Title: The Power of Sunyaev-Zeldovich, Then and Now

Date: Apr 28, 2009 09:00 AM

URL: http://pirsa.org/09040039

Abstract: This talk will describe the theoretical history "THEN" of CITA's semi-analytic and simulation forecasts of the "ambient" (aka blank field) SZ effect, from the beginnings in the mid-80s to the "NOW" and near future of copious ACT and SPT ambient-SZ cluster detections, Along the way, we will recall the simulation and analytic state of SZ analysis of the CBI excess power in 2002 (and 2008) and the impact of ACBAR and BIMA on the results, now punctuated by recent QuAD and SZA releases, NOW the ACT, SPT and Planck pressure of high precision imminence in SZ is re-focussing us on pressure uncertainties in SZ power and maps from energy feedback, non-equilibrium and non-thermal processes, and cluster core complications as a function of redshift with large simulations. CITA's gassy-sim theoretical approach to this problem will be described, along with a conclusion that high resolution SZ and other observations must be our guide.

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Dick Bond

CIAR

the Power in Sunyaev & Zeldovich, then & now

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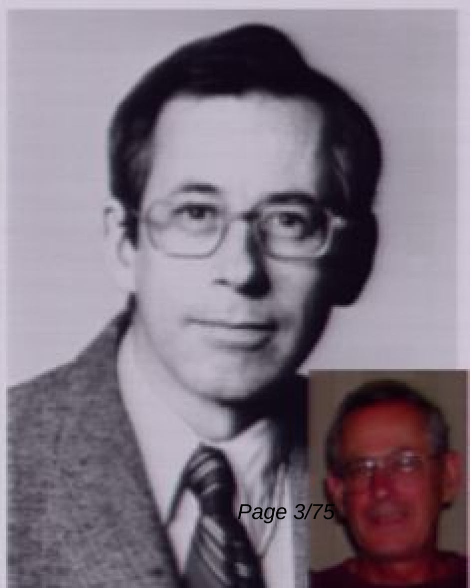
Dick Bond CIAR

the Power in Sunyaev & Zeldovich, then & now

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



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

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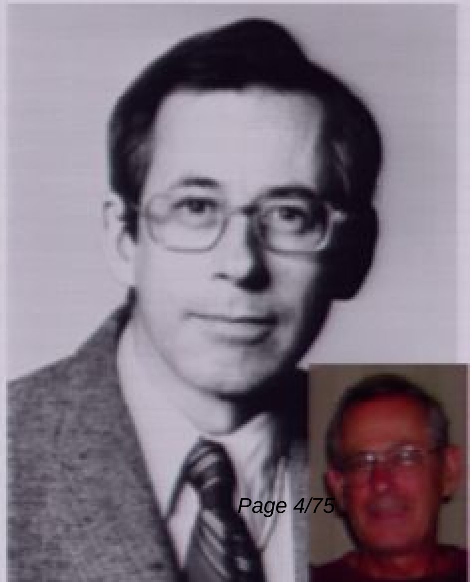

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e expts: **CBI, ACBAR to L~2500+, BIMA ~6000, Quad to 2000+, Planck ~ 2000, SZA ~ 000, APEX, ACT & SPT to ~10000, eventually SPTpol and ACTpol.** *+ high res follow-ups BT, SZI, ALMA, CCAT, ...*

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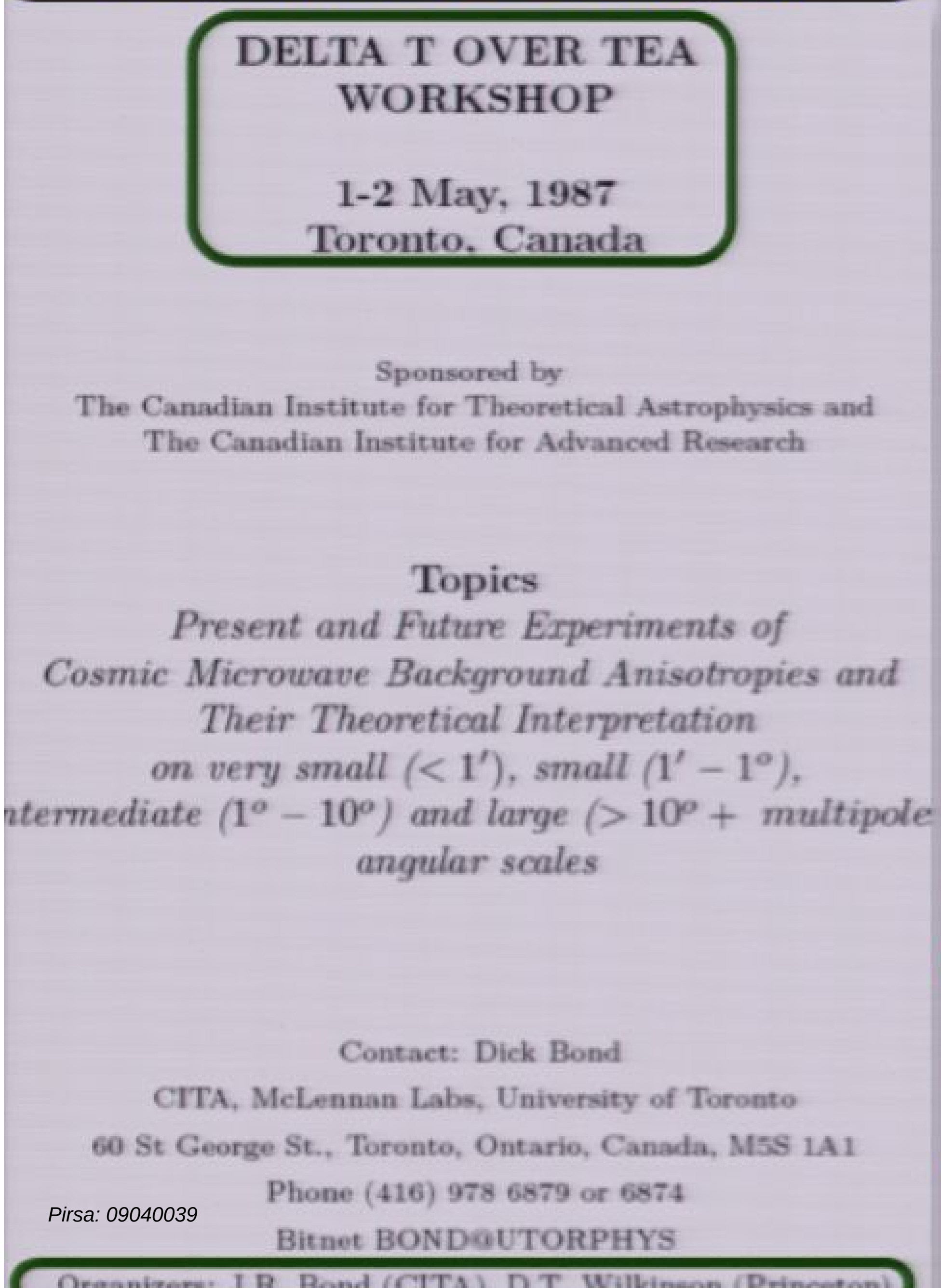
first dedicated CMB conference, exptalists + theorists, primary+secondary $\Delta T/T$



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
Fomalont, 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
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

Dave Wilkinson

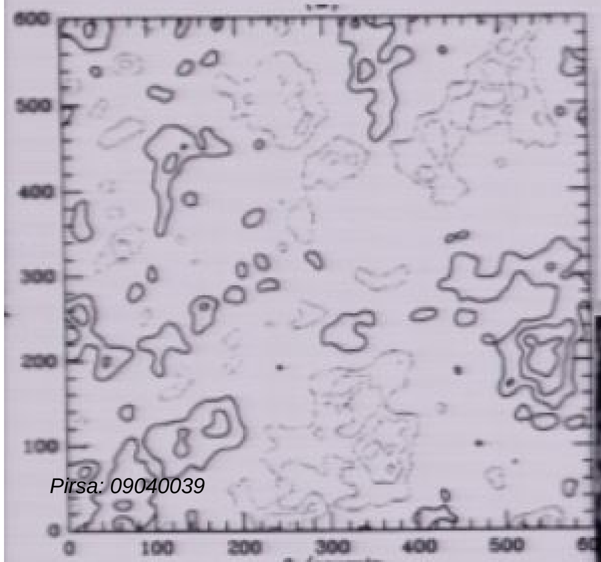
Rashid Sunyaev

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

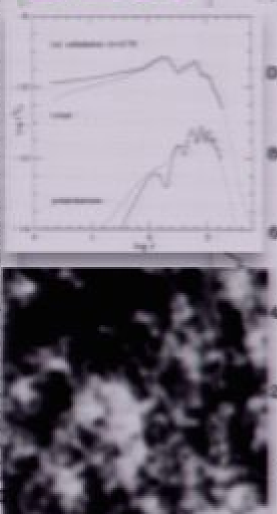
Primary Cosmic Microwave Background Radiation ~ a statistically isotropic all-sky GRF on the 2-sphere $C_L = \langle|\Delta T_{(LM)}|^2\rangle$ *with target* C_L *shapes*

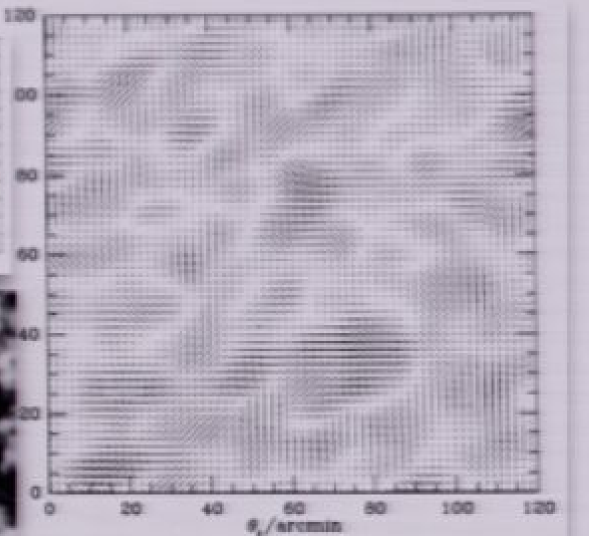
A tentative list of topics organized according to angular scale, with theory and observation intertwined, is:

- 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.

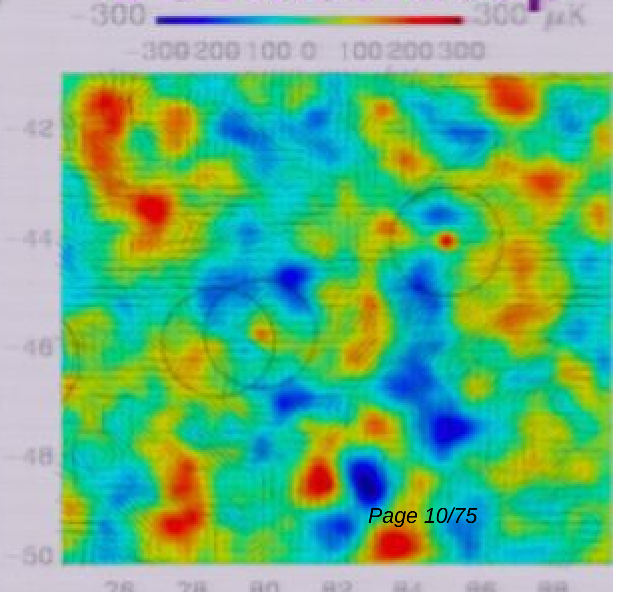


BE87

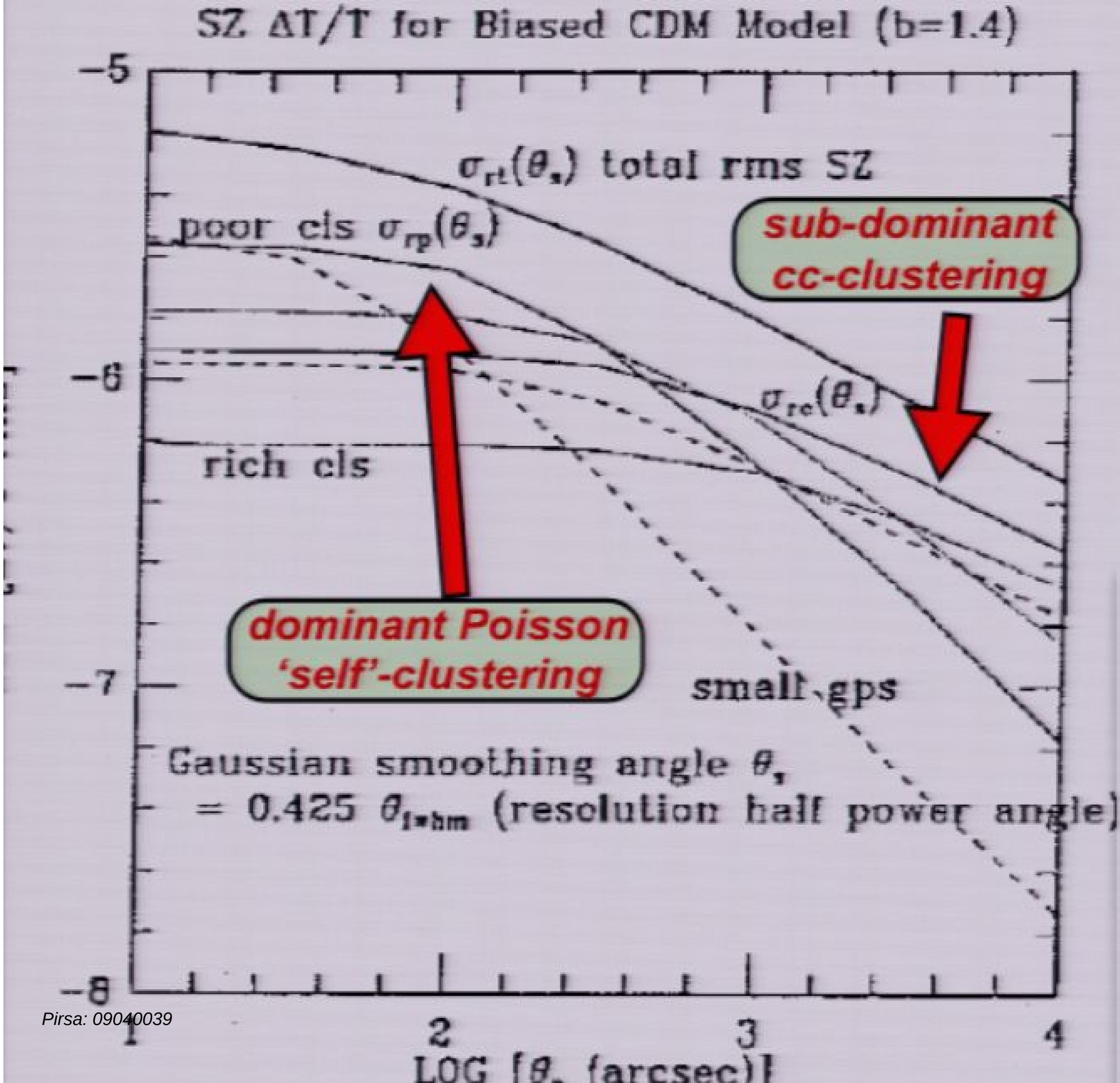




Boom05 deep



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



sub-dominant cc-clustering

dominant Poisson 'self'-clustering

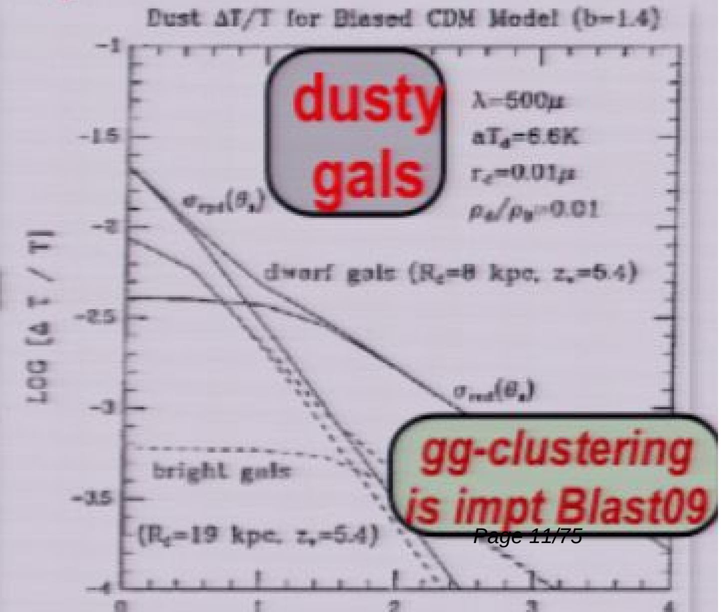
bond@ ΔT/Tea87:

"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



dusty gals

gg-clustering is impt Blast09

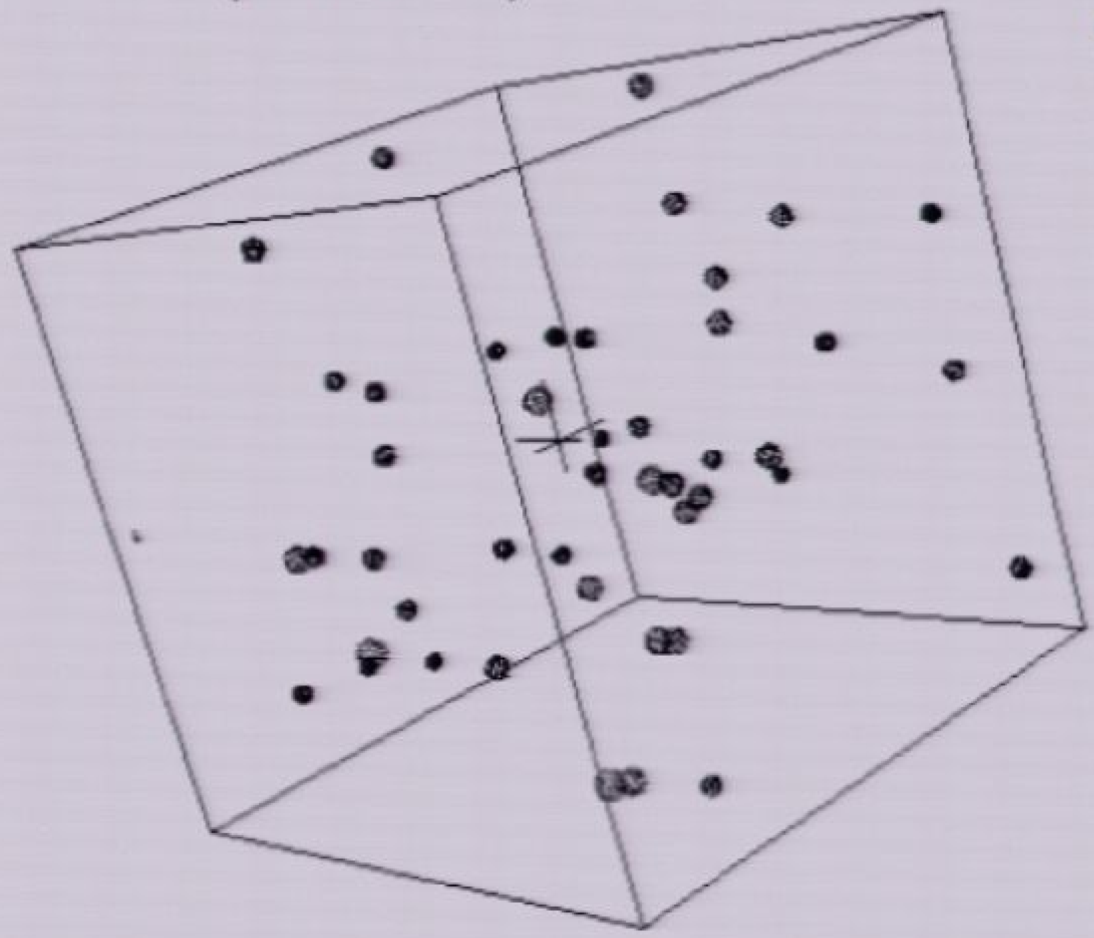
Cluster Peak Patches in Final State Space

(Eulerian)

peak patches
BM91-96

importance of tidal fields - virial mass from homogeneous ellipsoid dynamics

accurate cluster positions, masses, binding energies, clustering



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

N-body groups in Final State Space

(Eulerian)

peak patches BM91-96

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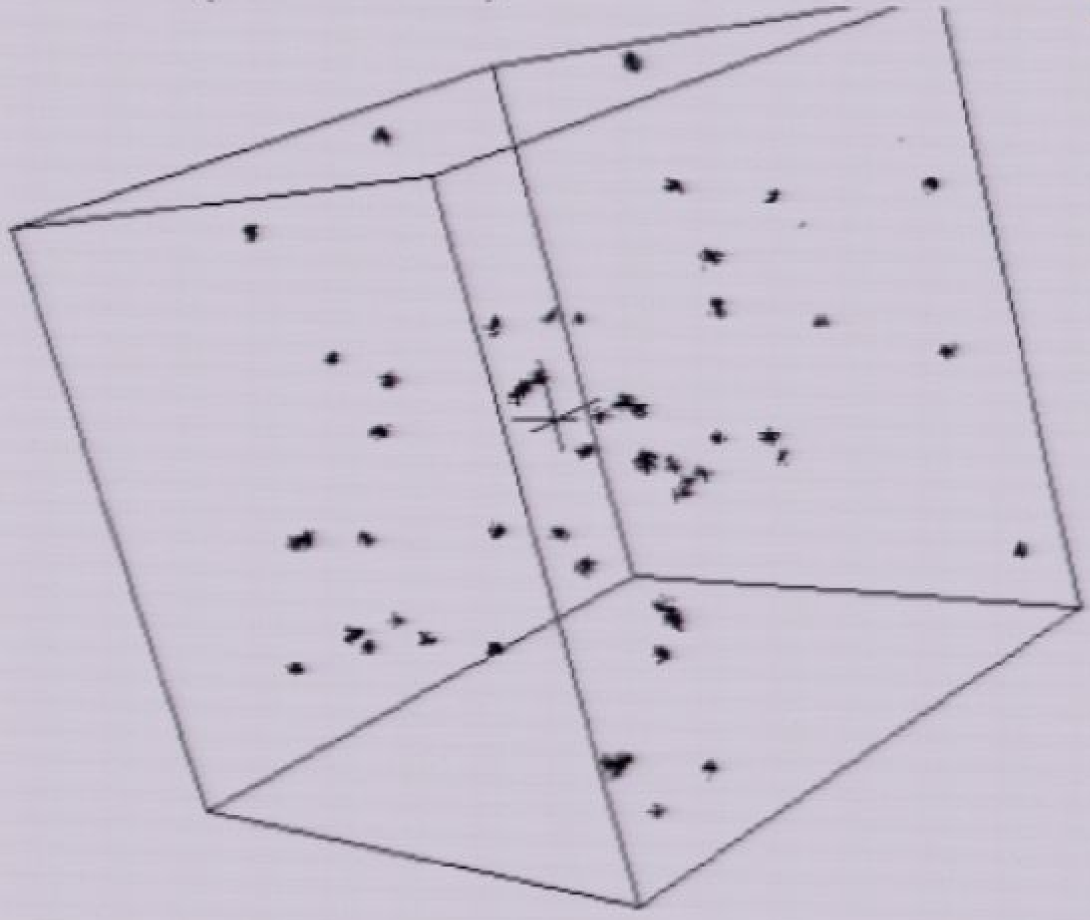

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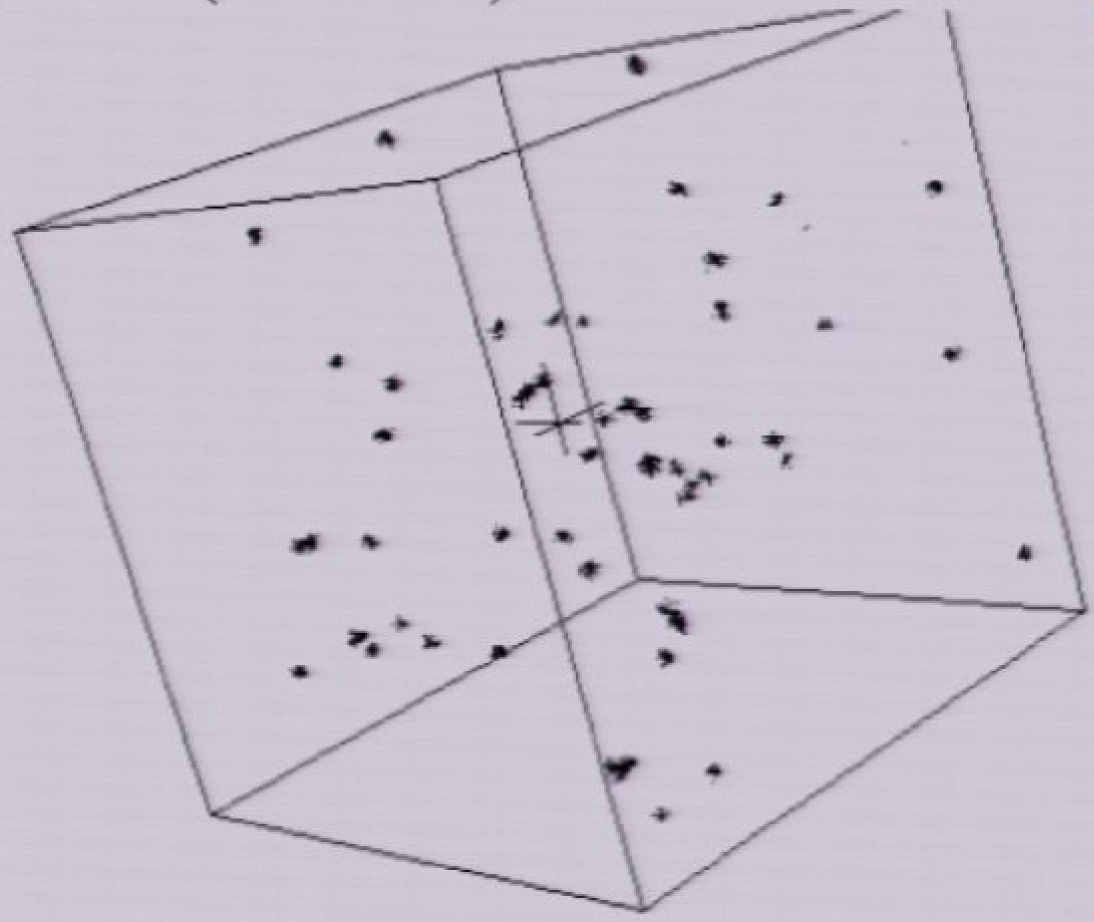

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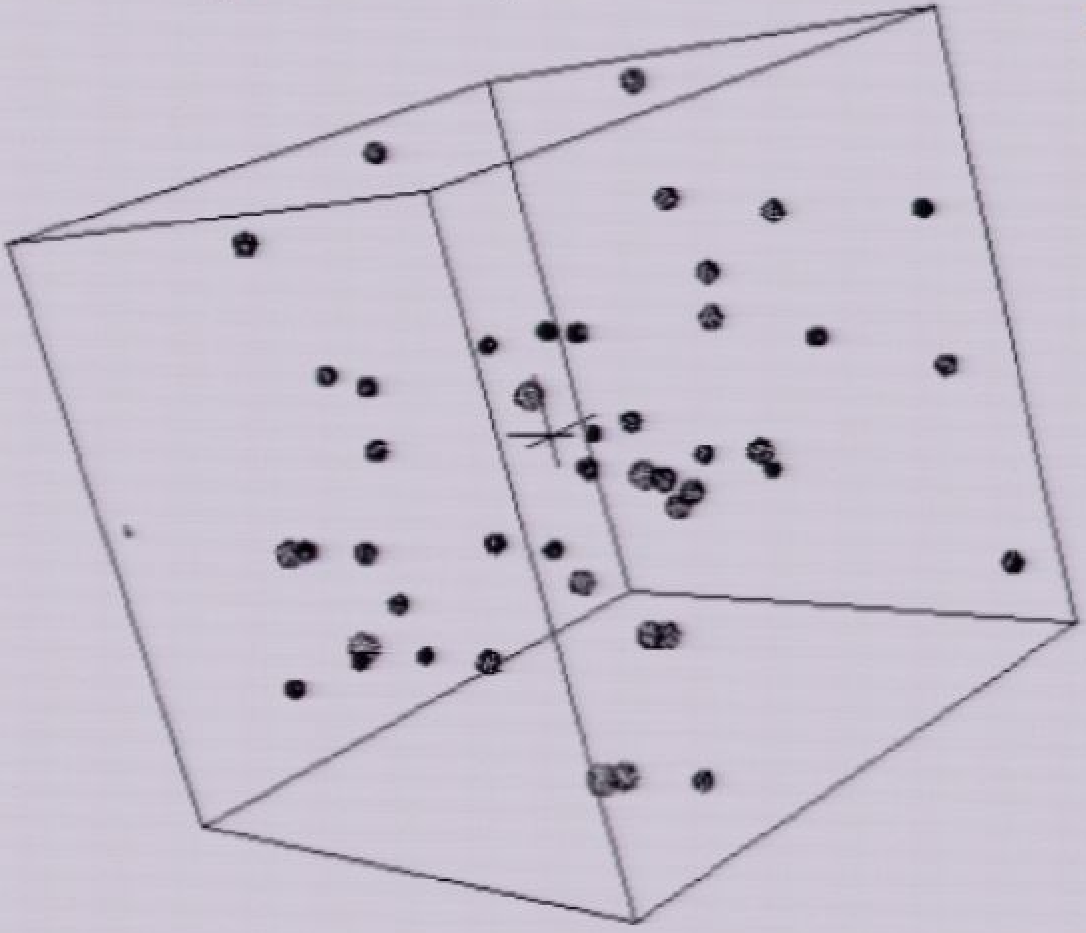

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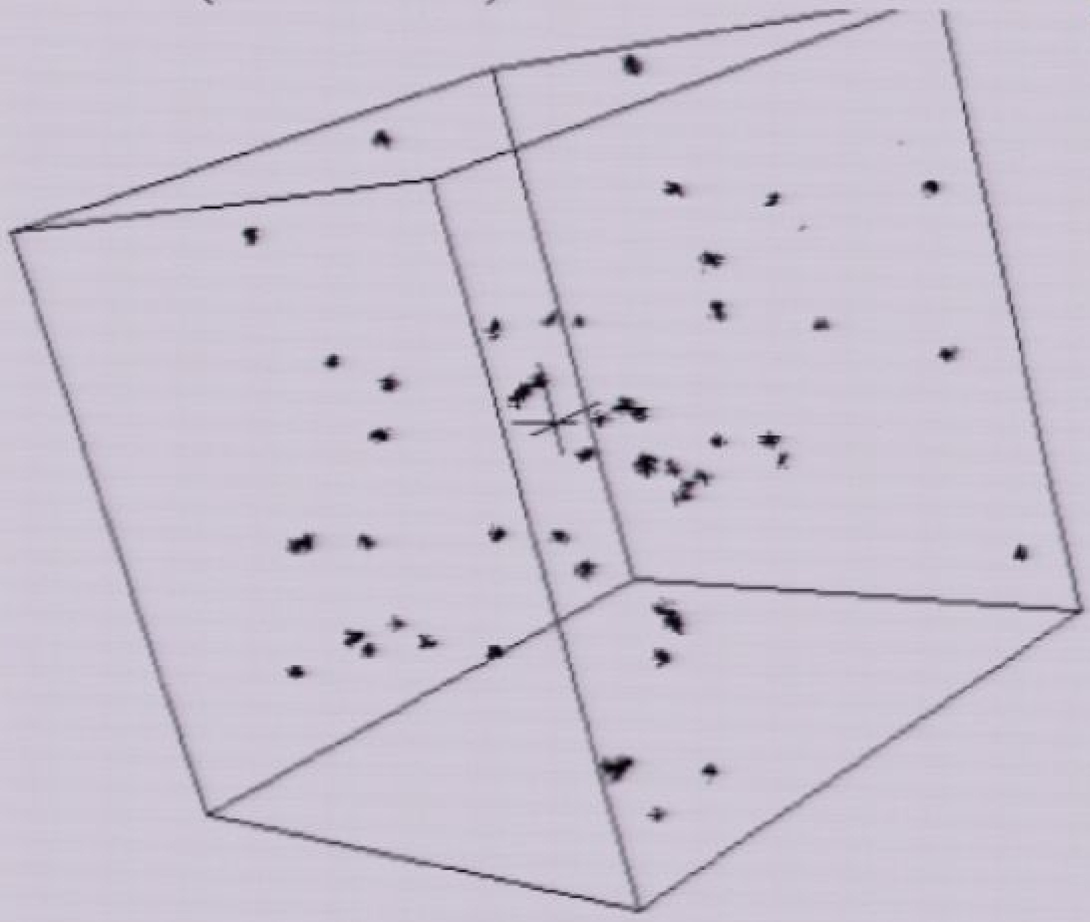

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importance of tidal fields - virial mass from homogeneous ellipsoid dynamics

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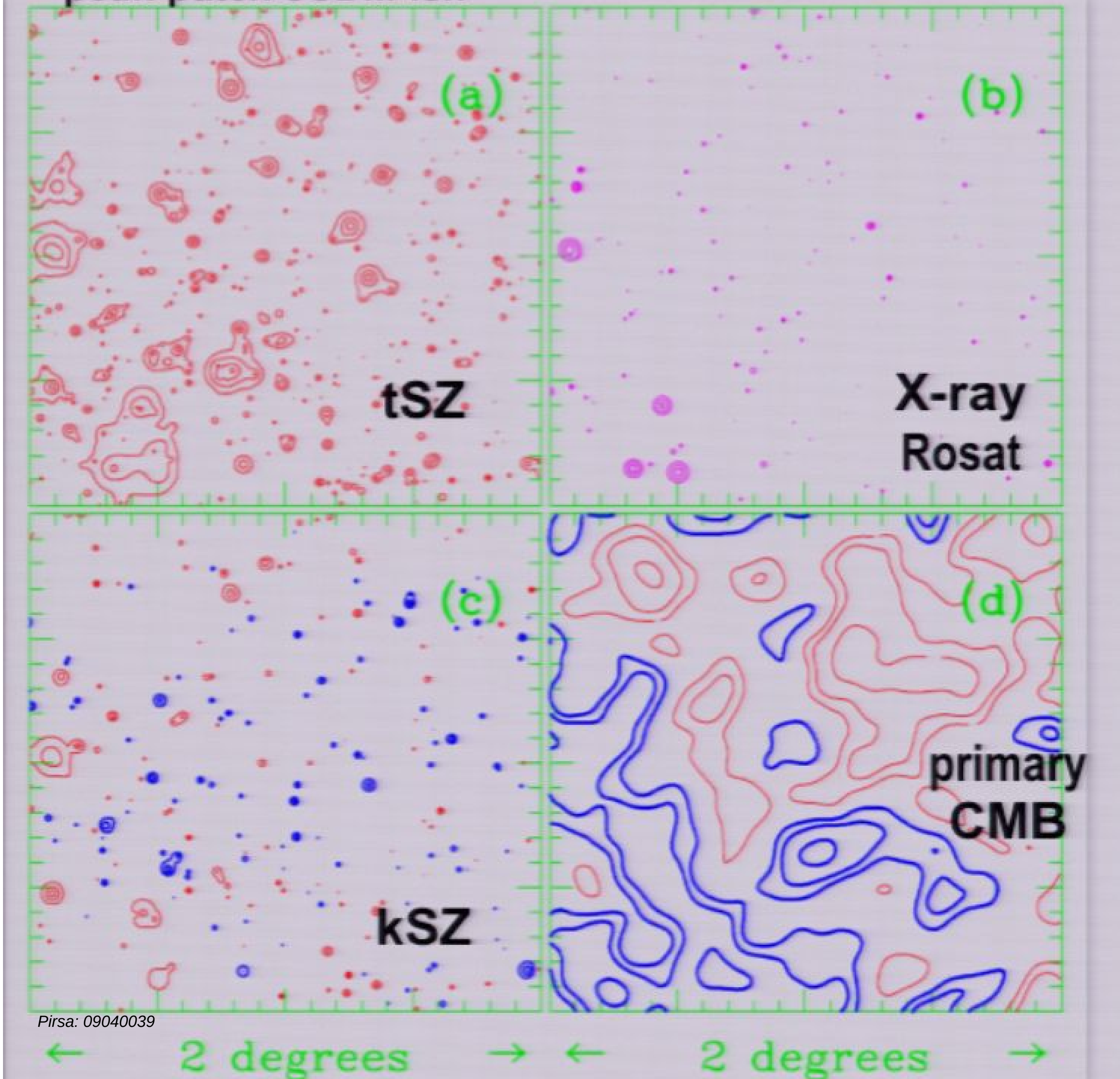
(400 Mpc)^3 simulation

peak-patch sCDM-ish



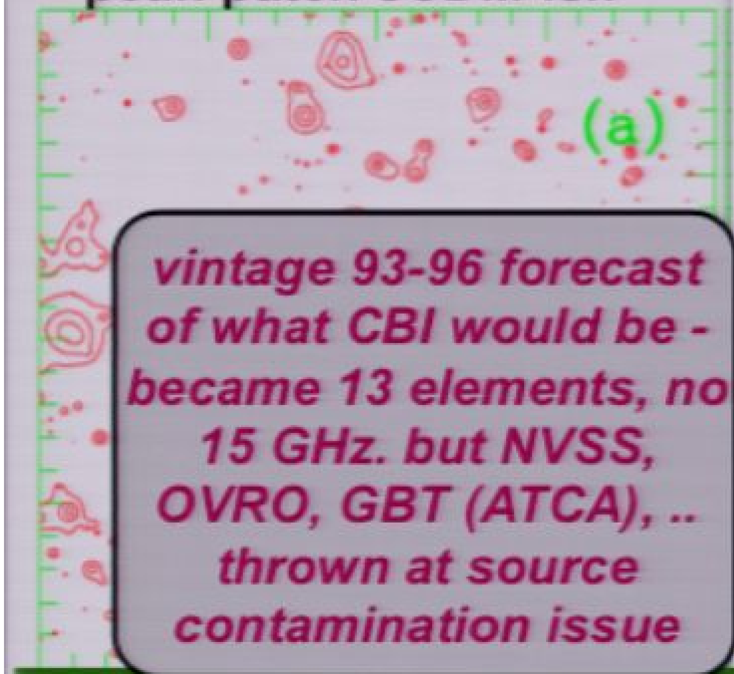
peak patches
BM91-96

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

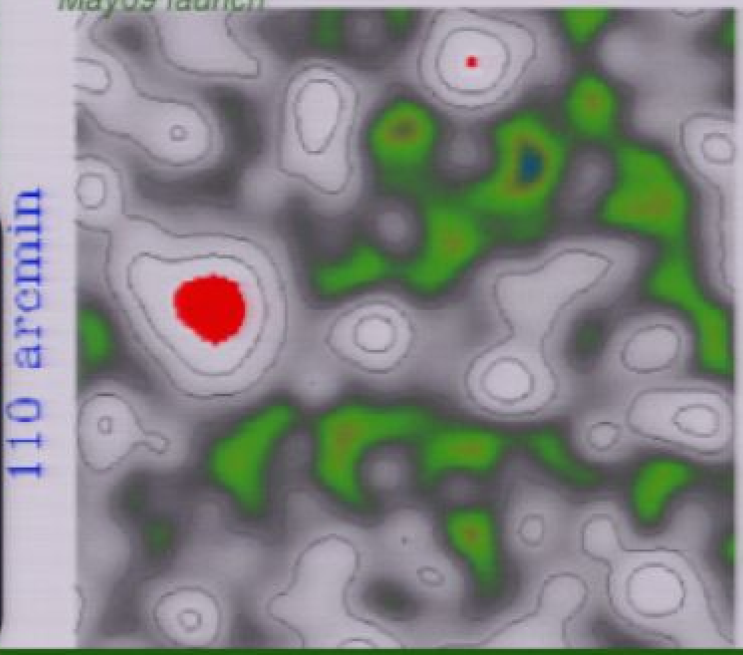
peak-patch sCDM-ish



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

Planck 6.6

May09 launch



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

from Planck

Figure 16: 2° × 2° 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

he 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

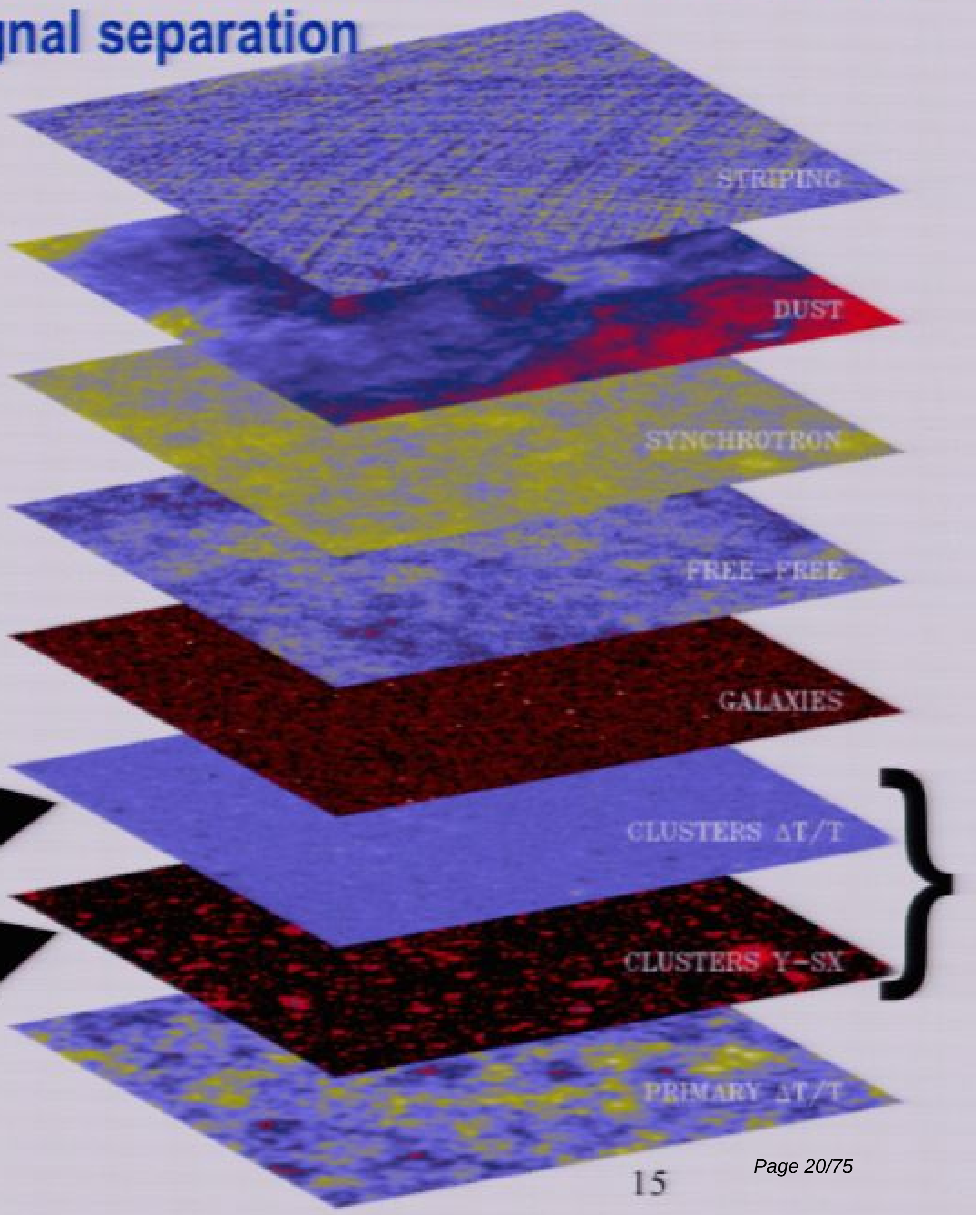
bremsstrahlung

dusty galaxies

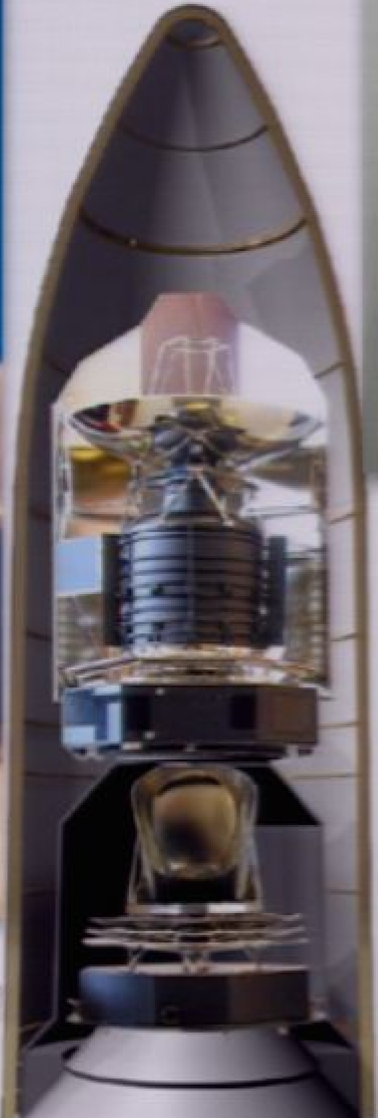
kinetic SZ

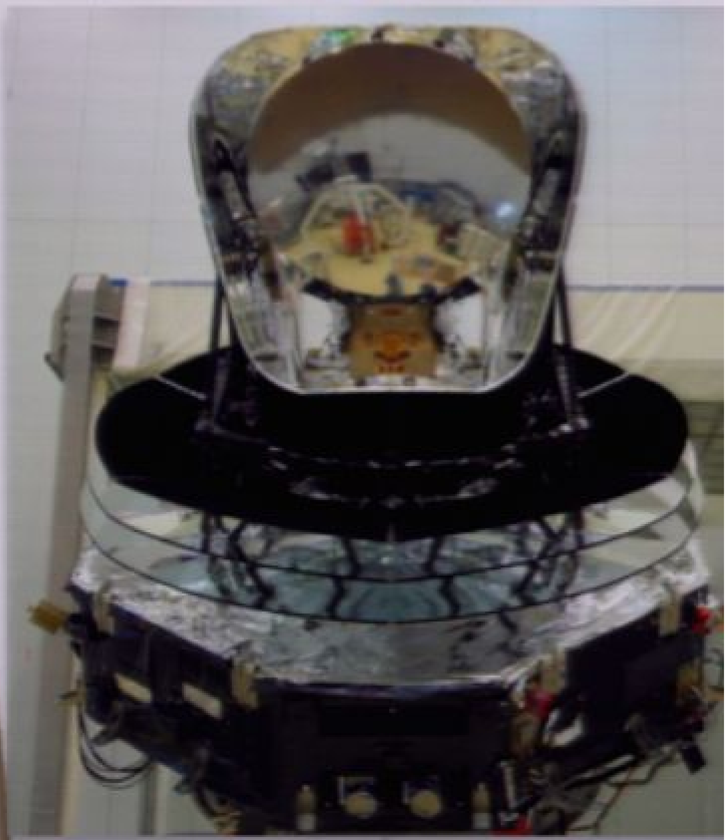
thermal SZ

PRIMARY



F.R. BOUCHET & R. GISPERT 1998





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*

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*

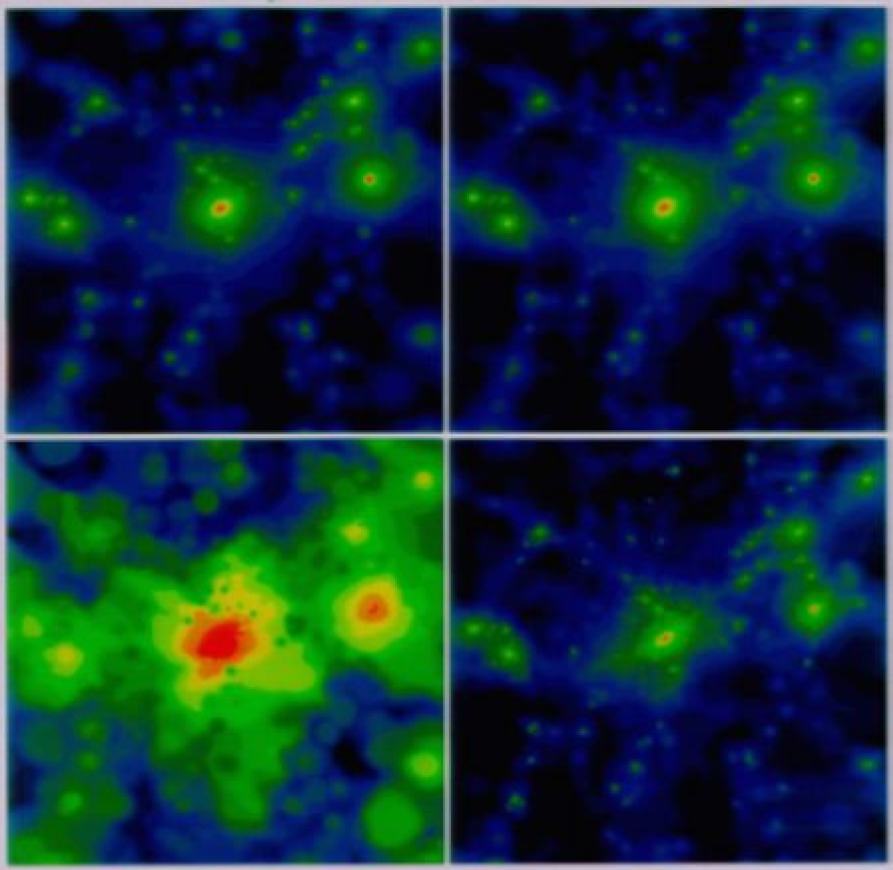
SB adiabatic cluster test *then*: ITP9

CALCULATIONS SUBMITTED

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

Coordinators: Frenk + White

← 32 Mpc →



Group	Method	CPU	machine	storage
	+treat^n	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

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 $H_0 = 50\,km\,s^{-1}$, $\Omega_b = 0.1$, $\sigma_8 = 0.65$ 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 $2\times10^{45}\,erg\,s^{-1}$, integrated out to $r_{200} = 2.7\,Mpc$. The peak temperature is $10^8\,K$.

ITP '95 CLUSTER COMPARISON

τCDM

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

$M_{cl} \approx 10^{15} M_\odot$

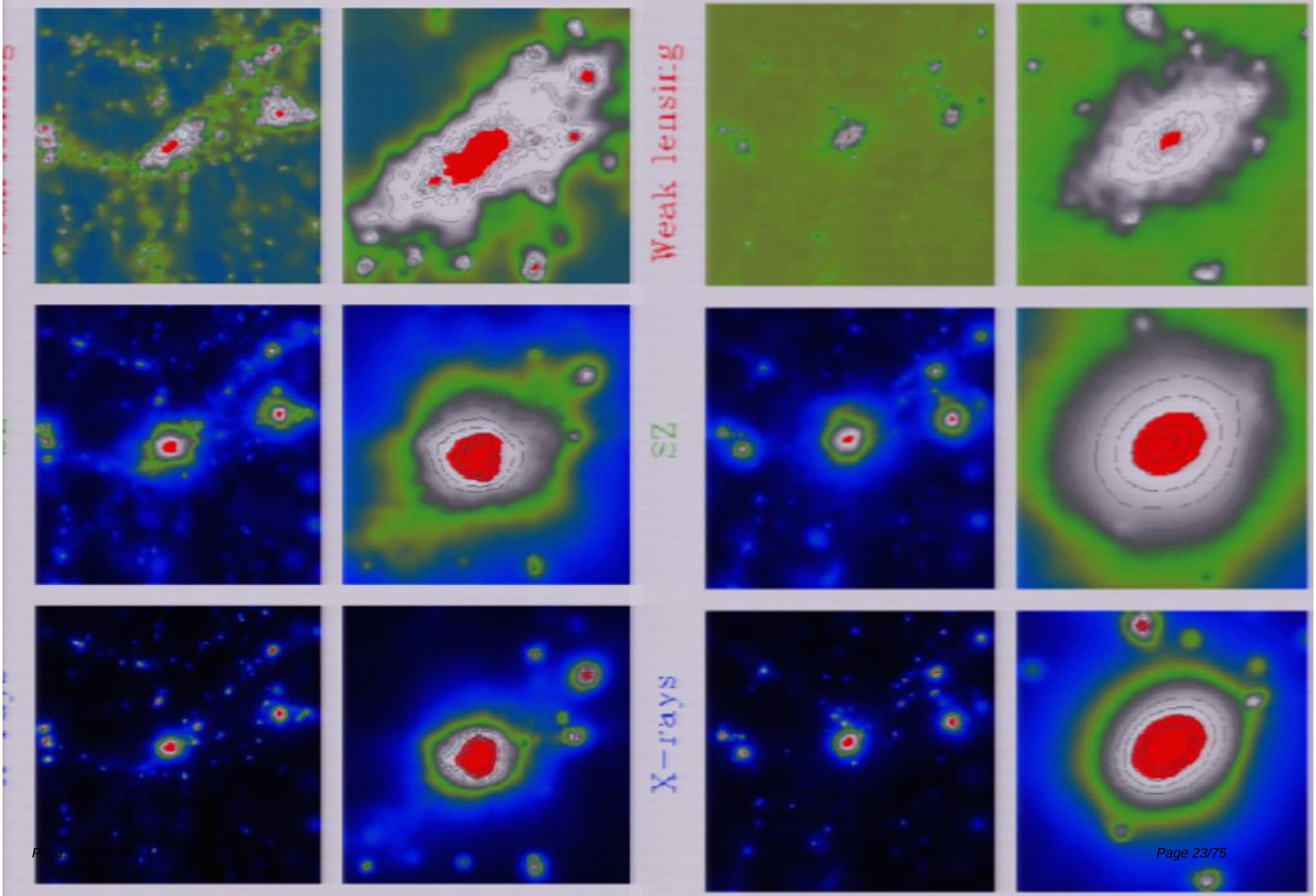
$L_x (< r_{200} = 2.7\,Mpc) = 2\times10^{45}$ erg/s

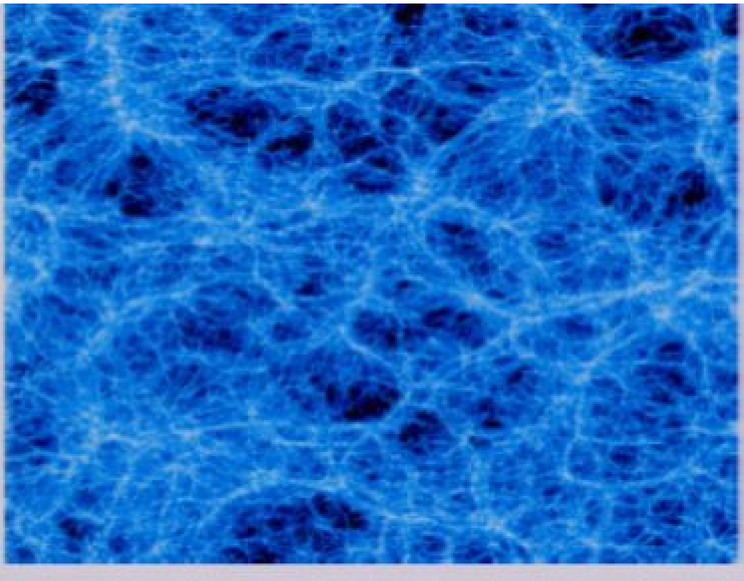
$T_{gas}|_{max} = 10^8$ K

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

Kravtsov, Marrone, Oh organizers

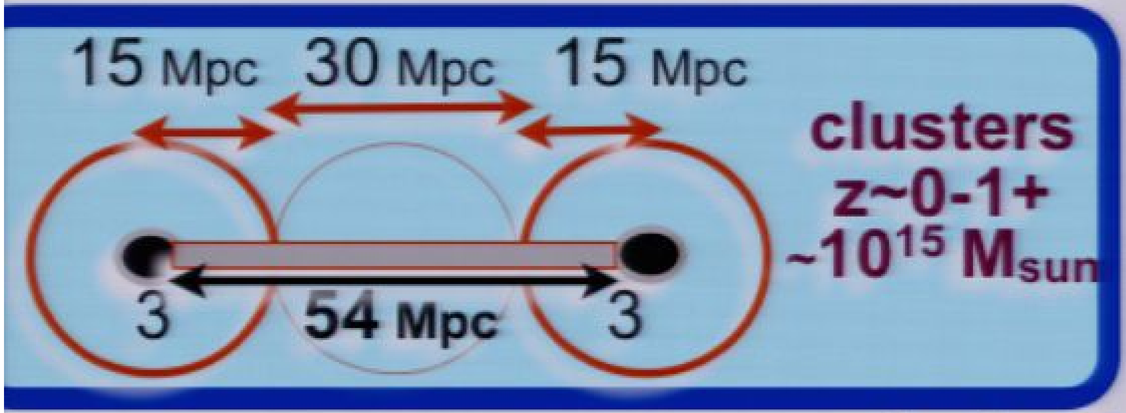
ITP95 Cluster Comparison seen in Lensing, SZ & X at z=0.5 & z~0





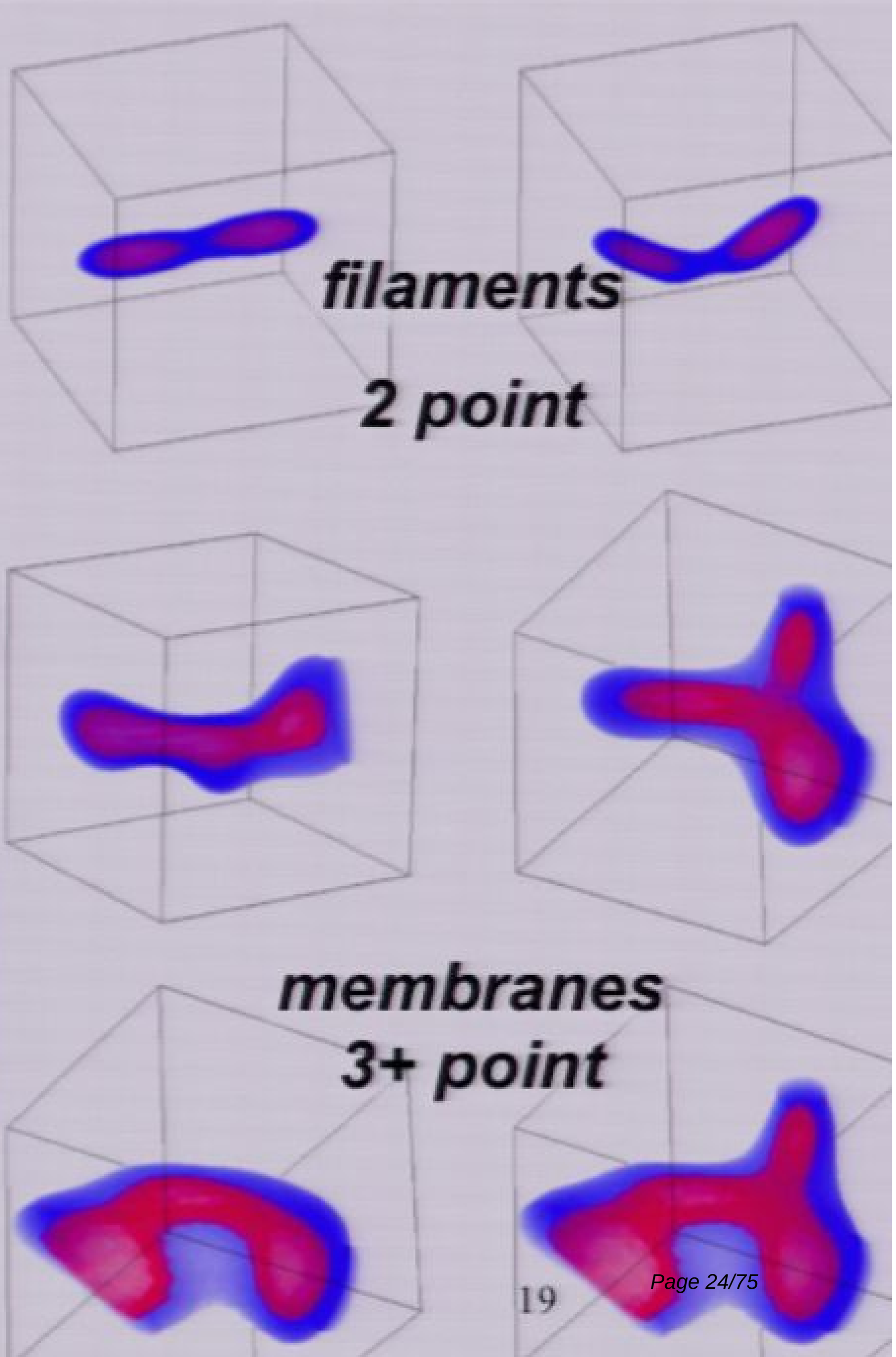
"Molecular" Picture of Filaments & Membranes in LSS

B+Kofman+Pogosyan 96-99



clusters
z~0-1+
$\sim 10^{15}$ M_{sun}

1 Mpc 2 Mpc 1 Mpc **galaxies**
3.6 Mpc **z~2-5**
$10^{11.5}$ M

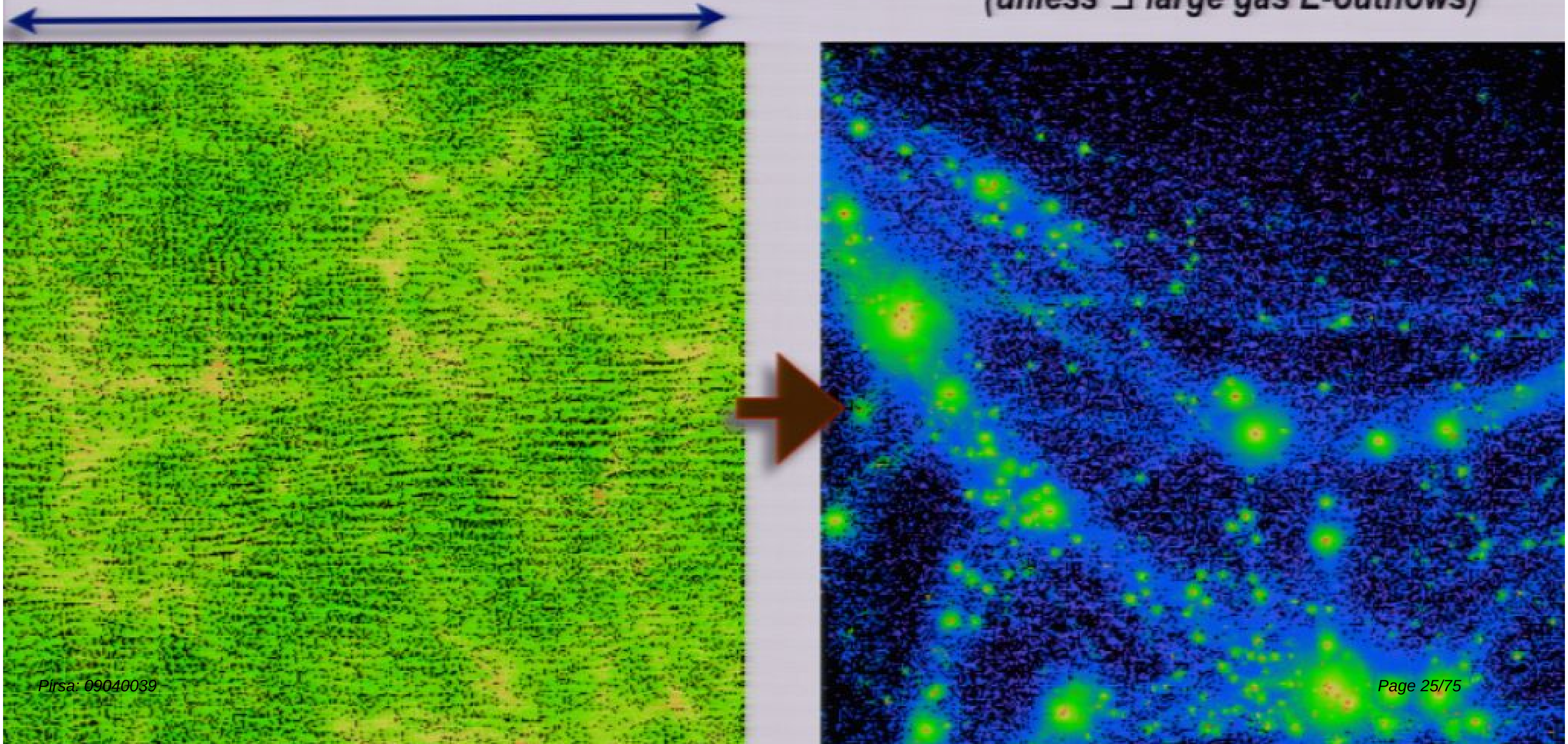


galaxy clusters: *intermittency in cosmic random fields* of mass, pressure, X-ray & optical luminosity, tides/shear (lensing) ...

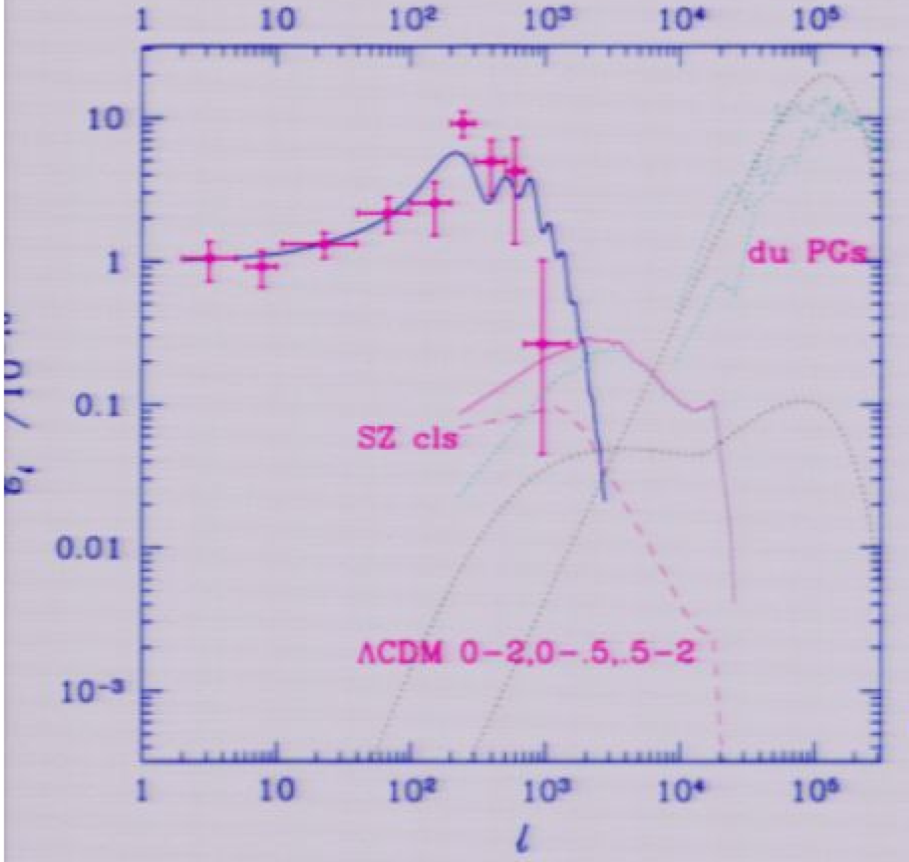
B+Kofman+Pogosyan+Wadsley 97/99

constrained supercluster treePM-SPH *sim* of ΛCDM +cooling
largest k-range of its time (>> Virgo sim)
104 Mpc HighResolution +166 MedRes +266 LoRes

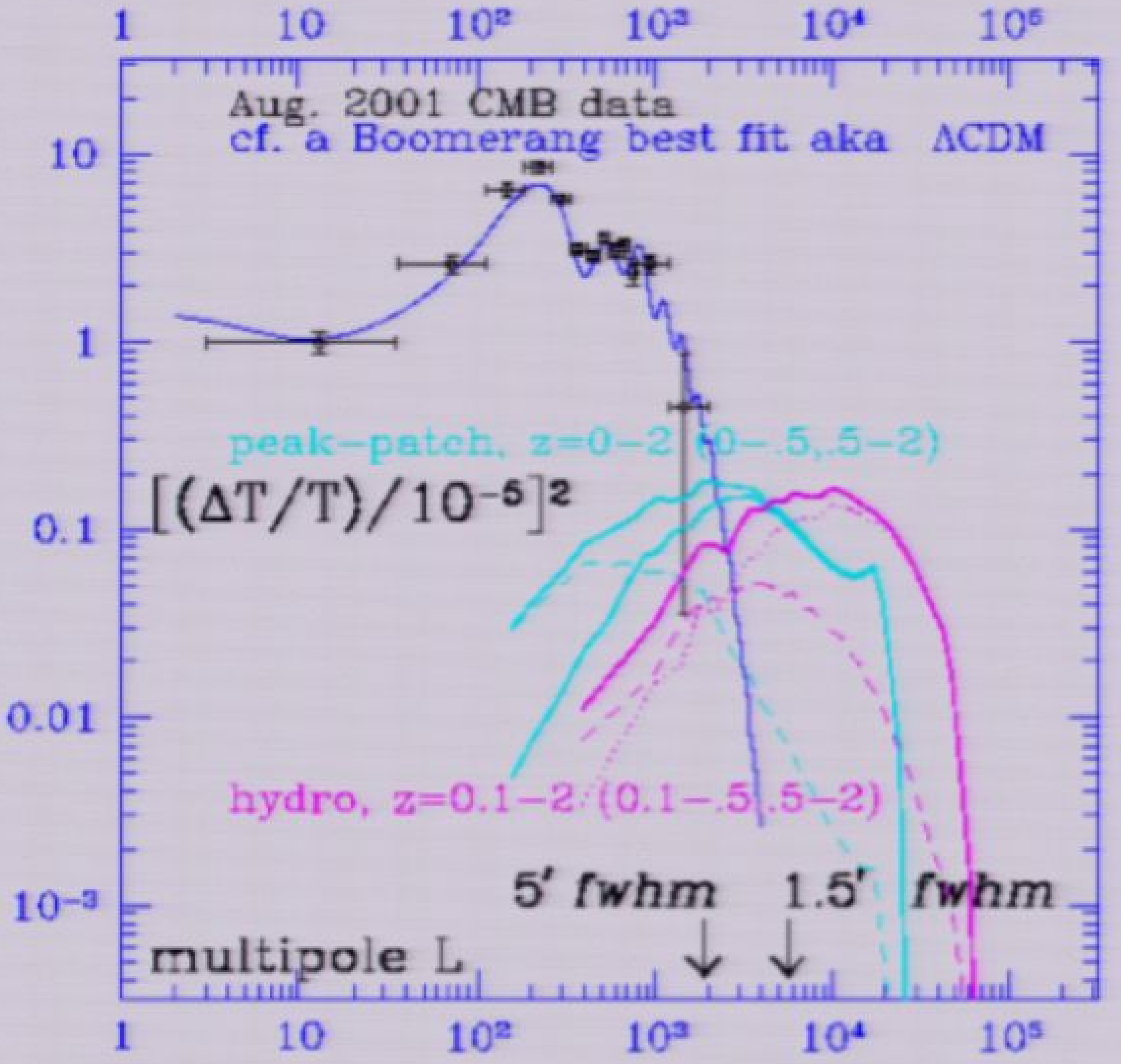
⇒ Sunyaev-Zeldovich effect in supercls may give outskirts of clusters & groups, but not filaments (unless ∃ large gas E-outflows)

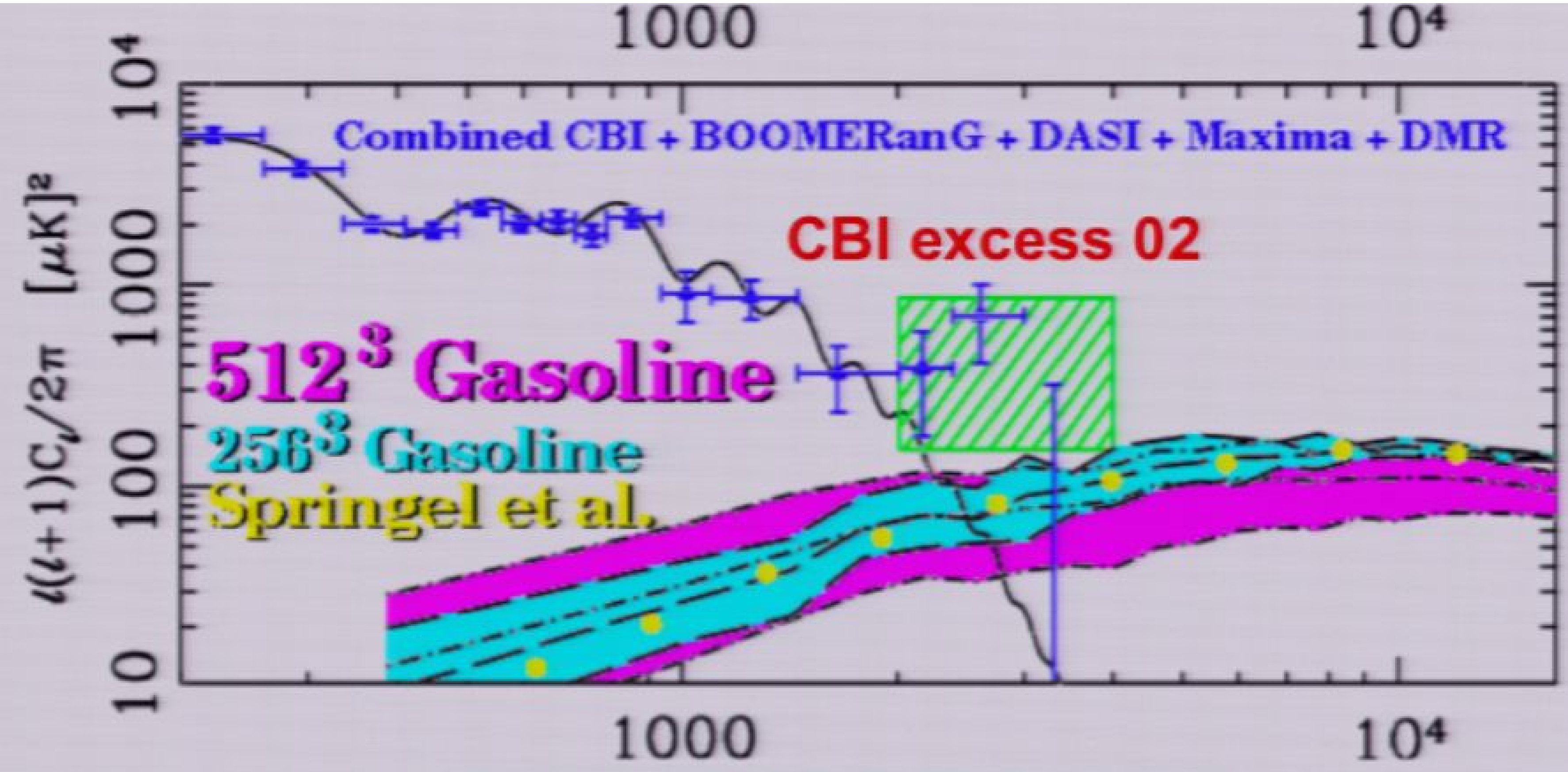


pre-Boomerang

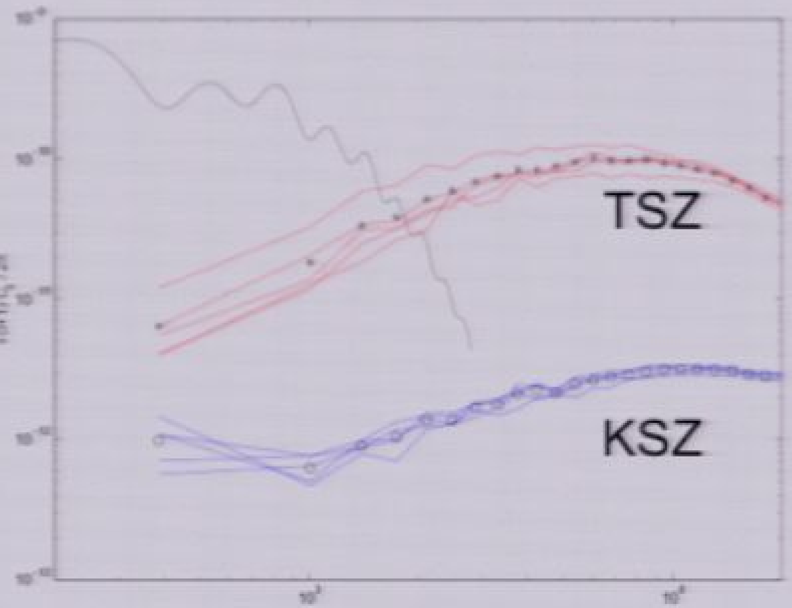


post-Boomerang

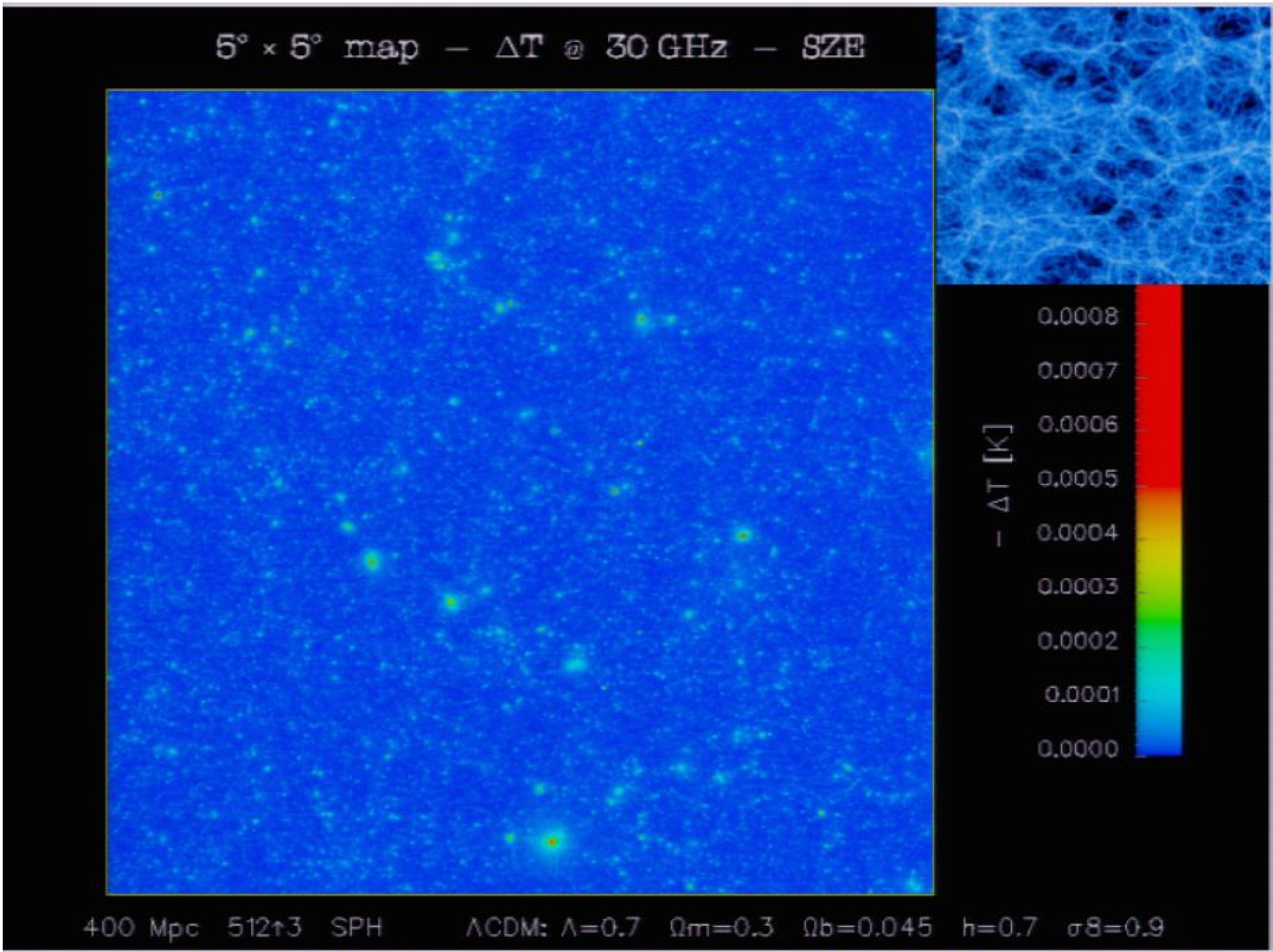




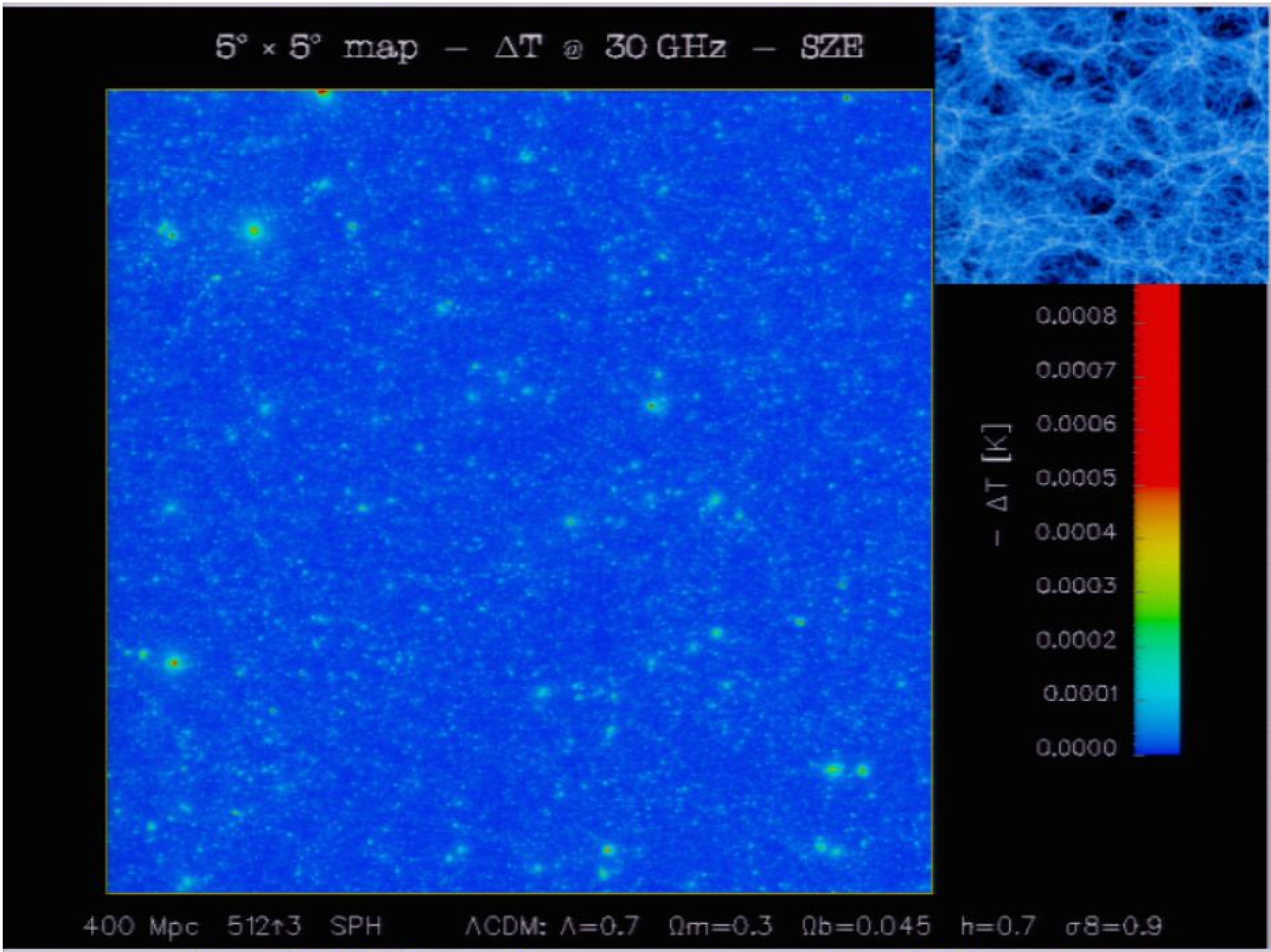
512^3 ΛCDM sim SZ power spectra for various realizations



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??



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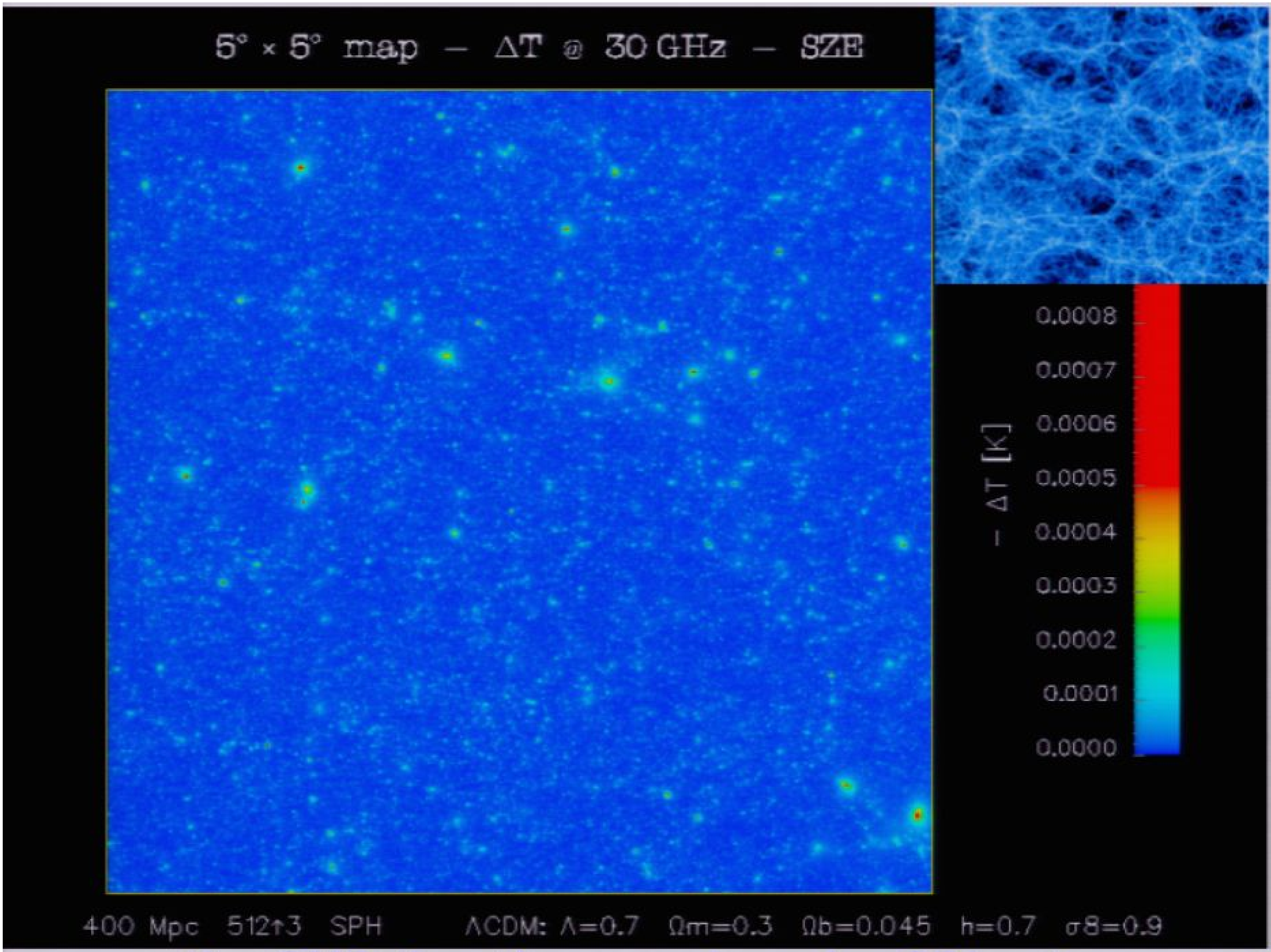

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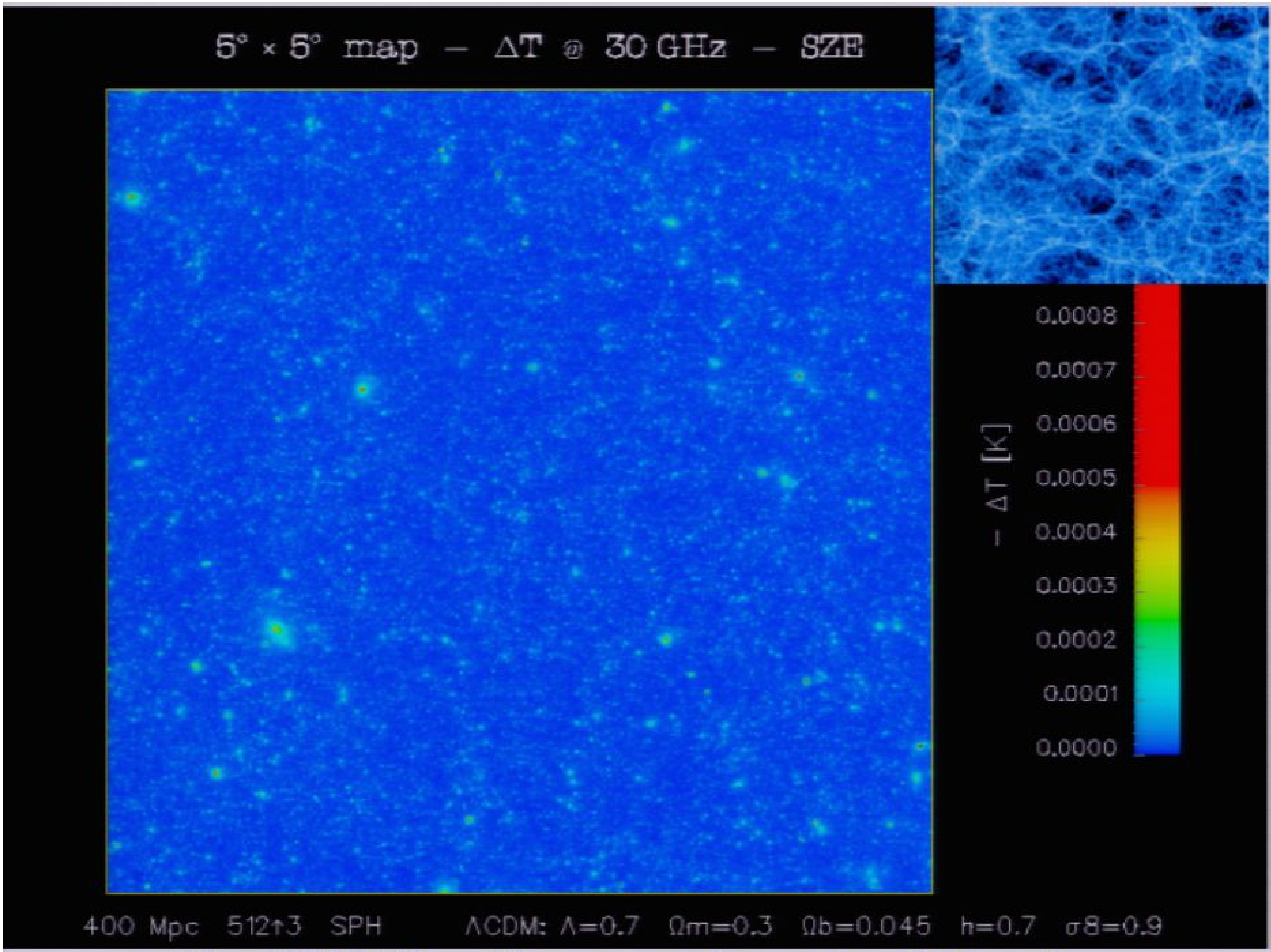

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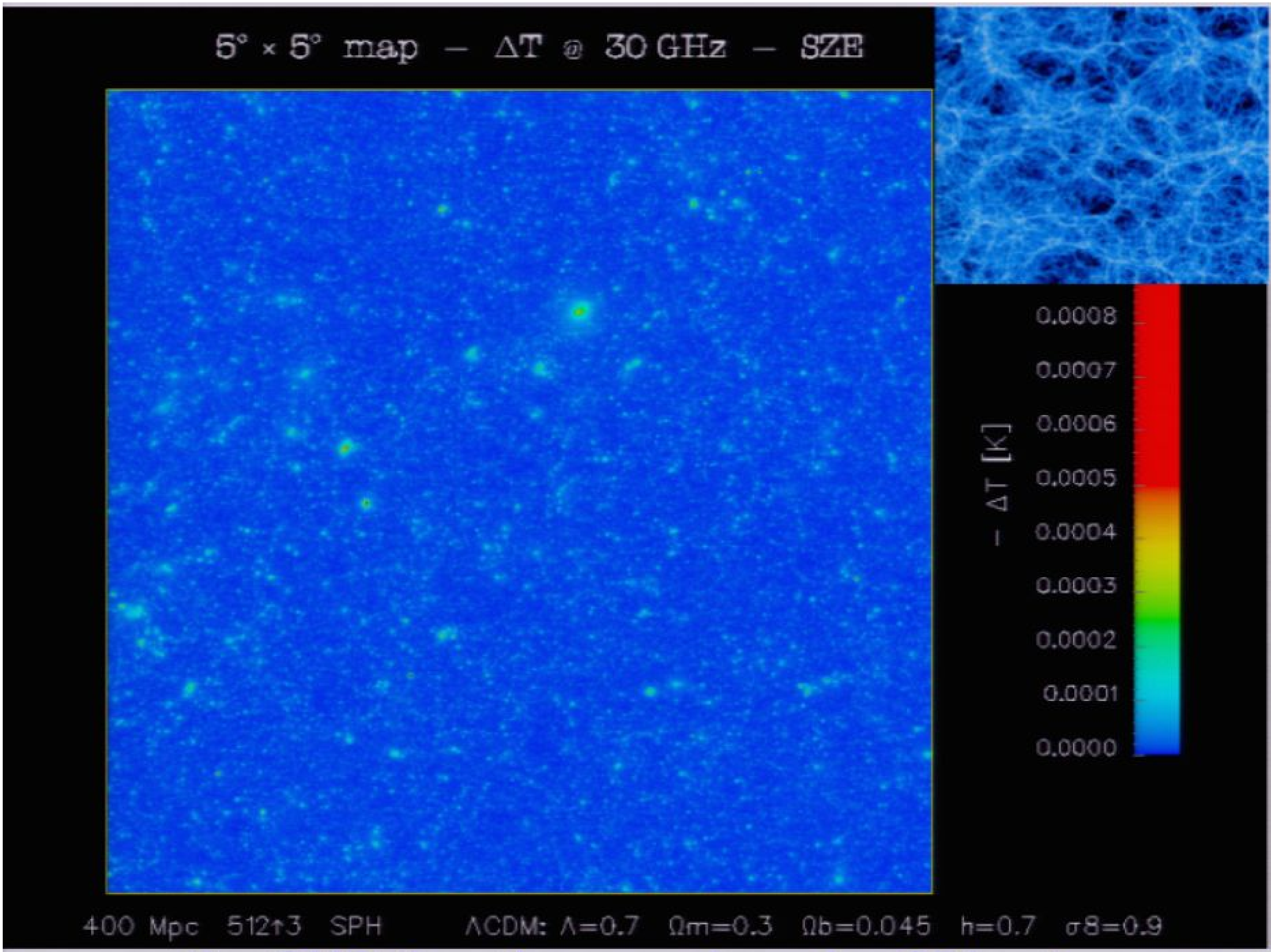

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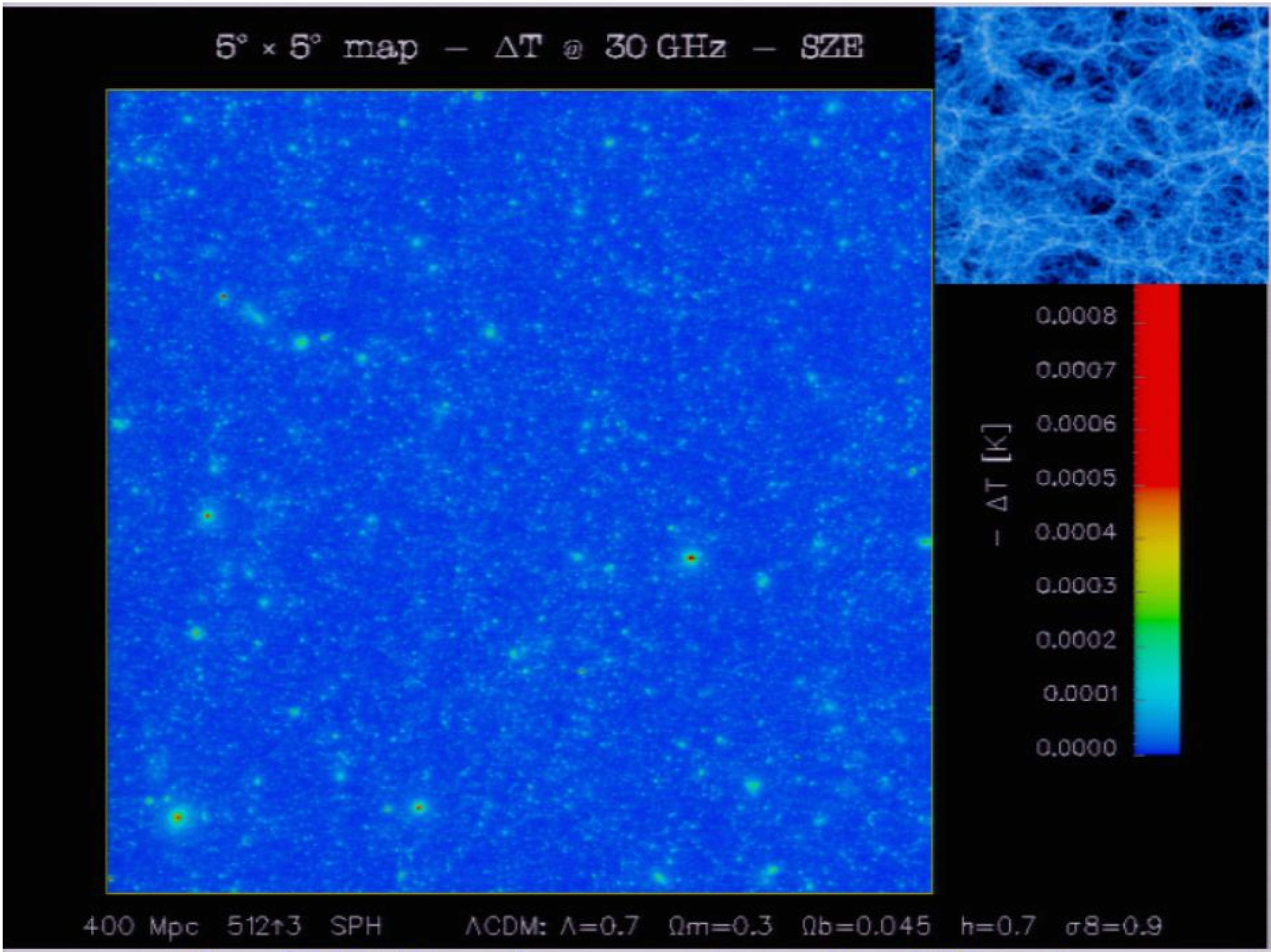
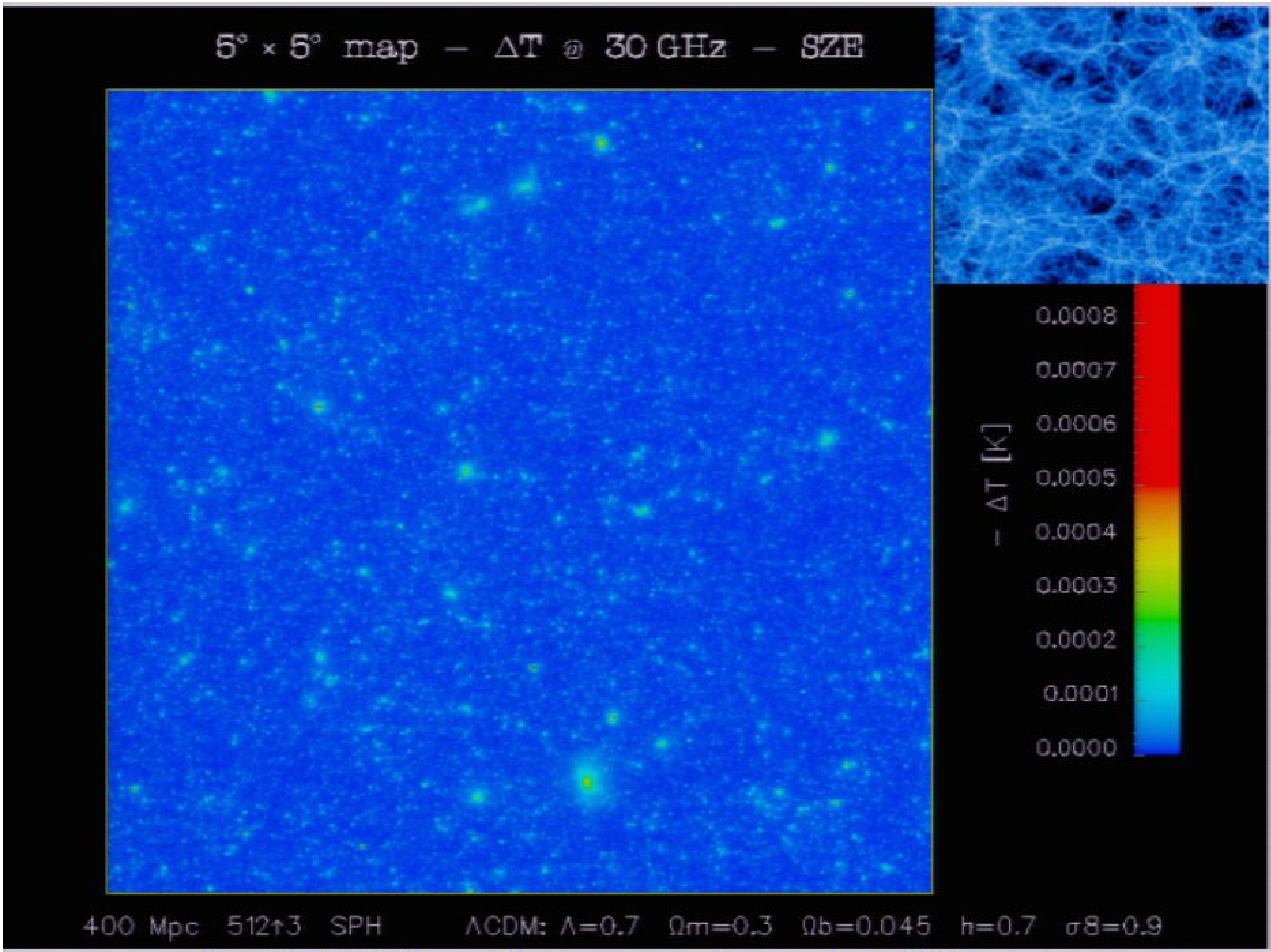


pass the CMB thru the cosmic web; CBI extra power??



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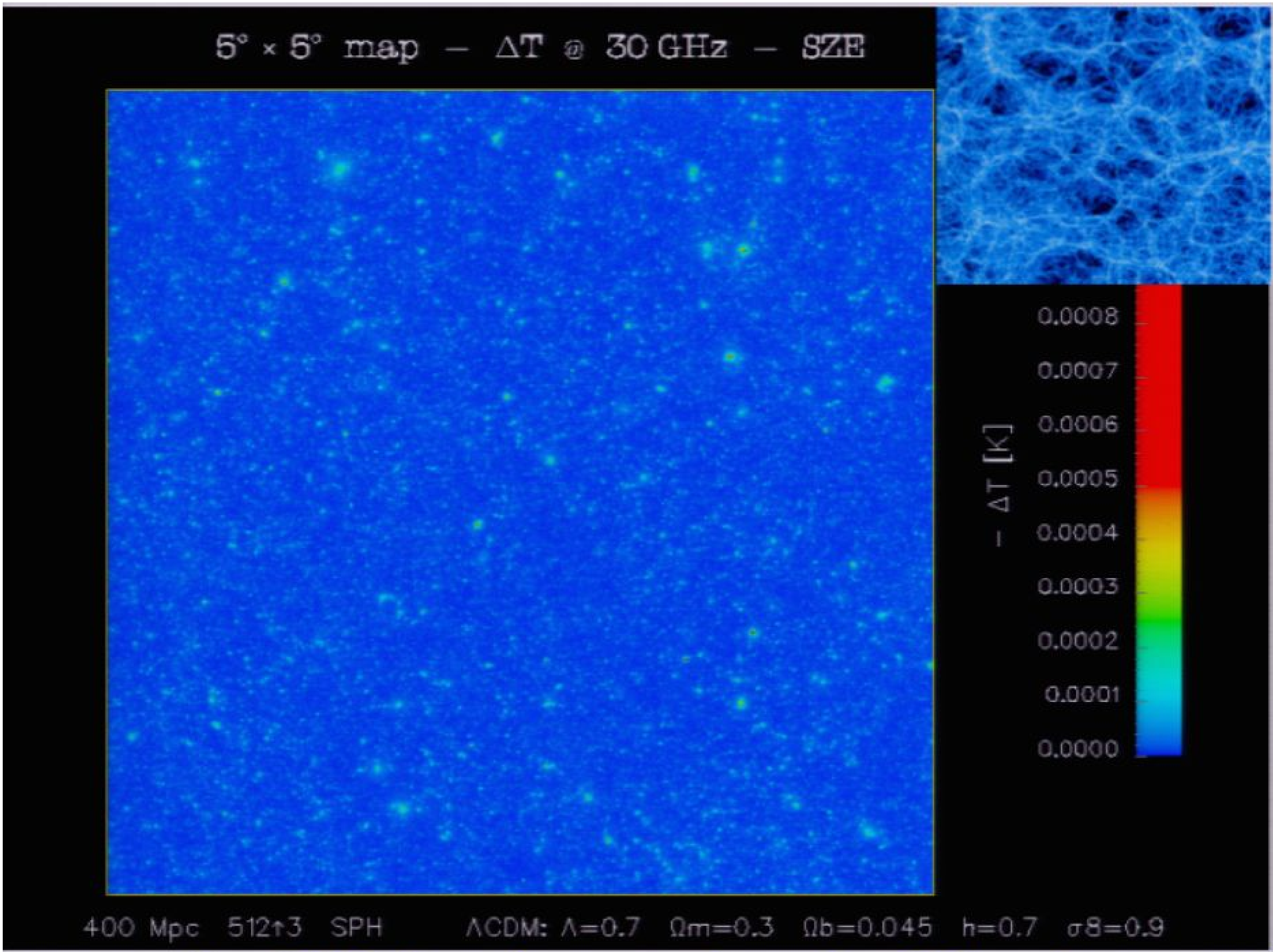

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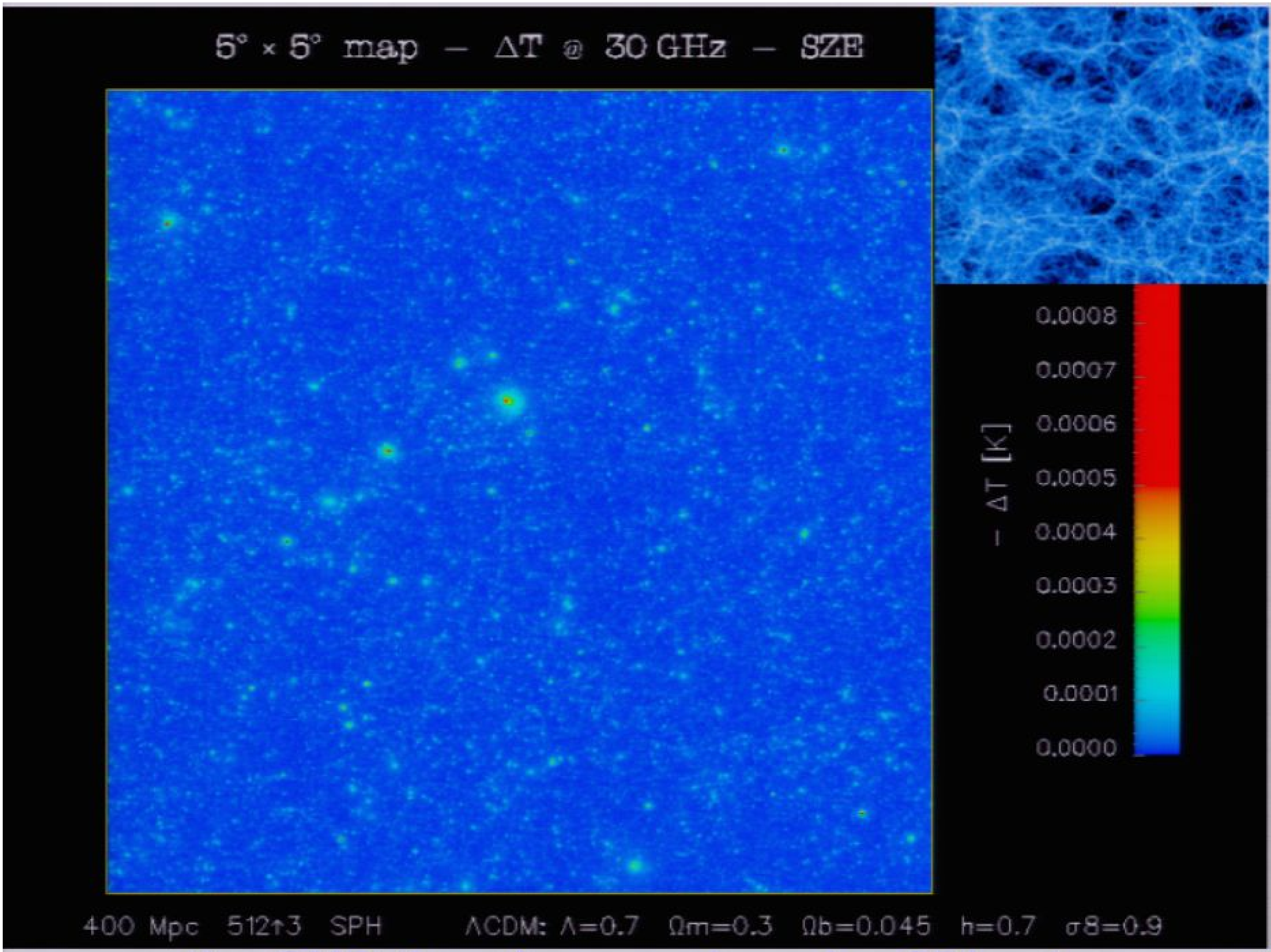
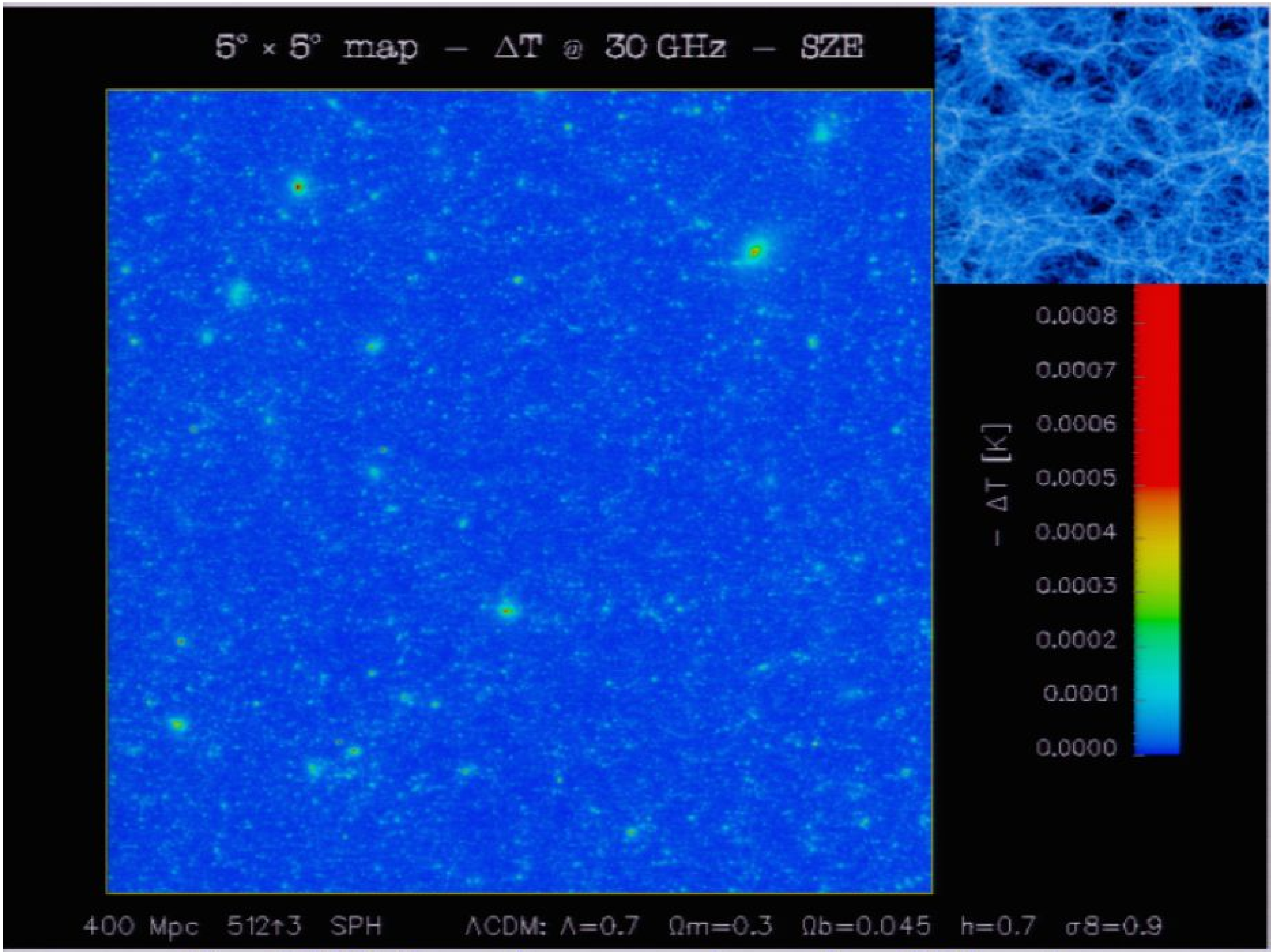


pass the CMB thru the cosmic web; CBI extra power??



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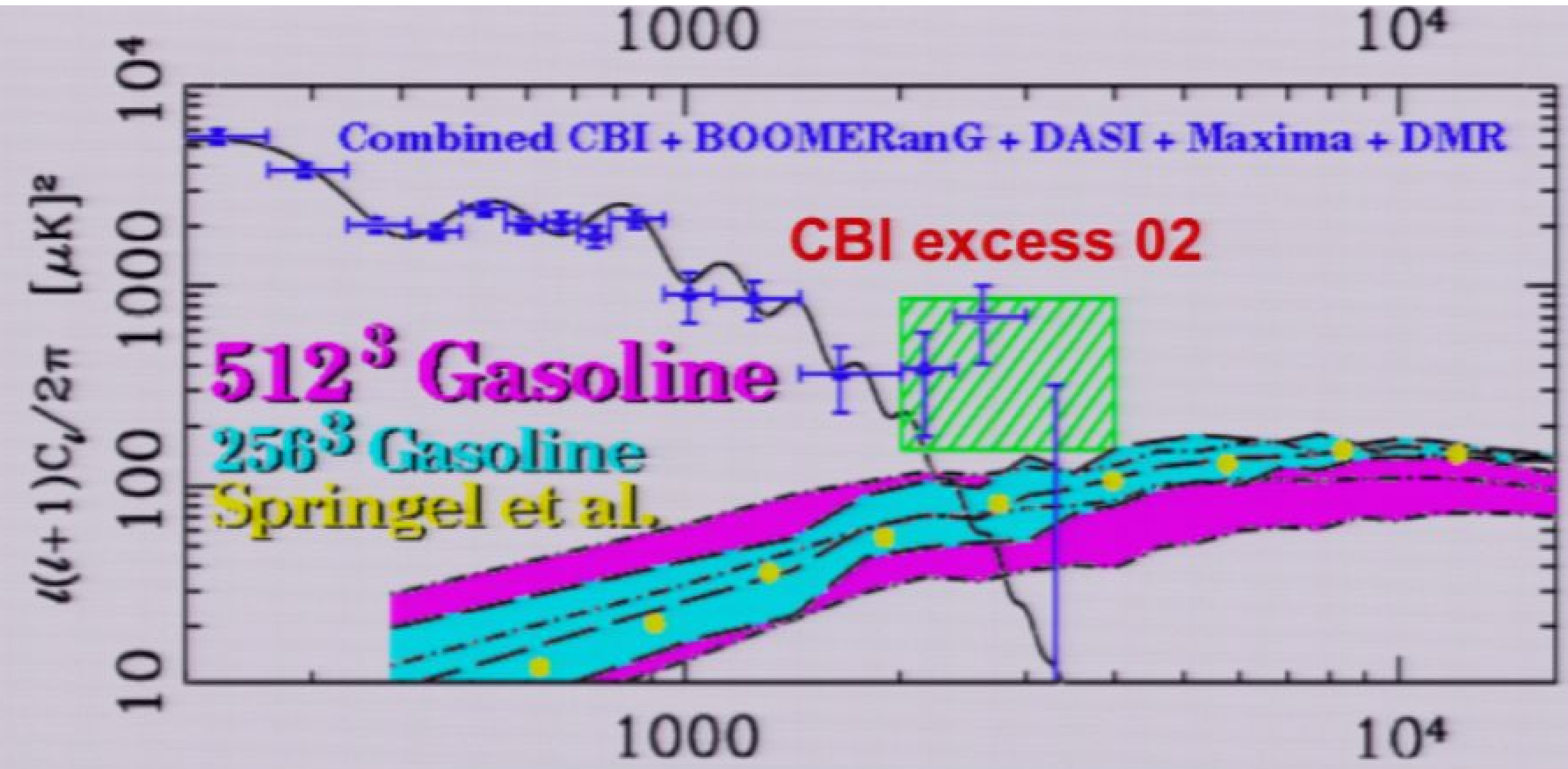
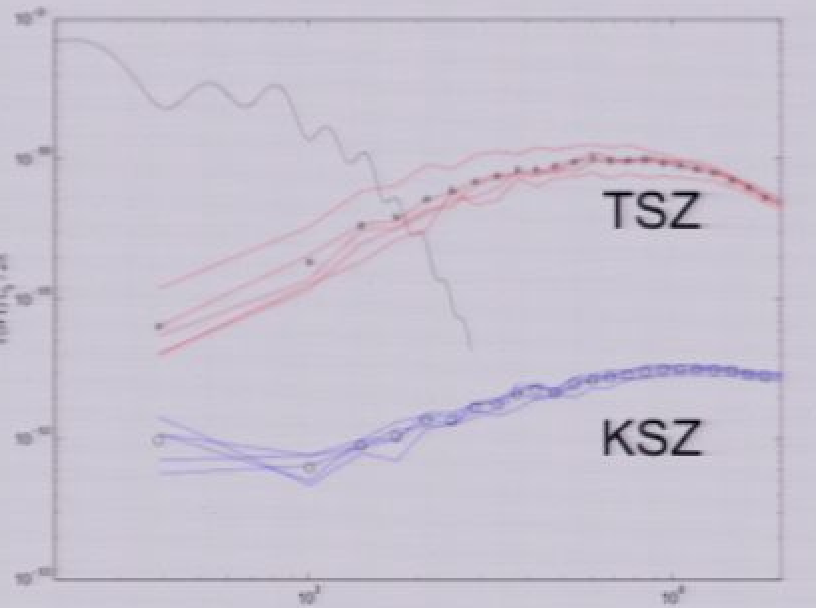


512^3 ΛCDM sim SZ power spectra for various realizations



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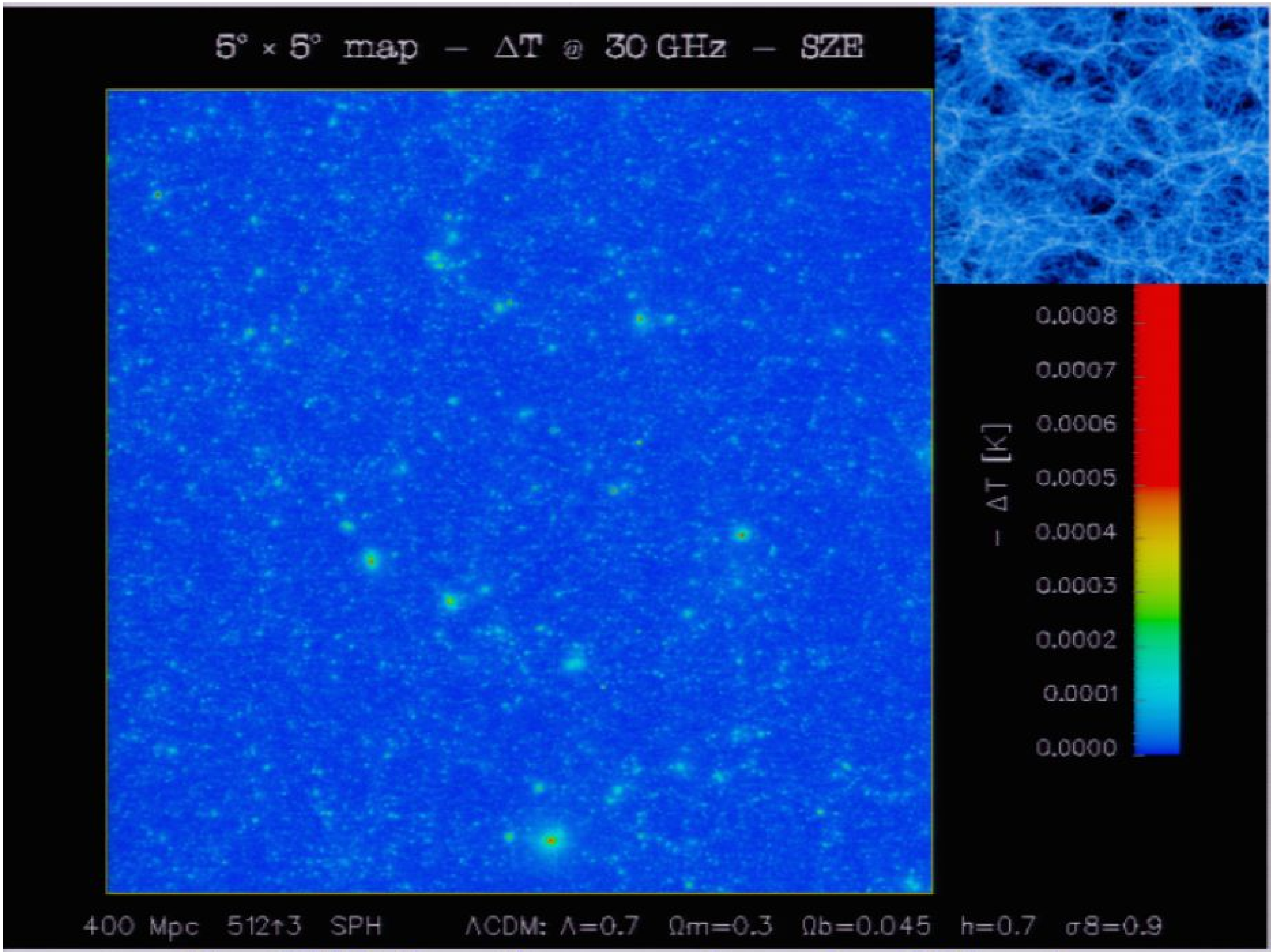
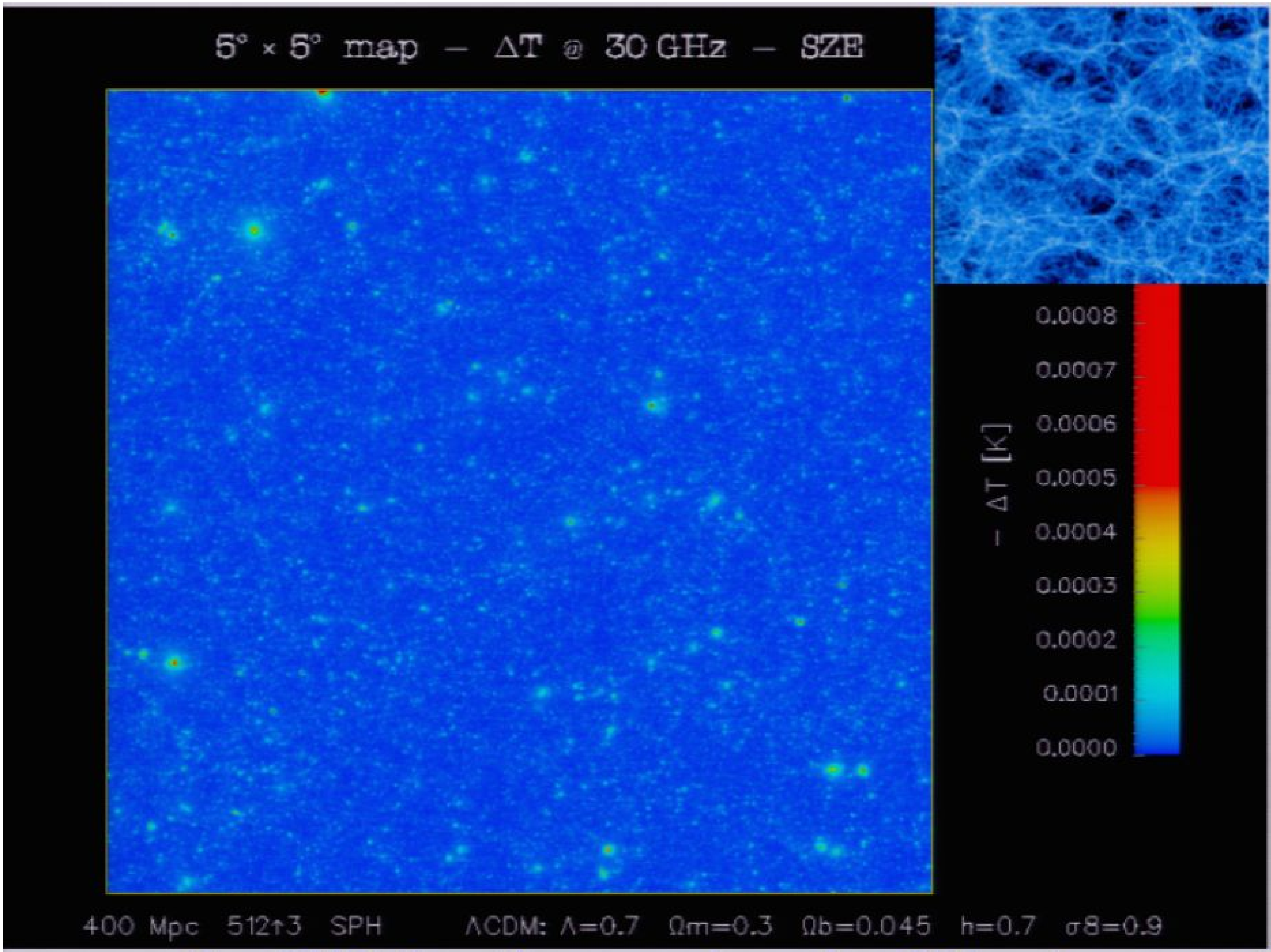


pass the CMB thru the cosmic web; CBI extra power??



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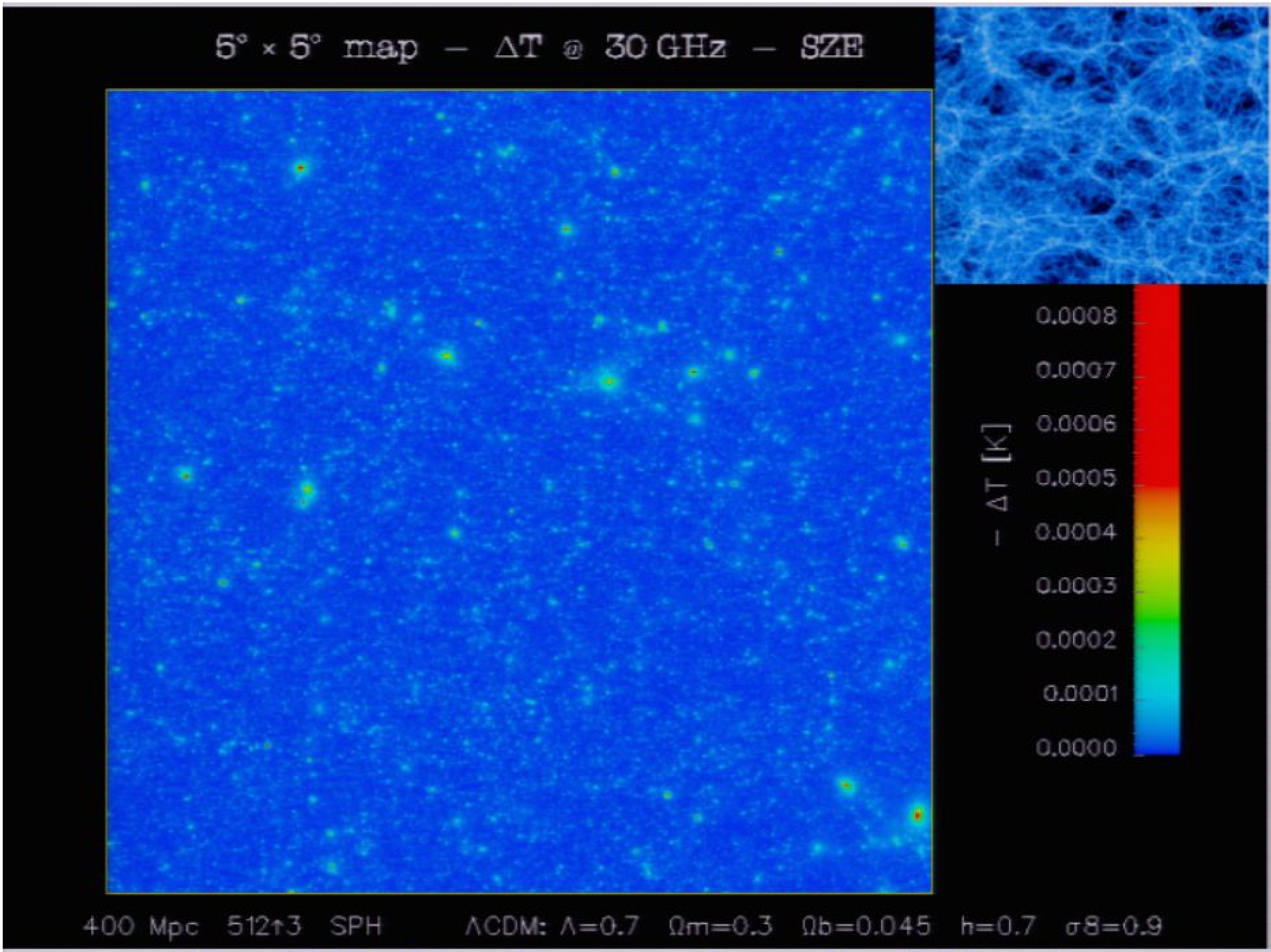
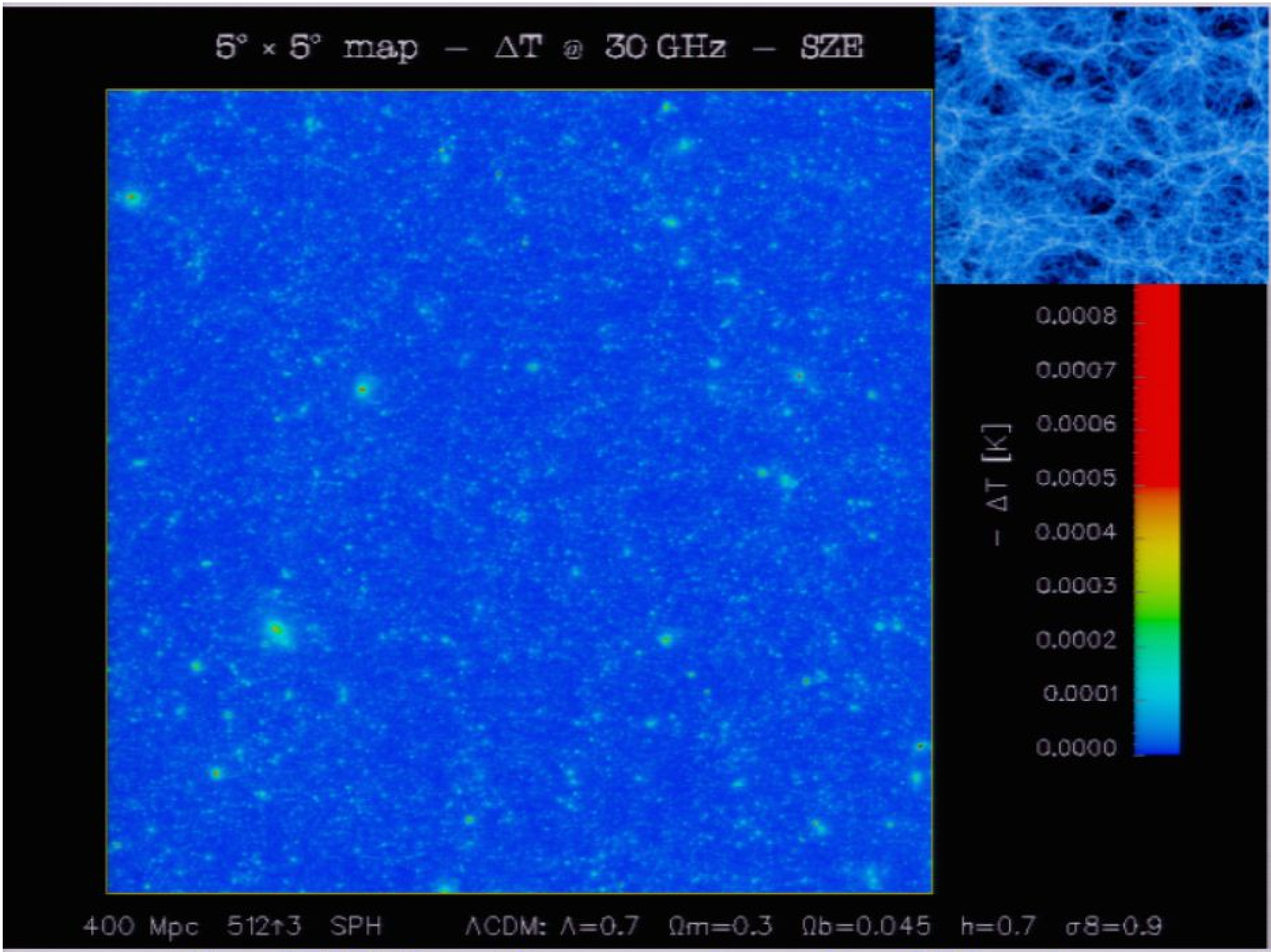


pass the CMB thru the cosmic web; CBI extra power??



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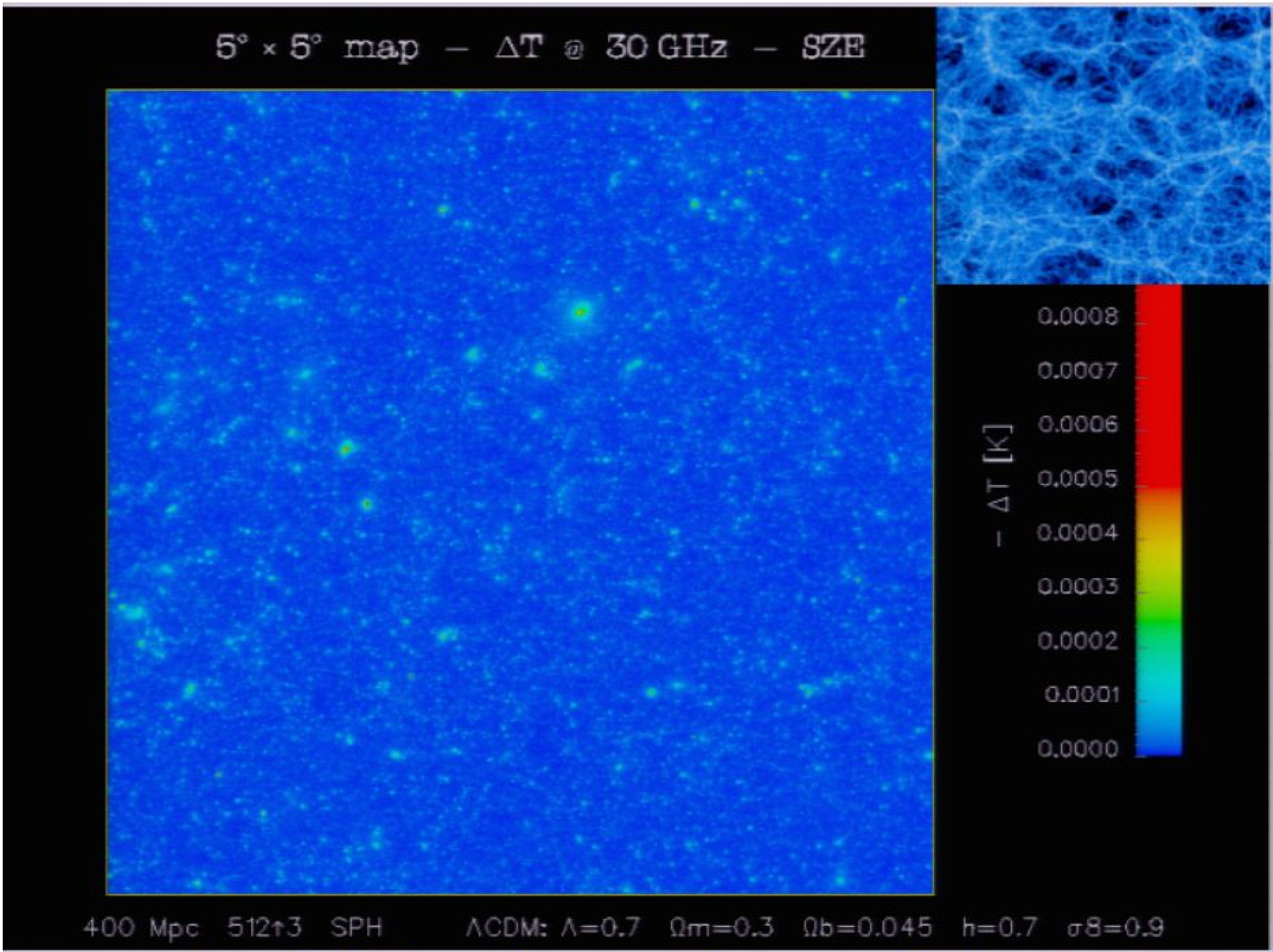
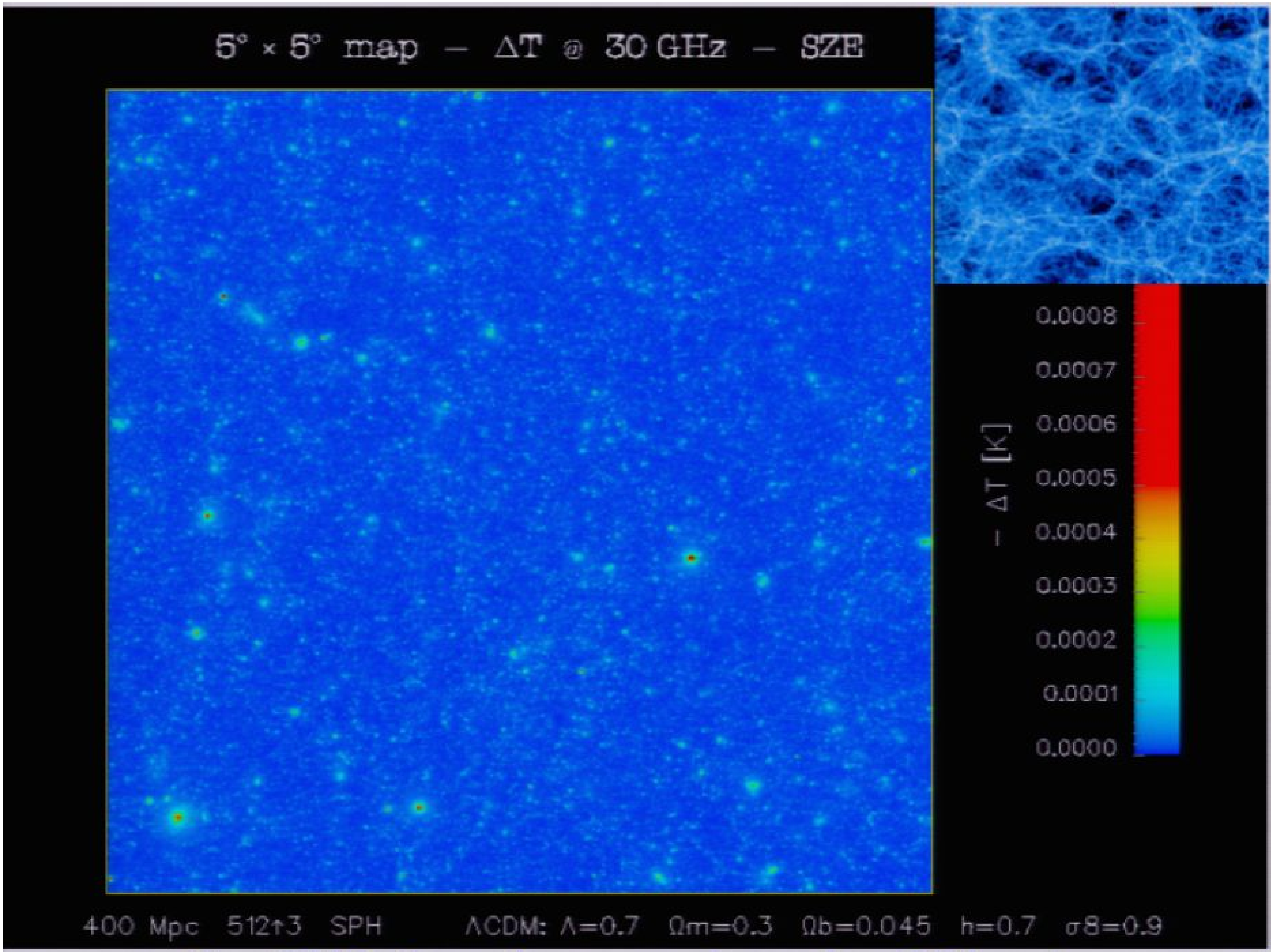
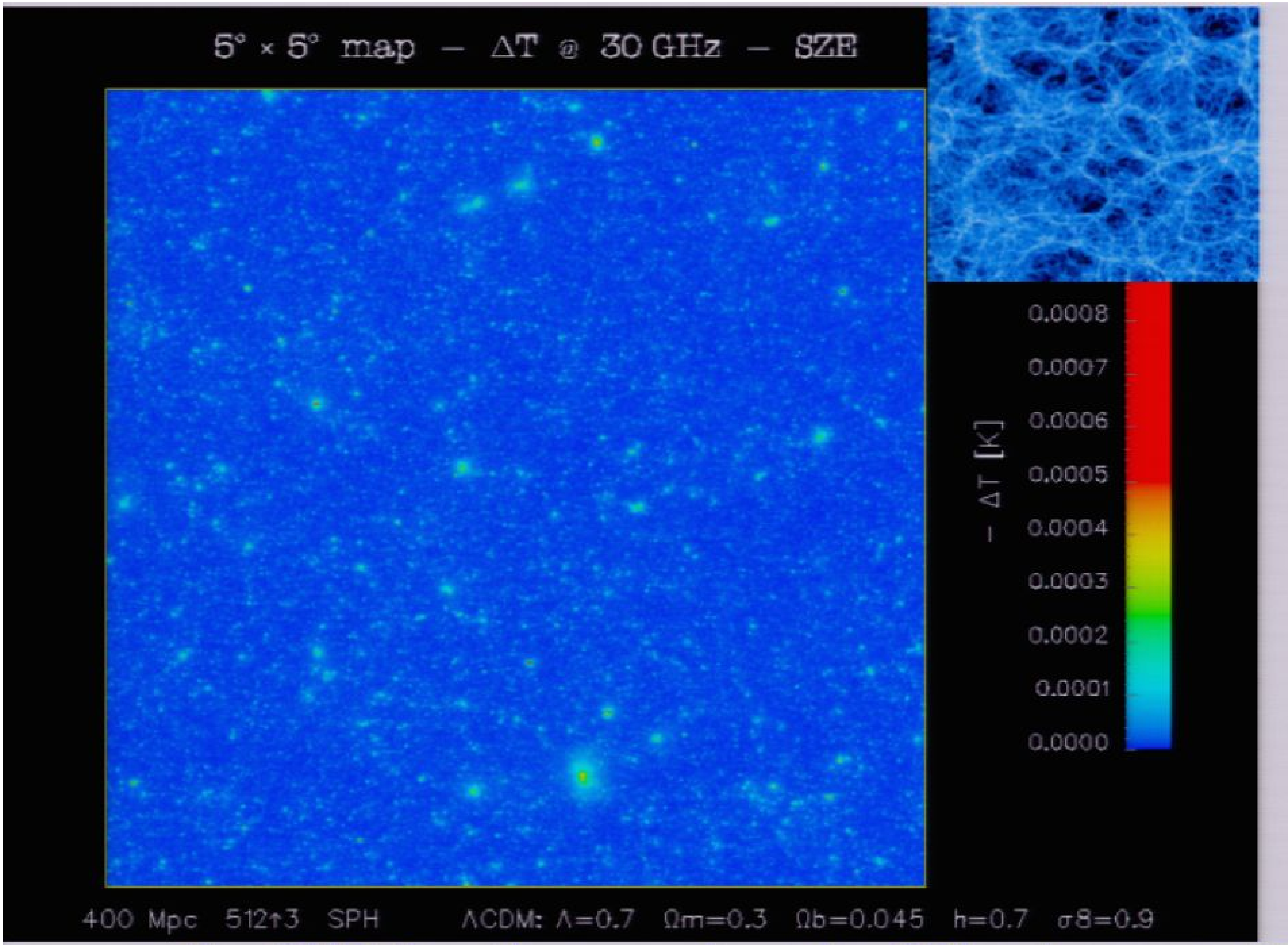


pass the CMB thru the cosmic web; CBI extra power??



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



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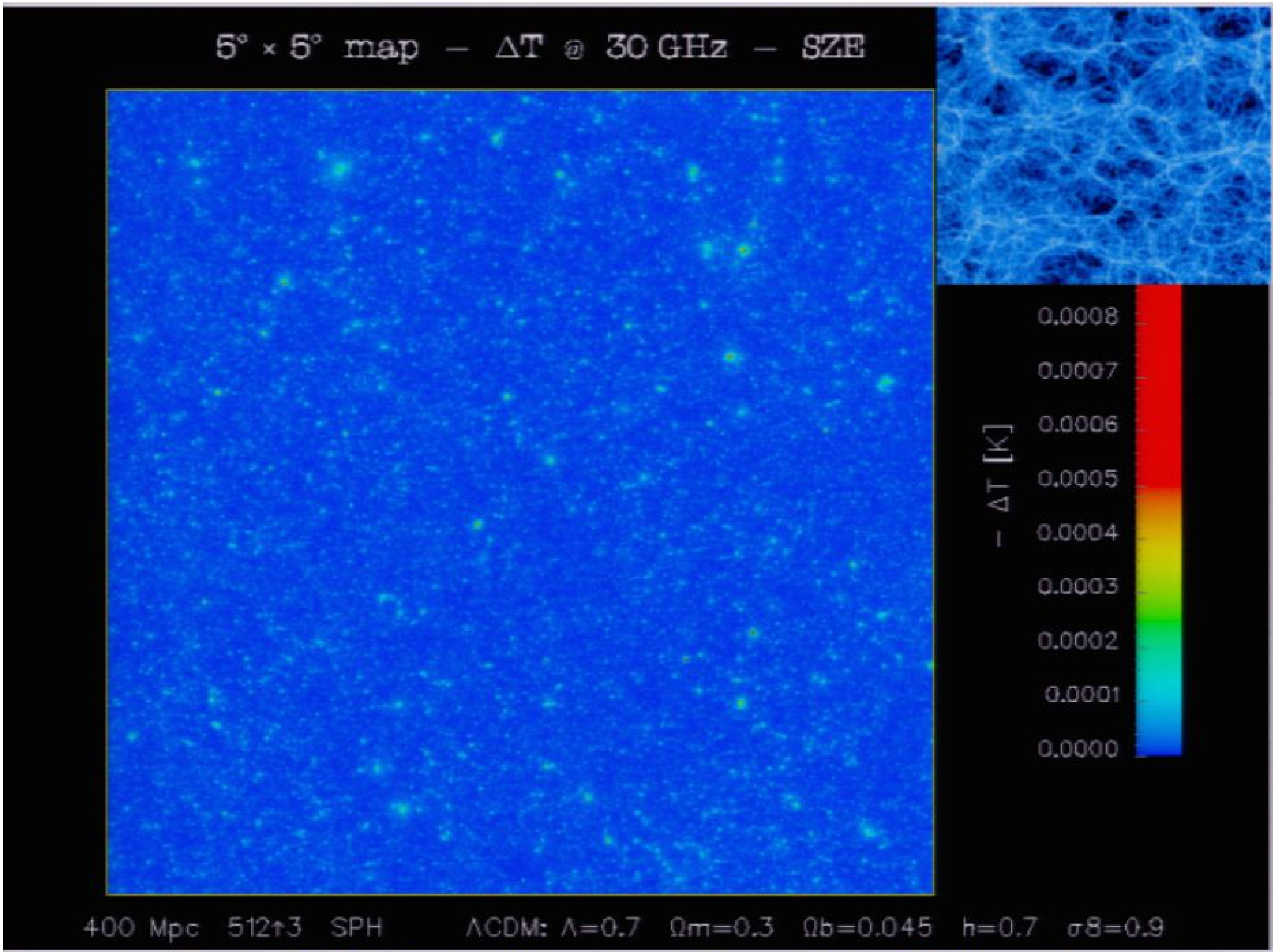
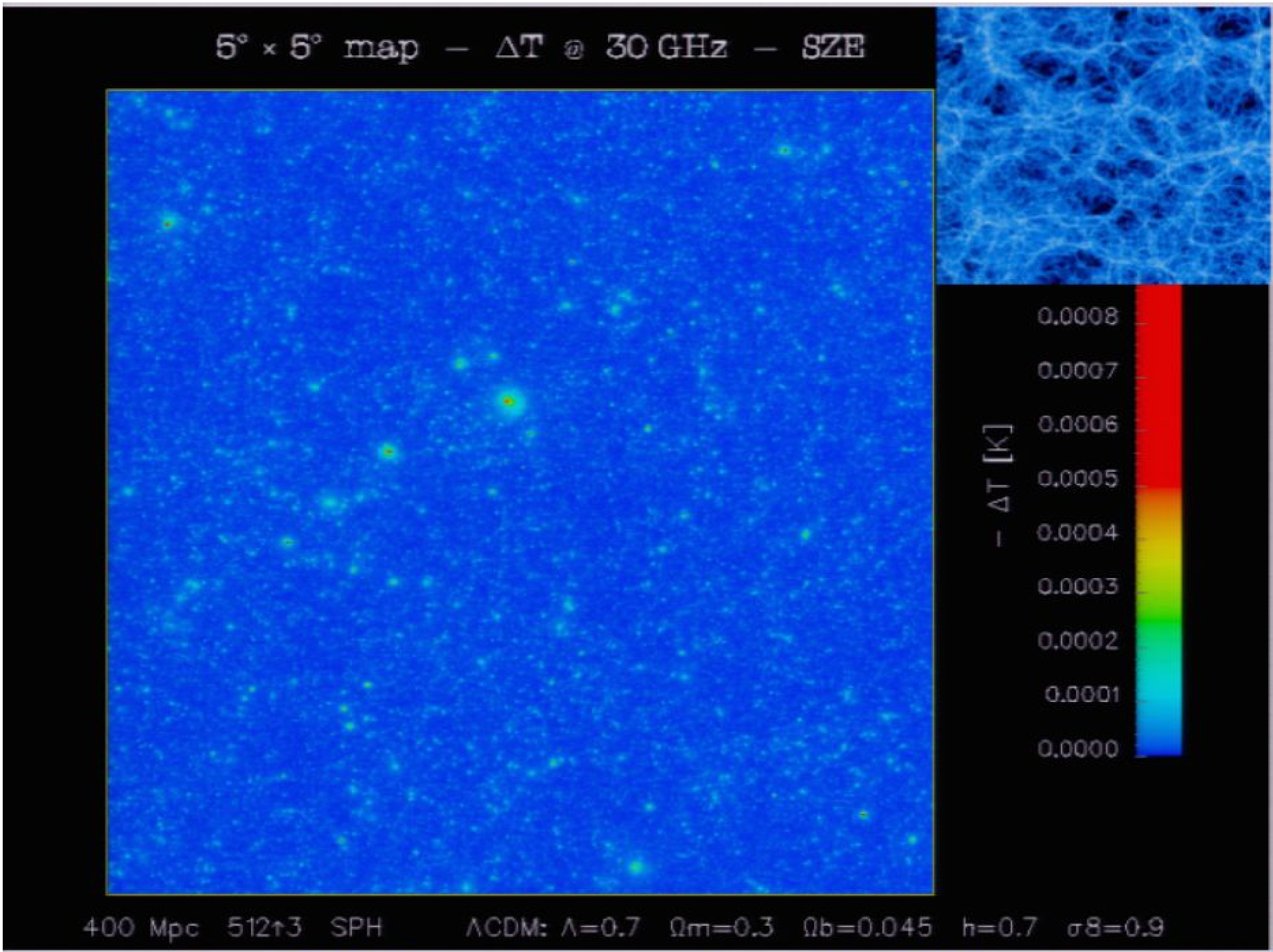
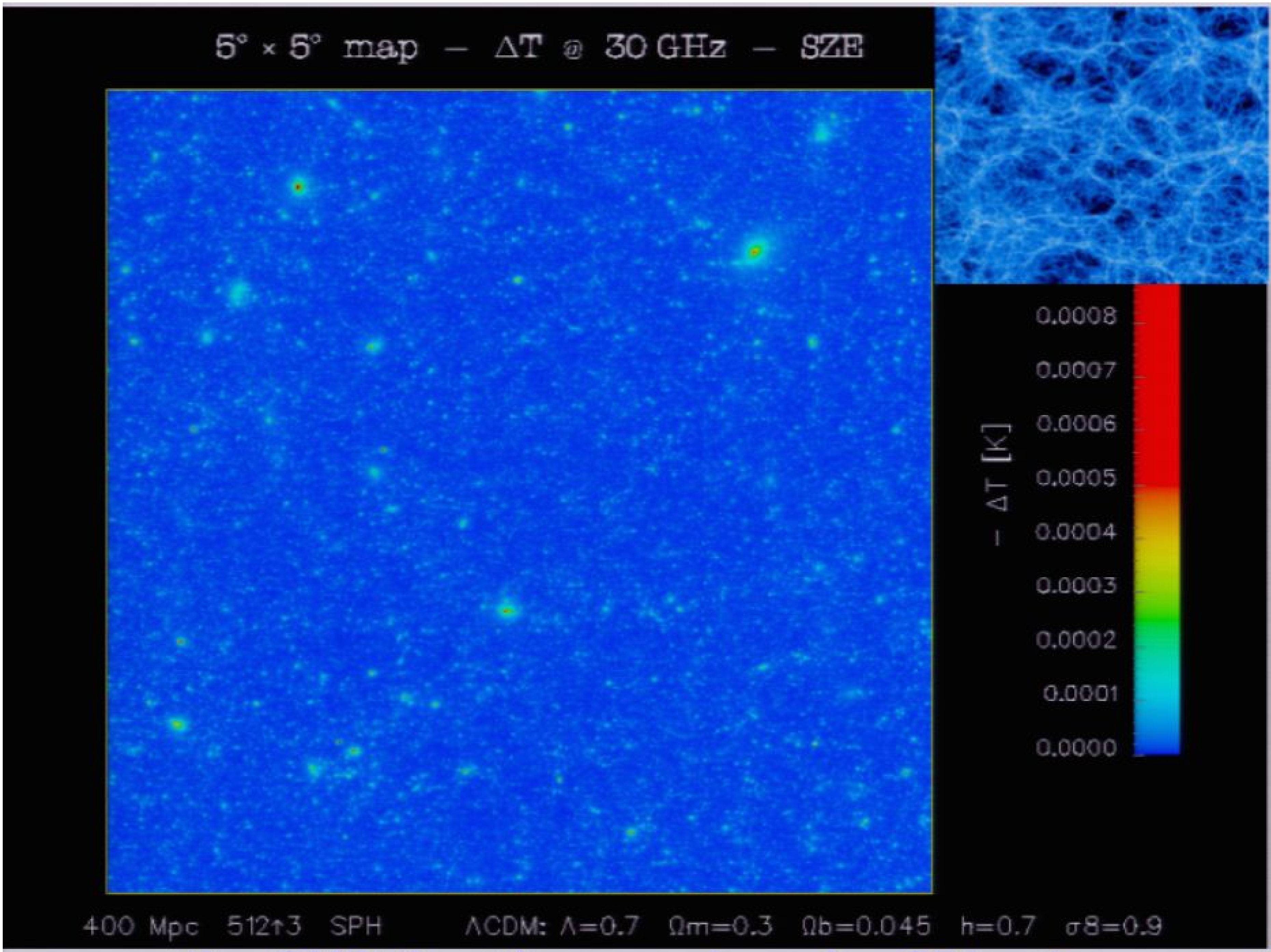


pass the CMB thru the cosmic web; CBI extra power??

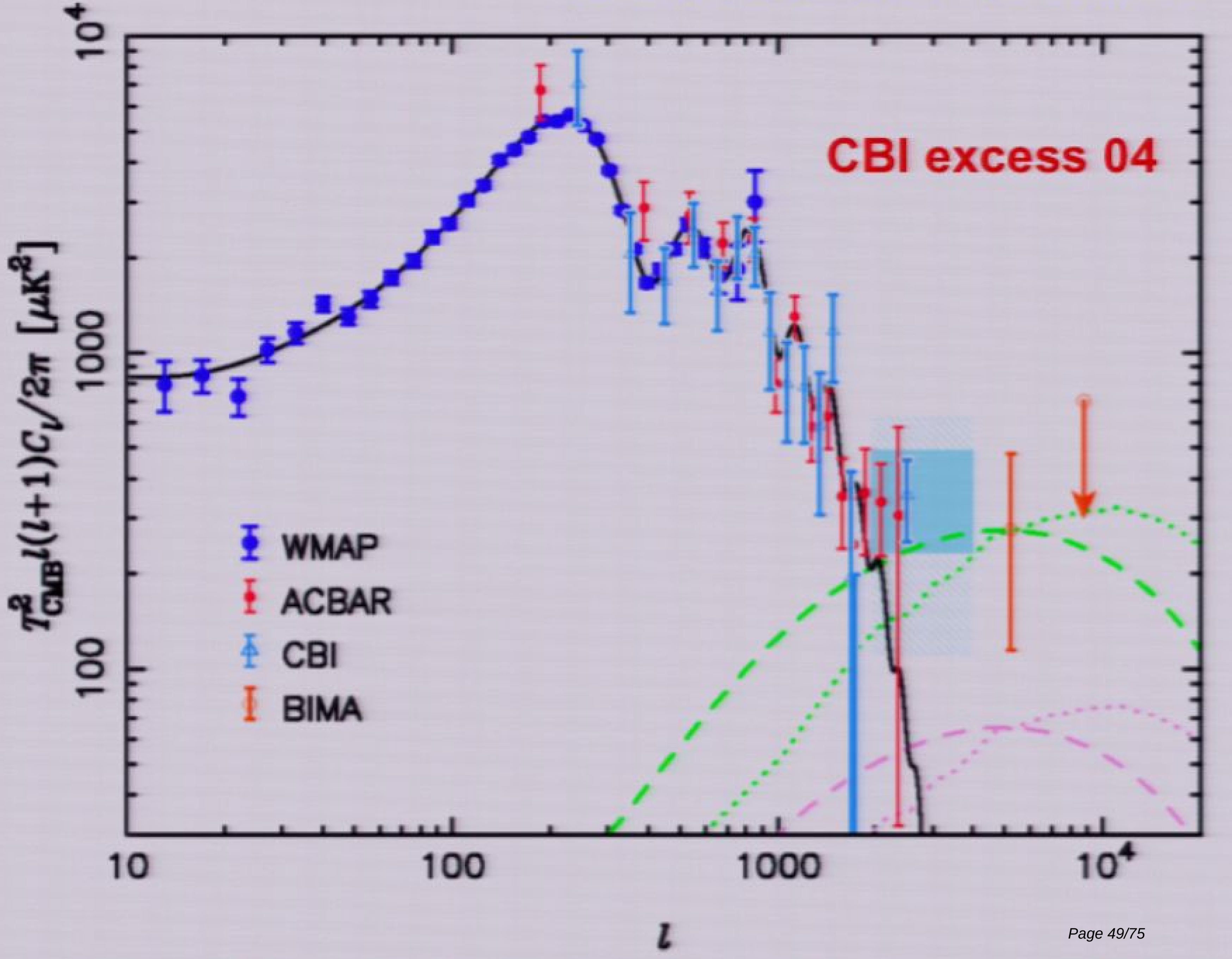


pass the CMB thru the cosmic web; CBI extra power??



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

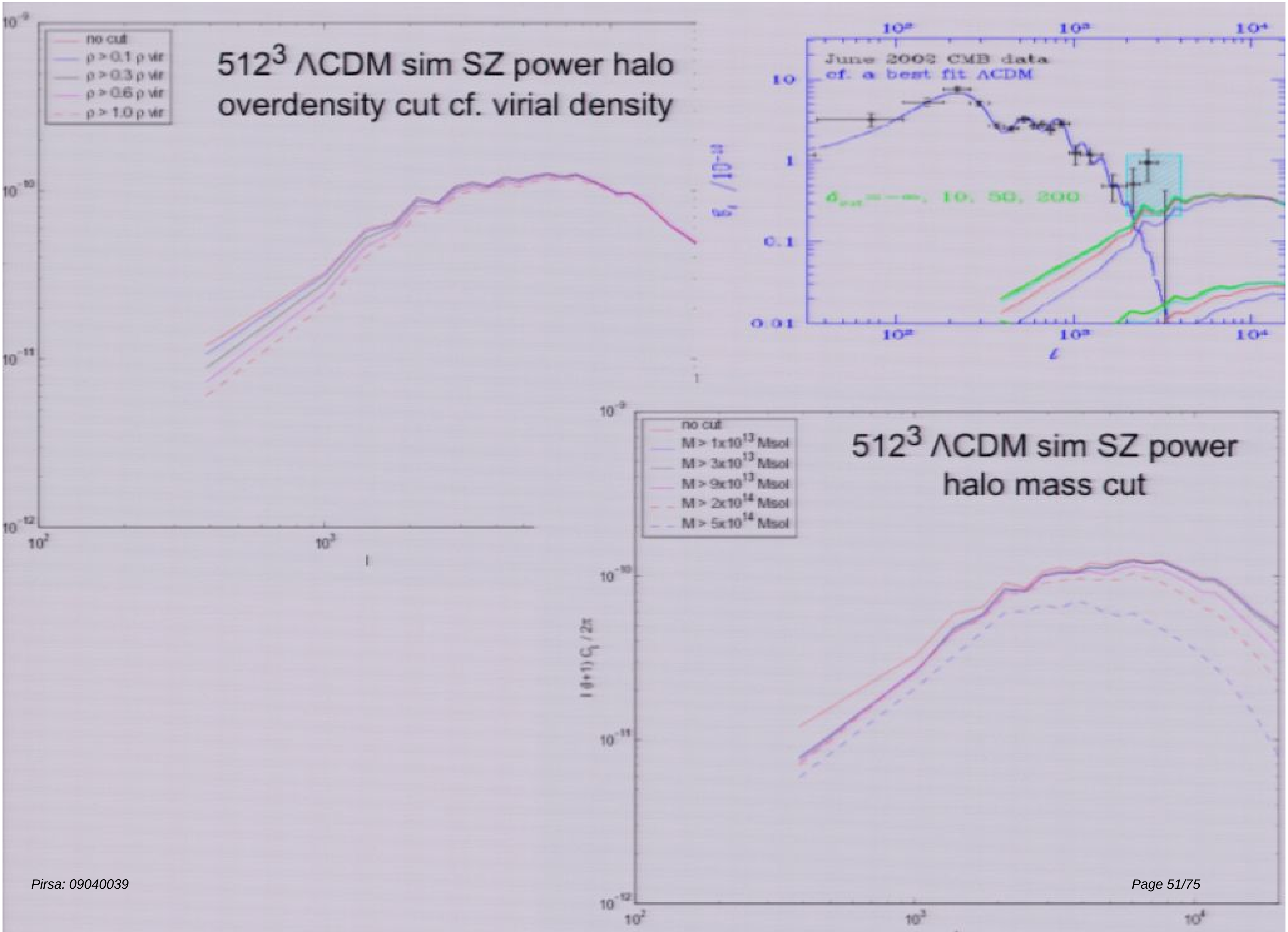
Readhead et al. 2004, ApJ 609, 498



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

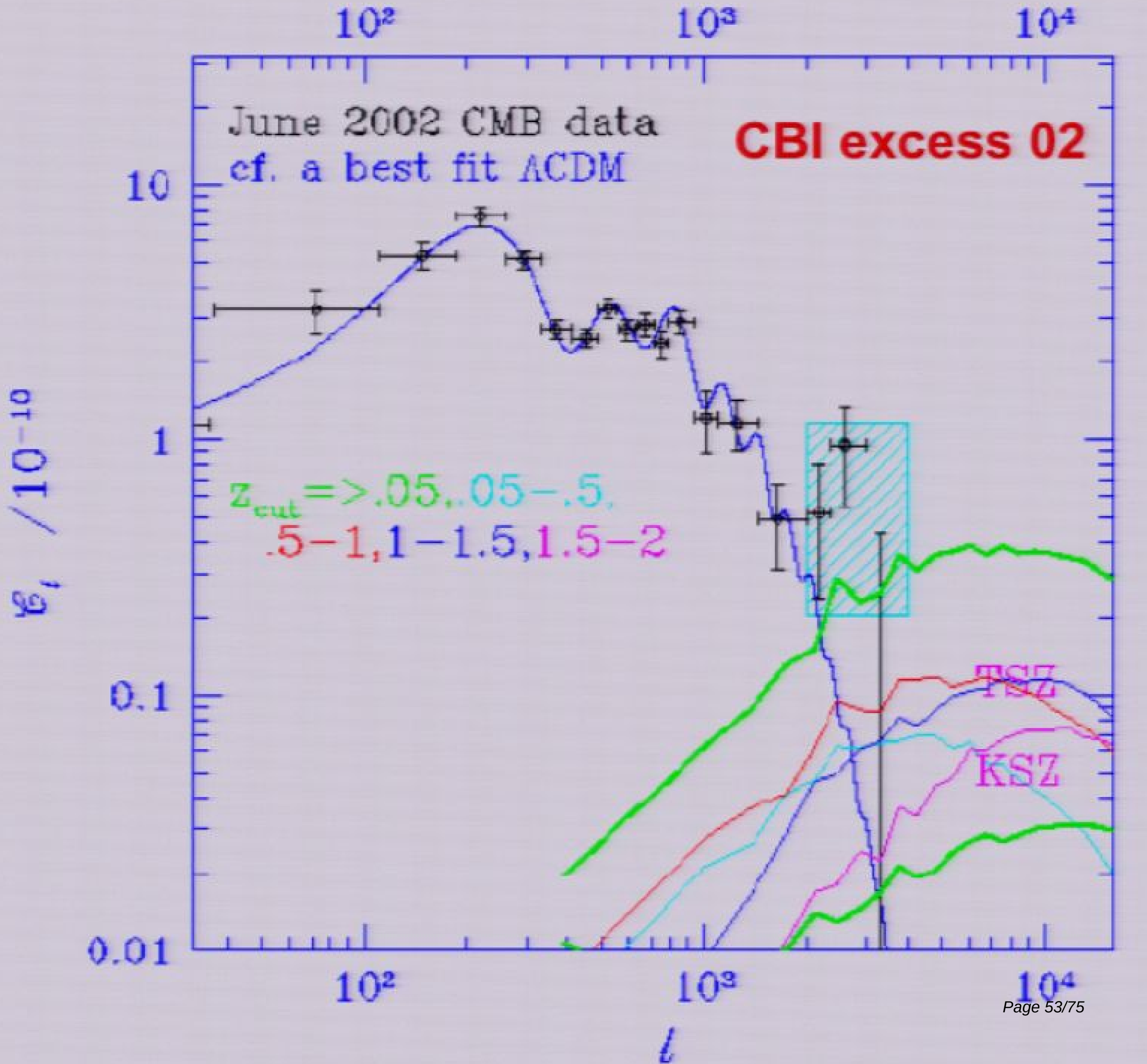


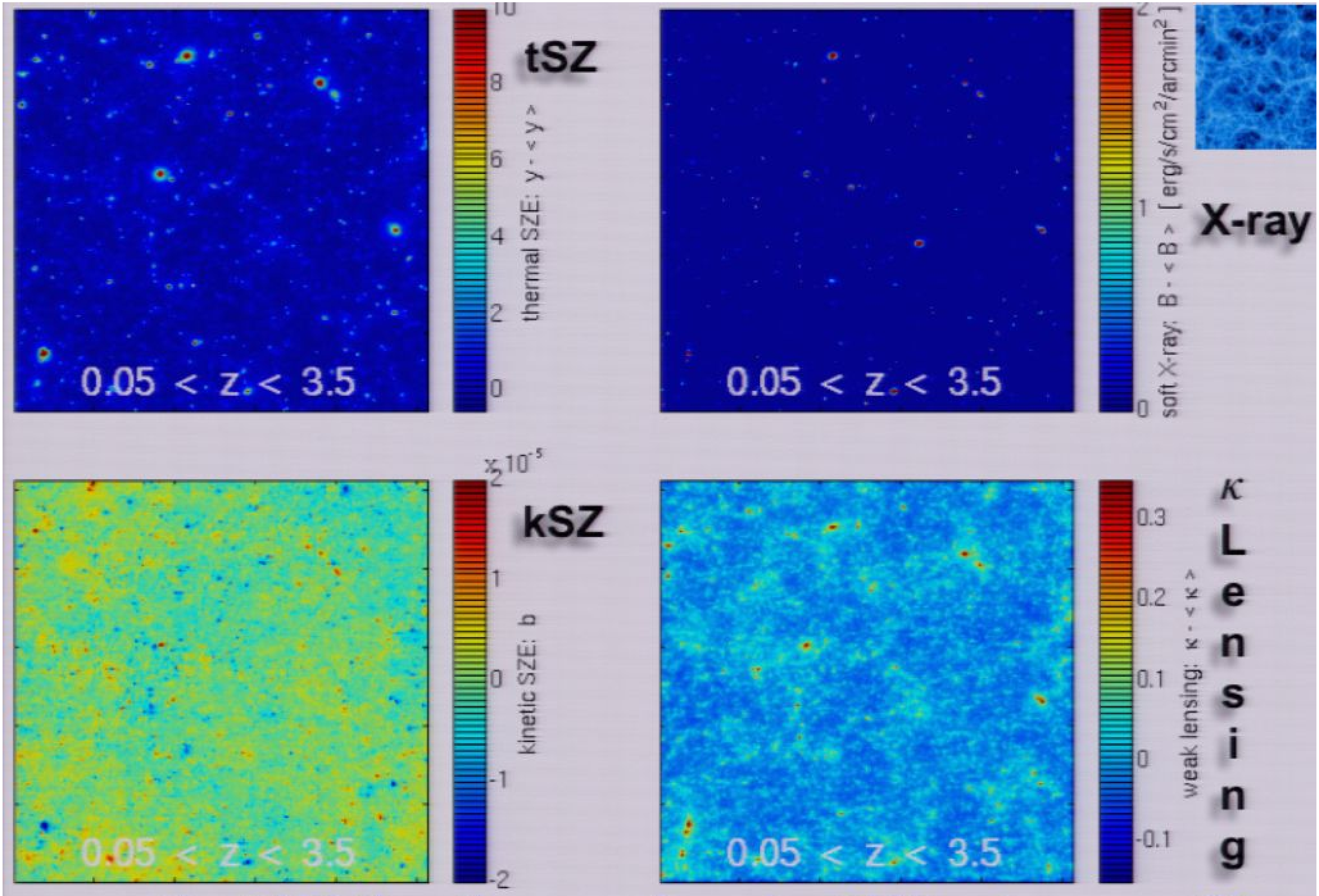
512^3 ΛCDM sim SZ power halo overdensity cut cf. virial density

512^3 ΛCDM sim SZ power halo mass cut

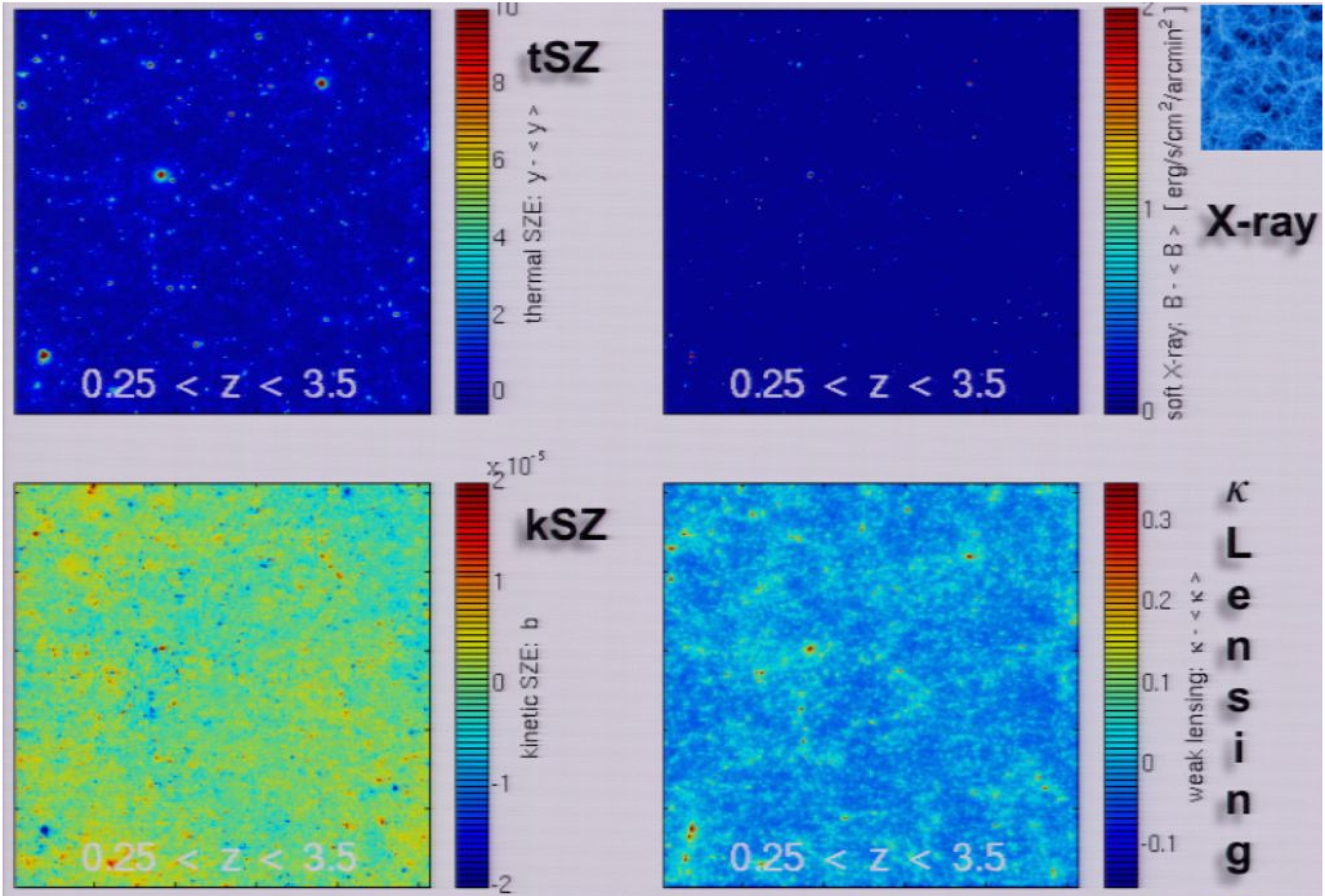
What is the redshift range that contributes to the SZ effect?

all from 0 to ~2

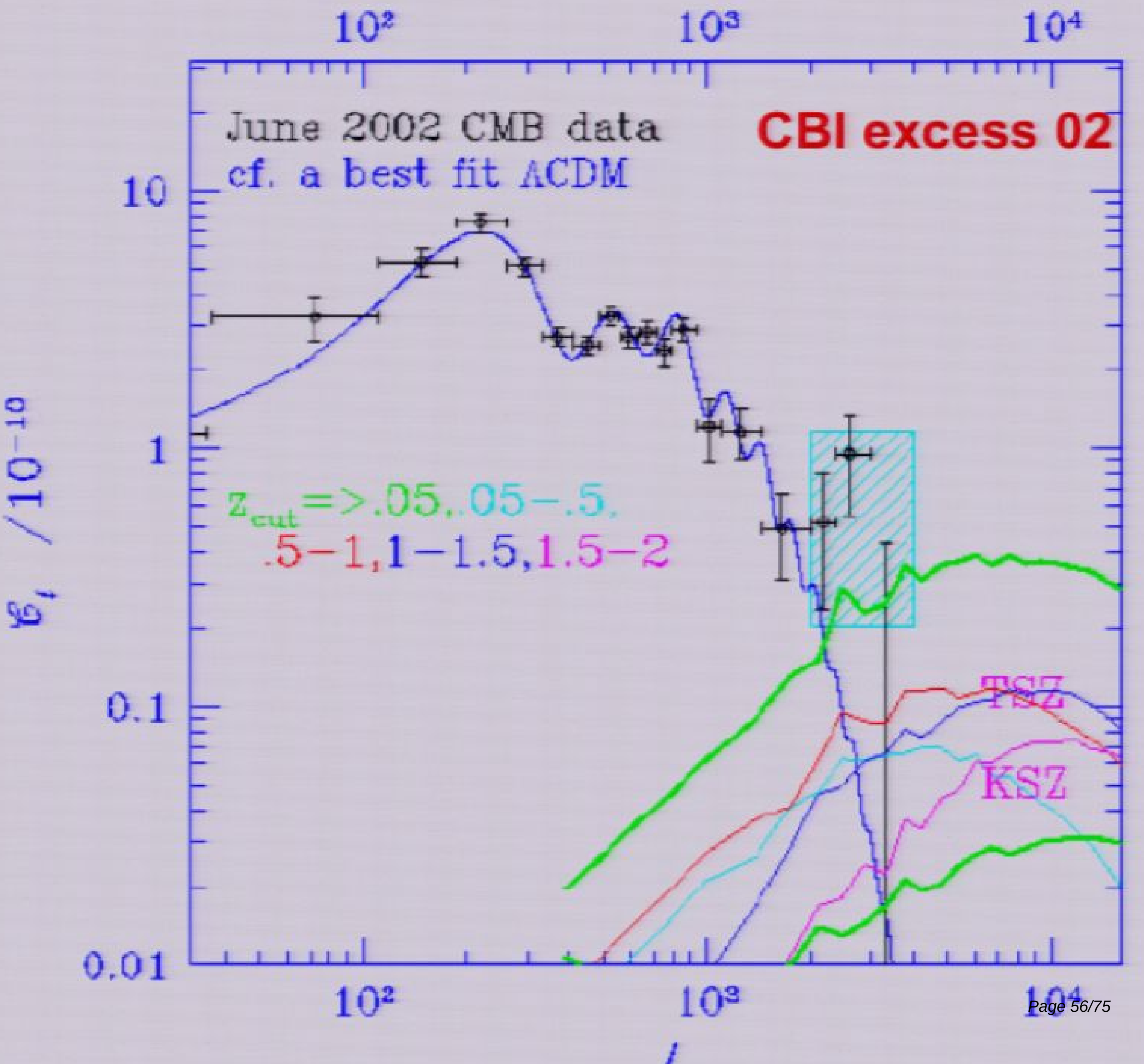

CBI excess 02
June 2002 CMB data
cf. a best fit ΛCDM
z_{cut}=>.05,.05−.5,
.5−1,1−1.5,1.5−2
TSZ
KSZ
$\mathcal{C}_\ell$ /10^{-10}
ℓ
10
1
0.1
0.01
10^2
10^3
10^4



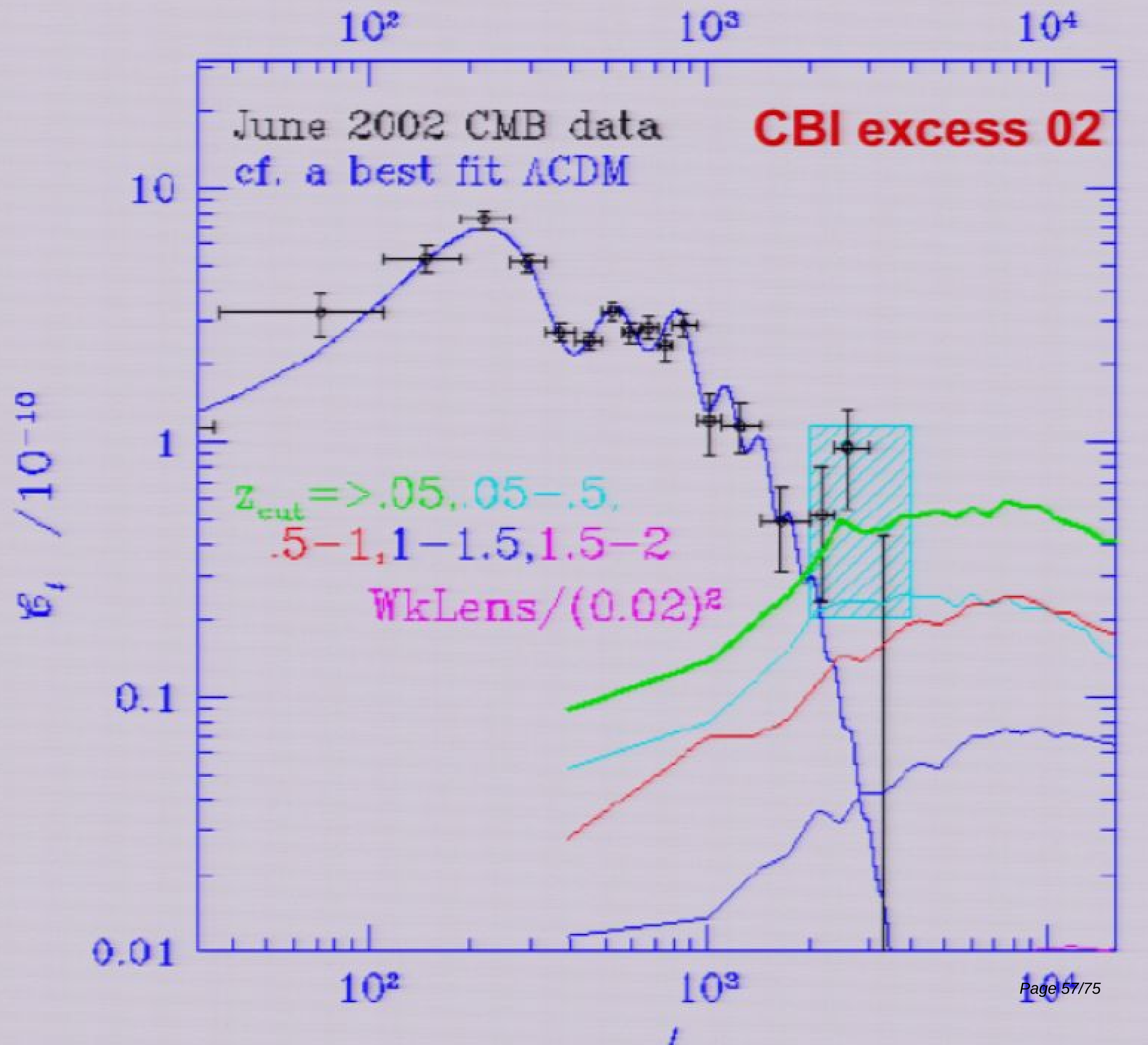
pass the CMB thru the cosmic web; CMB extra power??

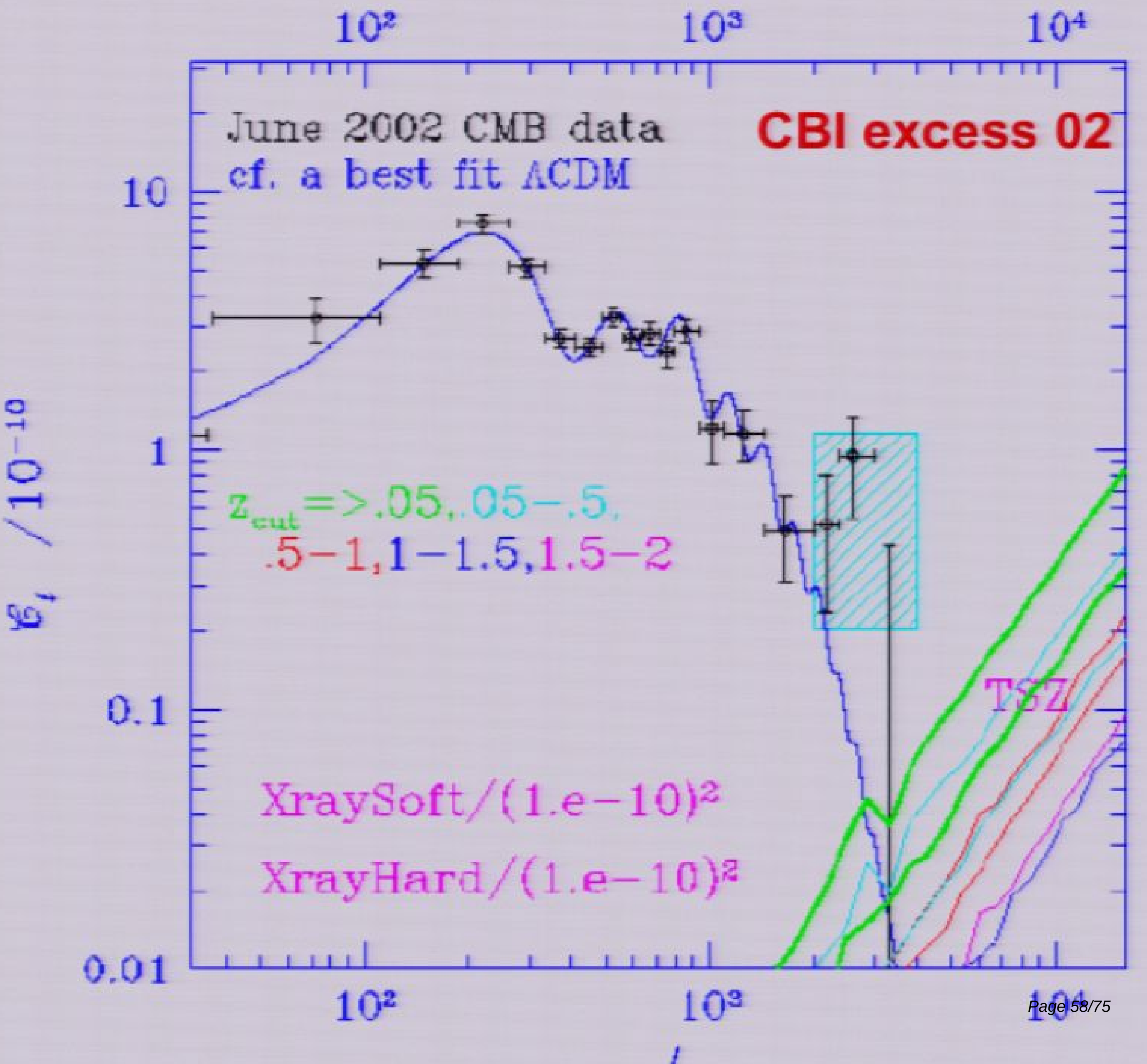


pass the CMB thru the cosmic web; CMB extra power??


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
TSZ
KSZ
$\mathcal{C}_\ell$ /10^{-10}
10
1
0.1
0.01
10^2
10^3
10^4

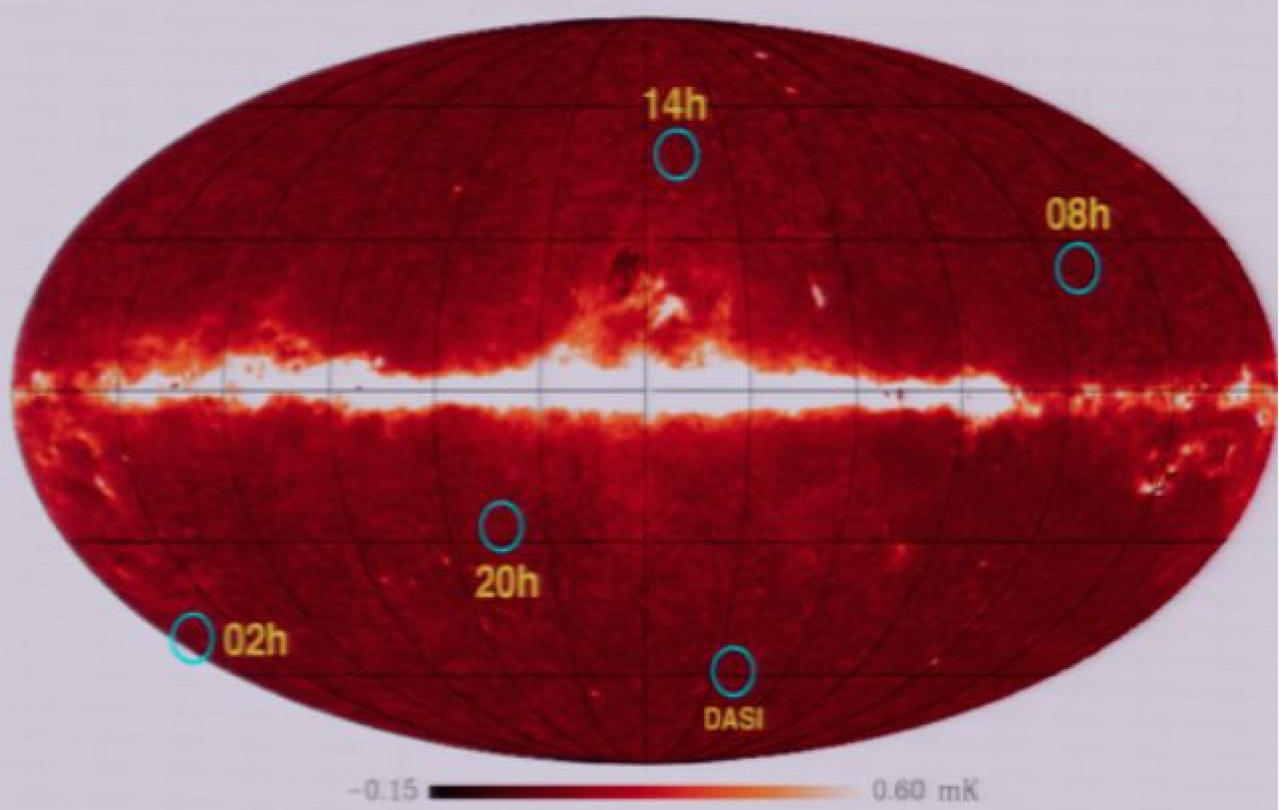
CBI excess 02

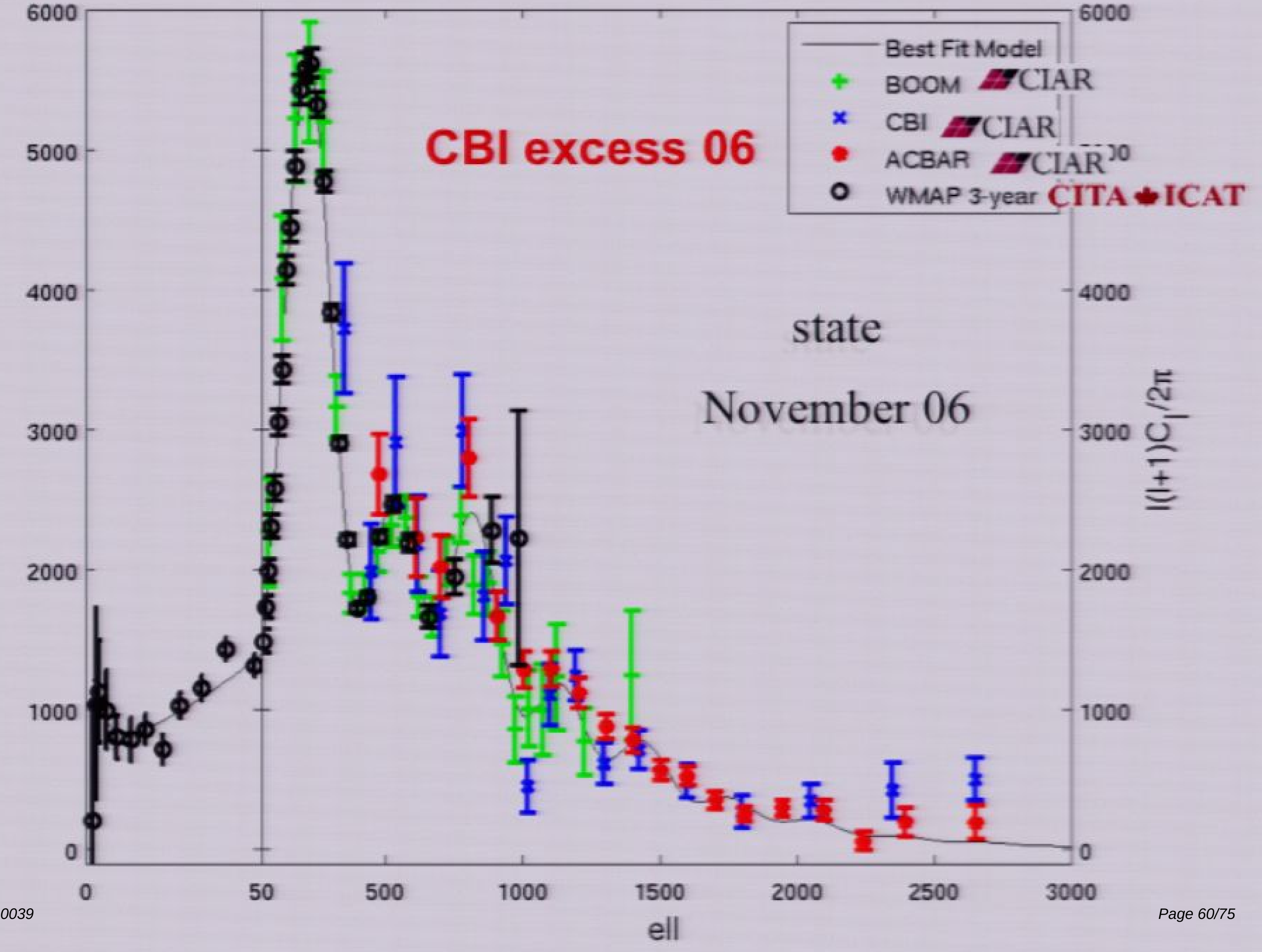



CBI excess 02
June 2002 CMB data
cf. a best fit ΛCDM
z_{cut}=>.05,.05−.5,
.5−1,1−1.5,1.5−2
XraySoft/(1.e−10)^2
XrayHard/(1.e−10)^2
TSZ
$\mathcal{C}_\ell$ /10^{-10}
10
1
0.1
0.01
10^2
10^3
10^4

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°², 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.



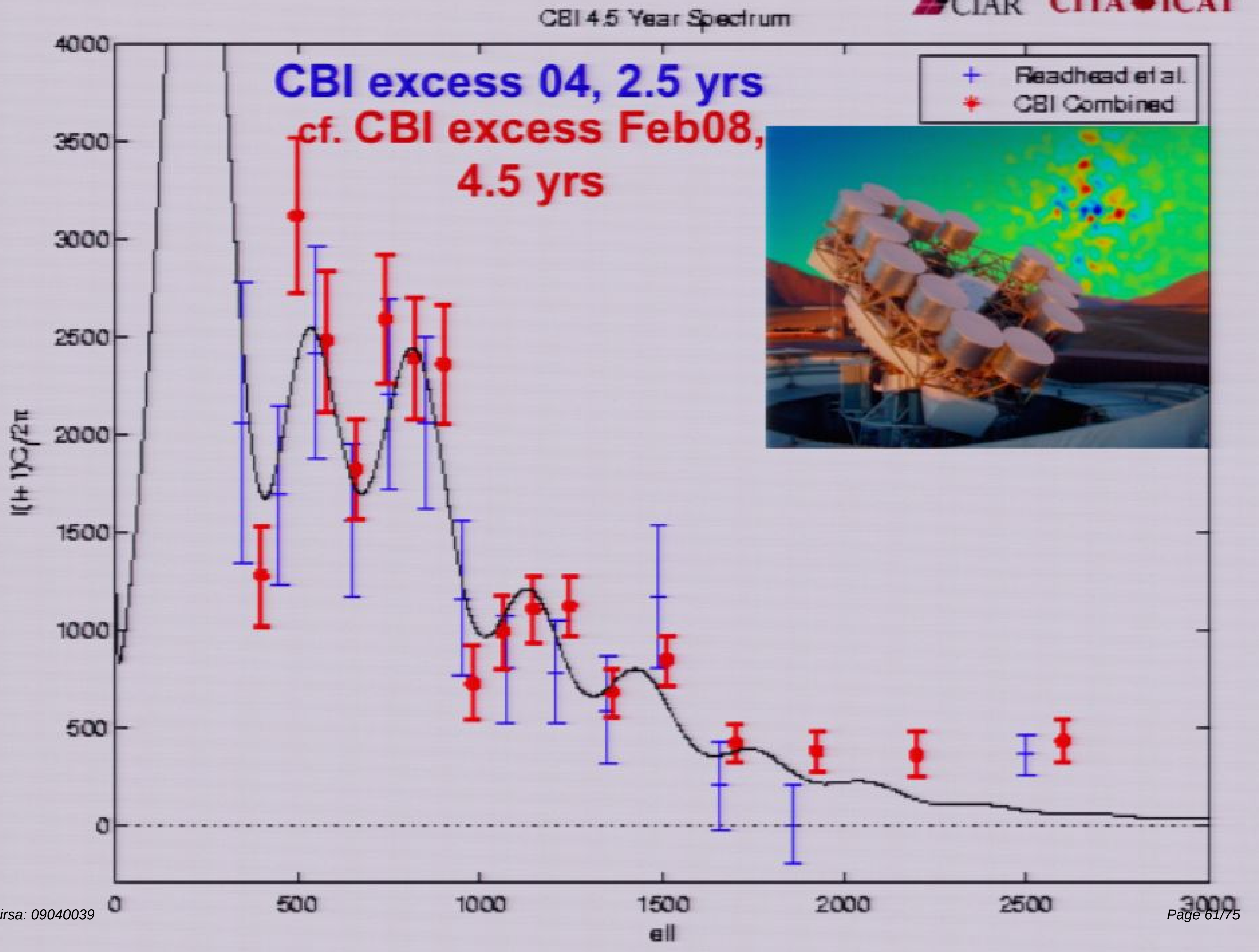


CBI excess 06

state

November 06

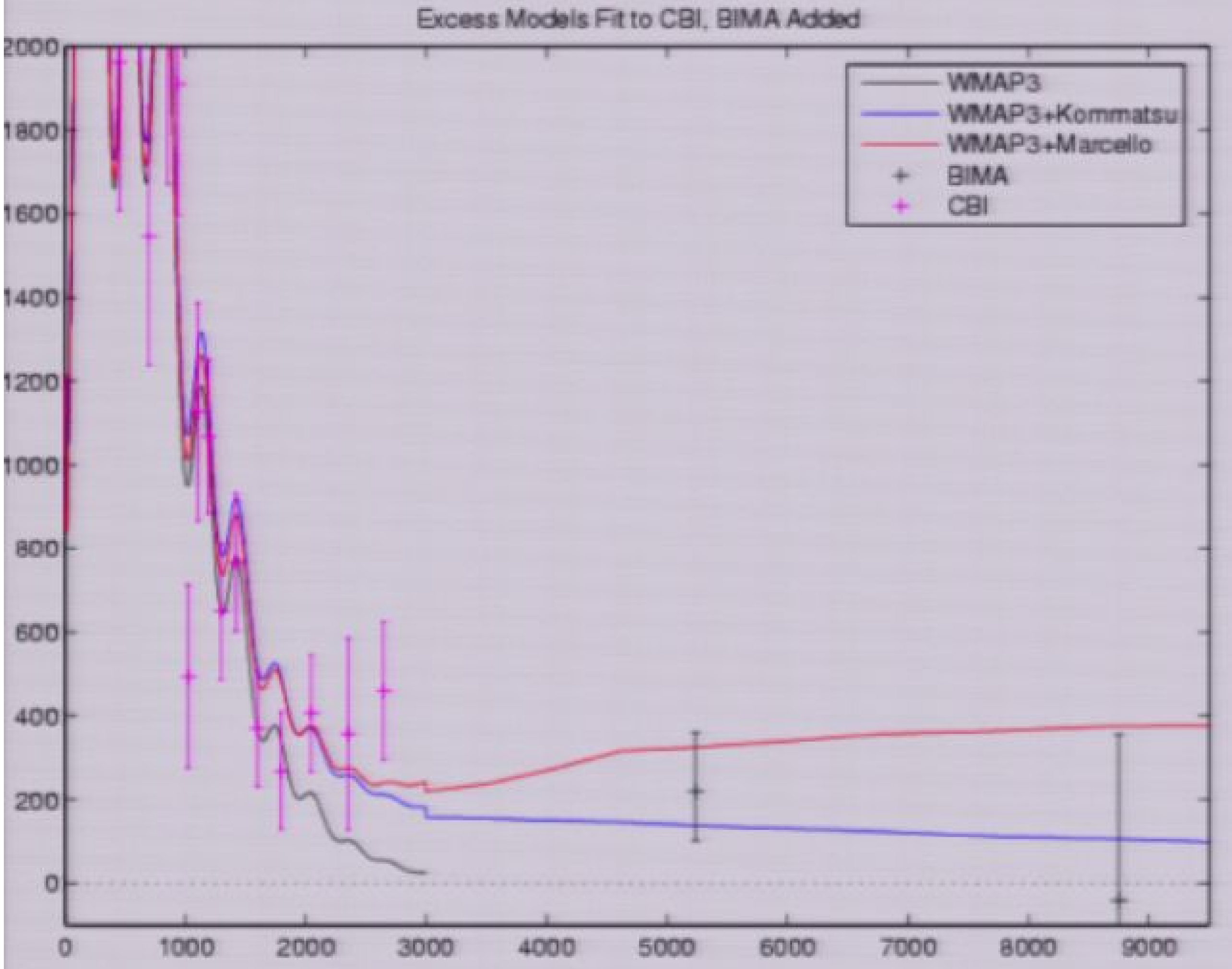
CIAR CITA ICAT



CBI excess 04, 2.5 yrs

cf. CBI excess Feb08, 4.5 yrs

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.

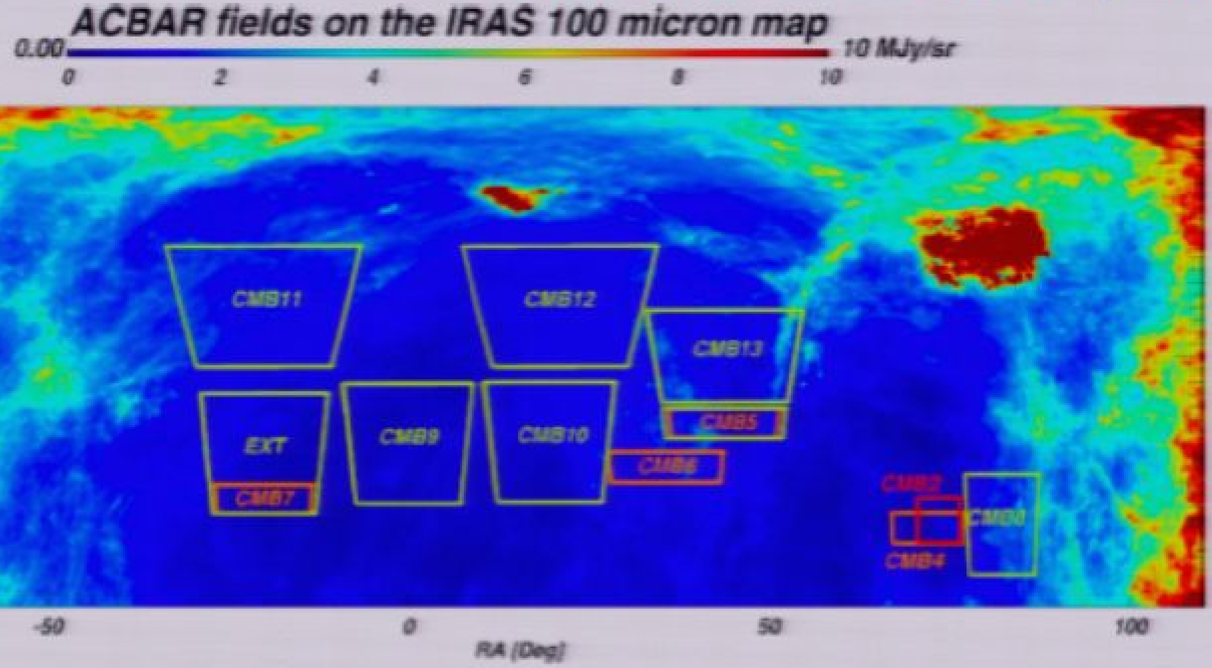
ACBAR08

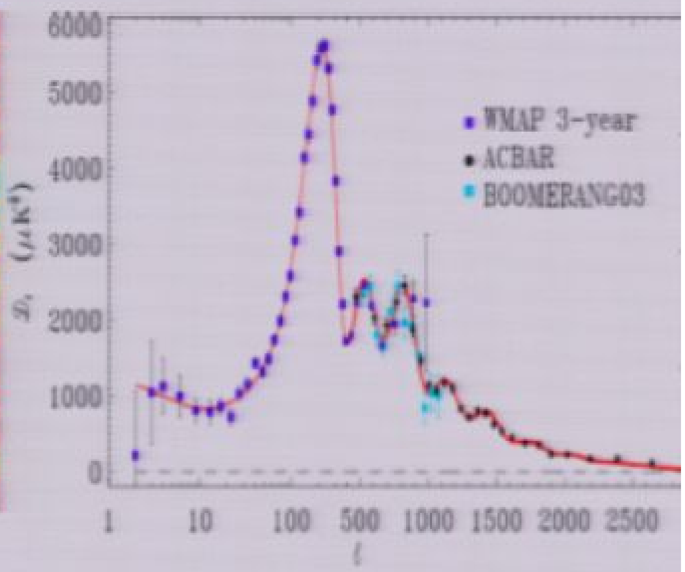
Reichardt et.al. astro-ph Thurs Jan 10

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

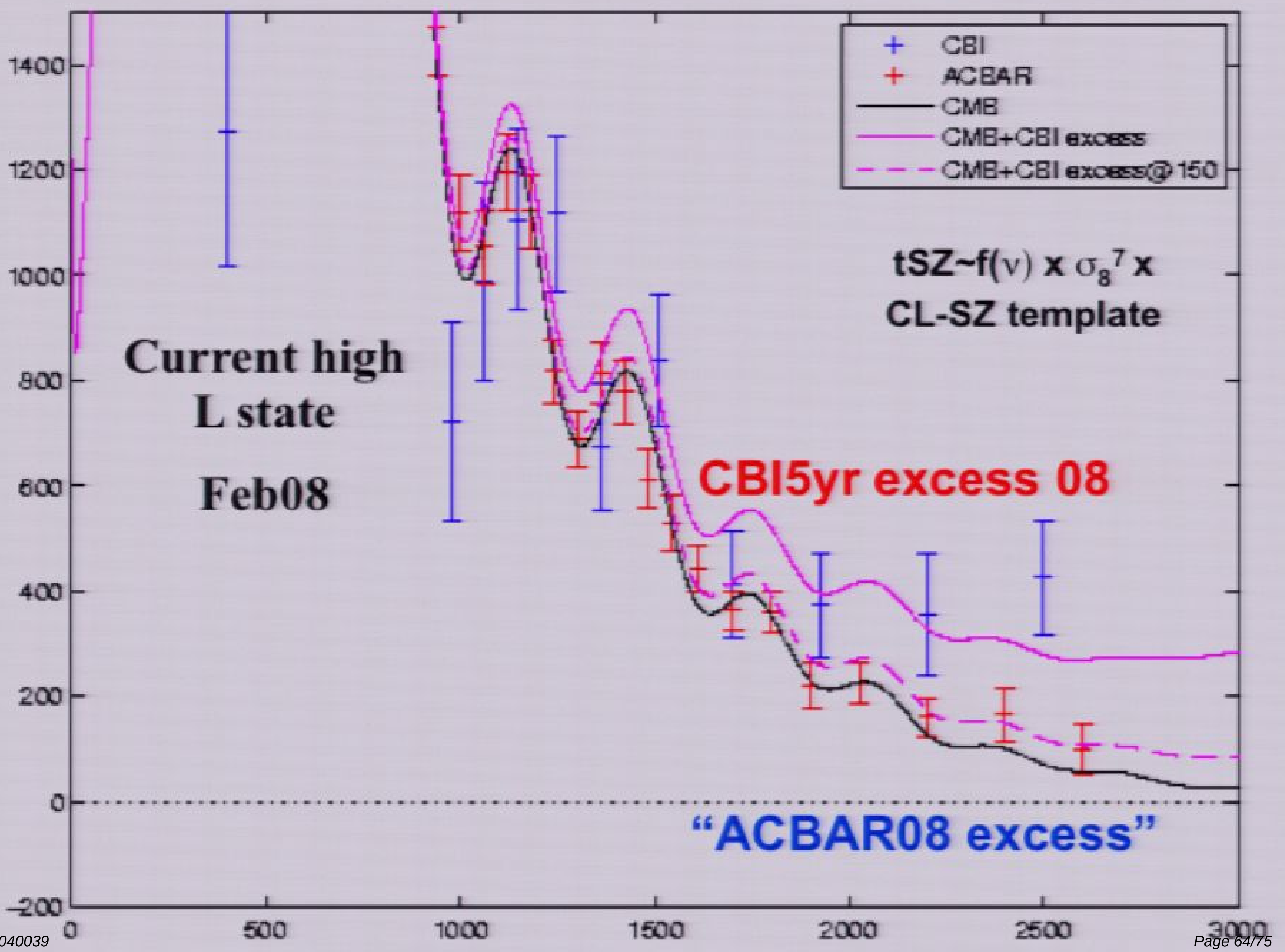

ACBAR fields on the IRAS 100 micron map



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



Current high L state

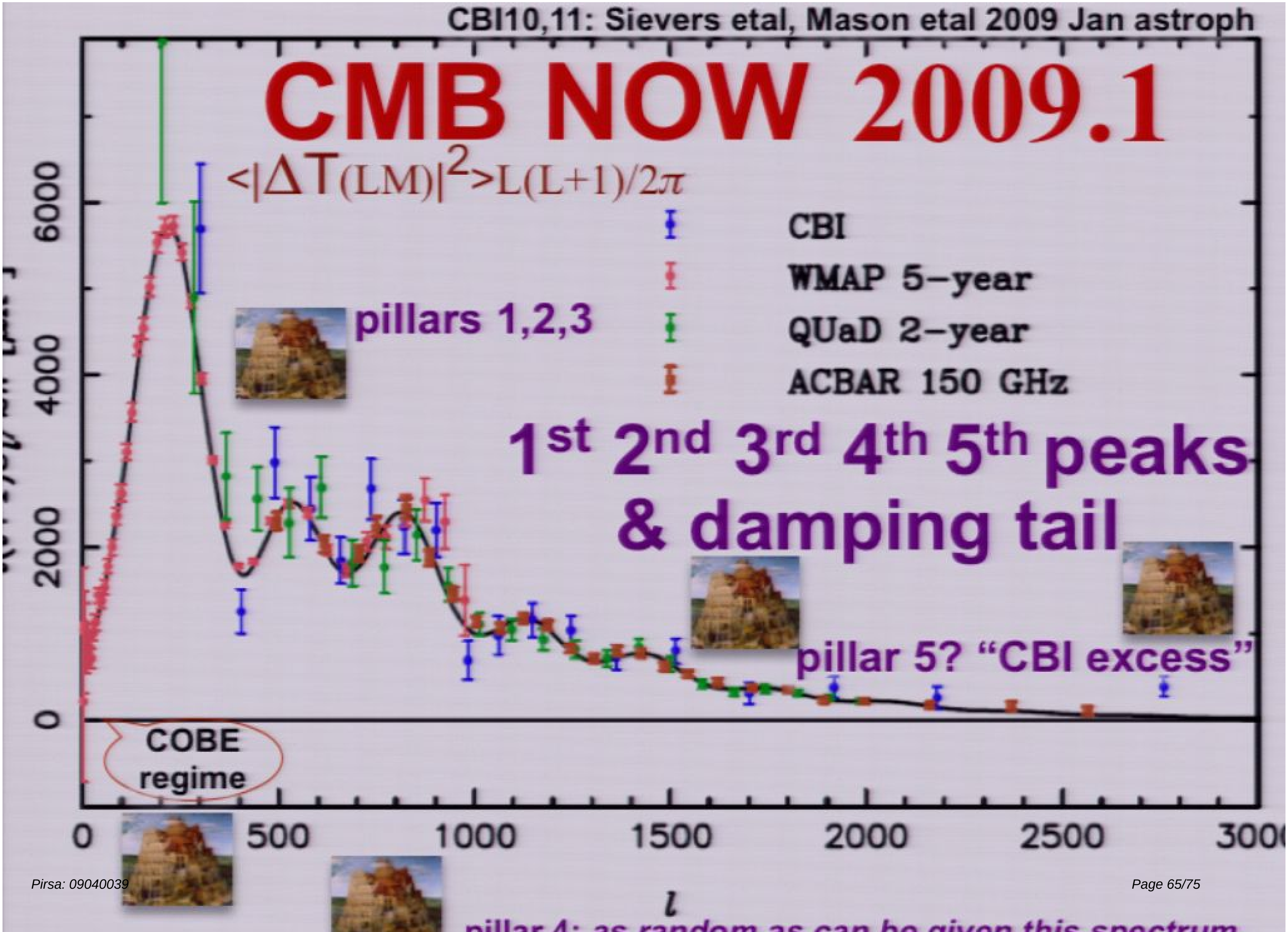
Feb08

tSZ~f(ν) x σ_8^7 x CL-SZ template

CBI5yr excess 08

"ACBAR08 excess"

marginalization critical to get n_s & $dn_s/d\ln k$: tSZ, radio, submm sources



CBI10,11: Sievers etal, Mason etal 2009 Jan astroph

CMB NOW 2009.1

$<|\Delta T_{(LM)}|^2>L(L+1)/2\pi$

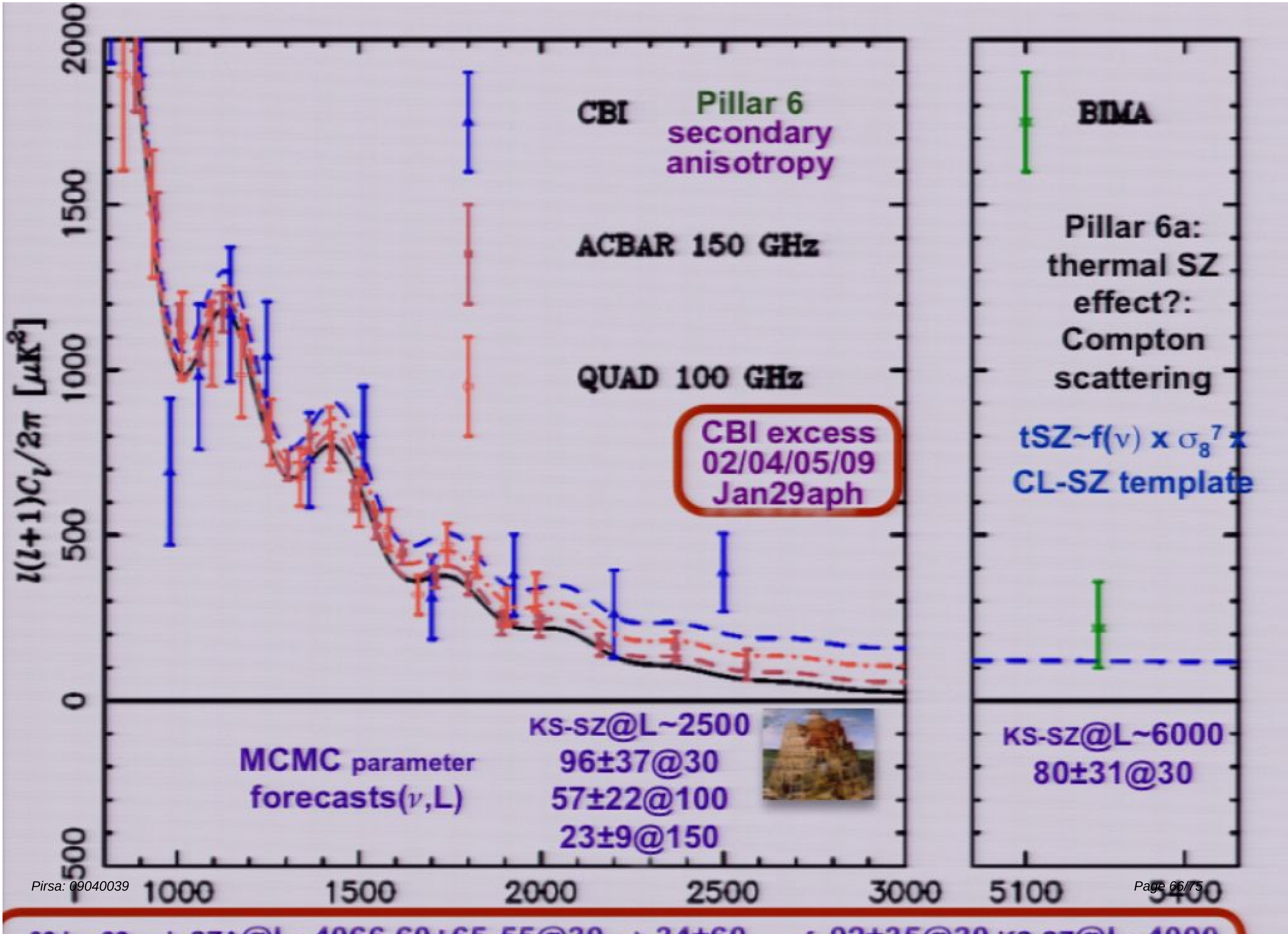
pillars 1,2,3

1st 2nd 3rd 4th 5th peaks
& damping tail

pillar 5? “CBI excess”

COBE
regime

pillar 4: as random as can be given this spectrum



Pillar 6
secondary
anisotropy

CBI excess
02/04/05/09
Jan29aph

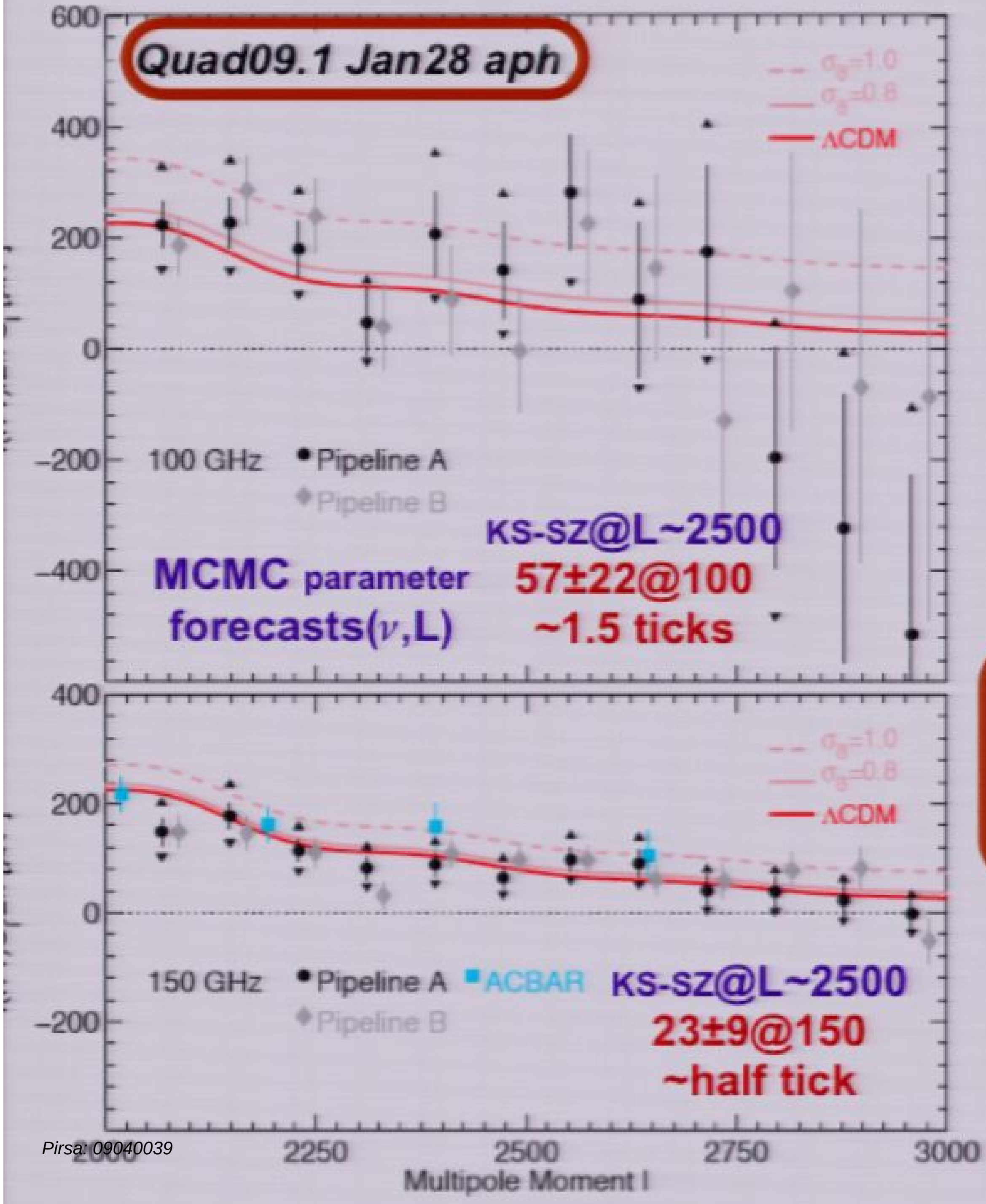
Pillar 6a:
thermal SZ
effect?:
Compton
scattering

tSZ~f(ν) x $\sigma_8{}^7$ x
CL-SZ template

MCMC parameter
forecasts(ν,L)

KS-SZ@L~2500
96±37@30
57±22@100
23±9@150

KS-SZ@L~6000
80±31@30



Quad09.1 Jan28 aph

KS-SZ@L~2500
57±22@100
~1.5 ticks

MCMC parameter forecasts(ν,L)

KS-SZ@L~2500
23±9@150
~half tick

Pillar 6
secondary anisotropy

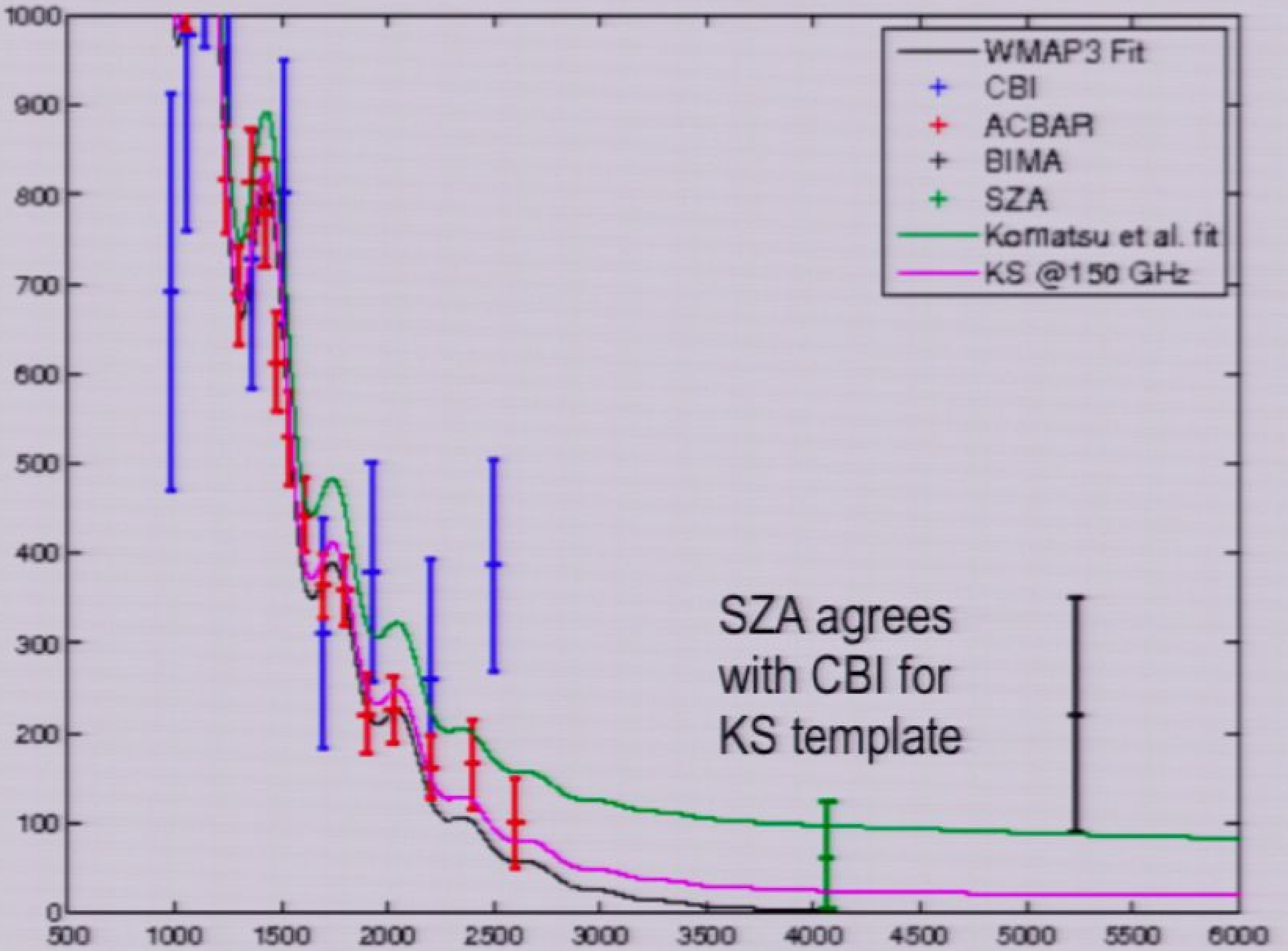
CBI excess
02/04/05/09.1

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



SZA agrees
with CBI for
KS template

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)

ecause of core overcooling and overproduction of stars, we decided to wait for a ubgrid 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.

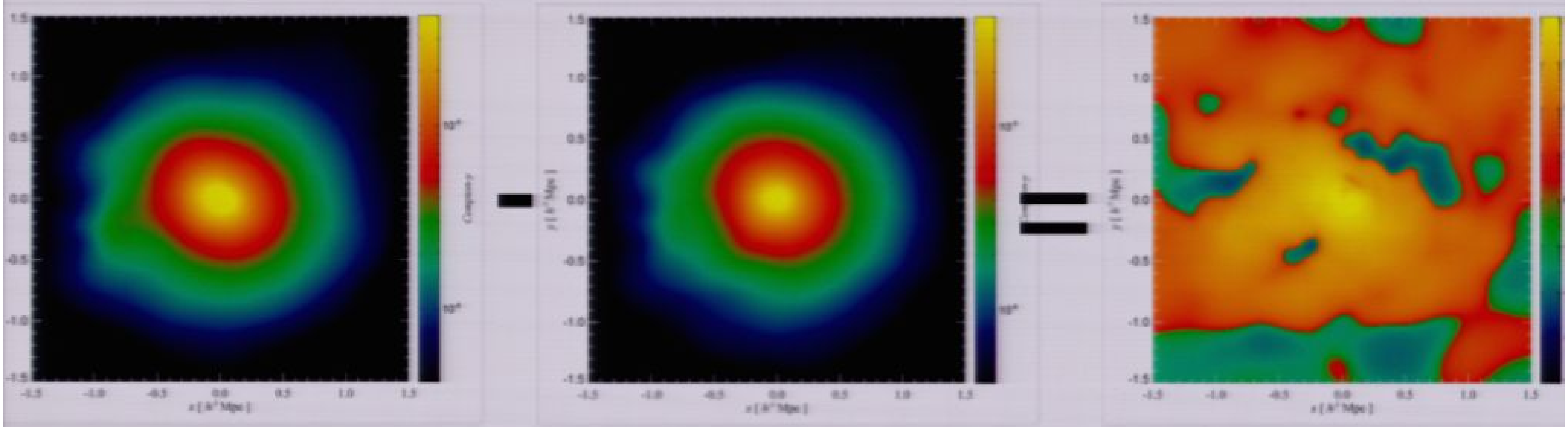
conclusion in 2009 is **silly us:** there will be no universal panacea to cure all cluster cores: episodic and cluster-history-dependent, if observables are overly sensitive to this, then we become gastrophysical weather reporters and not cosmological gold-sample miners delivering parameter purity.

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

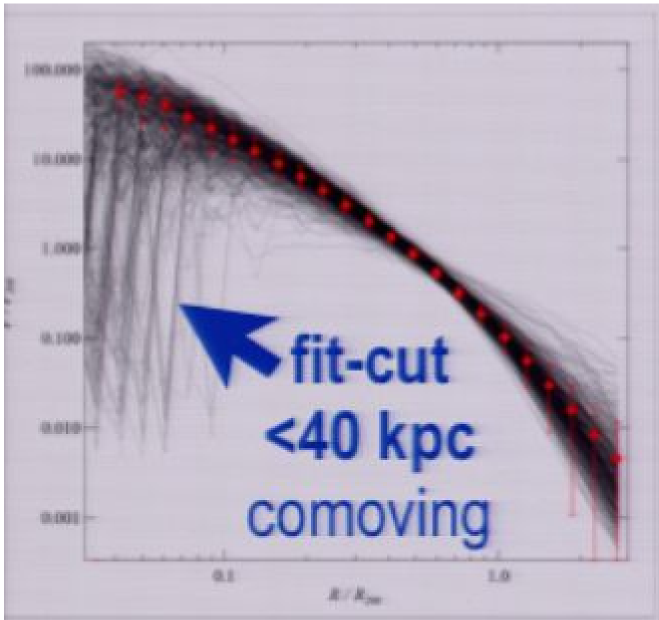
CITA SZ with feedback: Battaglia, Bond, Pfrommer & Sievers 2009

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

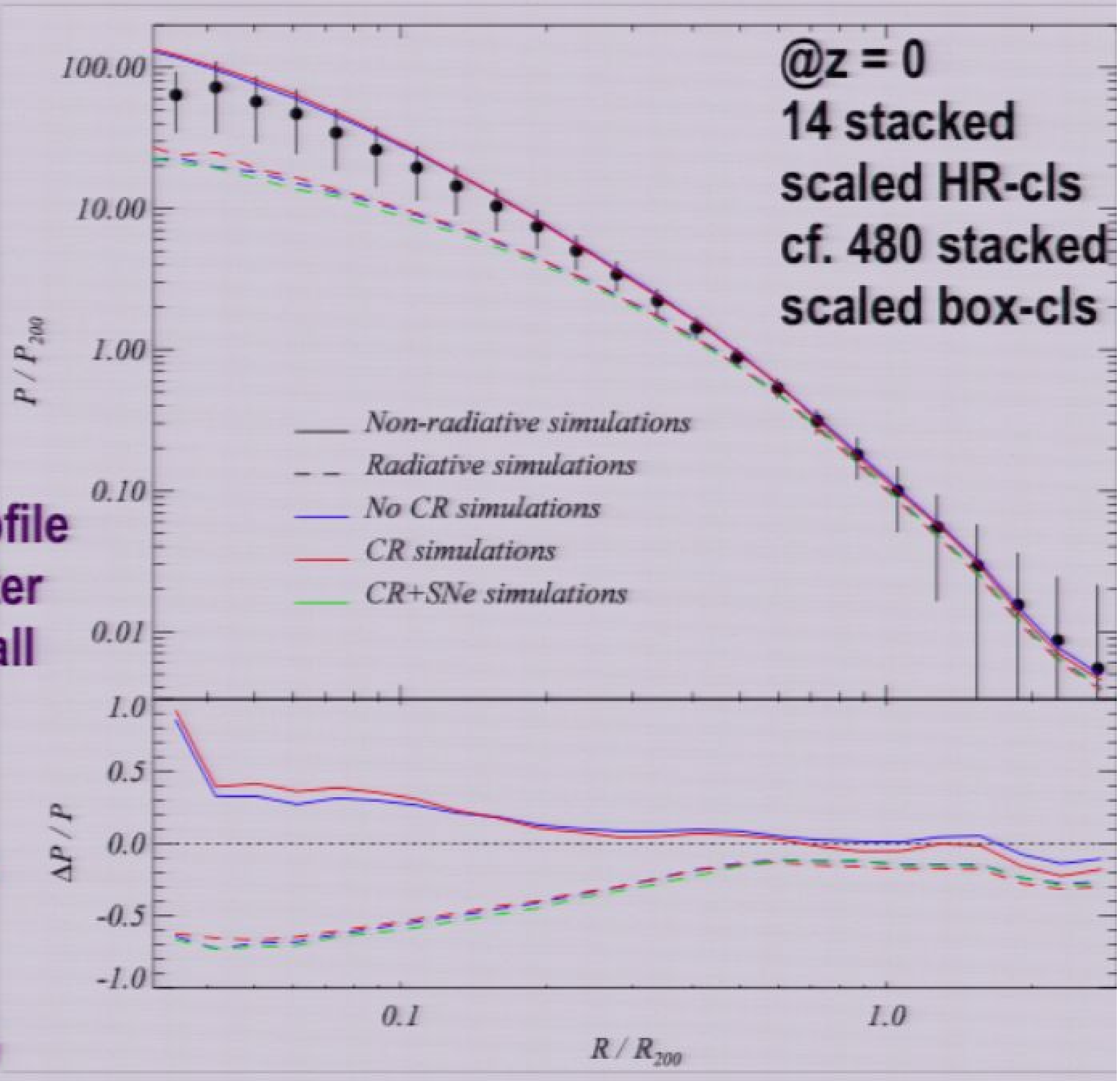


fit-cut
<40 kpc
comoving

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

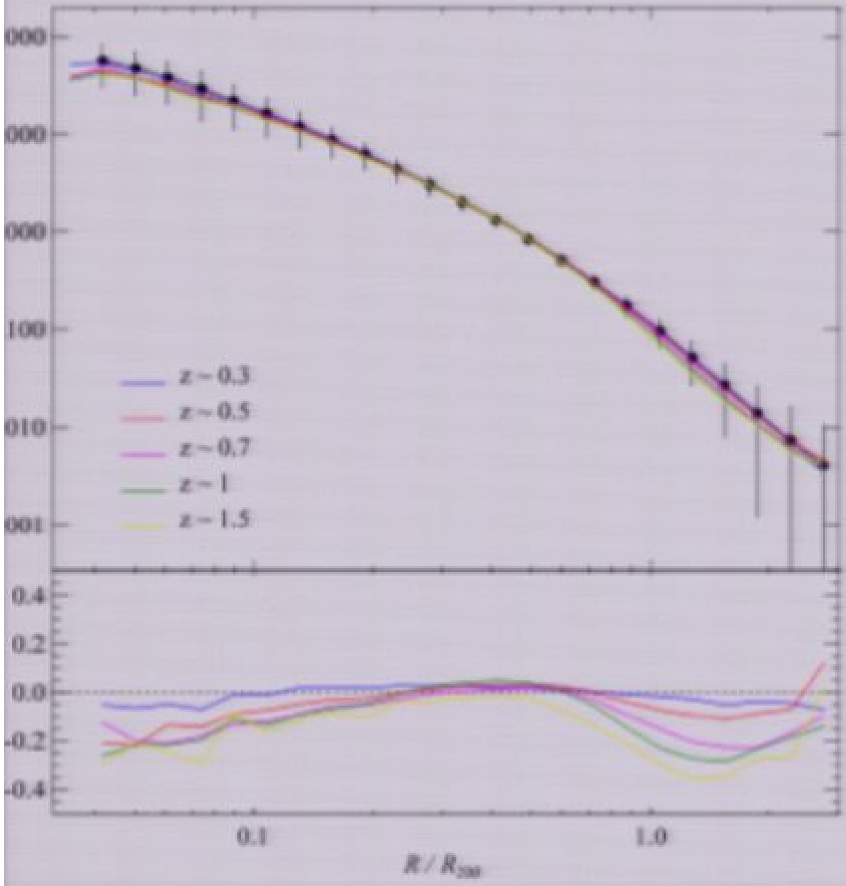
$$p(r)V_{norm}=$$
$$[PV]\,(1+r/r_c)^{-3\beta}$$

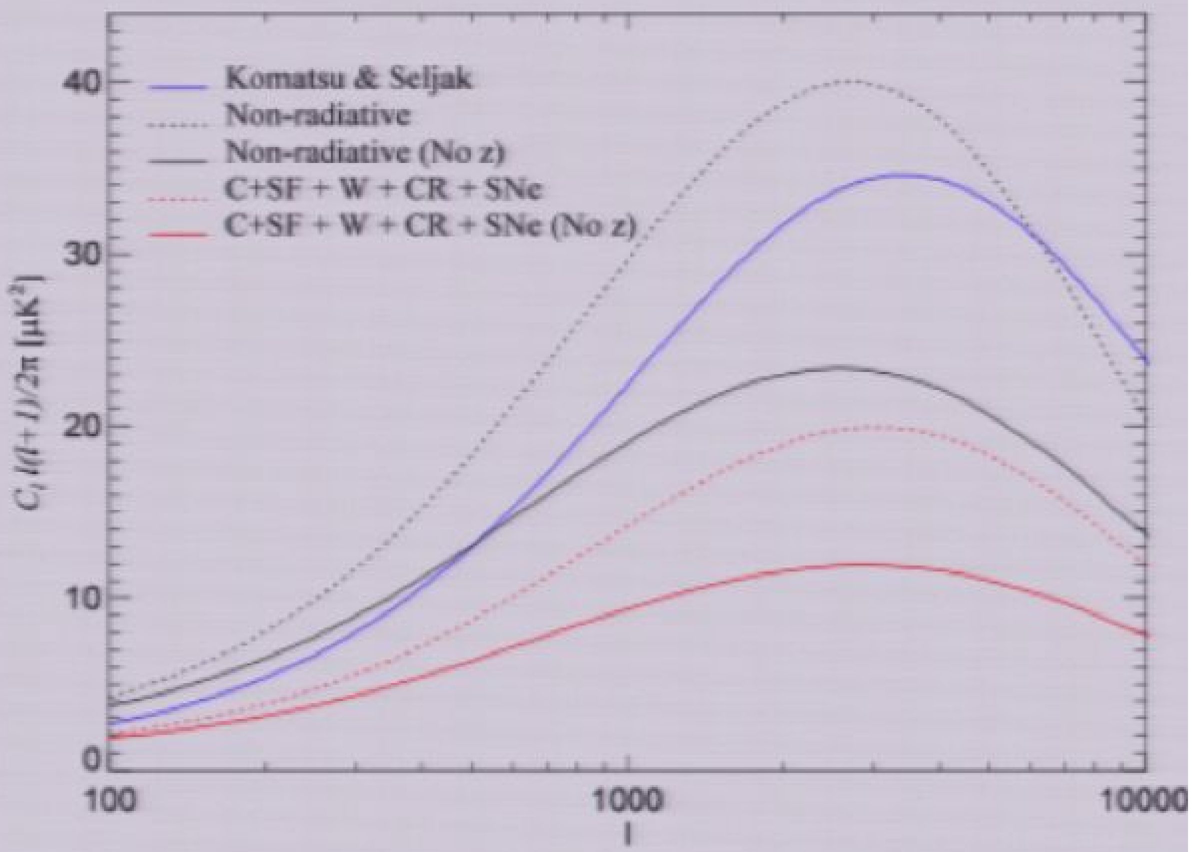
$$Y(z) \propto PV,\ \beta(z),$$
$$c_g(z) = r_{200}/r_c$$



@z = 0
14 stacked
scaled HR-cls
cf. 480 stacked
scaled box-cls

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





The SZ & cluster frontier

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

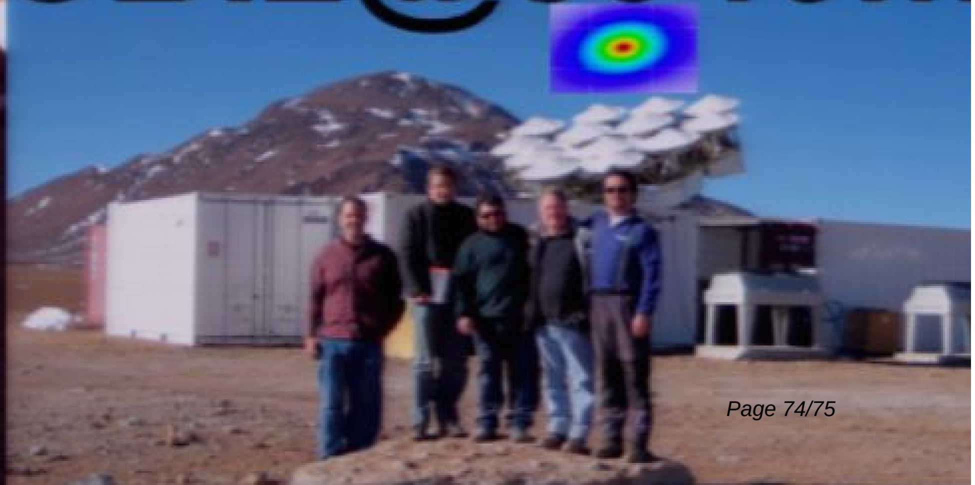
but non-equilibrium, non-thermal cluster complexities (*e.g.*, cosmic ray pressure, merging, inhomogeneous entropy injection, cooling flow avoidance, AGN feedback) must be fully addressed for high precision on other parameters to be realized. Improved theoretical CL templates and better development of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



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