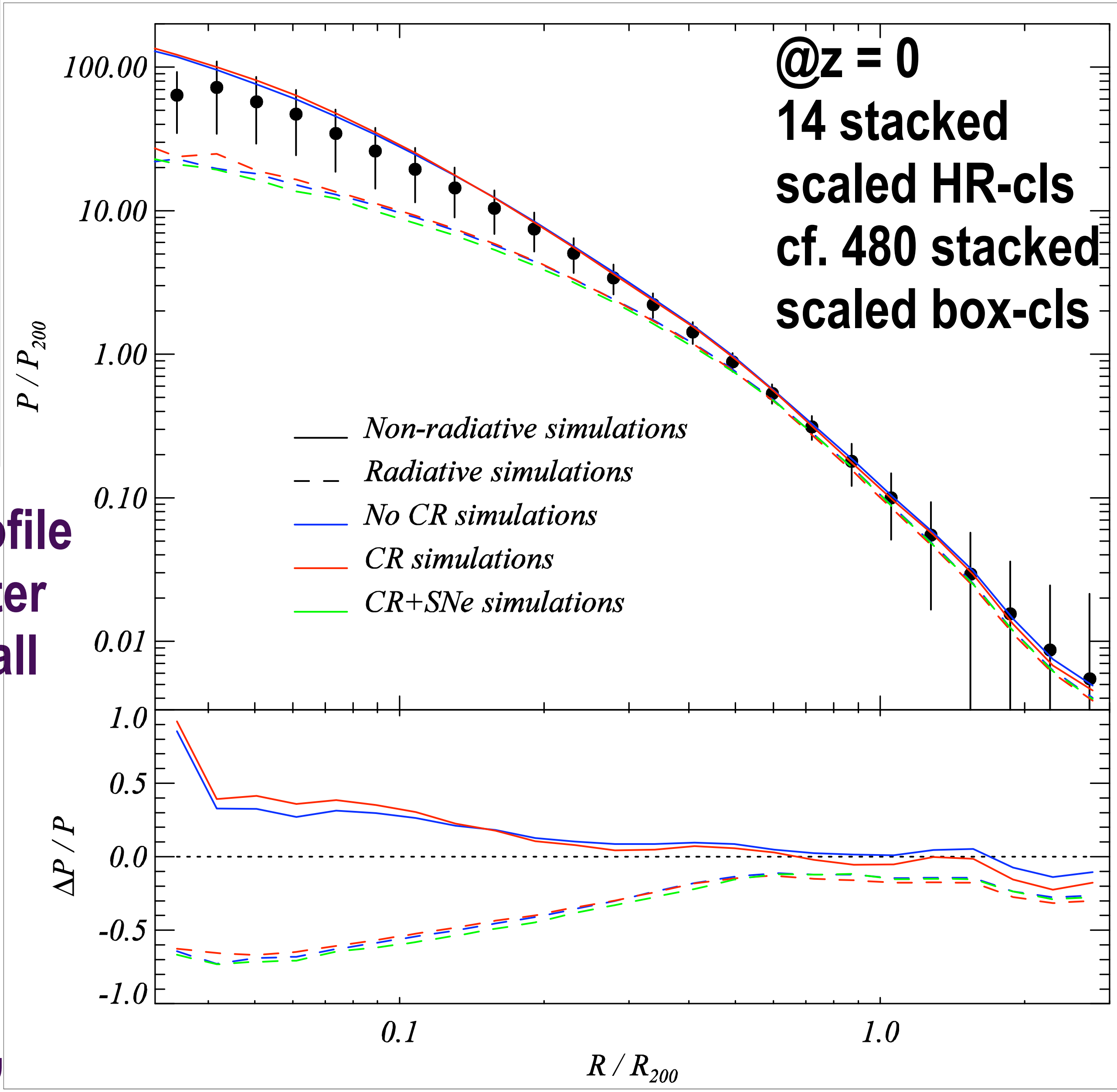
strategy: hi res single cluster sims, 14 cls so far, but really many more as pre-merge cl-subunits at higher redshift
+ many (!) large 512^3 box sims for stats **(256^3 workhorse so far & even 128^3 checks)**
instead of rotate and translate a single periodic box at various redshifts to tile $0<z<2$, with bad correlations built in, stack sphericalized cluster pressure profiles and use with cluster abundances to get C_L^{SZ}



adiabatic, except for shock heating

radiative cool + SN energy + winds + CRs from cluster shocks



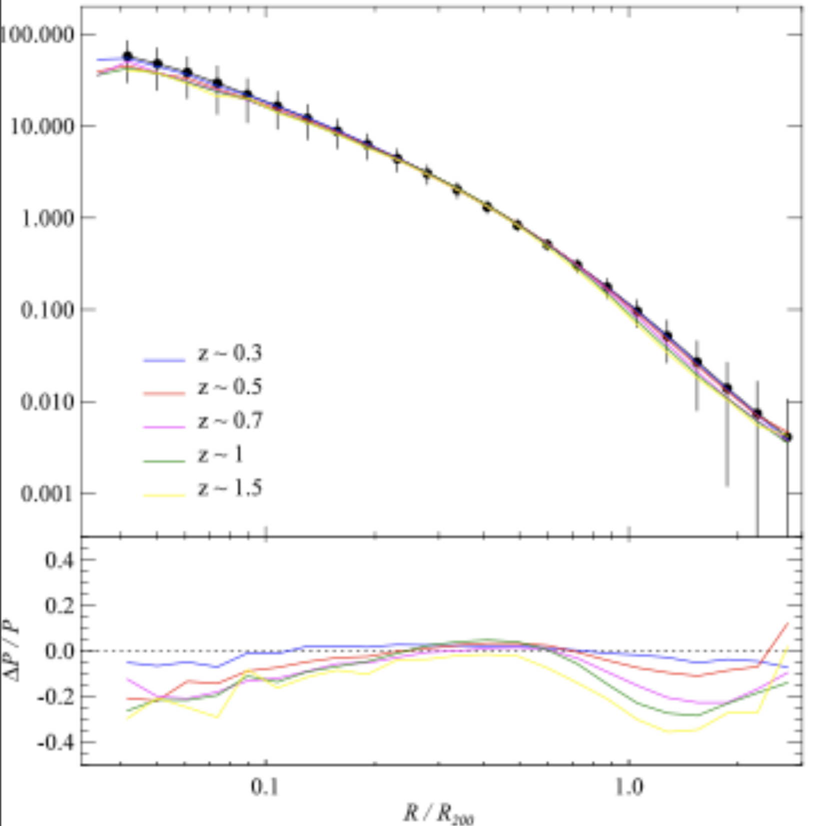


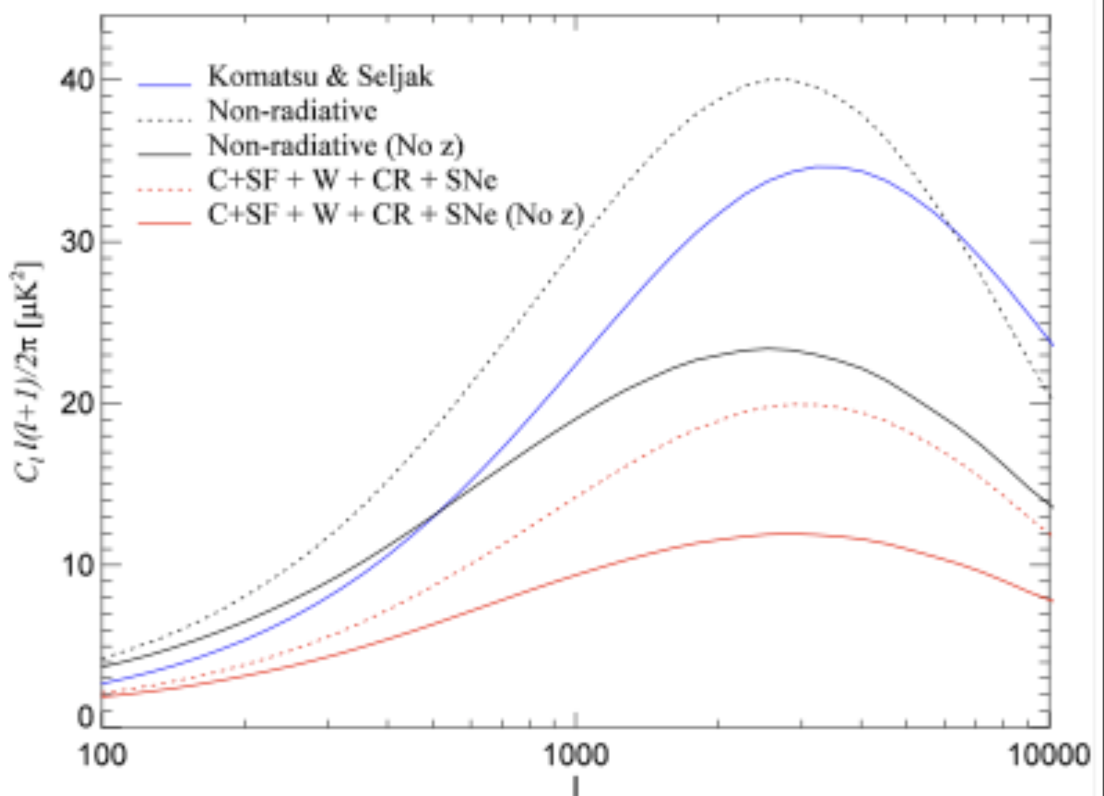
universal modified β-profile fits all cases much better than expected, and at all relevant redshifts

$$p(r)V_{norm} = [PV]\,(1+r/r_c)^{-3\beta}$$

$$Y(z) \propto PV,\ \beta(z),\ c_g(z) = r_{200}/r_c$$

z-independence of p-scaled vs. r-scaled $\oplus$ **$Y(z)$, $\beta(z)$, $c_g(z) = r_{200}/r_c$** $\Rightarrow$ impact on $\mathbf{C_L^{SZ}}$





The SZ & cluster frontier

high/low σ_8 **issue will be resolved (soon: ACT/SPT, Planck)**

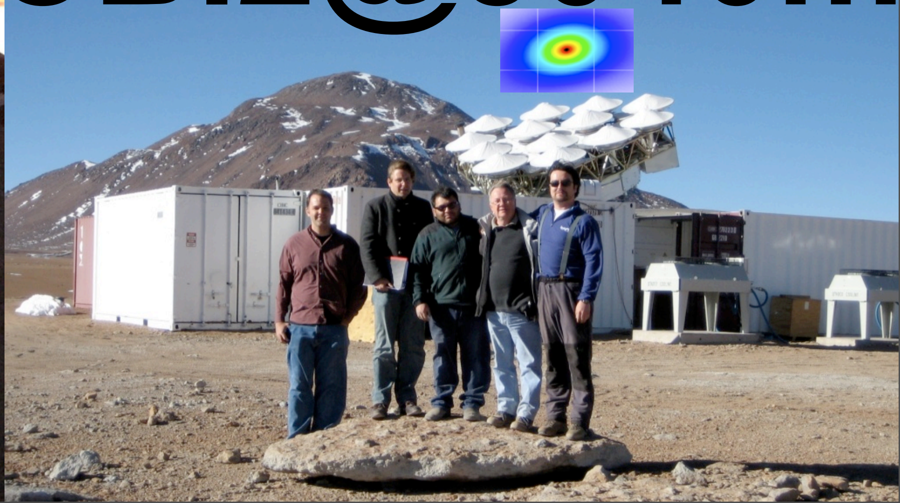
but non-equilibrium, non-thermal cluster complexities (*e.g.*, cosmic ray pressure, merging, inhomogeneous entropy injection, cooling flow avoidance, AGN feedback) must be fully addressed for high precision on other parameters to be realized. Improved theoretical CL templates and better development of non-Gaussian probes are essential in conjunction with theory & observations of

SZ at varying resolution + optical + gravitational lens + X-ray + embedded IR/radio source observations +..

ACT@5170m

why Atacama? driest desert in the world. thus: cbi, toco, apex, asti, act, alma, quiet, clover

CBI2@5040m



end