CIFAR
CANADIAN INSTITUTE FOR ADVANCED RESEARCH

Dick Bond

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

MOCK*ing* HEAVEN

Cosmic Web cross-correlations in theory & in observations

ANALECTS of CONFUSE-I-US: on LSS

Super-duper LSS & the Super-WEB aka the gravitational potential web = 3-curvature web

cf. the density web= strain web

$$d\mathbf{X}^j/a = (\mathbf{V}^i - H\mathbf{X}^i)/a\, dt + \mathbf{e}_J^j(r,t)d\mathbf{r}^J \qquad \mathbf{e}_J^j \equiv exp(\boldsymbol{\varepsilon})_J^j$$

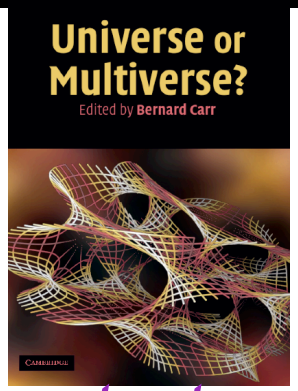
$\mathbf{e}$= *drei*bein, triad, deformation tensor, Lagrangian-space metric $\mathbf{e}\mathbf{e}^\dagger$

$\boldsymbol{\varepsilon}$=strain tensor $\propto$ tidal tensor $\Rightarrow$ *ln* $\rho/\langle\rho\rangle$= -Trace $\boldsymbol{\varepsilon}$

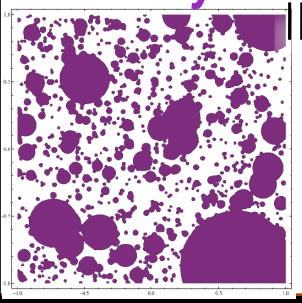
Scale space: resolution = the 5th dimension

ultra-Ultra Large Scale Structure of the Universe

Horizons: the ultimate-speed constraint on light & information



quantum tunnels = bubbly-U



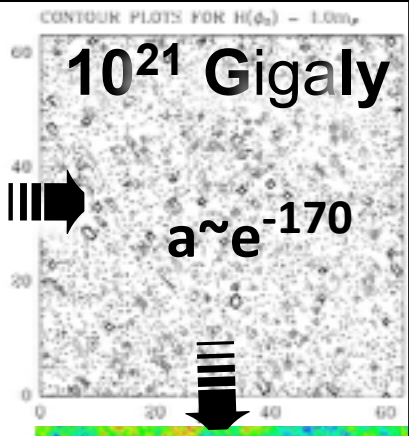
END
a future DE-Void

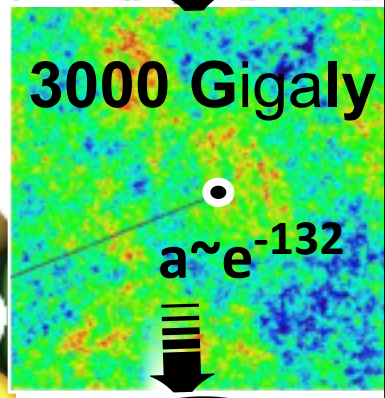
$a \sim e^{+++}$

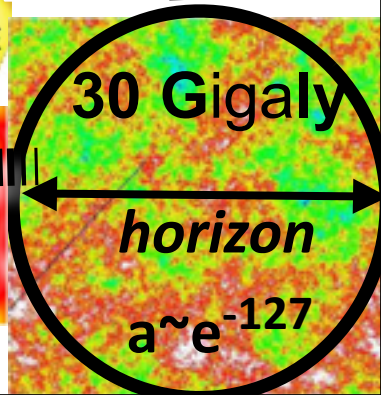
UNIVERSE

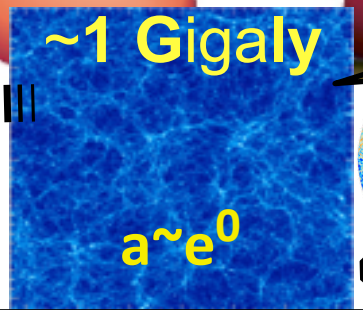
a-bubbles

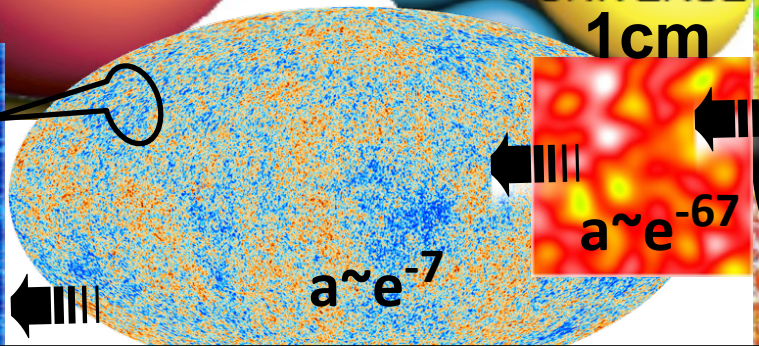
our horizon







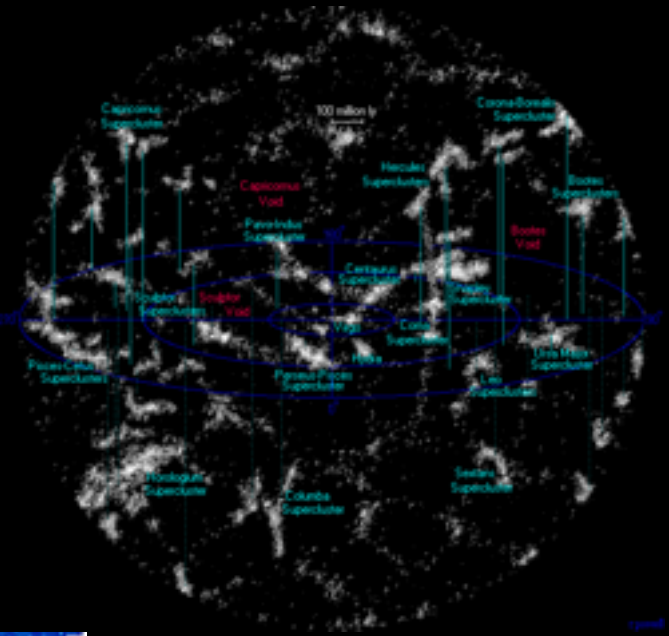




Simulation of the 7^{+} numbers

begets the **Cosmic Web** of clusters

now a~1 & galaxies then a~1/4



SIMPLICITY to COMPLEXITY under Gravity

filament

void

cluster

supercluster

~ billion light years

state of the art simulations
a~1 to 1/1.1

ordinary matter
dark matter
dark energy

1st light simplicity

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

Surveys of the Web(z)

the LSS data bases for

cross-correlations

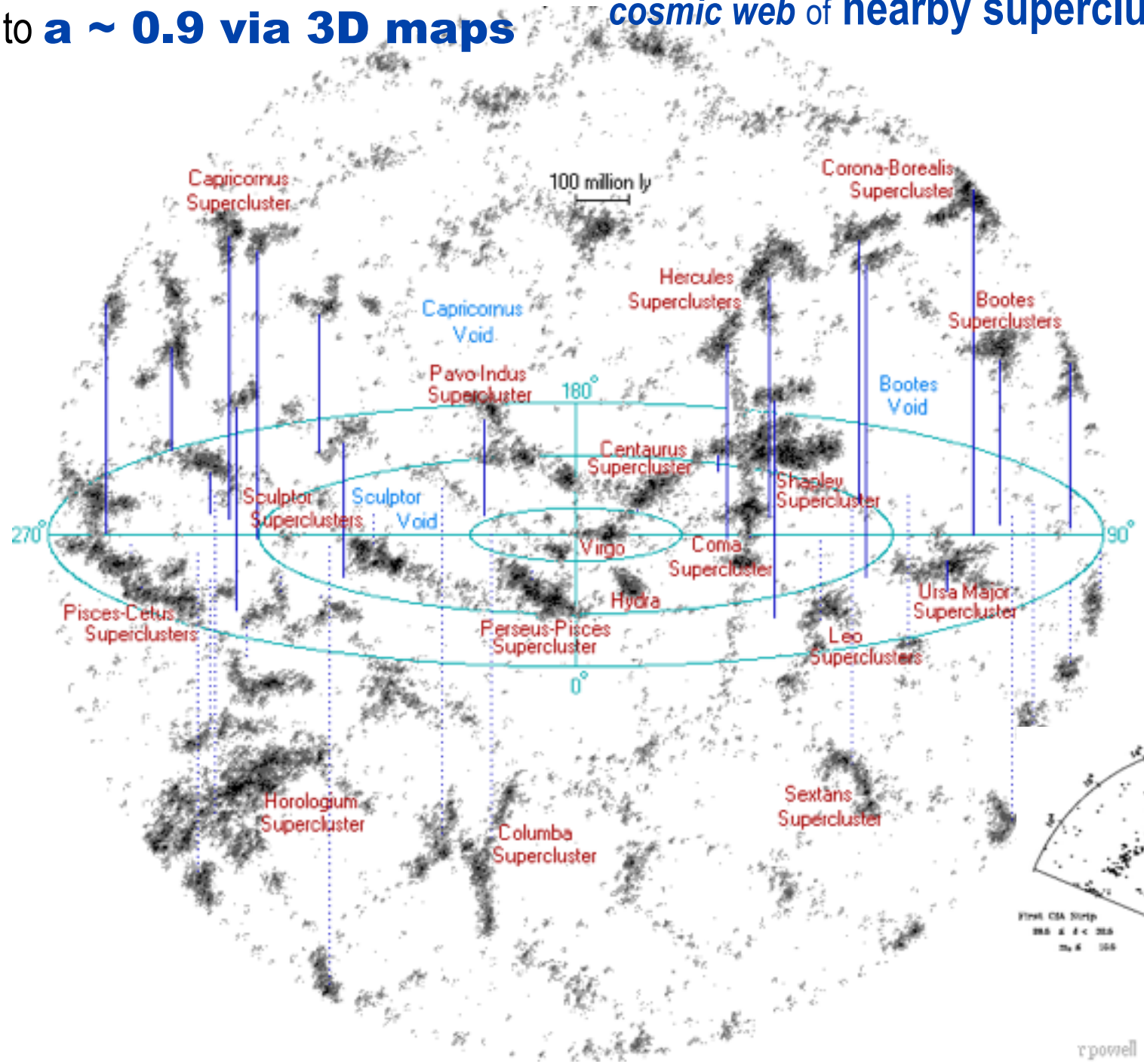
optical z-surveys, weak lensing surveys (CFHT, Euclid,..), small hi-z galaxy surveys (Ly break ...), sub-mm surveys (SCUBA, Blast, Herschel), radio (NVSS, FIRST, CHIME, .., SKA, ..)

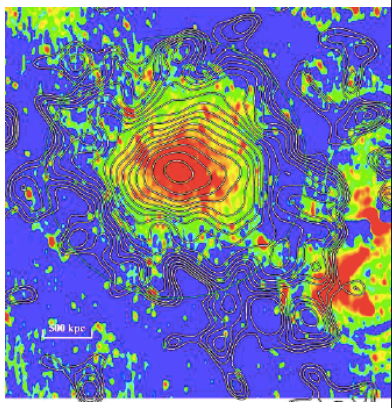
to **a ~ 0.9 via 3D maps**

cosmic web of **nearby superclusters < 1 Giga*ly***

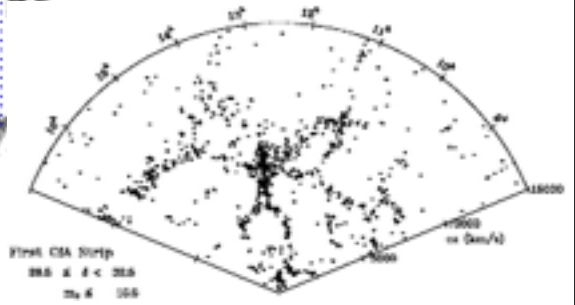
$a=e^{0}=1$ now *to*

$a \sim e^{-0.1}=1/1.1$



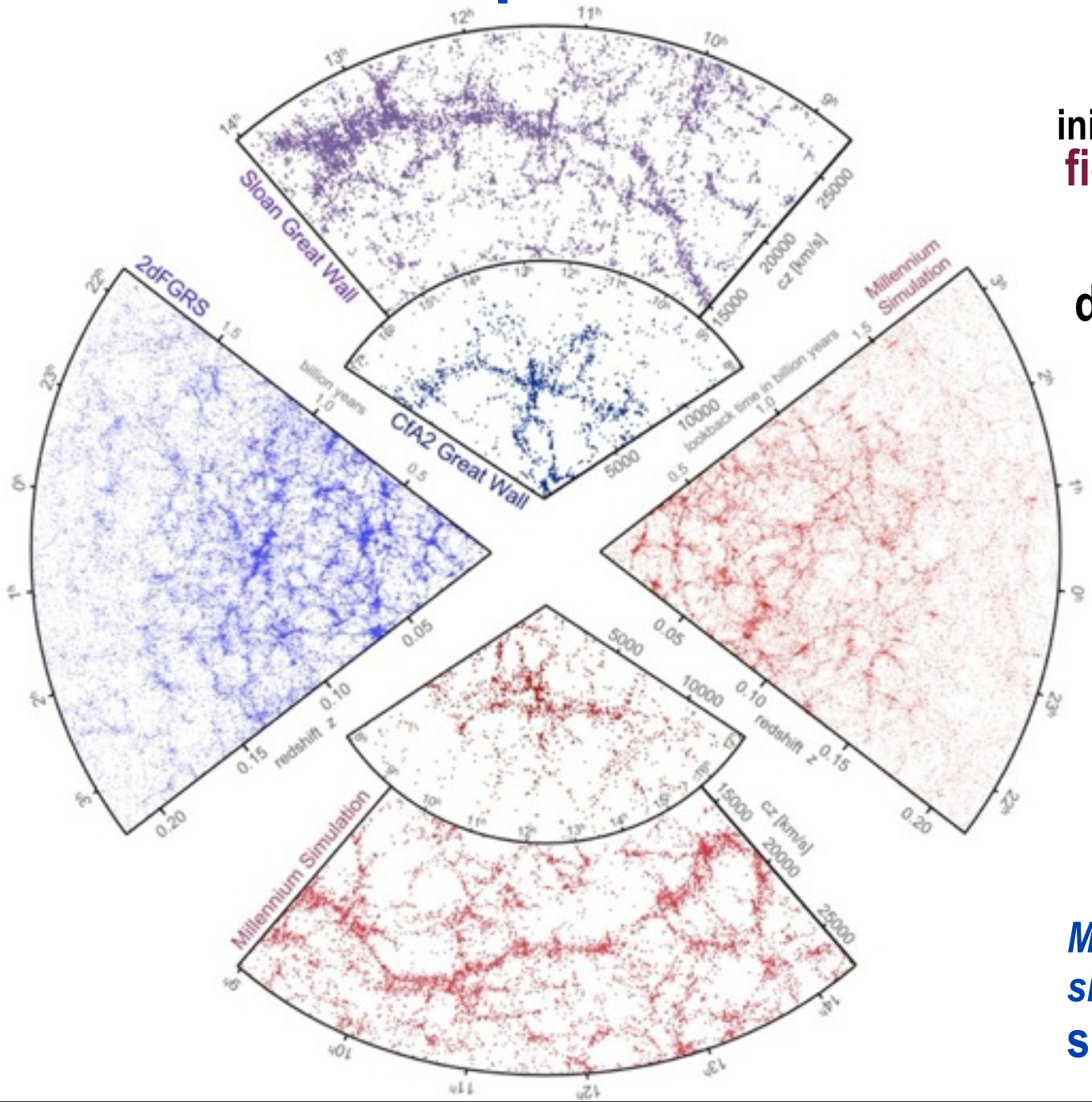


COMA cluster
(100 Mpc, z=0.023)
$M_{bind} \sim 0.7 \times 10^{15}\ M_{\odot}$



r powell

to **a ~ 0.8 via 3D maps**



Collisionless matter

Simulation of the initial **Gaussian random field** characterized by

7^{+} numbers

does indeed beget the

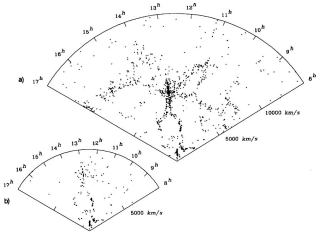
Cosmic Web

Millenium simulation web site "propaganda" on

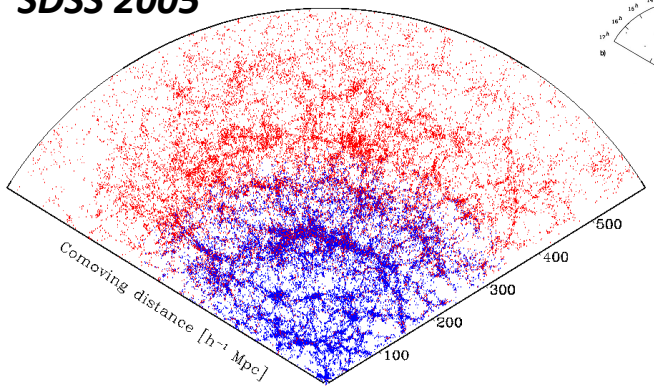
sims *cf.* **z-space data**

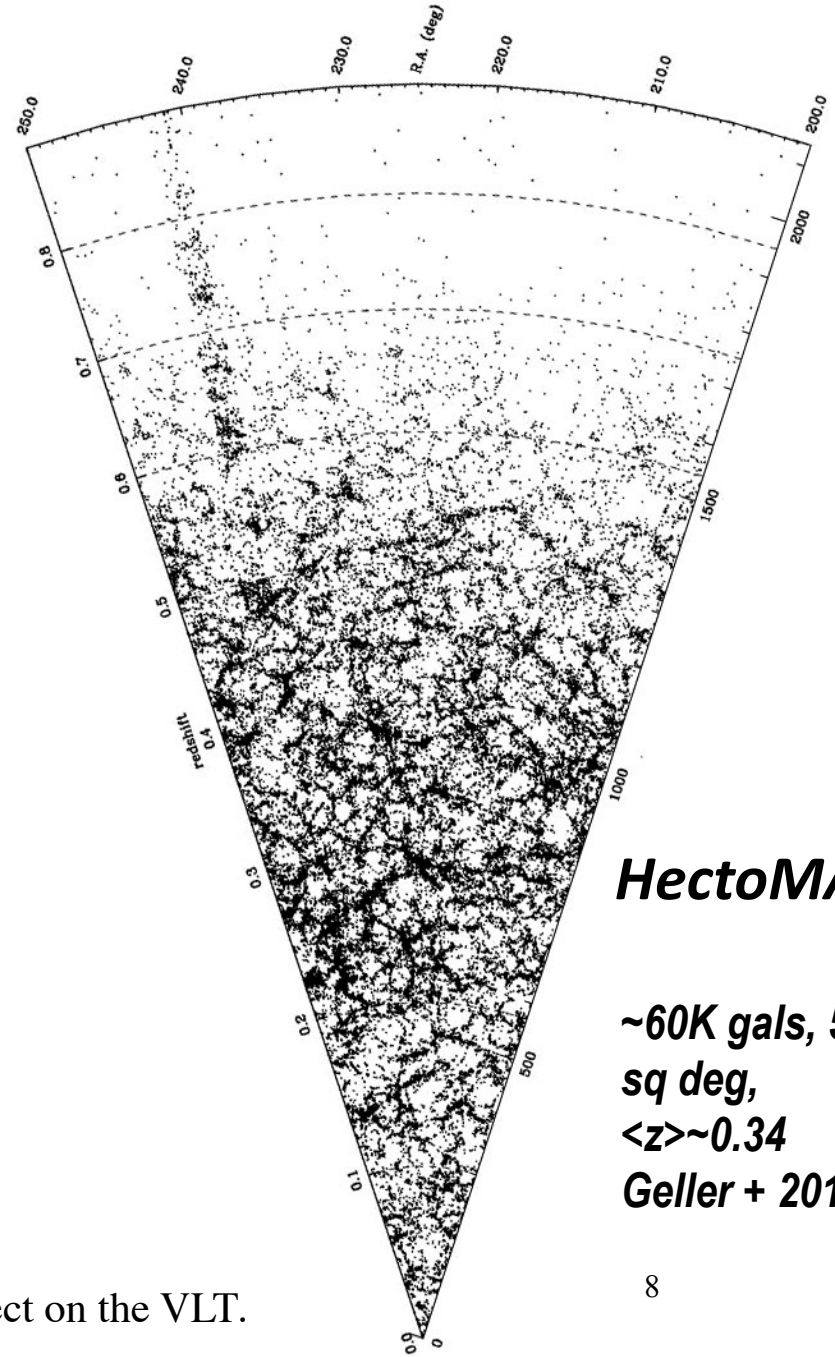
and to **a ~ 0.6 via 3D maps**

CfA 1986



SDSS 2005





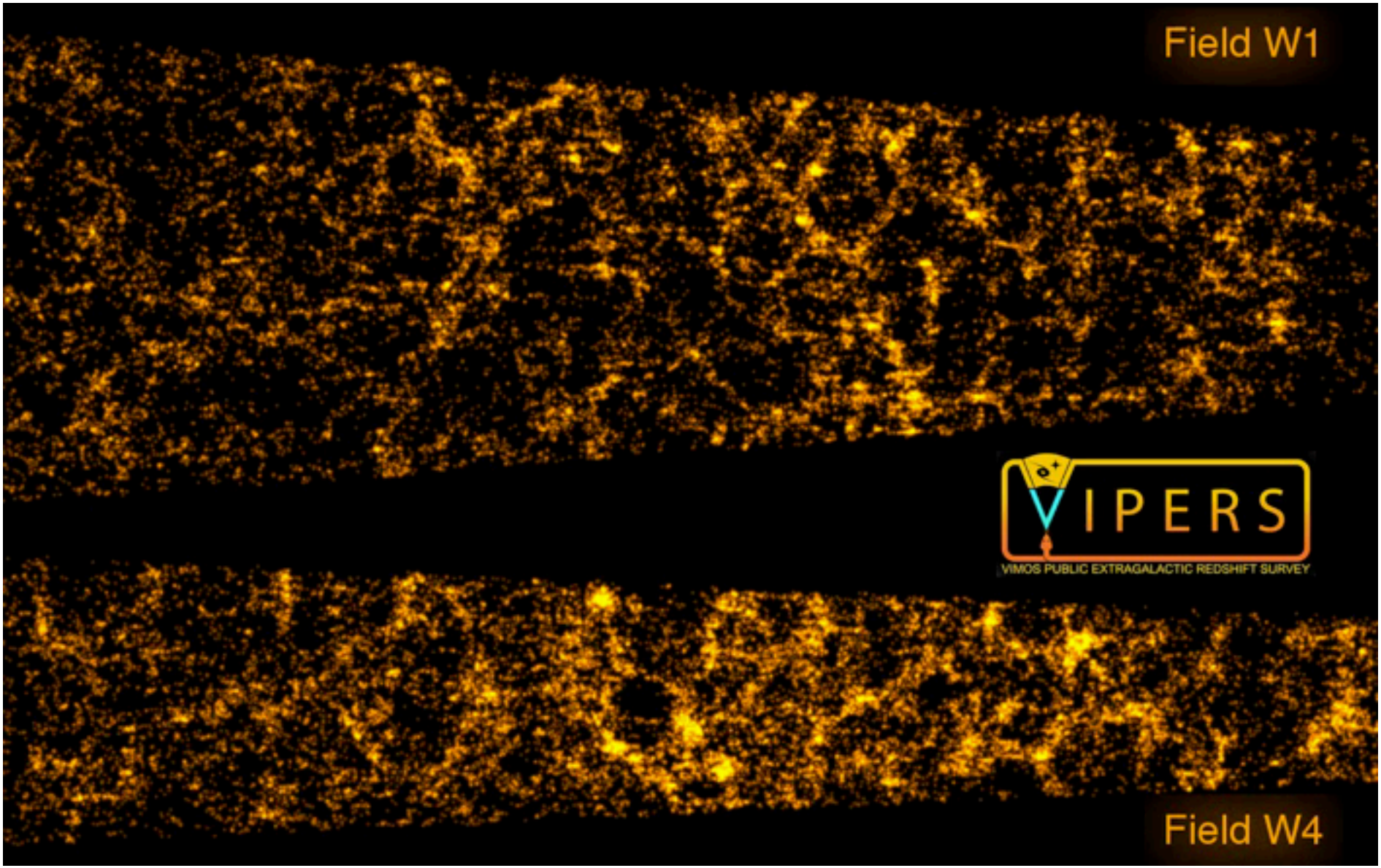
HectoMAP

~60K gals, 50 sq deg, <z>~0.34 Geller + 2013..

- AAT 2dF:
- 2dF QSO redshift survey
- 2 MASS: 2 micron all sky survey
- The VLA FIRST
- ISO nearby Abell cluster survey
- EDisCS: ESO distant clusters survey
- LCRS: The Las Campanas Redshift Survey
- ESP: ESO Slice Project
- CNOC: Canadian
- The CfA redshift survey
- SDSS: Sloan Digital Sky Survey
- DEEP2: deep extragalactic evolutionary probe
- The VIRMOS-VLT Deep Survey (VVDS) project on the VLT.
- The 6dF GS

and to **a ~ 0.7 to 0.5 via 3D maps**

VIPERS using VIMOS@VLT release Oct 4, 2013, 57K redshifts, z=0.45 to z=0.95, 6e7 (h^-1Mpc)^3, higher sampling than LRG BAO surveys Guzzo+13 cover CFHTLS wide fields, 64% done, 24 sq deg



and to the **big f_{sky} future**

Table 4. Summary of current or planned BAO capable spectroscopic surveys.

Instrument	Telescope	Ref	Nights/ year	No. Galaxies	sq deg	Ops Start	
SDSS I+II	APO 2.5m	1	dedicated	85K LRG	7600	2000	KC
Wiggle-Z	AAT 3.9m	2	60	239K	1000	2007	
BOSS	APO 2.5m	3	dedicated	1.4M LRG + 160K Ly-α	10000	2009	K
HETDEX	HET 9.2m	4	60	1M	420	2014	
eBOSS	APO 2.5m	-	dedicated	600K LRG + 70K Ly-α	7000	2014	KC
MS-DESI	NOAO 4m	5	tbd	32M + 2M Ly-a	18000	2018	KC
SUMIRE PFS	Subaru 8.2m	6	20	4M	1400	2018	JT
4MOST	VISTA 4.1m	7	dedicated	6-20M bright objects	15000	2019	
EUCLID	1.2m space	8	dedicated	52M	14700	2021	

Galaxy And Mass Assembly survey (GAMA) ~375K galaxies in the local Universe over a 360 sq deg

The Primus survey of galaxies at z~1.
Pan-STARRS:

C=china, not canada

UKIRT infrared deep sky survey

DES: the Dark Energy Survey
LSST: the large-aperture synoptic survey telescope

from MS-DESI proposal, MWhite home page

HALOs in the Web(z)

SIMULATIONS

N-body cf. Hydro

Dark Matter

Gas

Stars

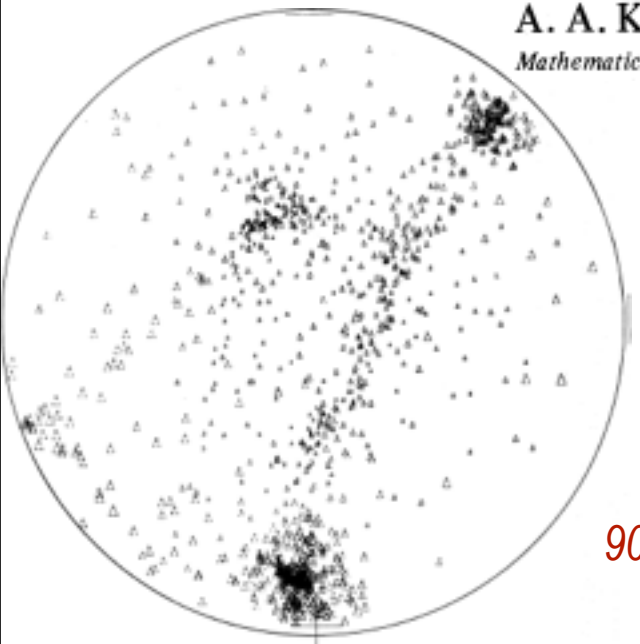
Black Holes

FEEDBACK

A. A. Klypin and S. F. Shandarin *The Keldysh Institute of Applied Mathematics, Academy of Sciences of USSR, Miusskaja Sq. 4, Moscow 125047, USSR*

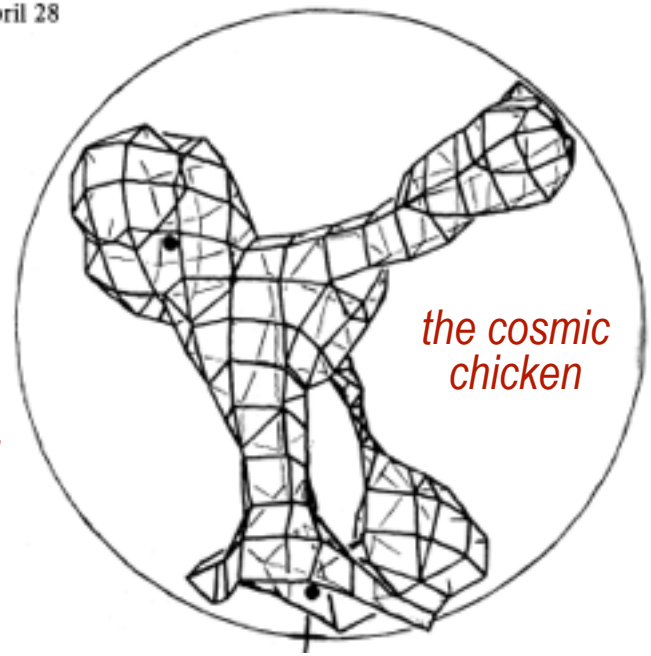
Received 1982 November 15; in original form 1982 April 28

3D numerical model of the Universe

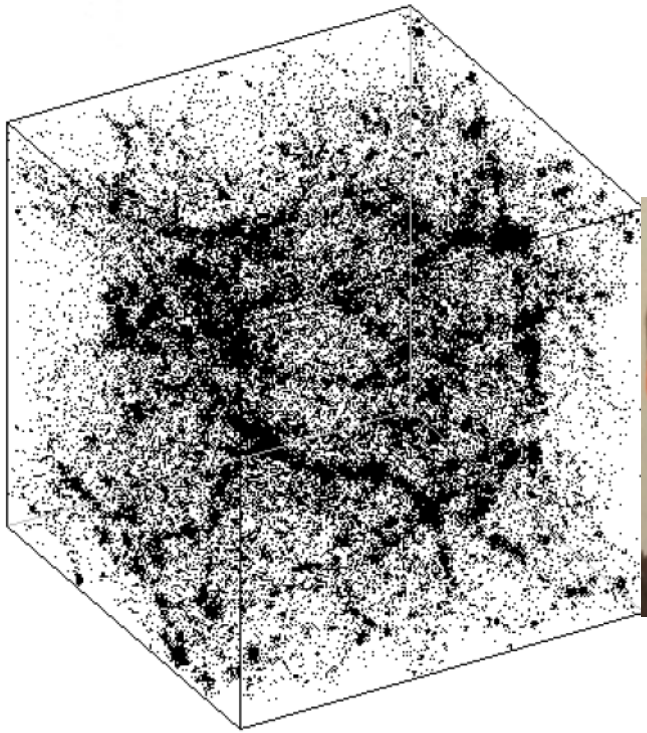


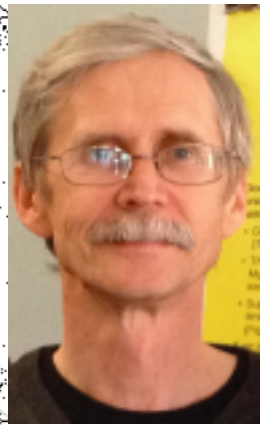
Klypin's vintage 82
160h^{-1}Mpc box 32^3 hDM

It is possible to recognize some webs connecting these 'clusters of galaxies'

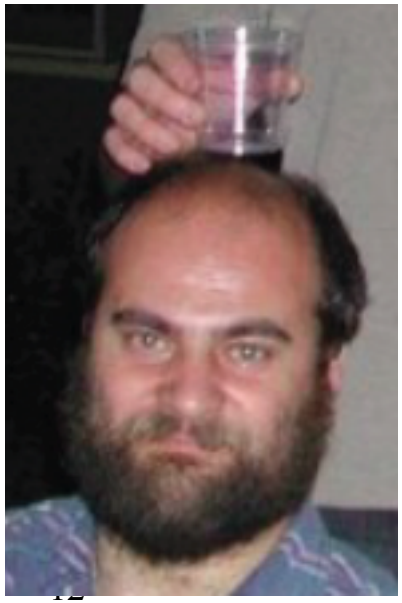


90s Klypin to CITA, 'the west is best'

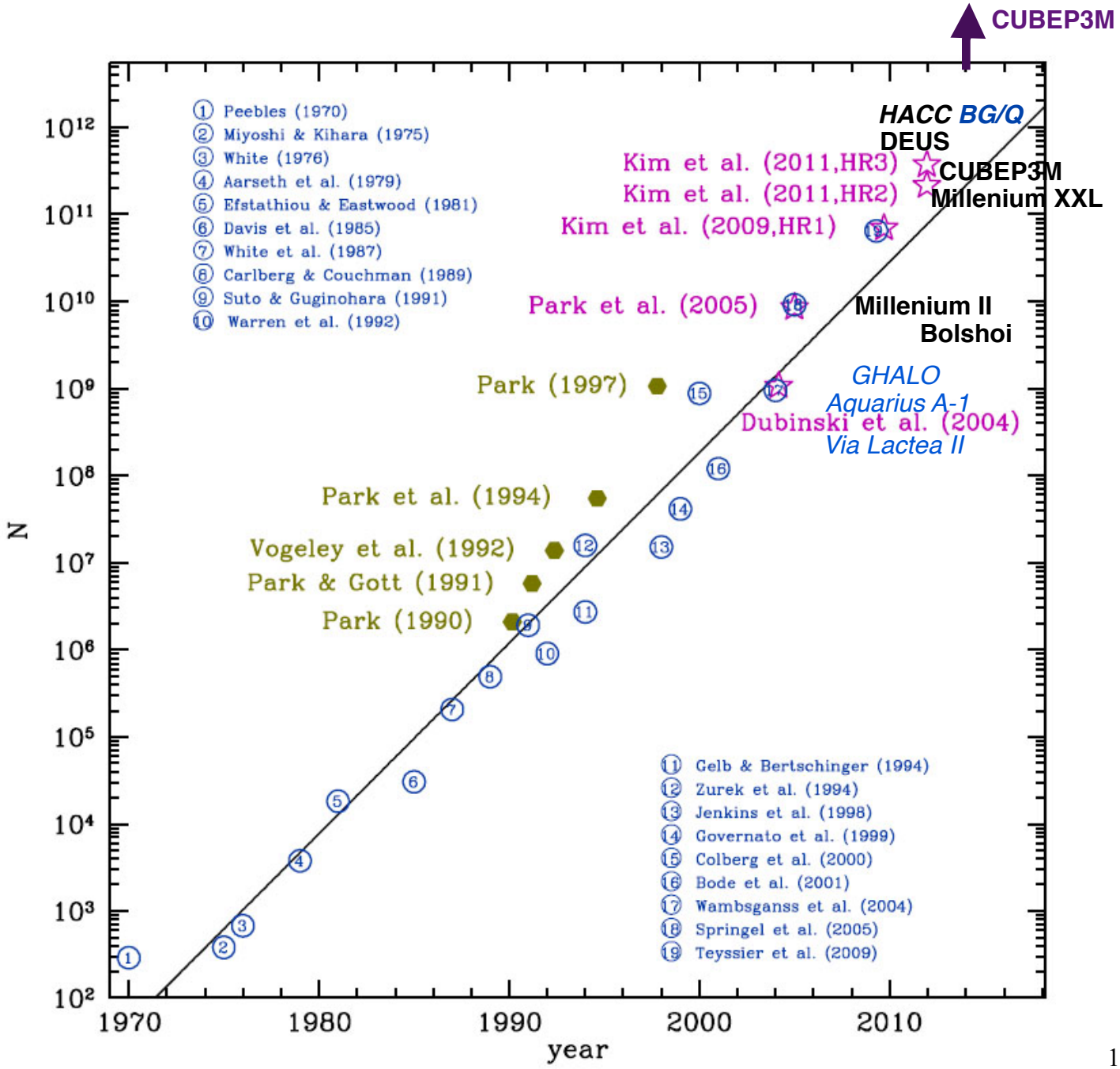




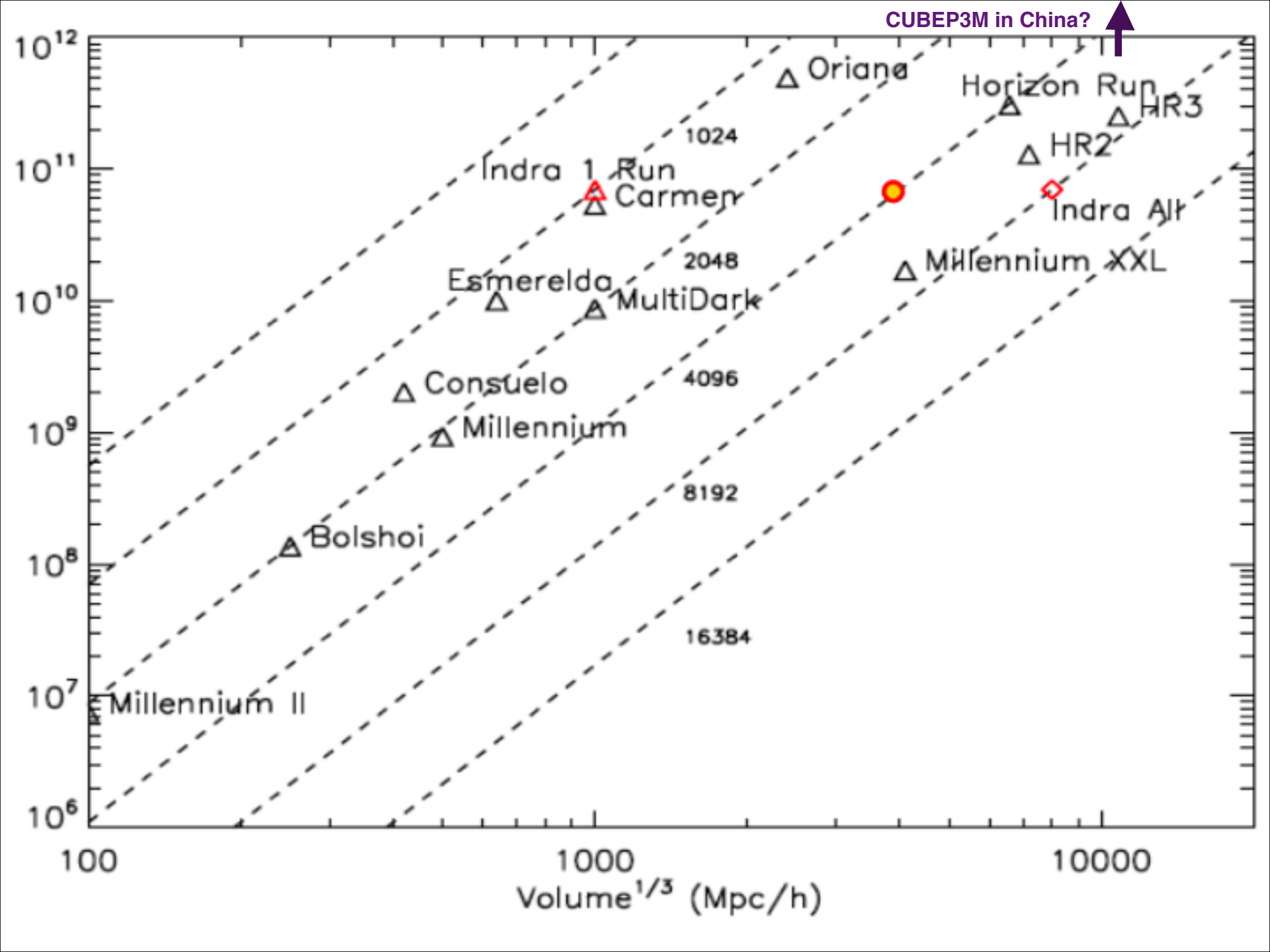
60th bday!'



Klypin's vintage 93 50h^{-1}Mpc box 128^3 sCDM = BKP98 web workhorse; +Couchman AP^{3}M



(Juhan Kim et al. 2011)♪


CUBEP3M in China?
Oriana
Horizon Run
HR3
HR2
Indra 1 Run
Carmen
Indra All
Esmeralda
MultiDark
Millennium XXL
Consuelo
Millennium
Bolshoi
Millennium II
1024
2048
4096
8192
16384
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
100
1000
10000
Volume$^{1/3}$ (Mpc/h)

BigBox Sims By total particle number, N:

BG/Q Run (HACC) 2012
N = 10240^3 L = 9.14 Gpc rsoft = 7 kpc mparticle = 1.9e10 Msun

DEUS FUR (RAMSES) 2012
N = 8192^3 L = 29 Gpc (21 Gpc/h) rsoft = 56 kpc mparticle = 1e12 Msun

Horizon Run 3 (Park et al. TREEPM) 2013 *grew out of Horizon Run 1, N = 4120^3 Kim, Park, Gott, Dubinski 2009@ CITA*
N = 7210^3 L = 15 Gpc (10.82/h Gpc) rsoft = 208 kpc mparticle = 3.4e11 Msun

Emberson et al. in prep (CUBEP3M) 2013-14
N = 6912^3 L = 2.9 Gpc (2/h Gpc) rsoft = 40 kpc mparticle = 3e9 Msun

Millenium XXL (GADGET) 2012
N = 6720^3 L = 4.1 Gpc (3/h Gpc) rsoft = 13.7 kpc mparticle = 8.5e9 Msun

Big Jubilee (CUBEP3M) 2013
N = 6000^3 L = 8.8 Gpc (6/h Gpc) rsoft = 71 kpc (50/h kpc) mparticle = 1.1e11 Msun (7.5e10/h Msun)

Millenium Simulation II (GADGET) 2009
N = 2160^3 L = 140 Mpc (100/h Mpc) rsoft = 1.4 kpc (1/h kpc) mparticle = 9.4e6 Msun

The Bolshoi Simulation (ART) 2011
N = 2048^3 L = 347 Mpc (250/h Mpc) rsoft = 1.4 kpc (1/h kpc) mparticle = 1.9e8 Msun (1.35e8/h Msun)

Indra 2013-14 Gadget2 512 X N = 1024^3 L = 1 Gpc/h box; Data loaded into SQL database, public 1048TB

Millennium 2005 DB is the poster child/ success story – 600 registered users: N = 10^{10} PB data, VO-oriented, SQL-queryable

SingleHalo Sims By total particle number, Nhalo:

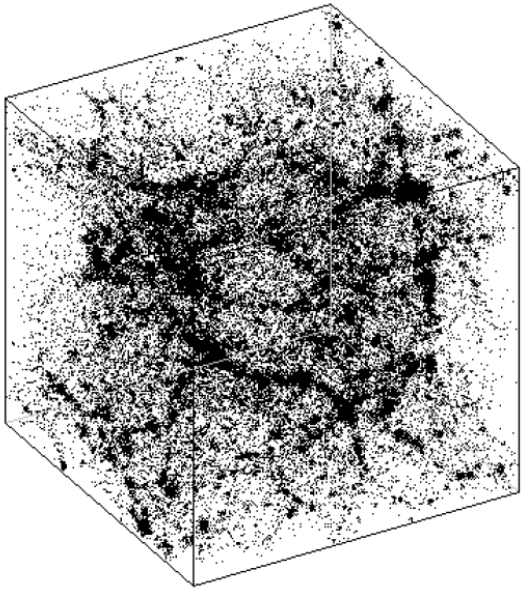
GHALO (PKDGRAV) 2009
M200 = 1.3e12 Msun (200 times MEAN) mparticle = 1e3 Msun Nhalo = 1.3e9

Aquarius A-1 (GADGET) 2008
M200 = 1.8e12 Msun (200 times MEAN) mparticle = 1.7e3 Msun Nhalo = 1.1e9

Via Lactea II (PKDGRAV) 2008
M200 = 1.9e12 Msun (200 times MEAN) mparticle = 4.1e3 Msun Nhalo = 4.6e8

Cosmic Web varies with initial density spectrum tilt

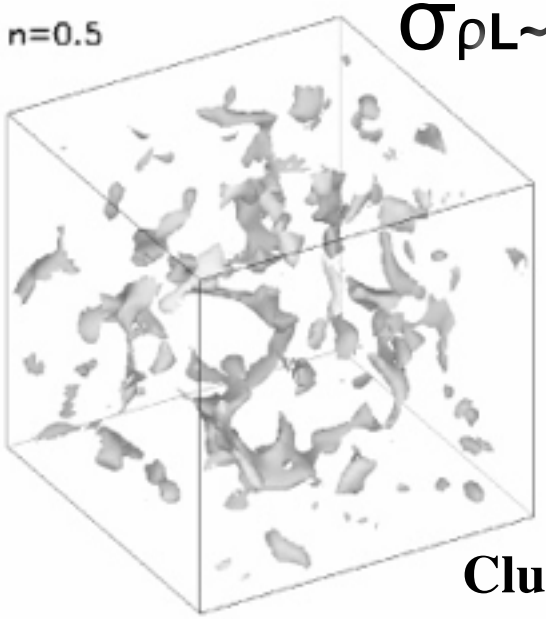
$d\sigma_{\rho L^2}/d\ln k \sim k^{(n+3)}$

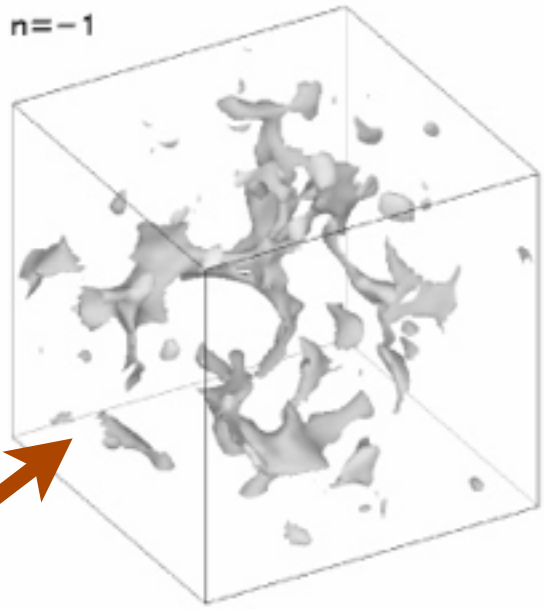


percolation threshold contour

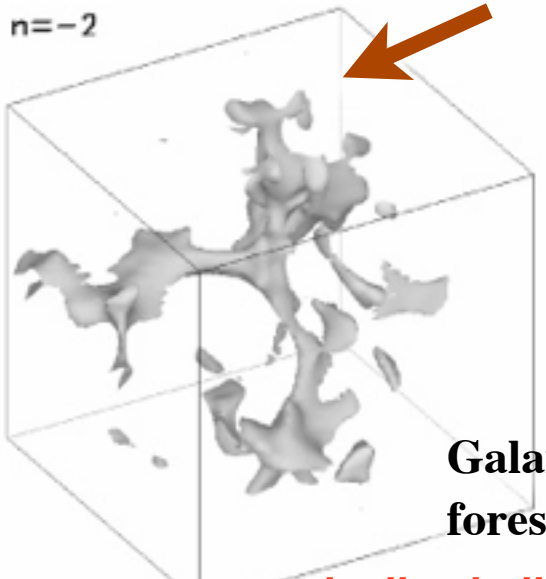
smoothing

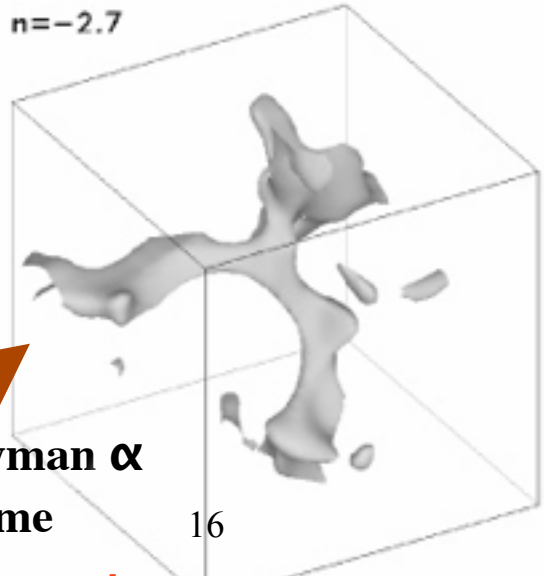
$\sigma_{\rho L} \sim 0.65$





Cluster regime





Galaxy, Lyman α forest regime

neff (k) *varies for 'standard' tilted ΛCDM*

~.962 ± .013 small k,

Planck1.3+WP+hiL+BAO

.9608 ± .0054 small k,

-1.3 cluster scale,

-2.3 galaxy scale,

-2.8 Lyman α scale

-3.04 large k, 1st star

beware: a numerically challenging regime ***extreme LSS tides***

HALOs in the Web(z)

Semi-Analytics

Halo Model

= Eulerian Peak Patches

Lagrangian Peak Patches

painting on internal halo physics: DM/gas density, galaxy number density (HOD), pressure, entropy, dust emissivity, HI, CO, ...

for **fast MOnteCKarlos,** vary cosmological contents (DE), non-Gaussianity variants,... *cf. big sims=fixed cosmology, even if 512 of them*

for **understanding the web**

thresholded excursion sets only for 1-point

beware, although DM-dominated, the gas/stars are - of course - highly biased inside the clusters, painting/splattering dark matter halo potential wells (e.g., $p_e(\Phi_N(x))$ can never be accurate; e.g., pressure clumping, DM ellipticity > gas ellipticity

The Cosmic Web

B+Kofman+Pogosyan 96-99

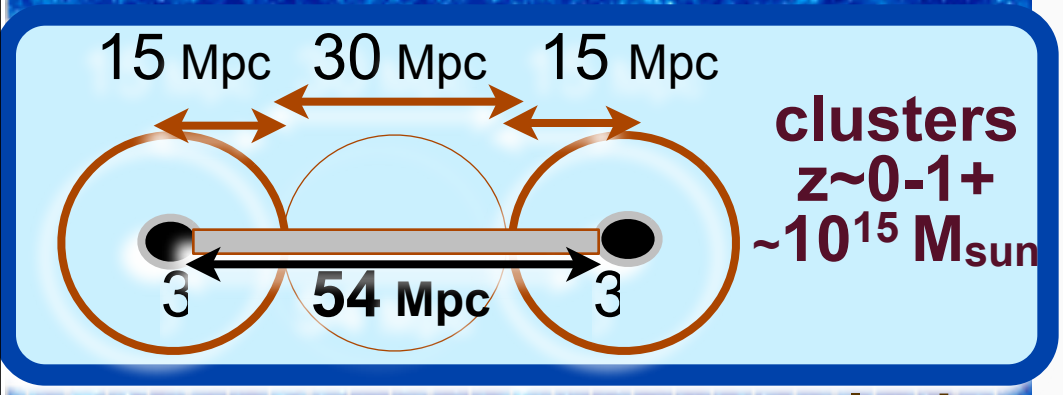
"Molecular" Picture of Filaments & Membranes in LSS

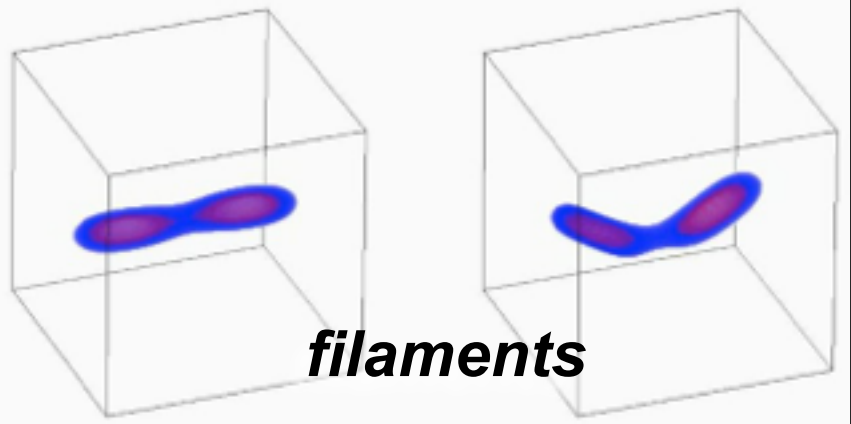
Constrained Correlation Functions

aka $F=\langle F|\{q\in\mathcal{C}\}\rangle + F_f$ (residual "noise")

$\langle F|\{q\in\mathcal{C}\}\rangle = \langle Fq^t\rangle\langle qq^t\rangle^{-1}q$, X-correlation

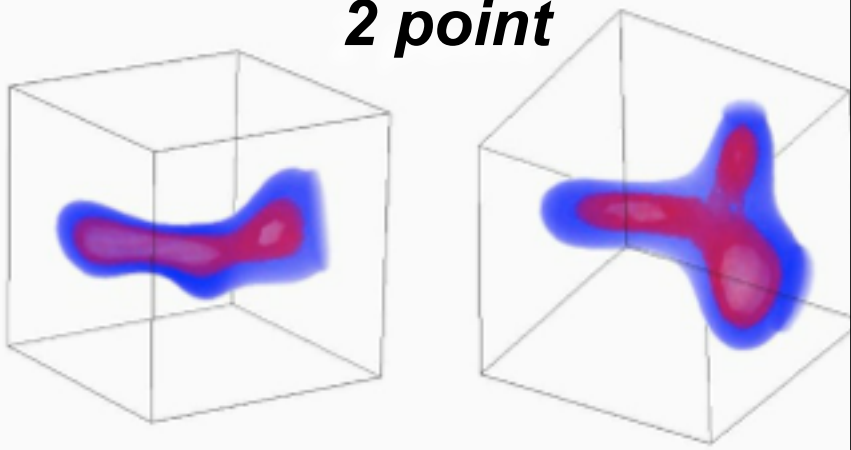
e.g., $F=\ln \rho/\langle\rho\rangle = -\mathrm{Trace}(\epsilon)$

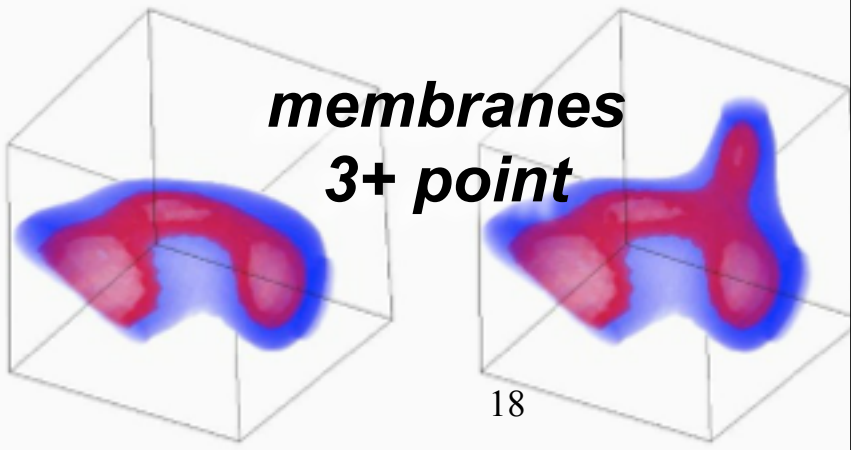




filaments

2 point





membranes

3+ point

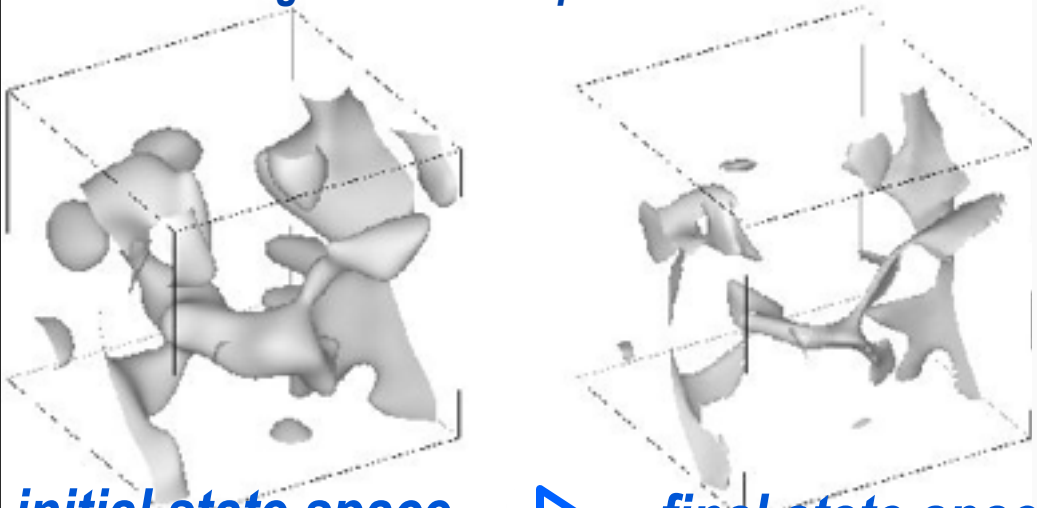
density field reconstruction of the filtered web

rank-order peak/void-patches(M) minimum info

LSS convergence as N_{patch} increases

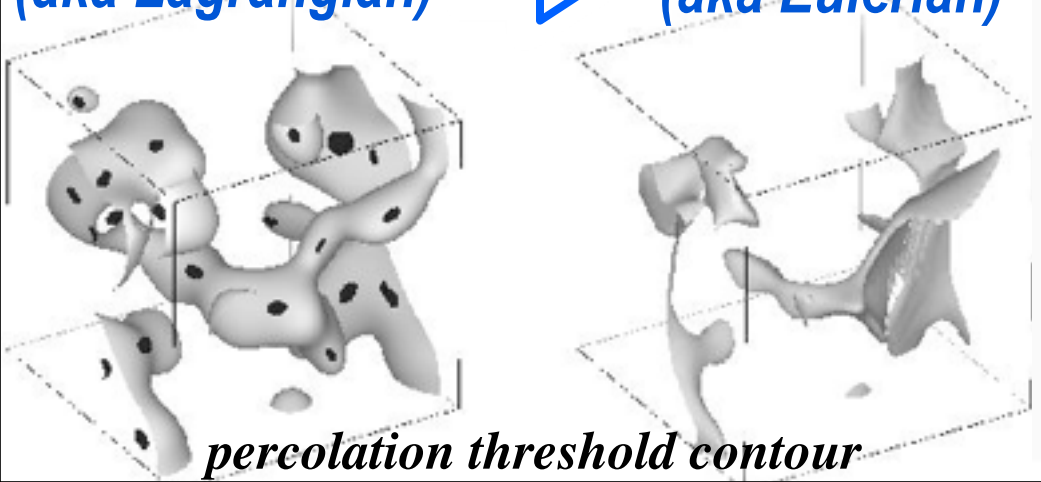
InformationQuality: clusters encode the web

interior and high resolution spatial detail <=> more info

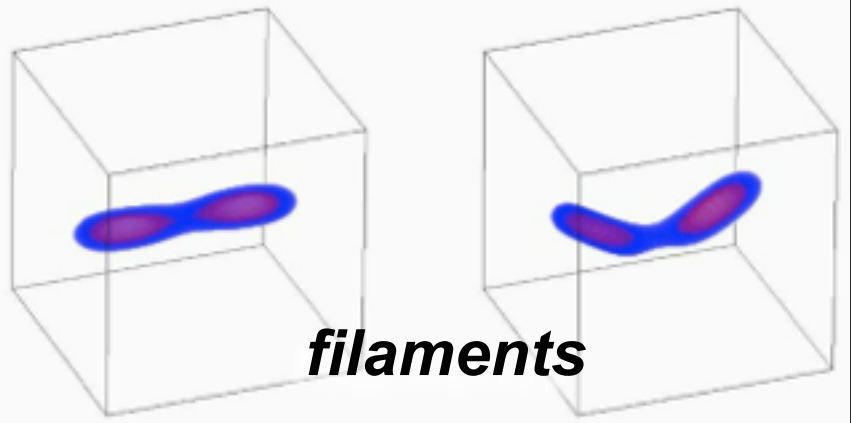


initial state space (aka Lagrangian)

final state space (aka Eulerian)

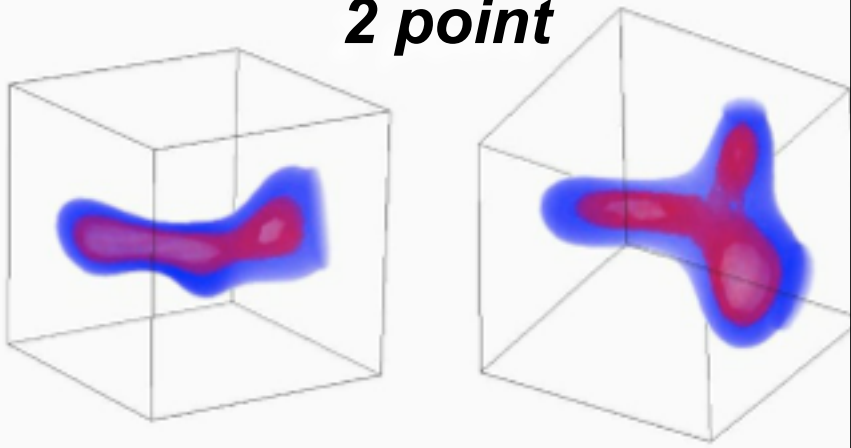


percolation threshold contour



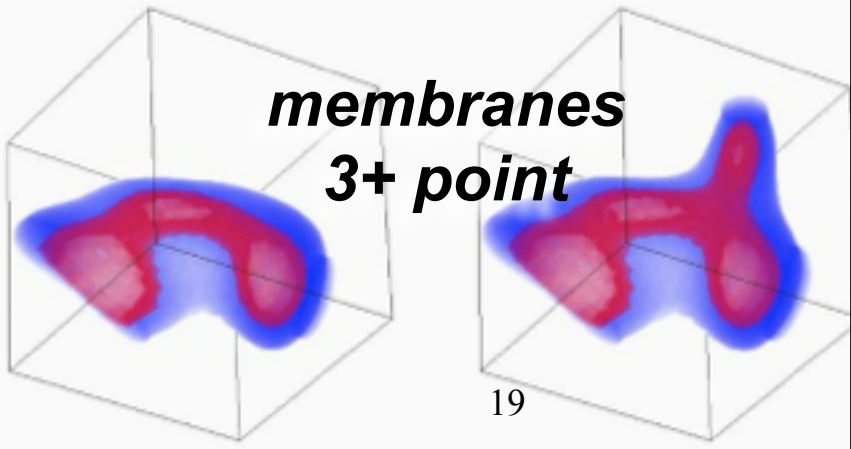
filaments

2 point



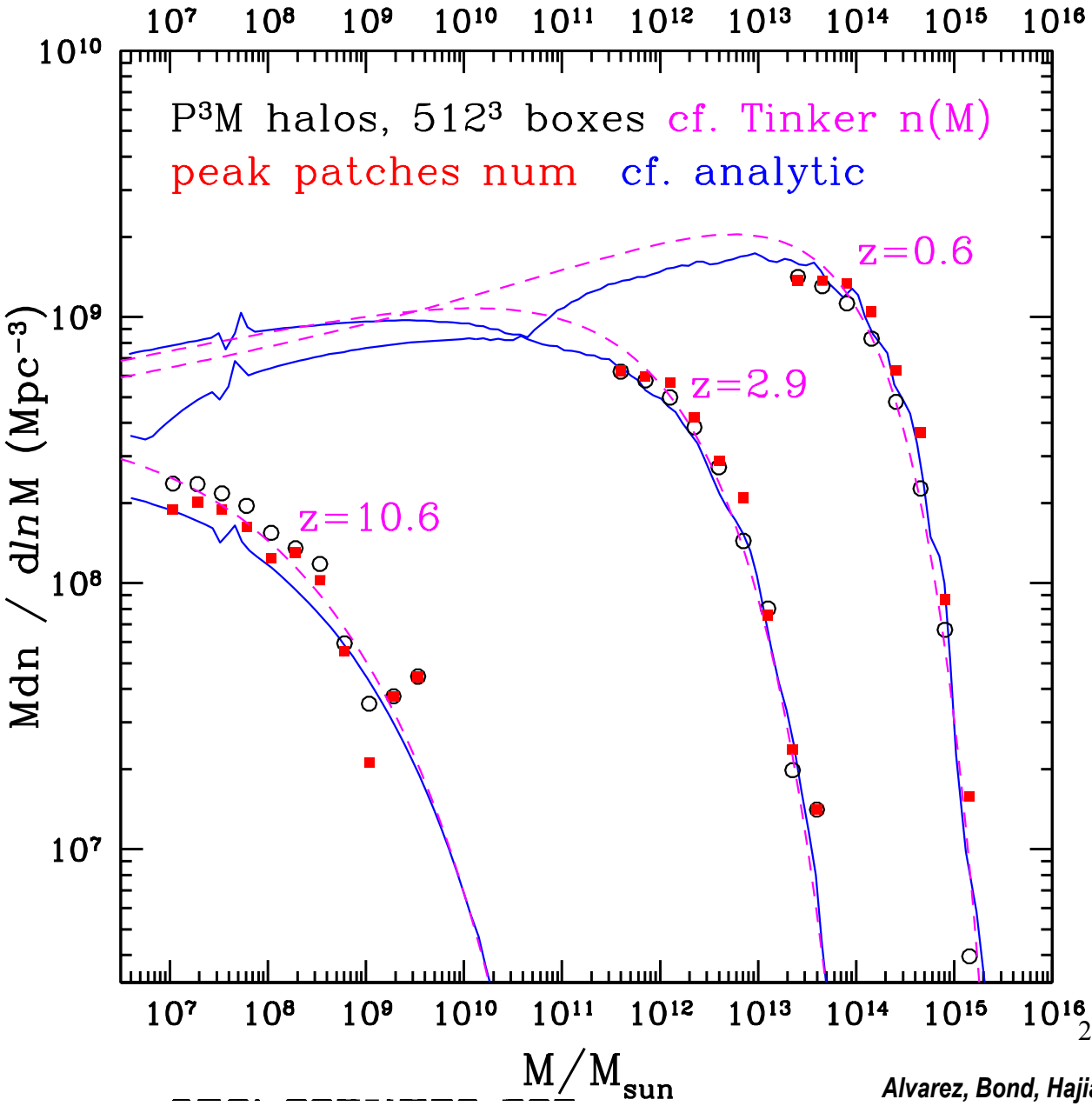
membranes

3+ point



Peak patches cf 512^3 CUBEP3M halos using SP-O, boxes are: 857 Mpc, 214 Mpc, 6.43 Mpc

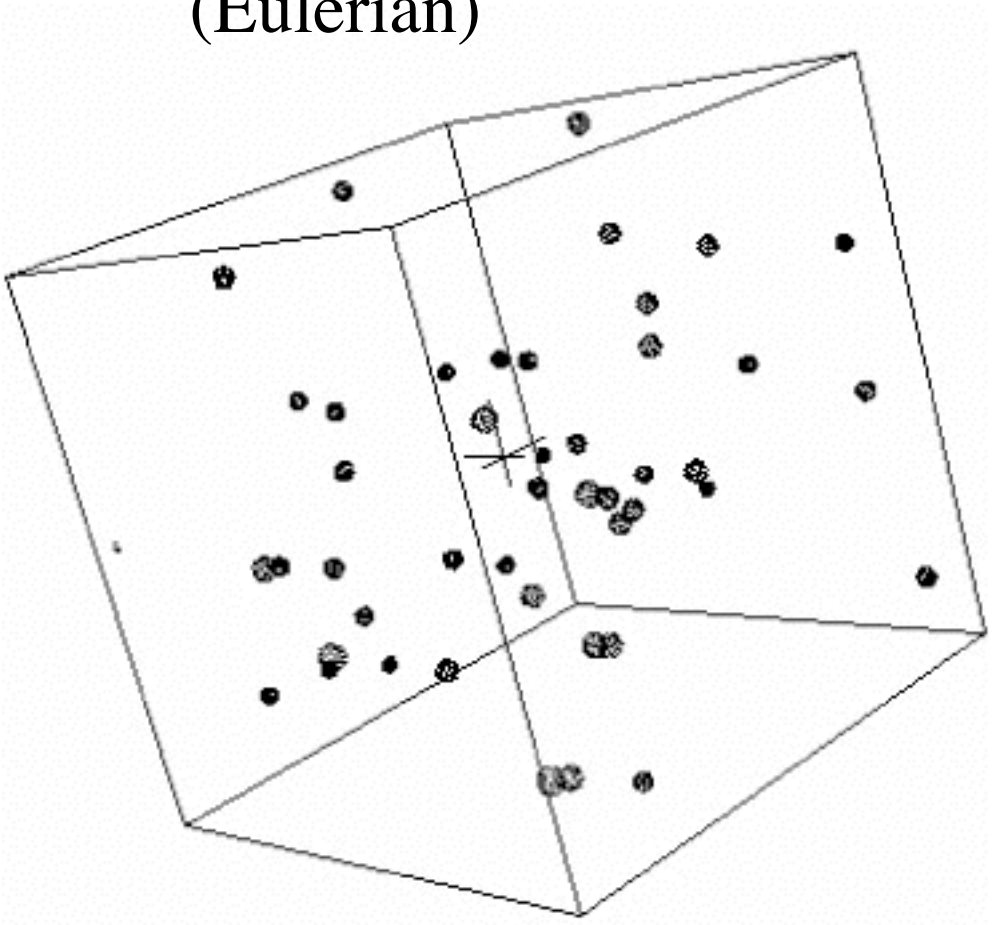
SP-O Halos are exactly **Eulerian-space** Peak Patches



Alvarez, Bond, Hajian, Stein, Emberson 2013

Cluster Peak Patches in Final State Space

(Eulerian)

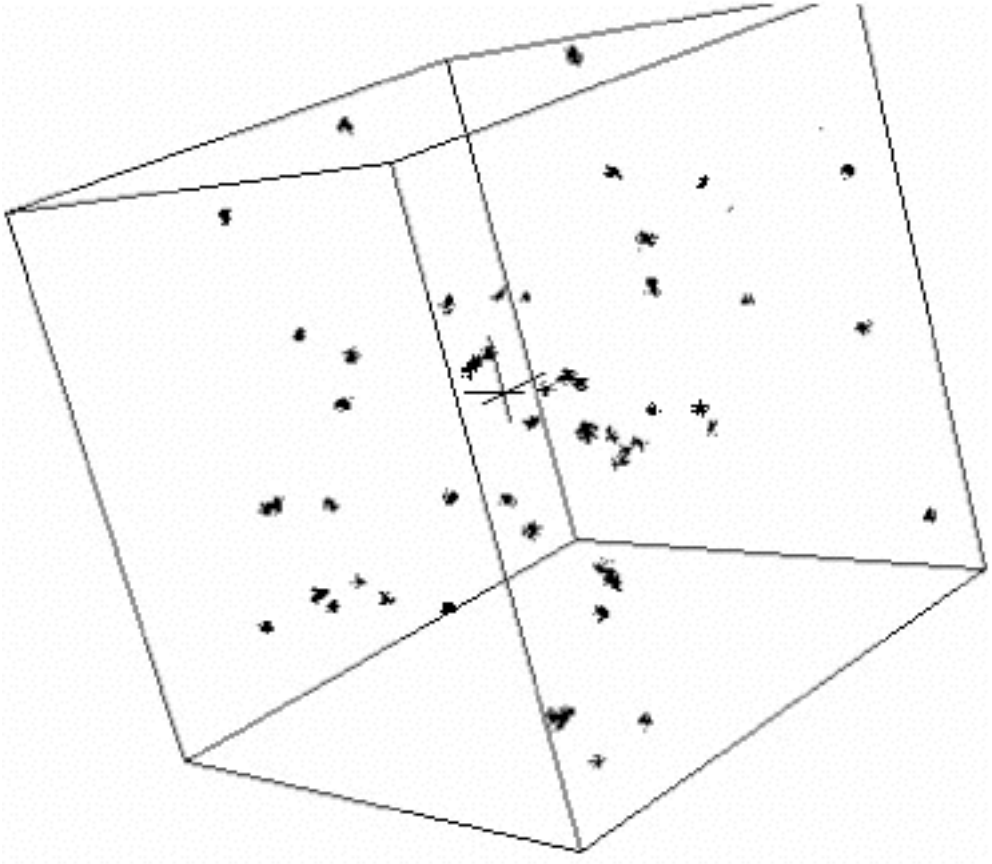


$(400\ \mathrm{Mpc})^3$ simulation

Bond Myers 1991-96

N-body groups in Final State Space

(Eulerian)



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

Bond Myers 1991-96

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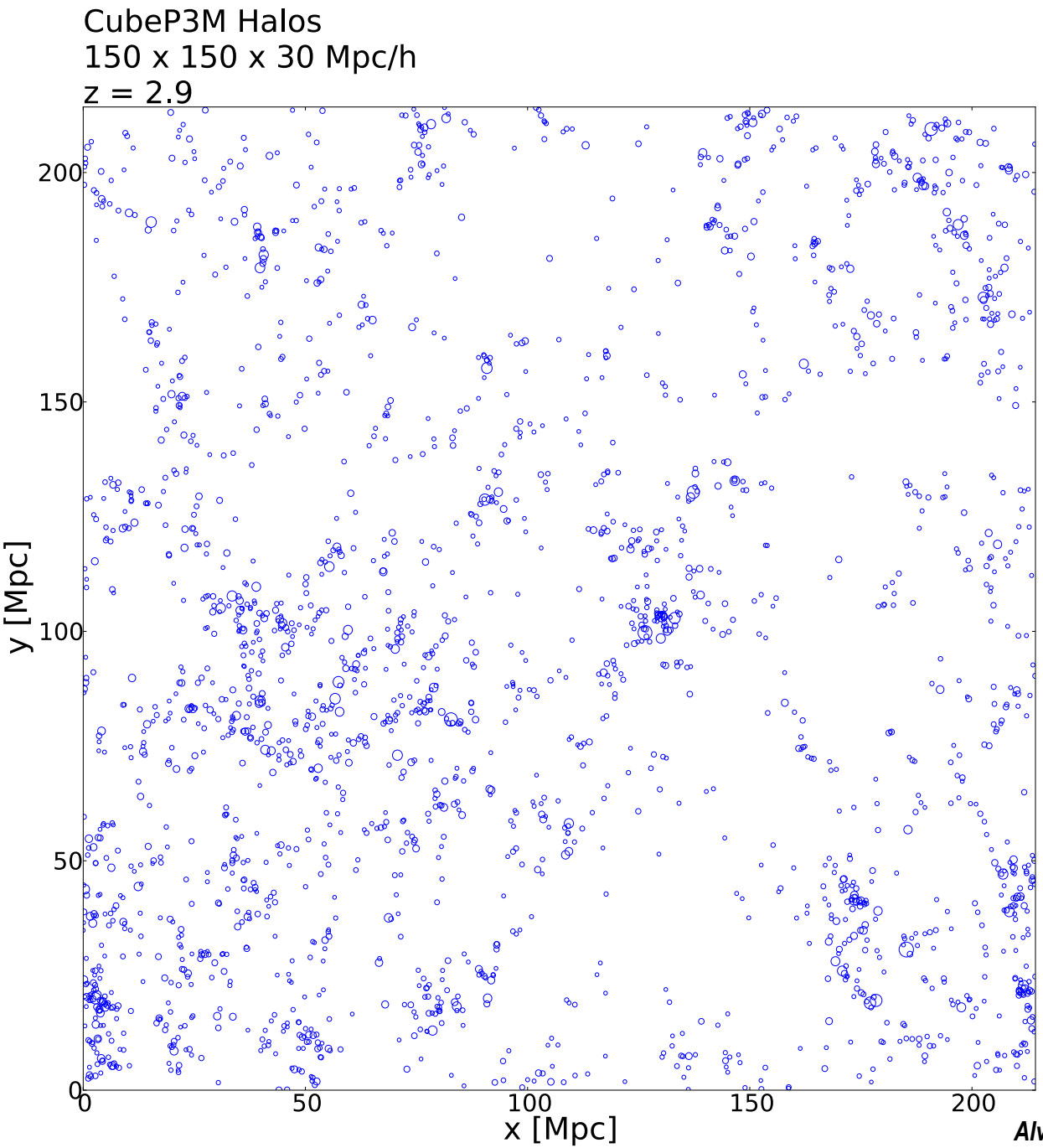

Alvarez, Bond, Hajian, Stein, Emberson 2013

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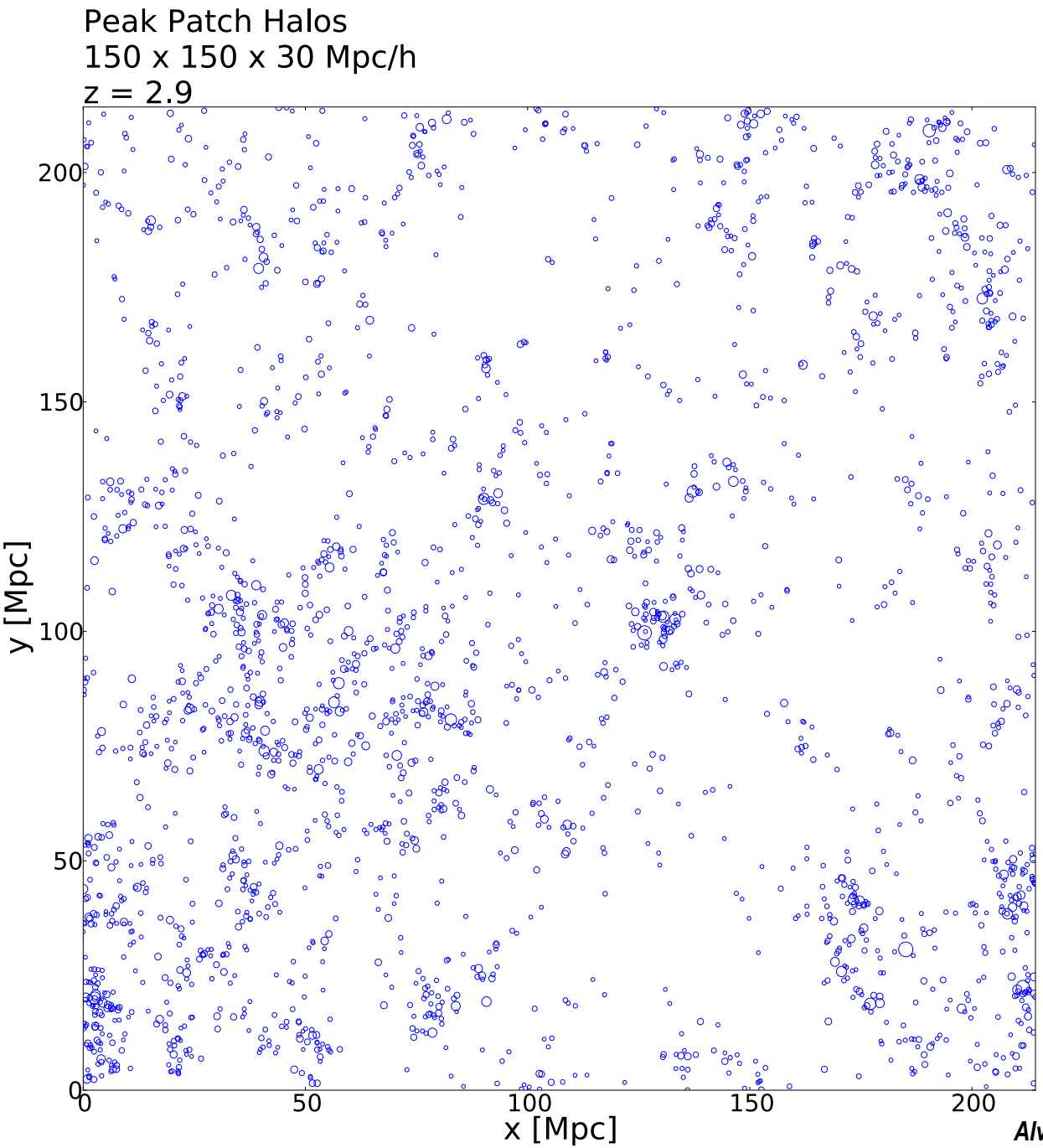

Alvarez, Bond, Hajian, Stein, Emberson 2013

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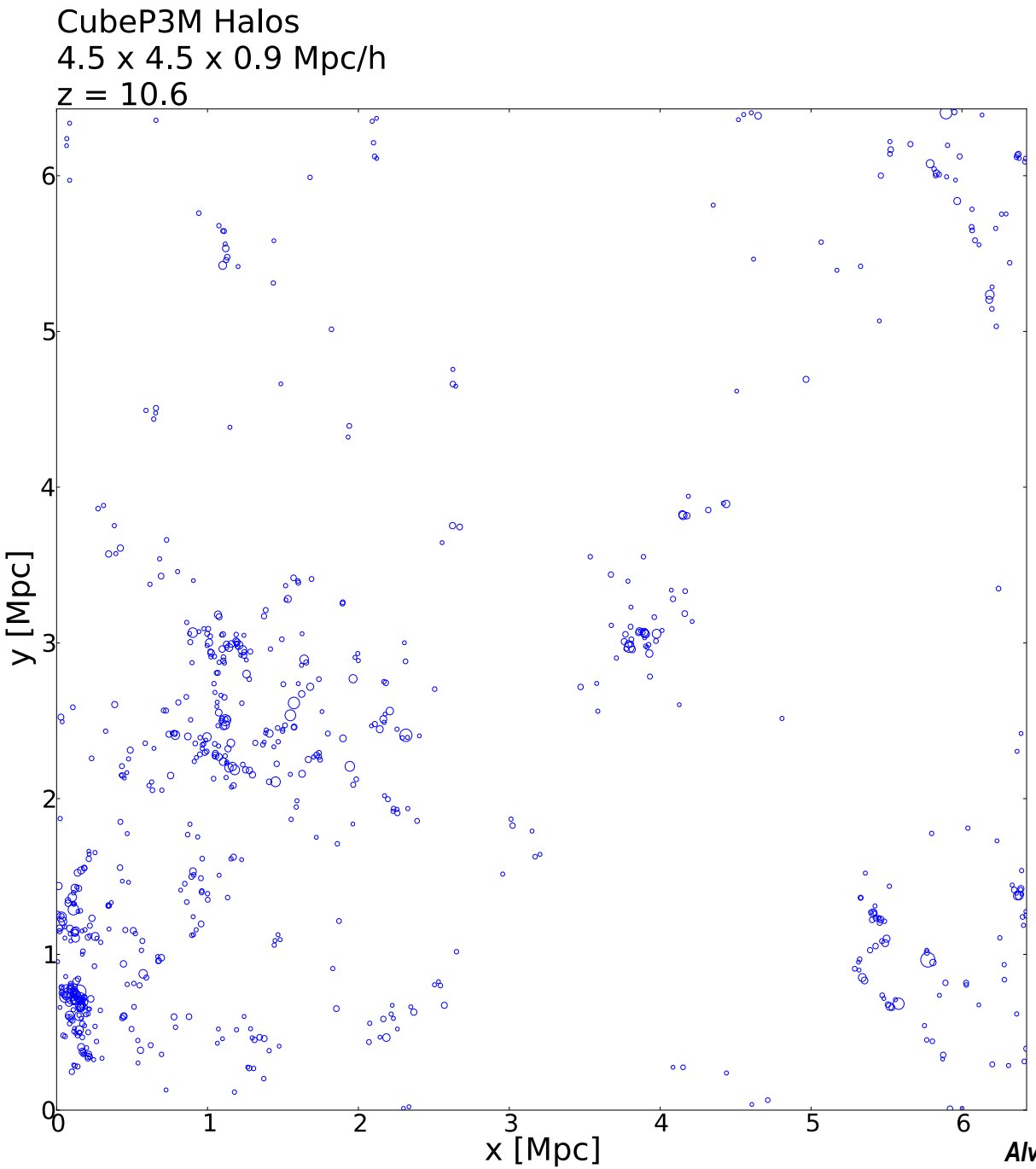
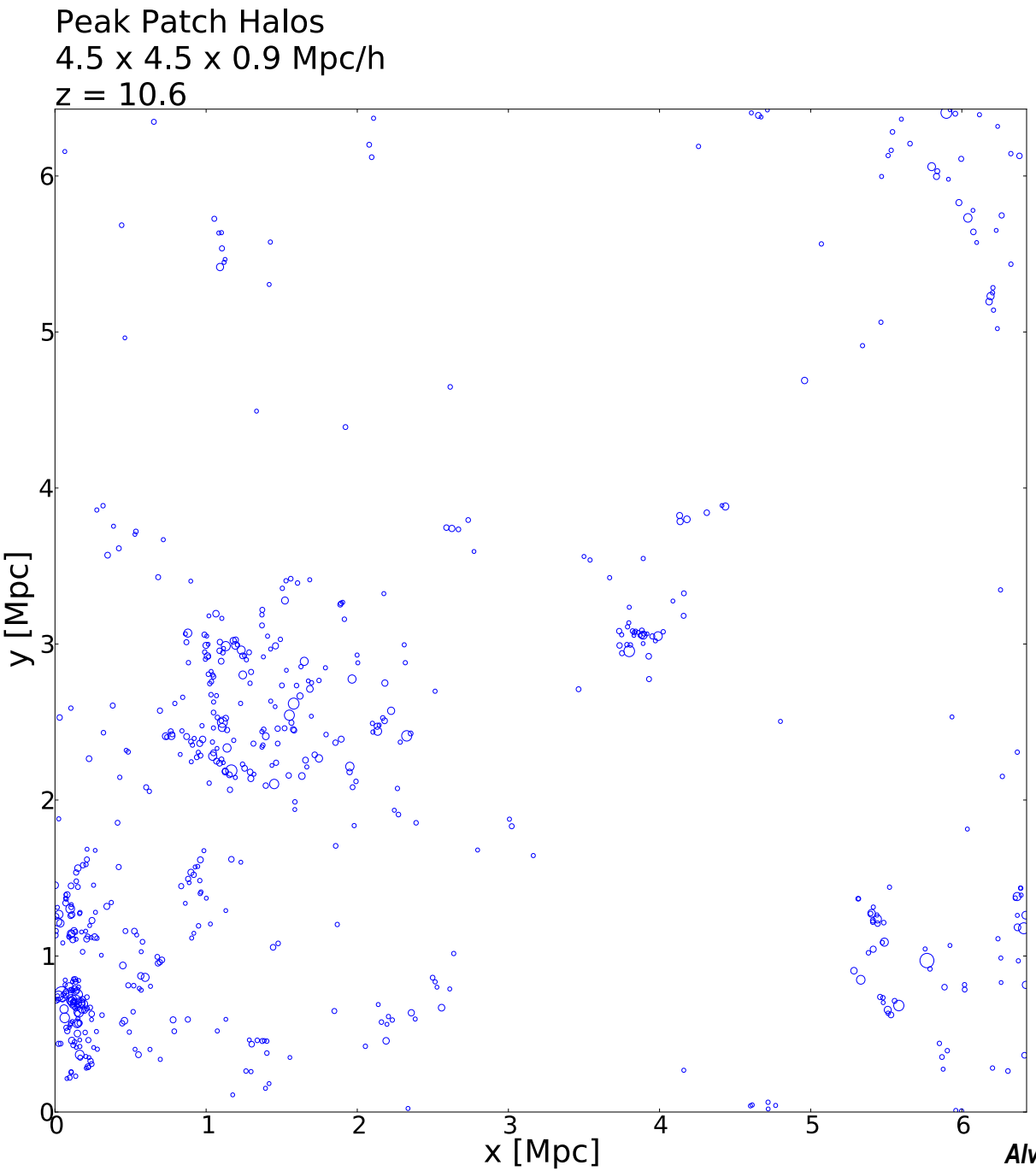


beware: a numerically challenging regime extreme LSS tides

still Peak Patches works!

Alvarez, Bond, Hajian, Stein, Emberson 2013

Peak patches cf 512^3 CUBEP3M halos using SP-O, boxes are: 857 Mpc, 214 Mpc, 6.43 Mpc



beware: a numerically challenging regime extreme LSS tides

still Peak Patches works!

Alvarez, Bond, Hajian, Stein, Emberson 2013

HALOs in the Web(z)

the CLUSTER SYSTEM example

Halos are Complex Systems

Painting is an Art Form

Mean-fields($x-x_{cl}$) =

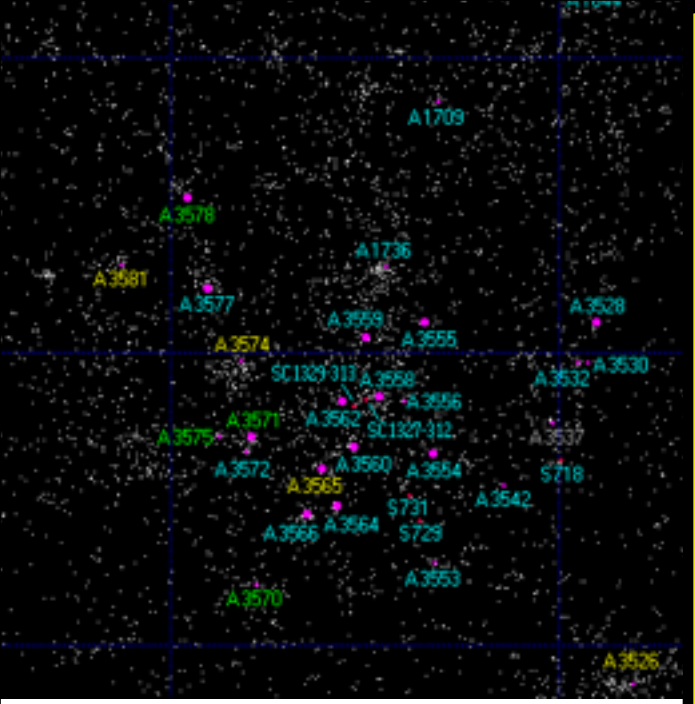
Cross-correlations = Stacking

(oriented, scaled) from sims or data

+

residual fluctuations (!!)

MOCKs *are not really real, but still useful*

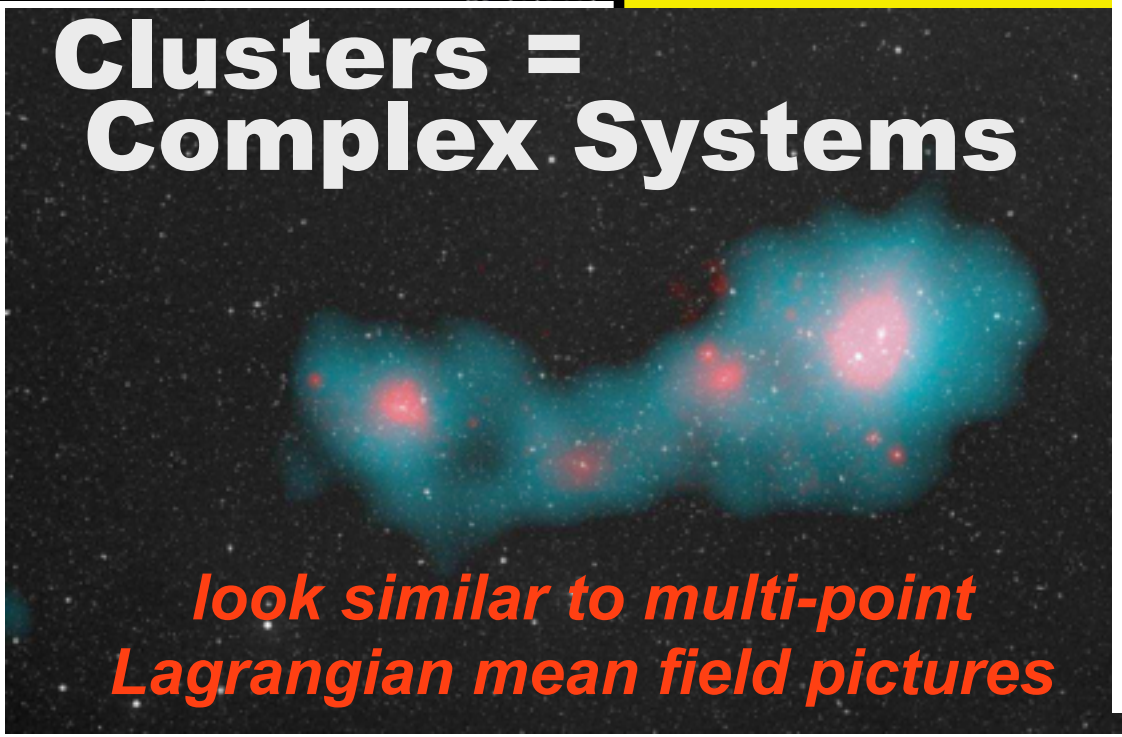


thermal SZ clusters

some nearby well-known clusters
from
Perseus to Virgo

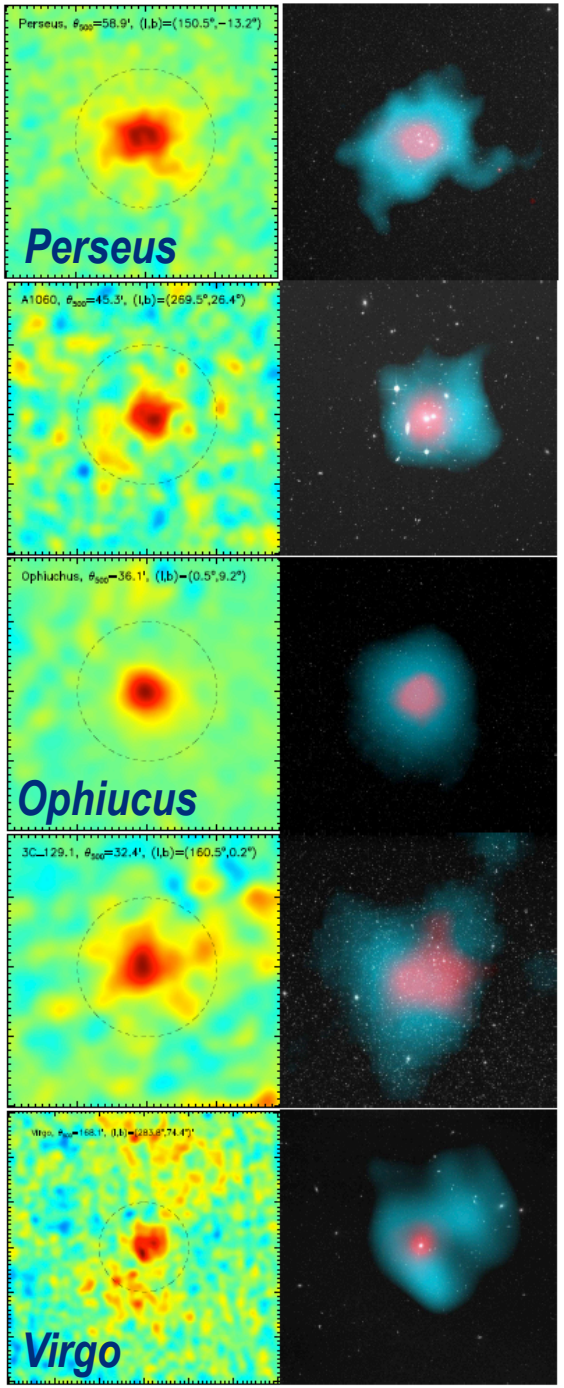
Shapley Supercluster
<overdensity> ~5

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



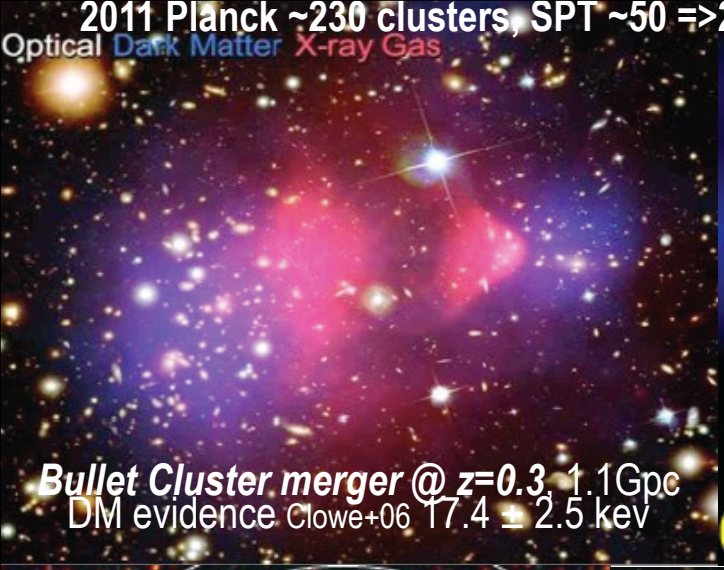
Clusters = Complex Systems

look similar to multi-point Lagrangian mean field pictures



2011 Planck ~230 clusters, SPT ~50 =>224cls, ACT ~91 cls; 2013 1000s

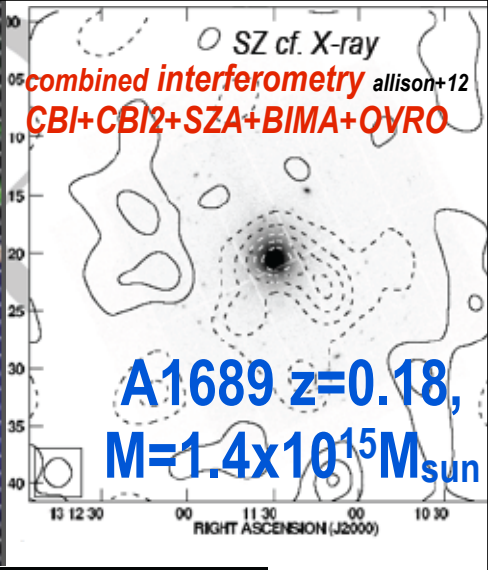
Optical Dark Matter X-ray Gas



Bullet Cluster merger @ z=0.3, 1.1Gpc
DM evidence Clowe+06 17.4 ± 2.5 kev

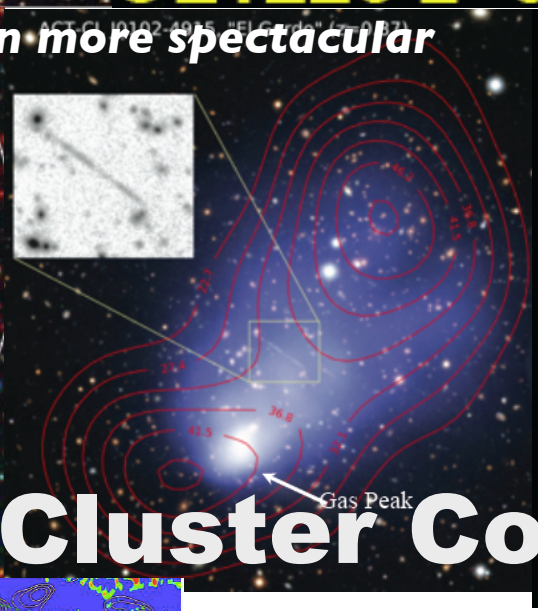
GBT's Mustang HiRes-SZ

CL1226 z=0.89



bullet-like merger - even more spectacular

ACT's el Gordo z=0.87
2x10^15Msun, Tx=14.5kev
Menanteau+12

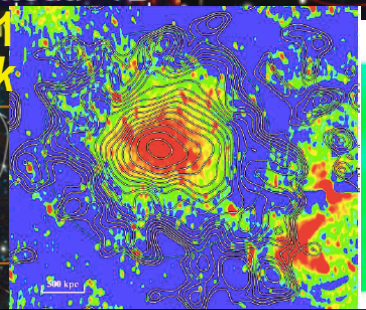


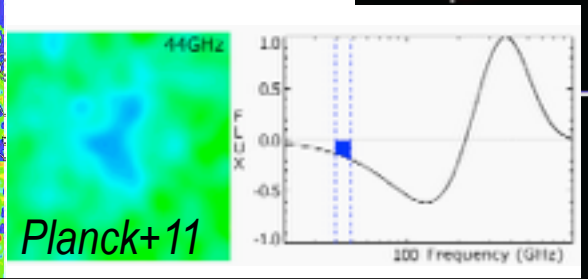
SPT's Phoenix z=0.60
2.5x10^15Msun

massive starburst +AGN
=>FEEDBACK

Clusters are Complex Systems!
Information Quantity (Shannon Entropy) & IQuality

Cluster Complexity



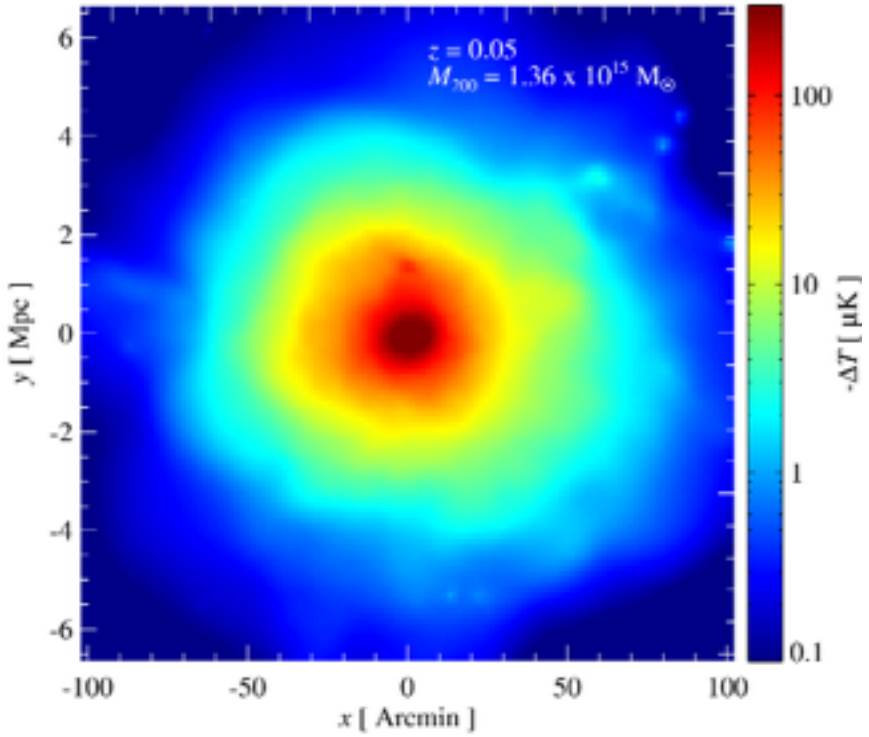


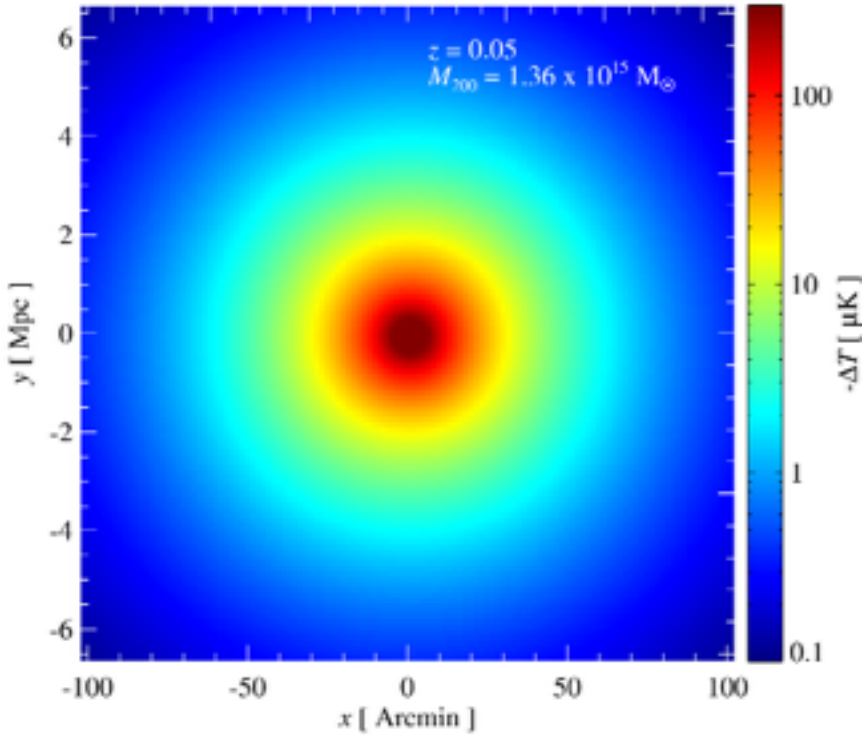
2D pressure exact vs. fit ➪ pressure sub-structure

Constrained X-Correlation ***Fns = scaled stacked pressure profiles***

aka $p=\langle p|\{q\in\mathcal{C}\}\rangle + p_f$ ***(residual "noise")*** $\langle p|\{q\in\mathcal{C}\}\rangle=\langle pq^{\dagger}\rangle\langle qq^{\dagger}\rangle^{-1}q$,

e.g., ***p or*** $\ln p/\langle p\rangle$. $\langle [p(X_c+Ux/x_\Delta)/p_{\Delta c}]\, n_{\mathcal{C}}(X_c)\rangle/\langle n_{\mathcal{C}}(X_c)\rangle = FormFactor(x/x_\Delta)$

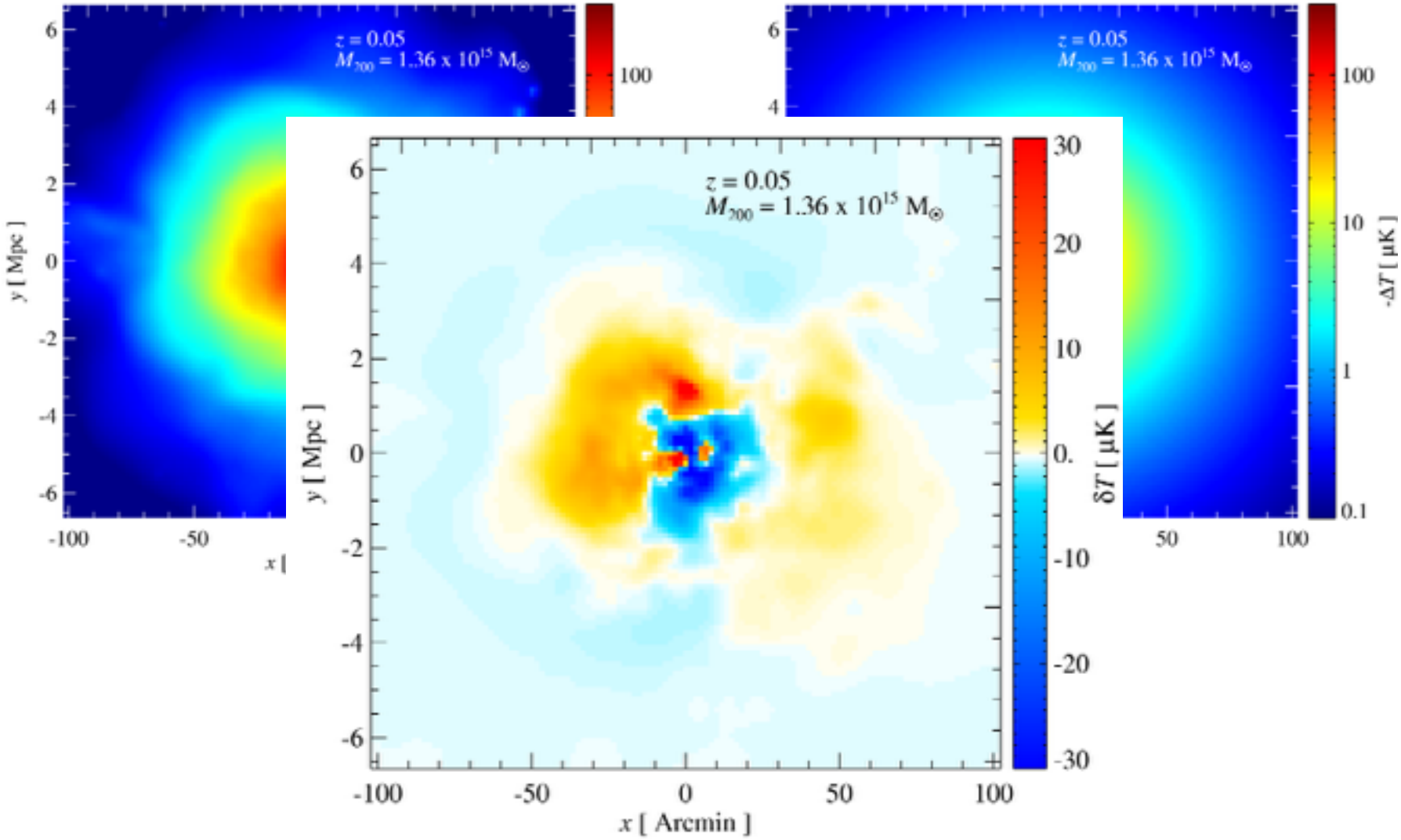




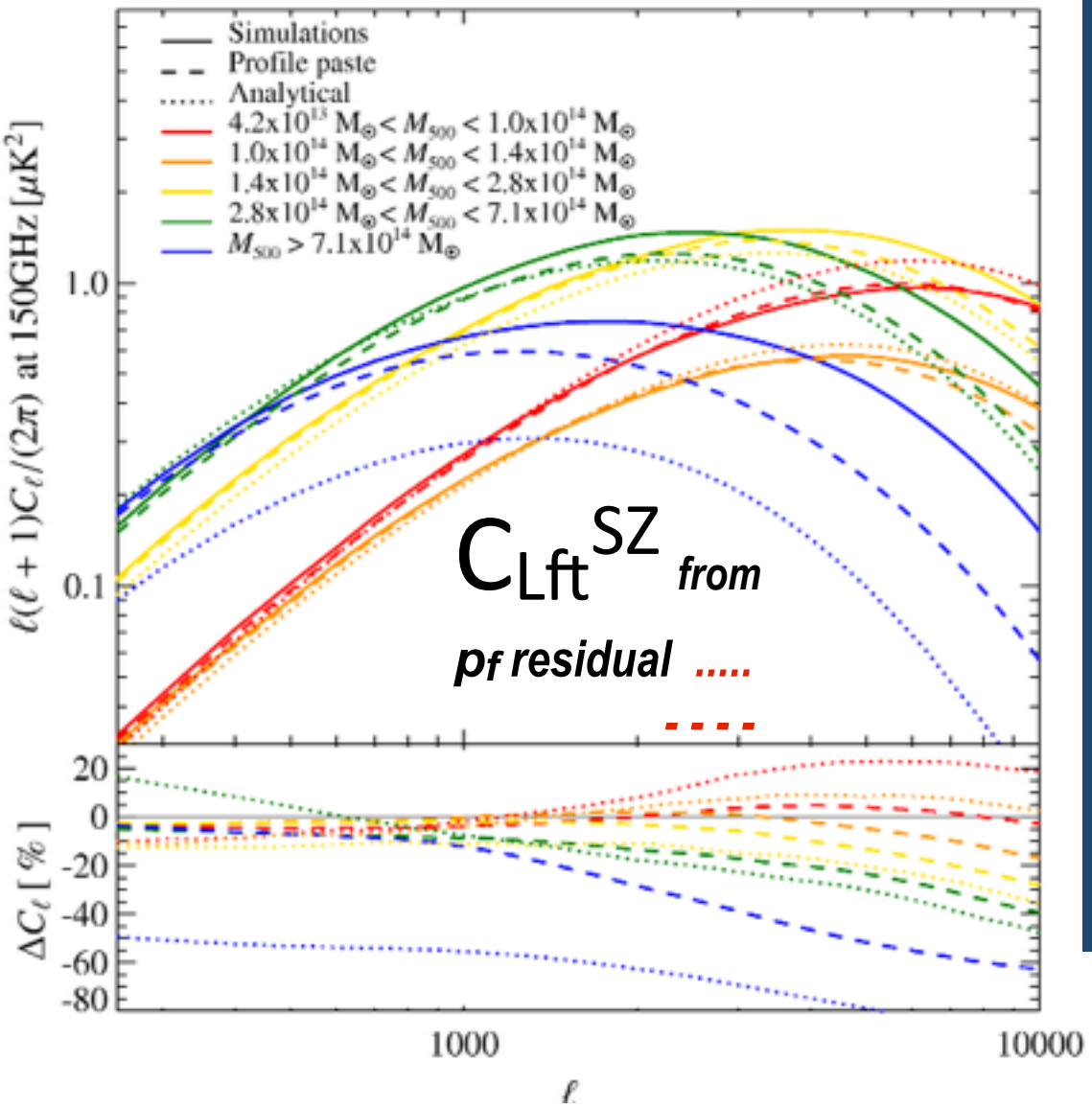
Same cluster (pasted on GNFW according to mass) @ 30 GHz, z = 0.05 Mass ~10^{15} M_{sun}

2D pressure exact vs. fit ⇨ pressure sub-structure

p_f (residual "noise")



pressure sub-structure contribution to C_L^{tSZ}



given the cluster catalogue from sims, paint on spherical GNFW-fit (M,z).
scaled X-correlation fn good, not perfect.

pressure-**sub-structure**
smaller fluctuations if the simulation halos are painted
=full analytics
painted on + fit mass function
= slightly bigger errors

cluster ELLIPTICITY TENSORS for gas and DM

$\mathbf{U_{g,ij} = \int dm_g\, x_i\, x_j\, w(x) / \int dm_g\, x^2\, w(x)}$, *weight moment of inertia*
w(x)=1 or w(x)= 1/x² (does not overweight the outskirts) => similar

$U_{dm,ij}$ for DM

($U_{p,ij} = \int dPV\, x_i\, x_j\, w(x) / \int dPV\, x^2\, w(x)$, dPV=pdV

p_{th} for SZ, p_{tot} for virial equation & cluster masses)

rotate to principal axes, scale & stack

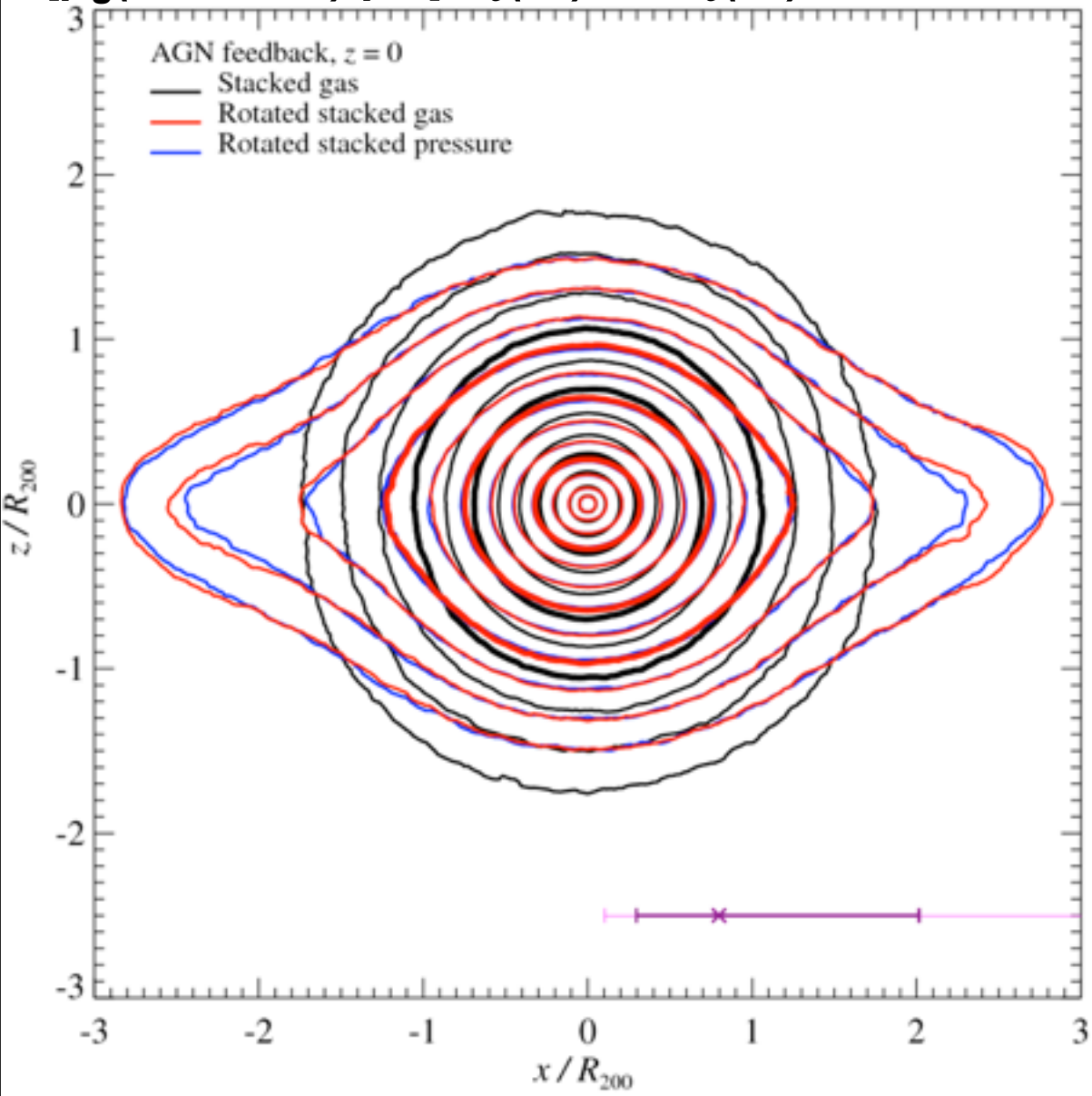
eigenvalues $u_1 > u_2 > u_3 \Rightarrow$

ellipticity e = (u_1-u_3) *I2Trace***U,**

prolaticity *(if >0, oblaticity if <0)* **p = $(u_1-2u_2+u_3)$** *I2Trace***U**

Halo X-corr Ellipticity ρ_g ρ_g z=0

$< [\rho_g(X_c+Ux/x_\Delta)/p_{\Delta c}]\ n_e(X_c) > / < n_e(X_c) > = FormFactor(x/x_\Delta)$



gas in cluster-Y_{SZ} "far-field" is increasingly elongated: a little near-field filament penetration

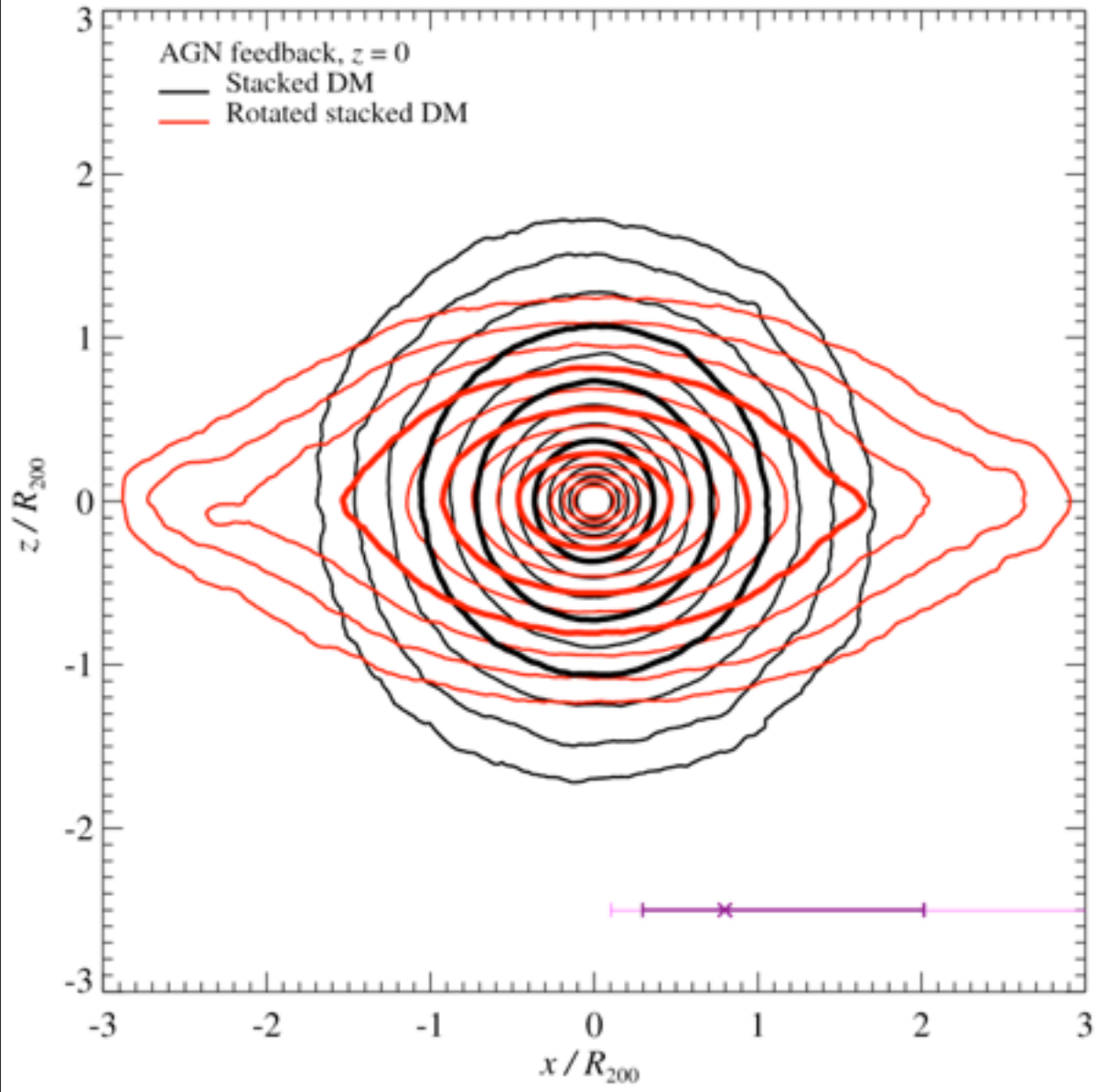
e(gas) < e(DM) /2

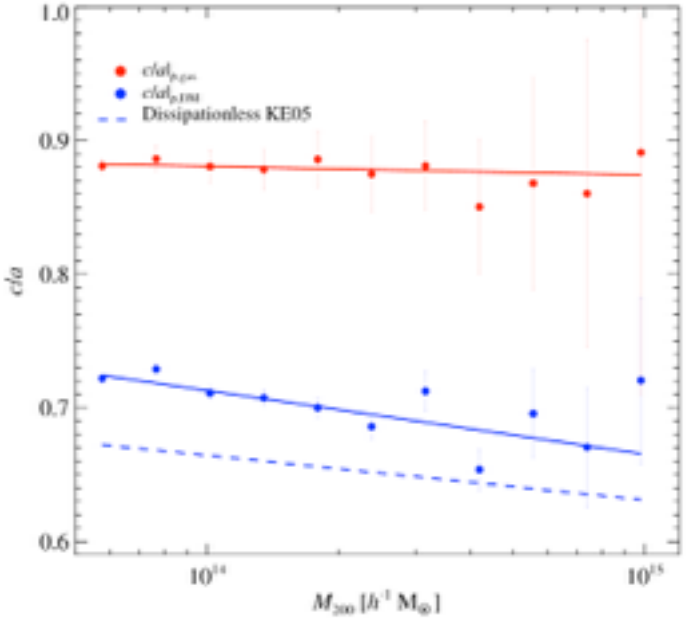
.

Halo X-corr Ellipticity ρ_{dm} z=0

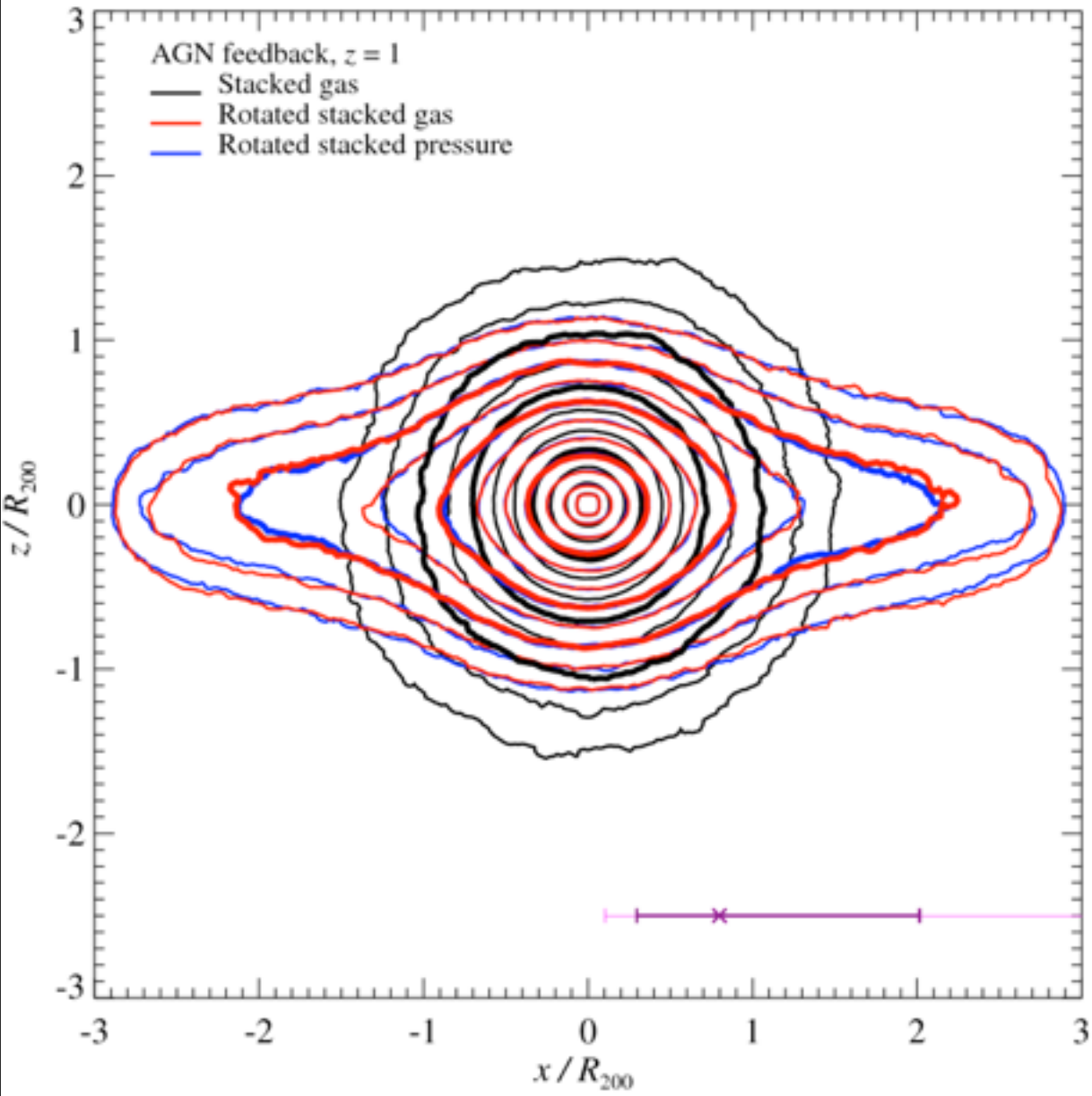
DM in cluster-Y_{SZ} "far-field" is more elongated: a little near-field filament penetration

e(gas) < e(DM) /2





Halo x-corr Ellipticity ρ_g ρ_g z=1

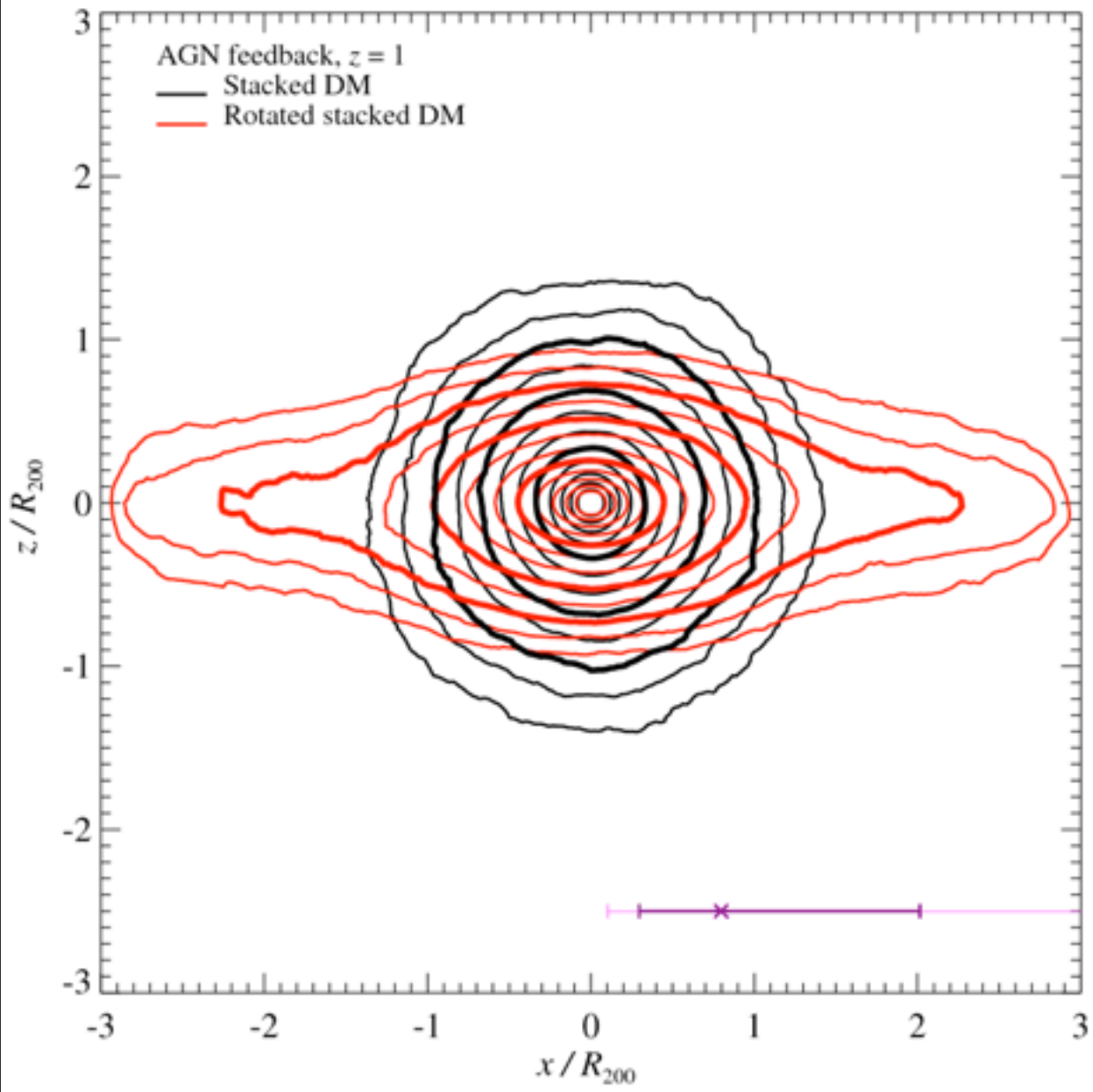


gas in cluster-Y_{SZ} "far-field" is increasingly elongated: a little near-field filament penetration

e(gas) < e(DM) /2

z=1 extreme cf. z=0

Halo X-corr Ellipticity ρ_{dm} z=1



DM in cluster-Y_{SZ} "far-field" is increasingly elongated: a little near-field filament penetration

e(gas) < e(DM) /2

z=1 extreme cf. z=0

HALOs in the Web(z)

the CLUSTER SYSTEM example

pressure$(x\text{-}x_{cl})$ =

Cross-correlations = Stacking

(unoriented, scaled) from sims & data

+ residual fluctuations (!!)

PUPPY = Planck universal pressure profile via stacking

sims => not quite universal (M,z) BBPS2 via stacking

gas entropy = less universal, not bad

DM entropy = universal, NFW-like

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*

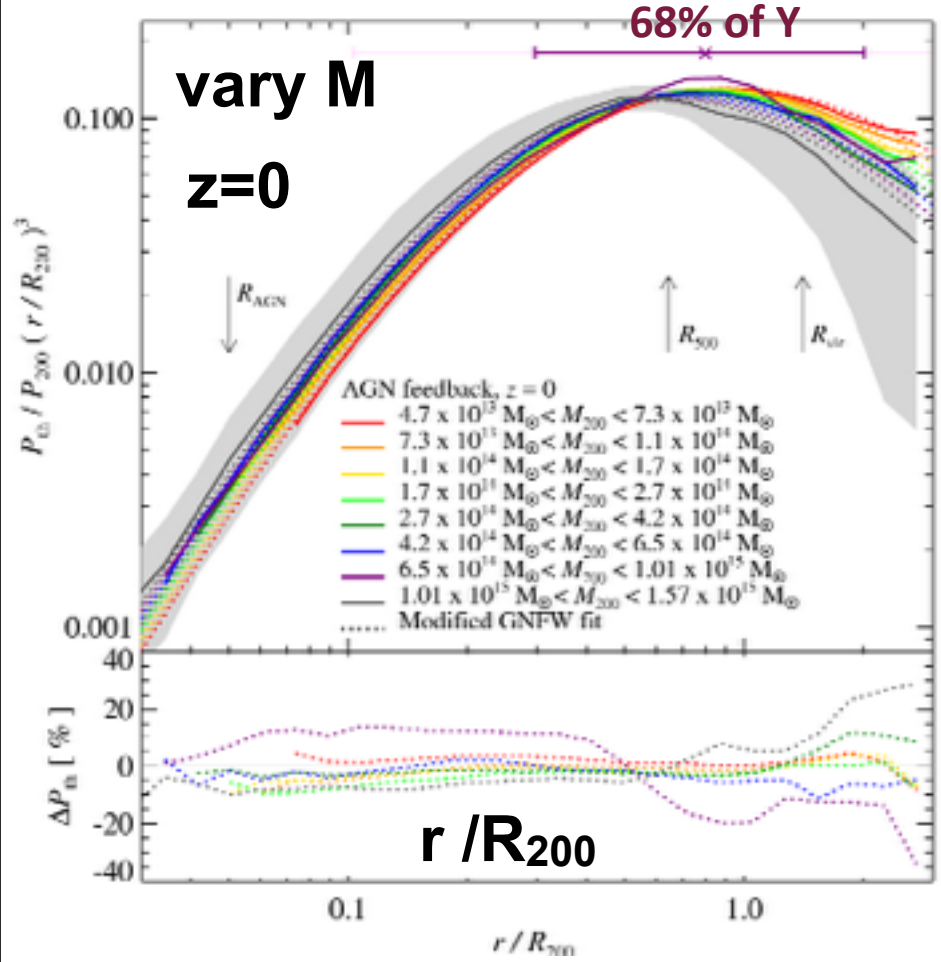
GNFW-fit(M,z) accuracy <10%
extends Arnaud universal profile PUPPY

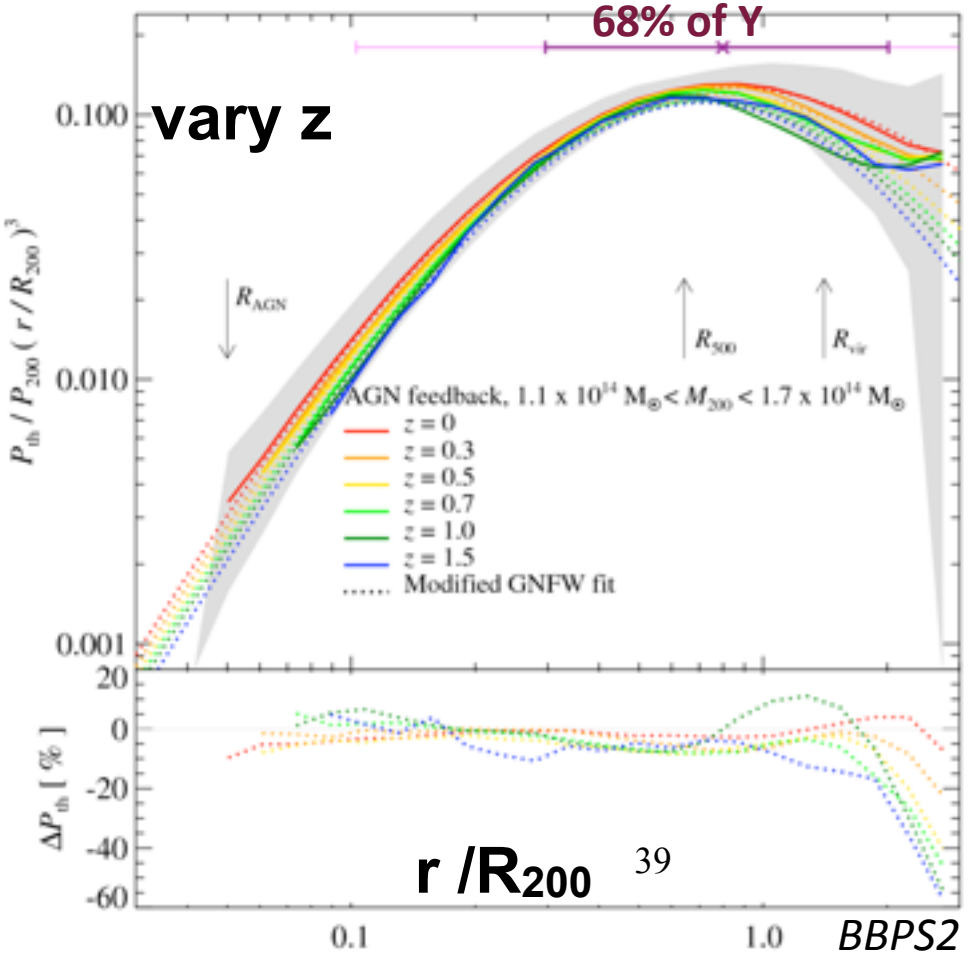
$\sim d\ln\langle P_{th} V | \text{scaled-}cl \in \text{class-}\mathscr{C} \rangle / d\ln r$

ln p_{th} & *ln* ρ_g & *ln* ρ_{dm} & Φ_{dm+g}

$s_X \sim T_e / \rho_g^{2/3}$ & $s_{th} \sim 3Y_T/2$ *ln* s_X

but it is p_{tot} *in the virial equation*



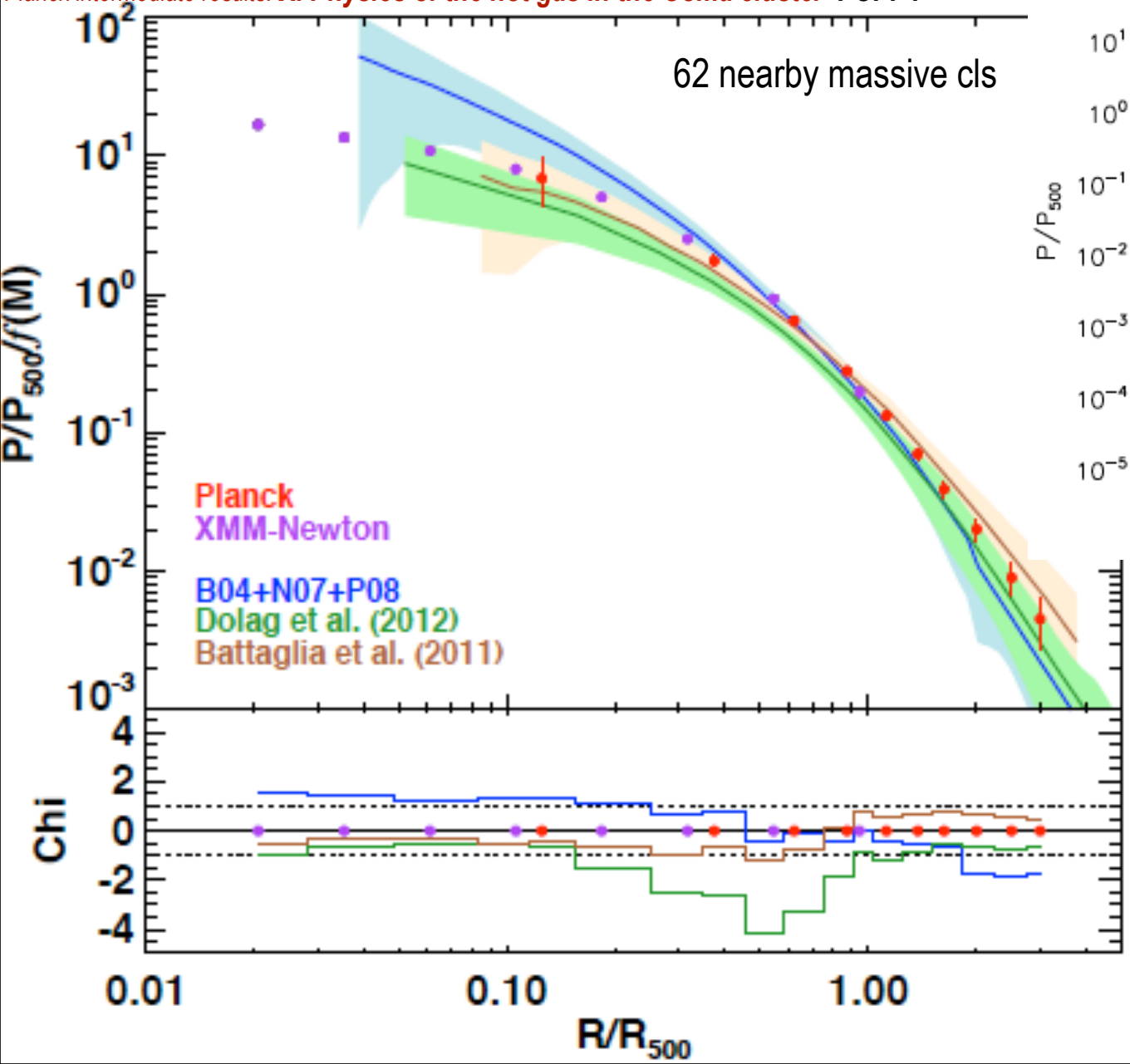


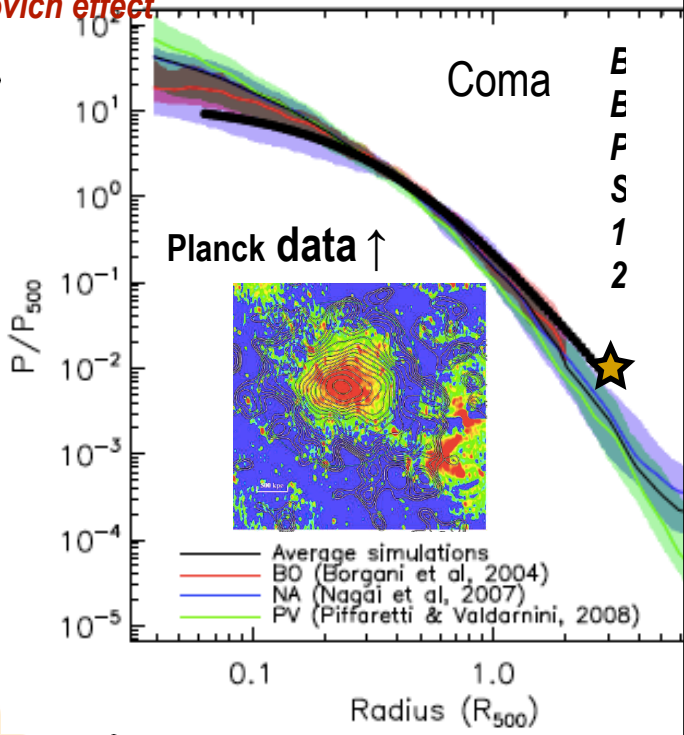
BBPS2

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***



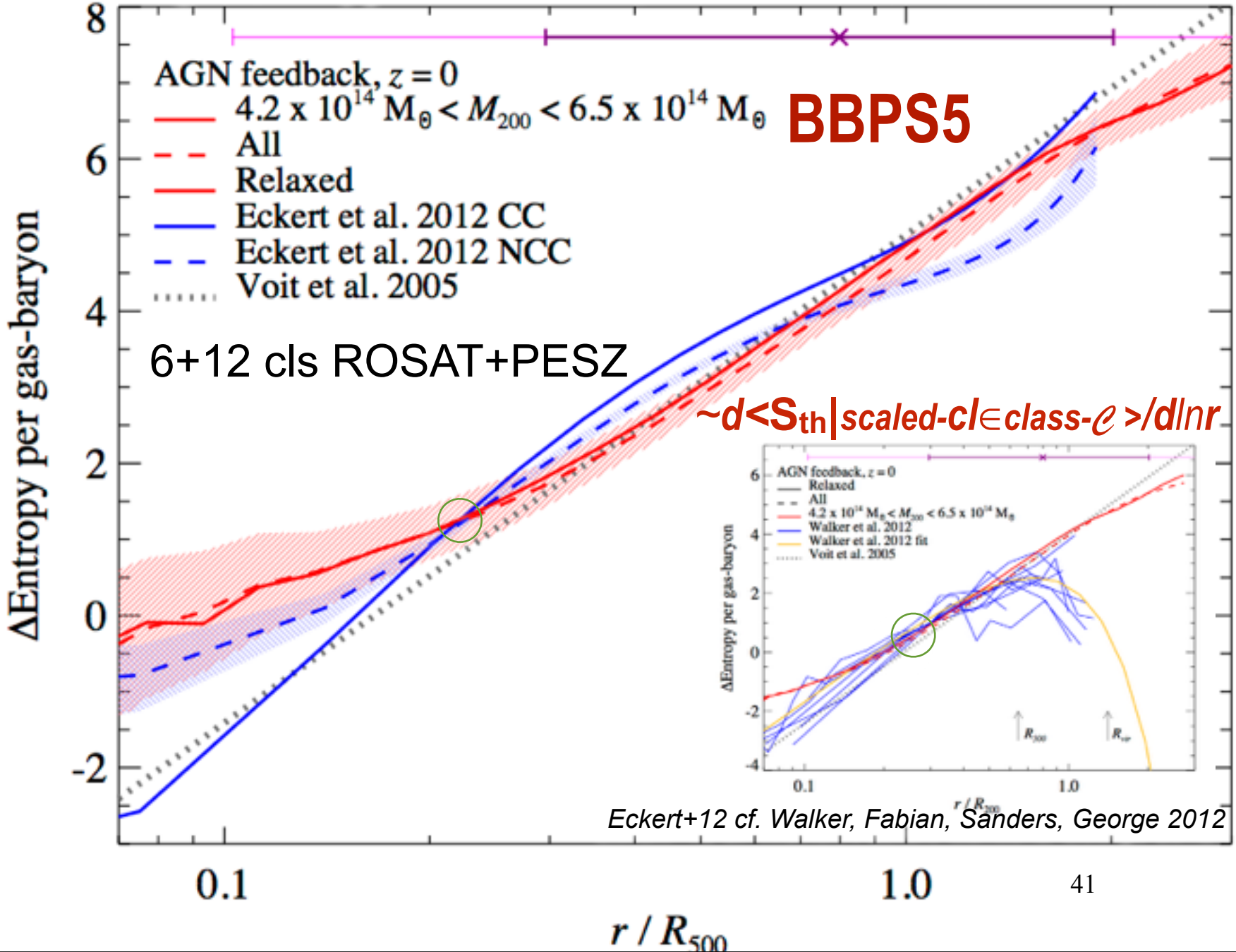


X-ray "universal pressure profile" (Arnaud+10) fails >R_{500}

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} => δp/p ~0.2 ↑ ~1

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



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

entropy intermittency *in the cosmic web, via gravitation-induced shocks (then E/S-feedback)*

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

$s_{b,th}(x,t)$

CMB gets entangled in the cosmic web

400 Mpc

ΛCDM

WMAP5

gas pressure

Gadget-3 SF+ SN E+ winds +CRs

512^3

BBPSS10

BBPS1,2,3,4,5

$\Delta s_{gas,th} \approx 30$

Universal dark matter Entropy Profile? yes!!

***Entropy**-per-gas-baryon*

$\Delta s_{gas,cluster} \approx$
3 *ln* X ~12bits/b +
1 bit/b non-thermal

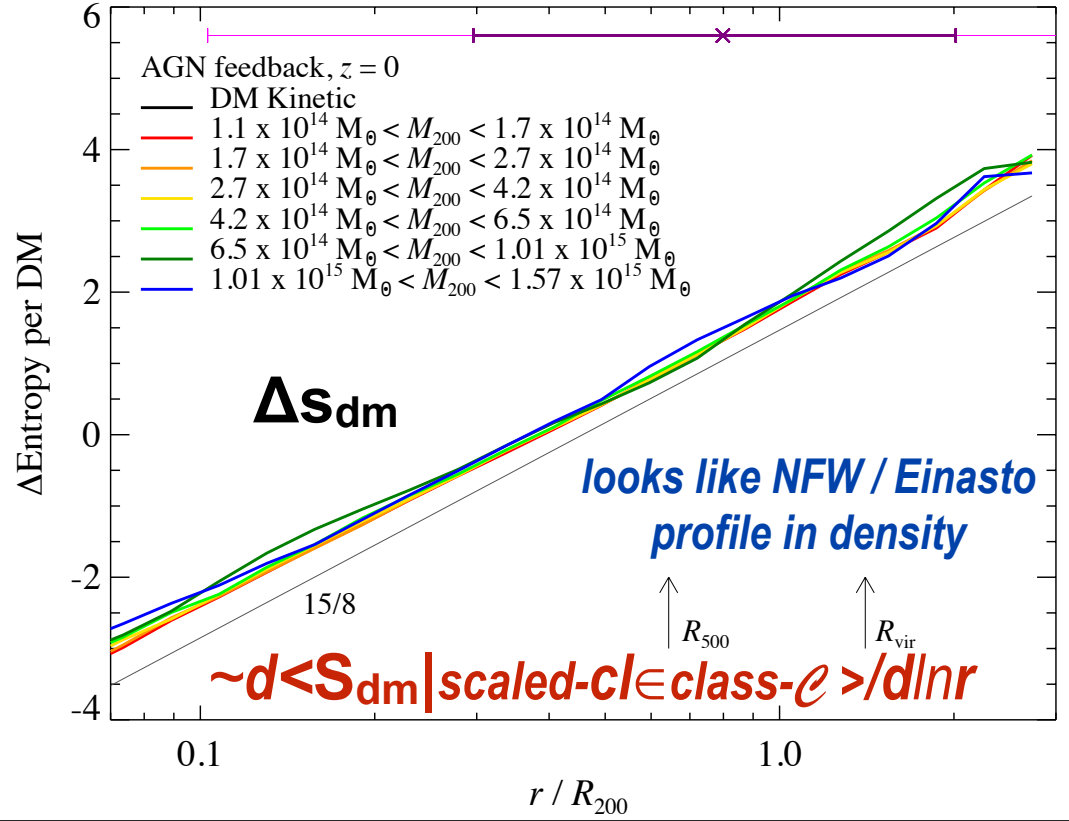
P_{kin}/P_{th}~0.1-0.6!

***Entropy**-per-dark-matter*

$\Delta s_{dm,halo}$
= 15/8 *ln* X
~7 bits/DM

beyond NFW

slope~self-similar radial infall Navarro
ongoing mystery - why halos have this entropy growth law



HALOs in the Web(z)

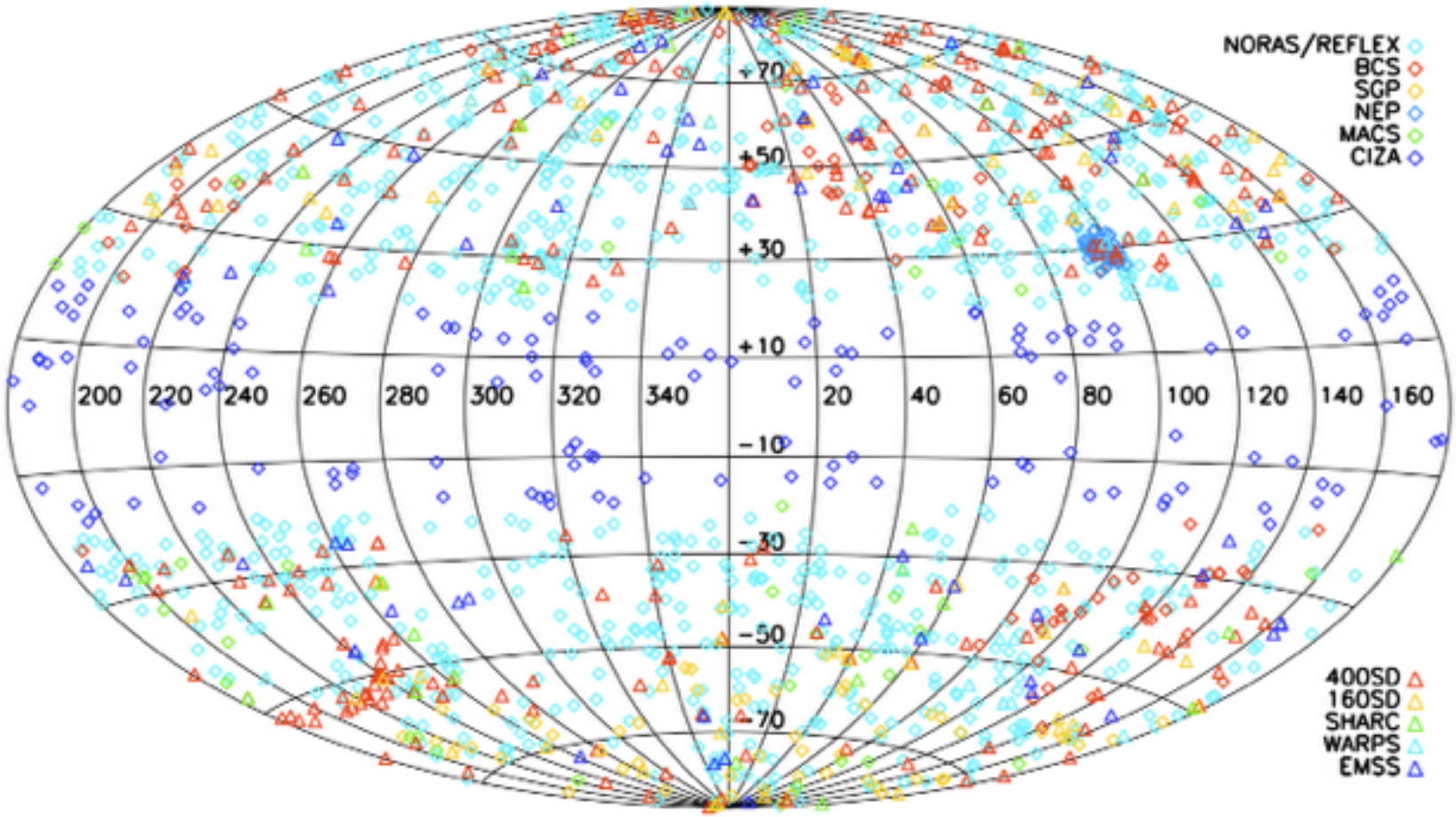
the CLUSTER SYSTEM example

Cross-correlations of X-rays and CMB maps = X-corr power spectra, a path to

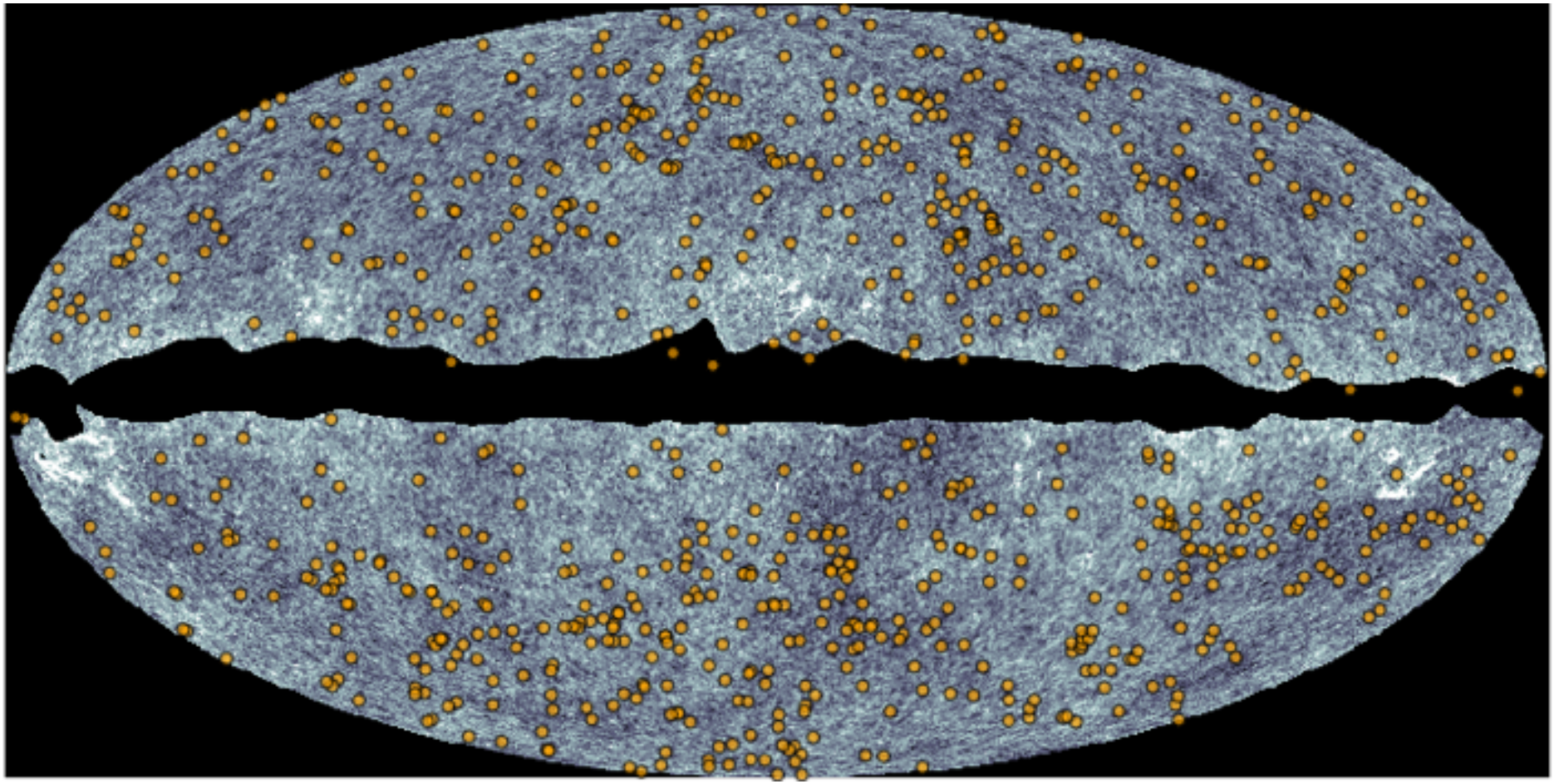
σ_{8SZ} =0.81+-.01 P13+X-SZ

Hajian, Battaglia, Spergel, Bond, Pfrommer, Sievers 2013 **Planck + WMAP9 x ROSAT (RBC subset of MXCC)**

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



Hajian, Battaglia, Spergel, Bond, Pfrommer, Sievers 2013 **Planck + WMAP9 x ROSAT (RBC subset of MXCC)**



Burst of tSZ 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

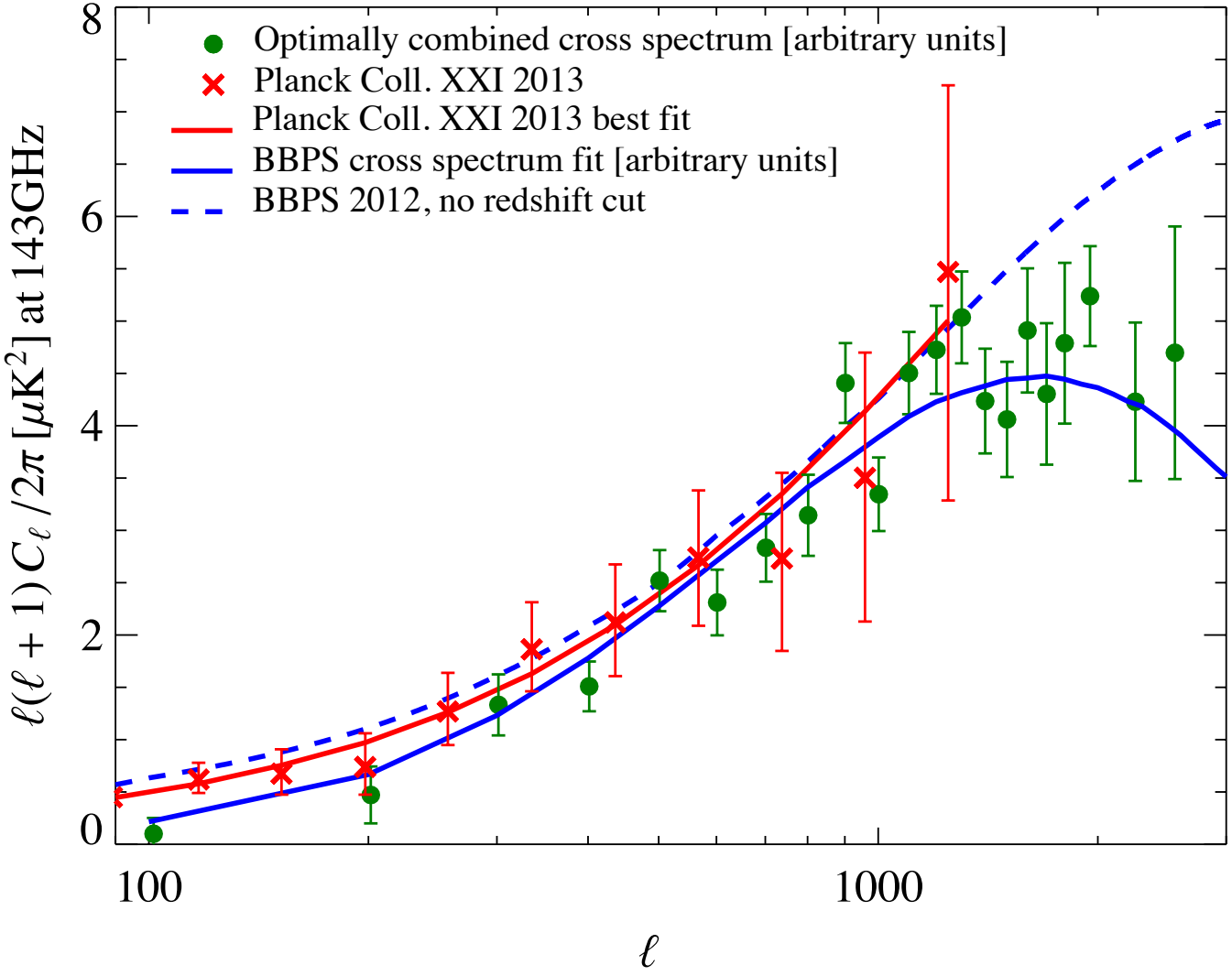
$\sim \sigma_{8SZ}^{7.4}\,\Omega_m^{1.9}$ **for L~ 1000**

$\sigma_{8SZ}\,(\Omega_m/0.30)^{0.26}$ **= 0.80 +- 0.02**

e.g., **= 0.796 +- 0.011** for "AGN feedback"

σ_{8SZ} **= 0.812 +- 0.010 cl+WMAP9**

= 0.812 +- 0.008 cl+Planck2013



Hajian, Battaglia, Spergel, Bond, Pfrommer, Sievers 2013 **Planck + WMAP9 x ROSAT (RBC subset of MXCC)**

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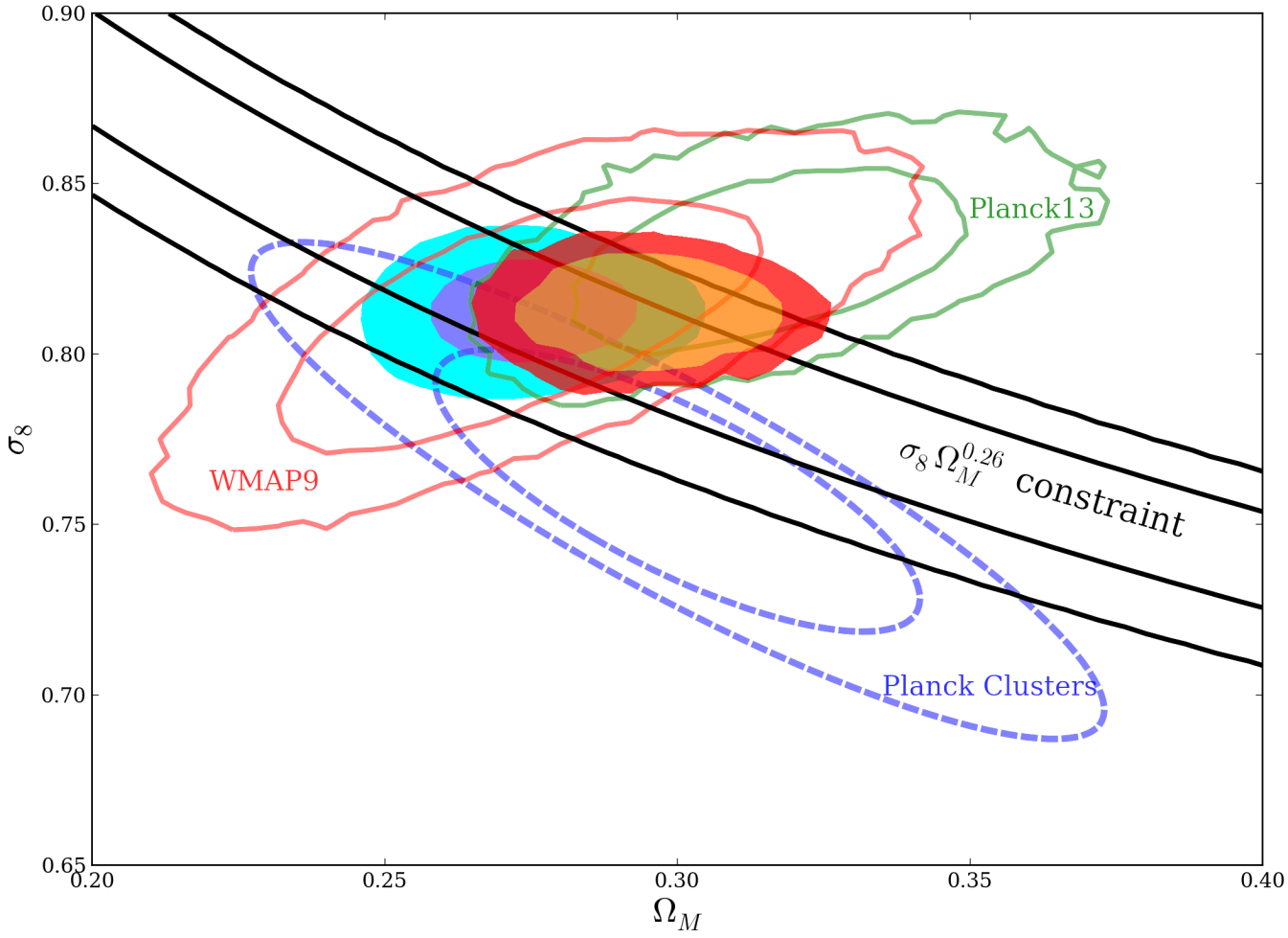
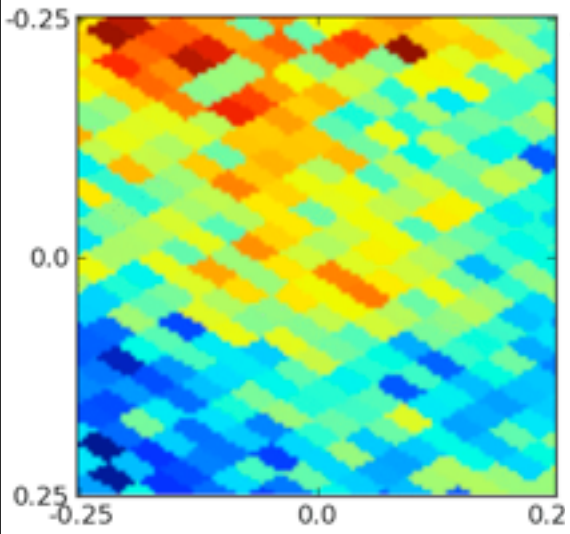
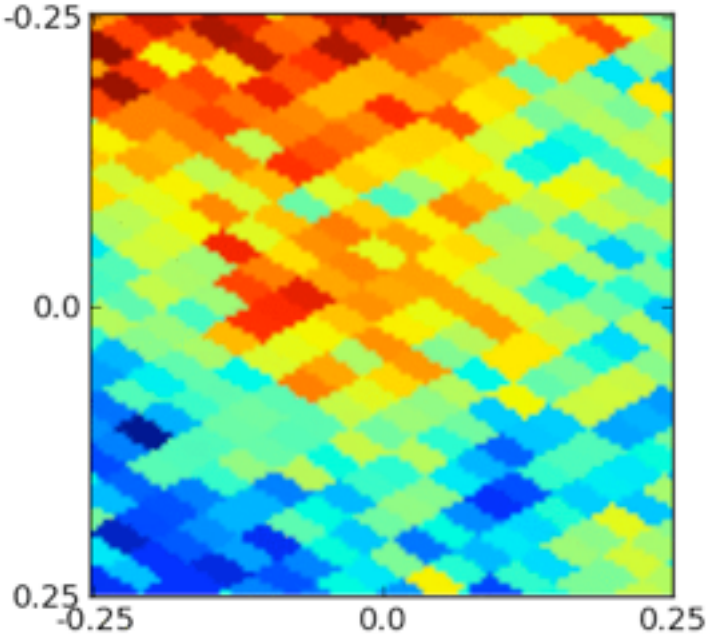


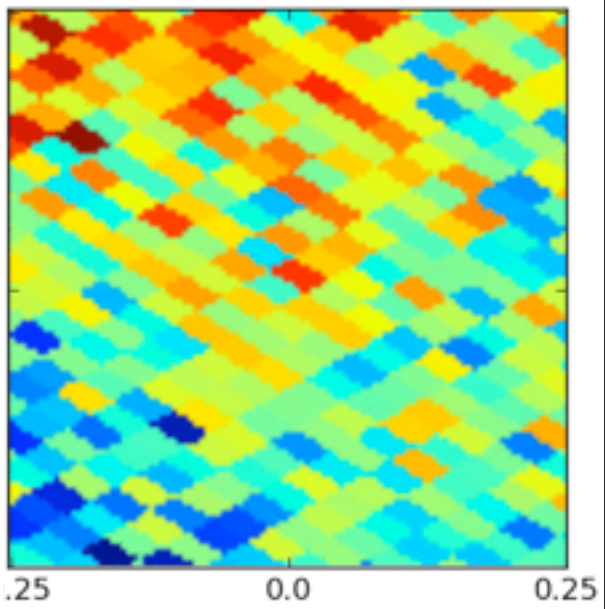
Hajian, Battaglia, Spergel, Bond, Pfrommer, Sievers 2013 **Planck + WMAP9 x ROSAT (RBC subset of MXCC)**



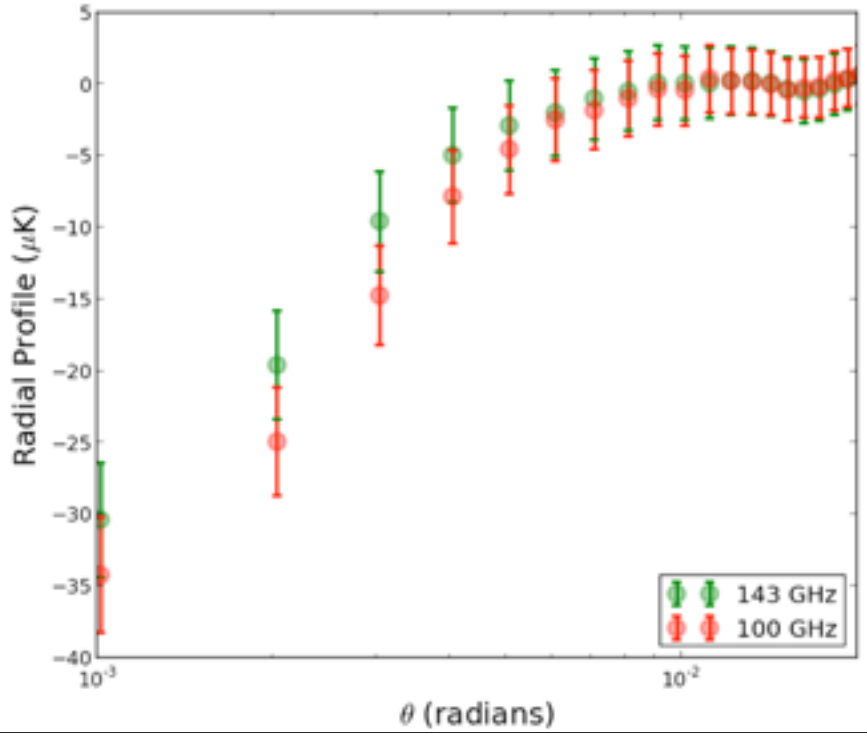
217 GHz



143 GHz



100 GHz



emergence of the cross-correlation

$\langle \Delta T_{SZ}(\theta) | cl \in class\text{-}\mathscr{C} = RBC \rangle$

from (unscaled) stacking of RBC clusters

@ the tSZ null (220), @ 143=best S/N, @ 100

Hajian, Battaglia, Spergel, Bond, Pfrommer, Sievers 2013

Planck + WMAP9 x ROSAT (RBC subset of MXCC)

HALOs in the Web(z)

Cluster/group web MOCKs

Hydro AGN feedback sims

cf.

Peak Patches mean-fields from sims

tSZ: rotated translated stacking of 10 periodic boxes

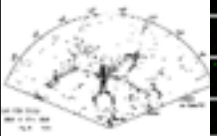
cf. **full light cone PkPatch** non-periodic sim

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

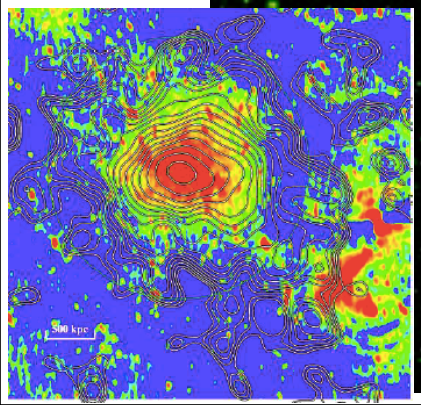
Secondary Anisotropies
(tSZ, kSZ, WL, reion, CIB; hydro)

$p_e(x,t)$

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



Planck's
Coma
2012.08
pip10



the ***thermal Sunyaev Zeldovich Probe***

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

$\langle \Delta E_\gamma / E_\gamma \rangle = 4T_e/m_ec^2$

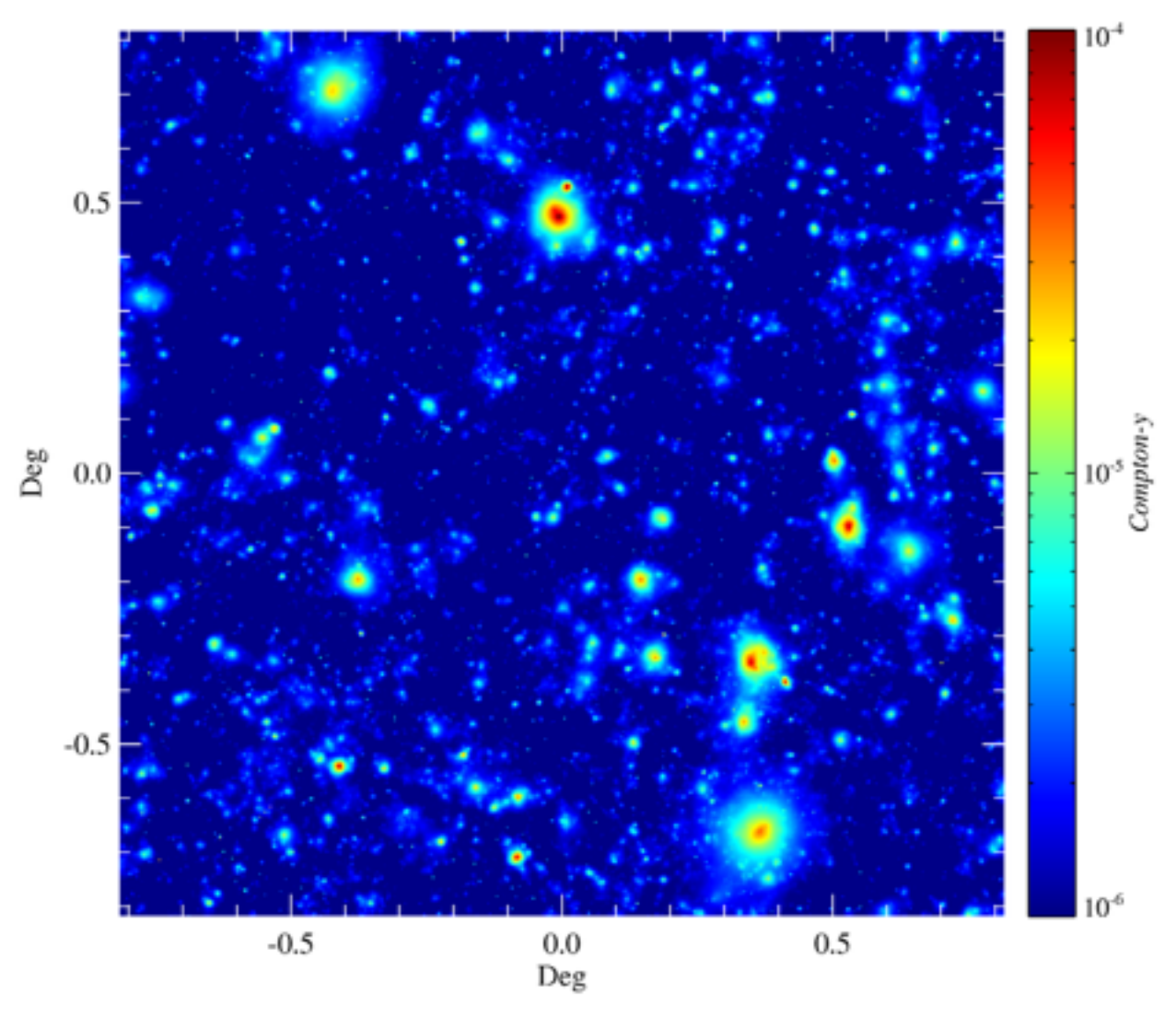
$y = \sigma_T \int p_e \, d\text{line-of-sight}$

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

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

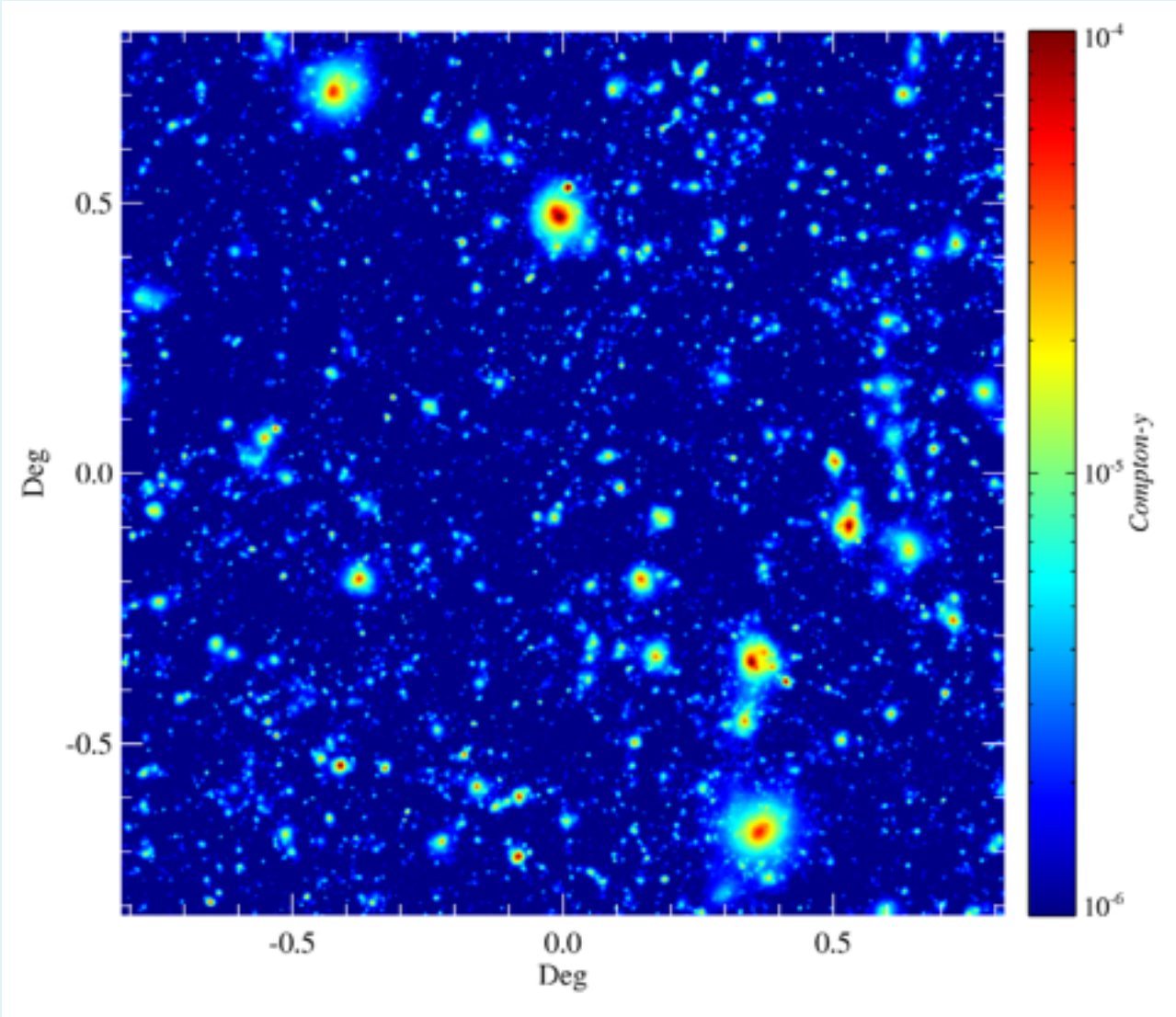
Compton-y map: Feedback

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

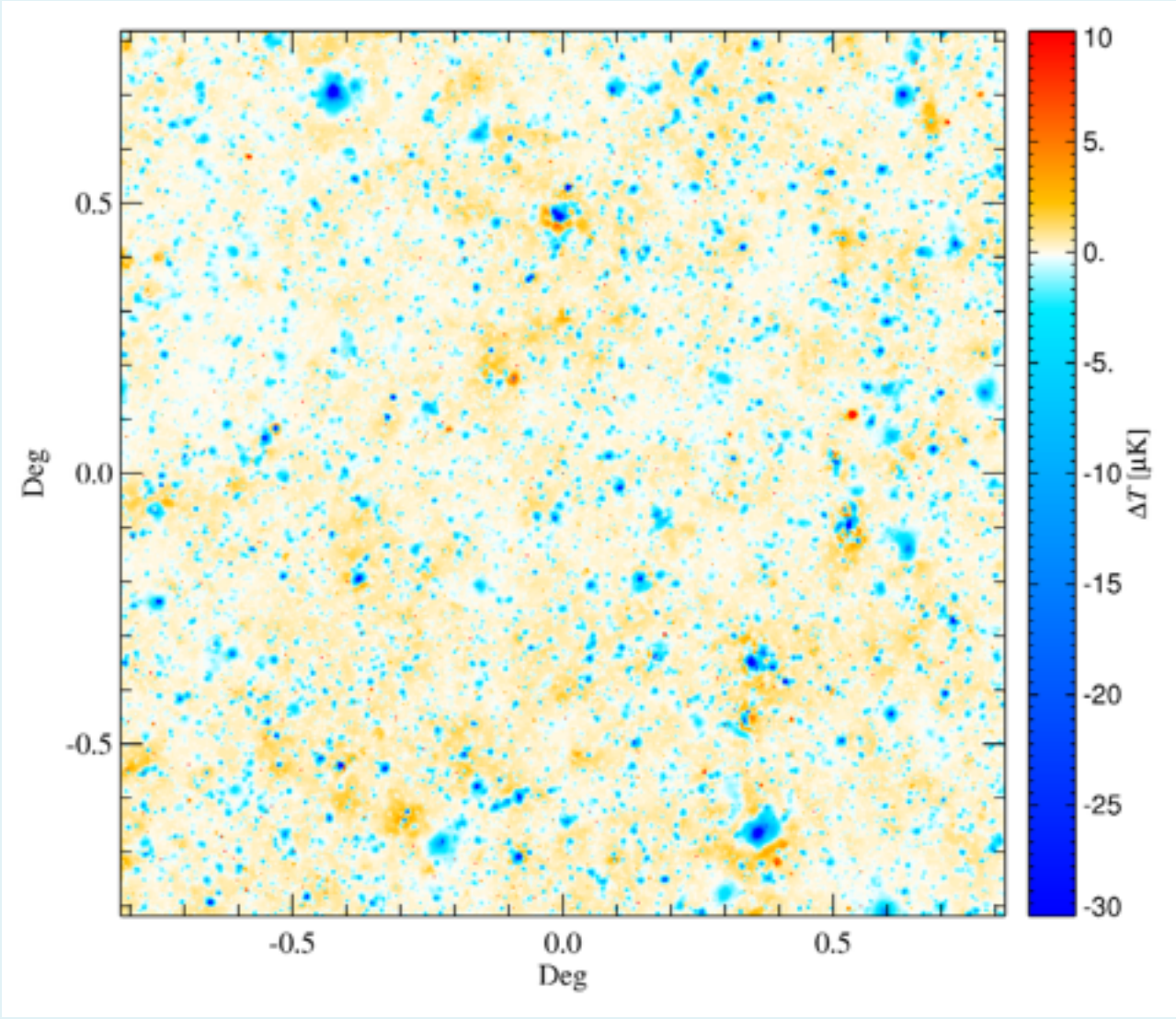


Compton-y map: “adiabatic”

= formation shock entropy from gravitational accretion only



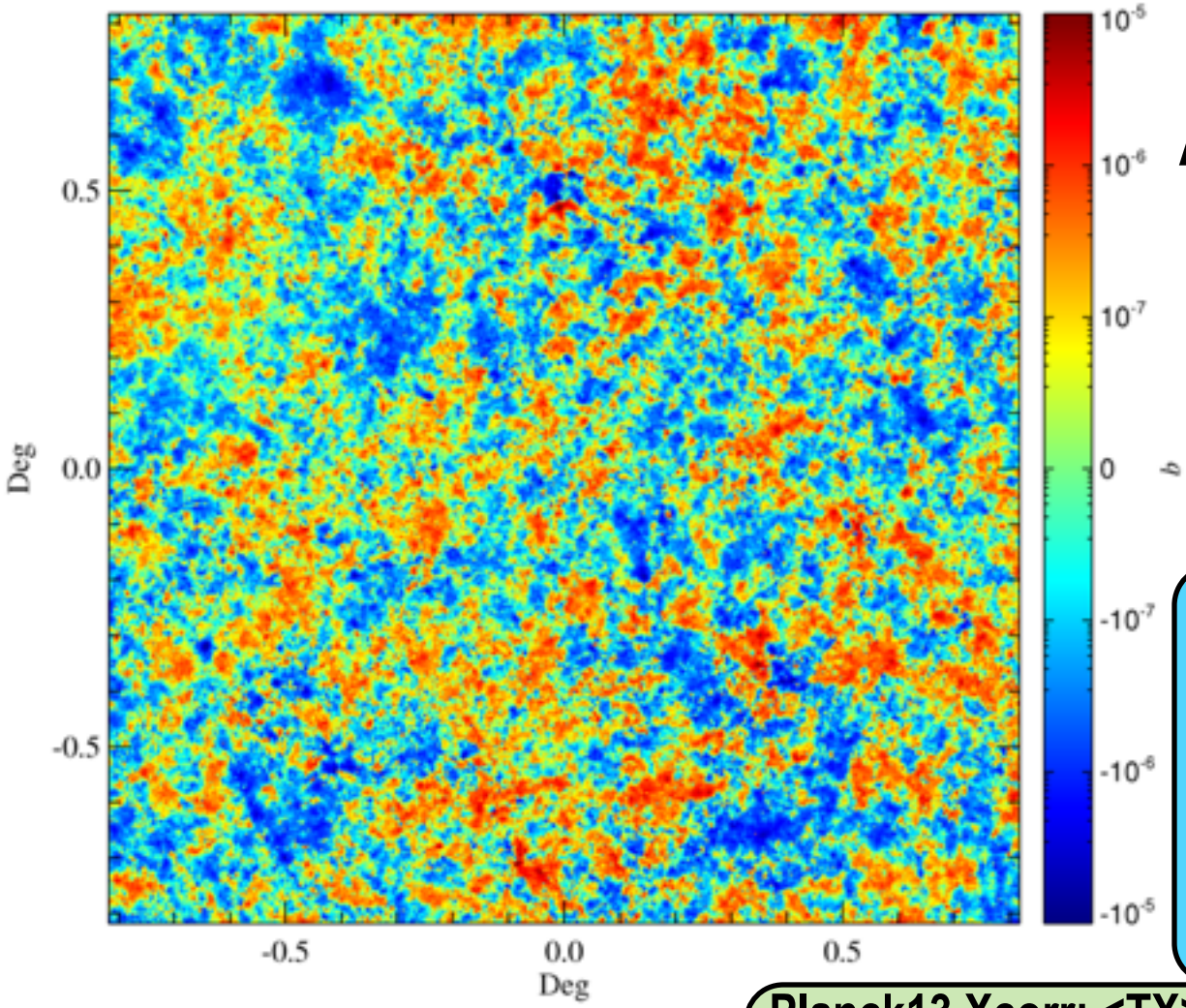
Adiabatic - Feedback



feedback gives "puffier" clusters, with lower core pressures

kinetic SZ map *(log)*: Feedback

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



kinetic SZ:

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

$\sim \int J_e \cdot dr$

spectrally degenerate with primary anisotropies

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

ACT x BOSS first kSZ - via Xcorr: $\langle \Delta T \, n_{gal} \rangle$

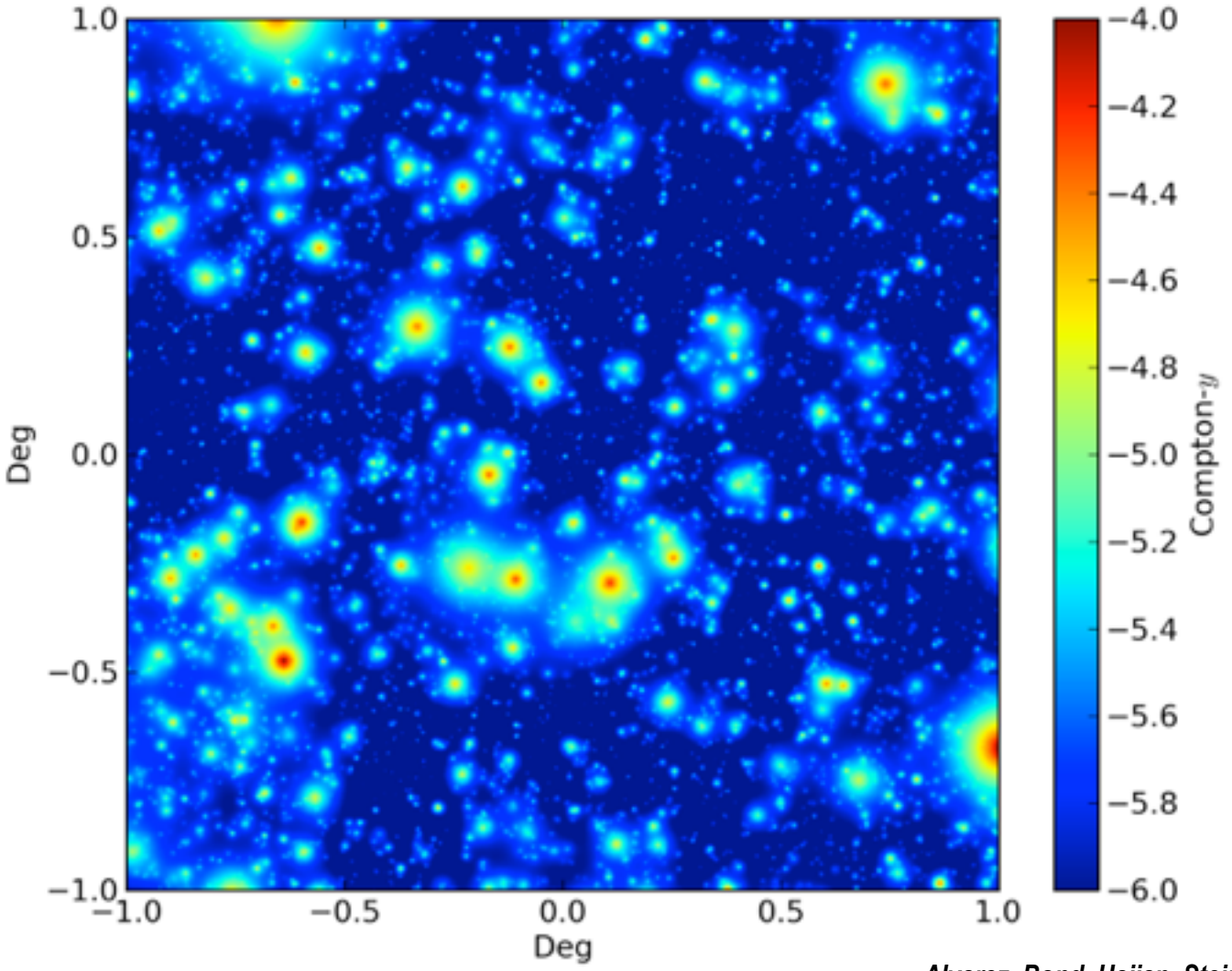
Hand+ 2012 arXiv/1203.4219 using 7,500 brightest of 27291 luminous BOSS galaxies 220 sq deg overlap with ACT equatorial strip 3x110 sq deg 2008-10 data. <z>~0.5.

Planck13 Xcorr: <TX> MCXC 1750 X-ray cls <z>~0.18 no *Dark Flow* ~1000 km/s, < 254 km/s 95% CL

BBPS1,2,3,4,5

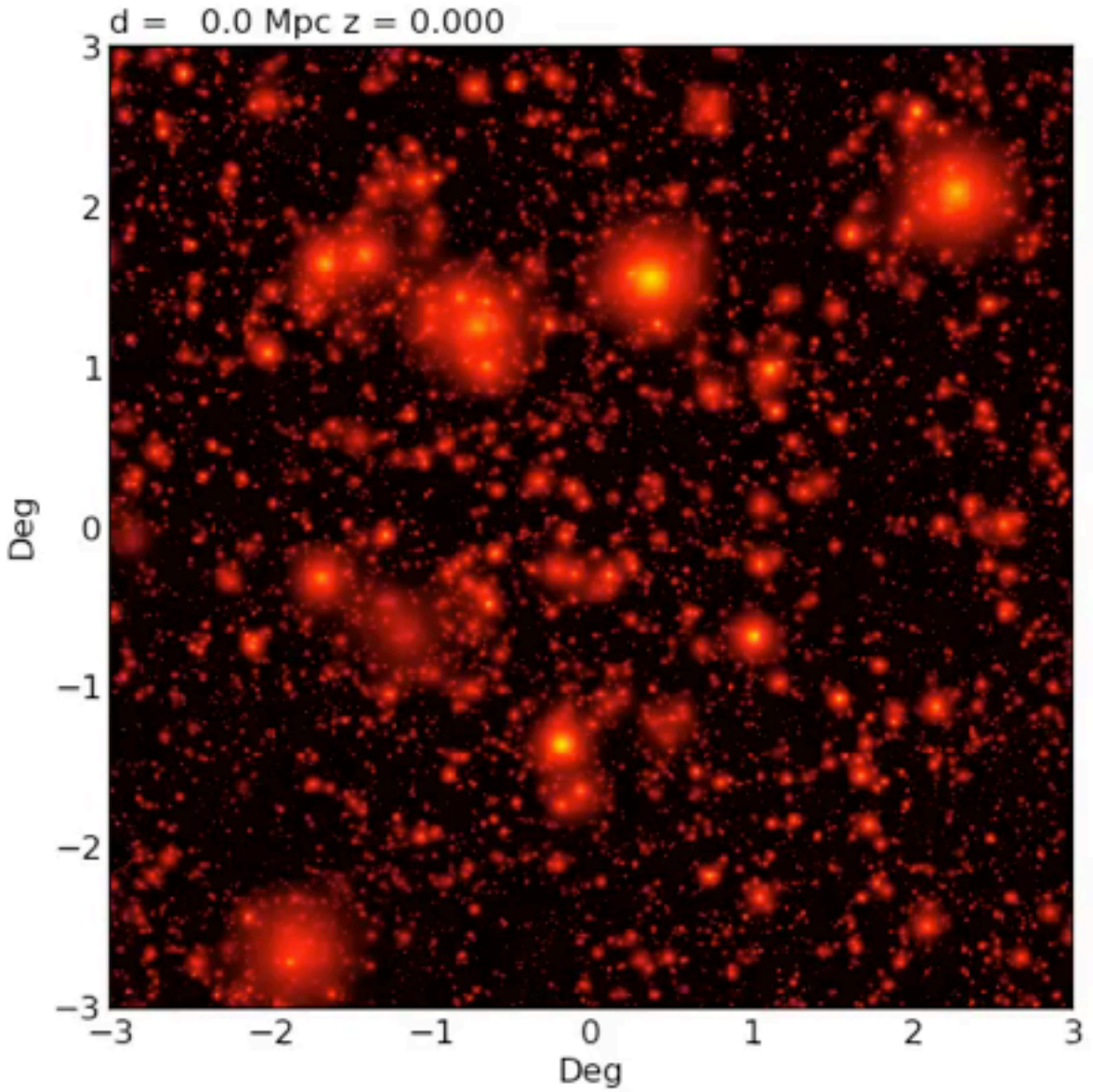
Compton-y map: Peak Patch

= mean Xcorr pressure field of BBPS2 painted on halos



Alvarez, Bond, Hajian, Stein, Emberson 2013

long-wavelength-threaded multi-box-tiled Peak Patch tSZ lightcone simulation for Planck-ish tLCDM. mean X-corr field, 6 sq deg, to z=2



tSZ PkPatch map needs intracluster residual pressure fluctuations & cluster orientation via Lagrangian strain to Eulerian pressure inertia-tensor information for higher tSZ map accuracy.

kSZ PkPatch maps use cluster/ group dominance as in the original moving cluster effect

Alvarez, Bond, Hajian, Stein, Emberson 2013

END

LSS conclusions in progressTBD