the LSS Effective Field Cluster Decomposition: the Peak Patch Picture of Halos, Then & Now

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Dick Bond @ Lorentz16.7.4

THEN BBKS, BCEK, BM, BKP, BW
NOW: CITA mini-industry
Alvarez, Berger, Bond, Stein, Bahmanyer, Battaglia,..Huang, Frolov 2016

the true Effective Field Theory of Large Scale Structure =
Hierarchical Peak Patches =Excluding Ellipsoidal Excursions E^3
in **Scale space:** resolution = a 5th dimension
4+1 dimensions => the ADS to our CRFT => scale dreibein => 4+6 dimensions

the fluctuation-background split aka peak-background split is our Effective Field Theory, coarse-grain rules LSS, but fine-grain talks to adaptive coarse-grain: hot entangled halos in to Warm web/ Cool Flows Adaptive multiscale fundamental to clusters/clustering in the statistical sense

Hot halos => Warm Cosmic Web Structure => Cool Linear Dynamics of 1Lpt/2Lpt

Lagrangian flows are good on unentangled unHEATed coarse-grained scales but Eulerian flows for fine-grain caustic zones

"couplings" are the susceptibilities/ response functions/ form factors of fine grained high entropy phenomena - approach to targeted measures via observations, hi res sims

from **SuperWeb simplicity** to **complex Intermittency** in the **Cosmic Web**

MOCK*ing* HEAVEN

painting the Euler/Lagrange Peak-Patch Picture of Cosmic ACTalogues aka halos (N-body/pp+hydro sims/HOD/obs)

fundamental physics from probes of the Cosmic Web: e.g., Dark Energy (BAO, lens, z-distortions, halo far-field structure), dark matter (halo near-field structure), neutrino masses, primordial non-Gaussianity, primordial power spectrum complexity?

or blockage from gastrophysical indigestion?

Zeldovich 100th, Tallin IAU 308 2014

NOW ish IAU 2014

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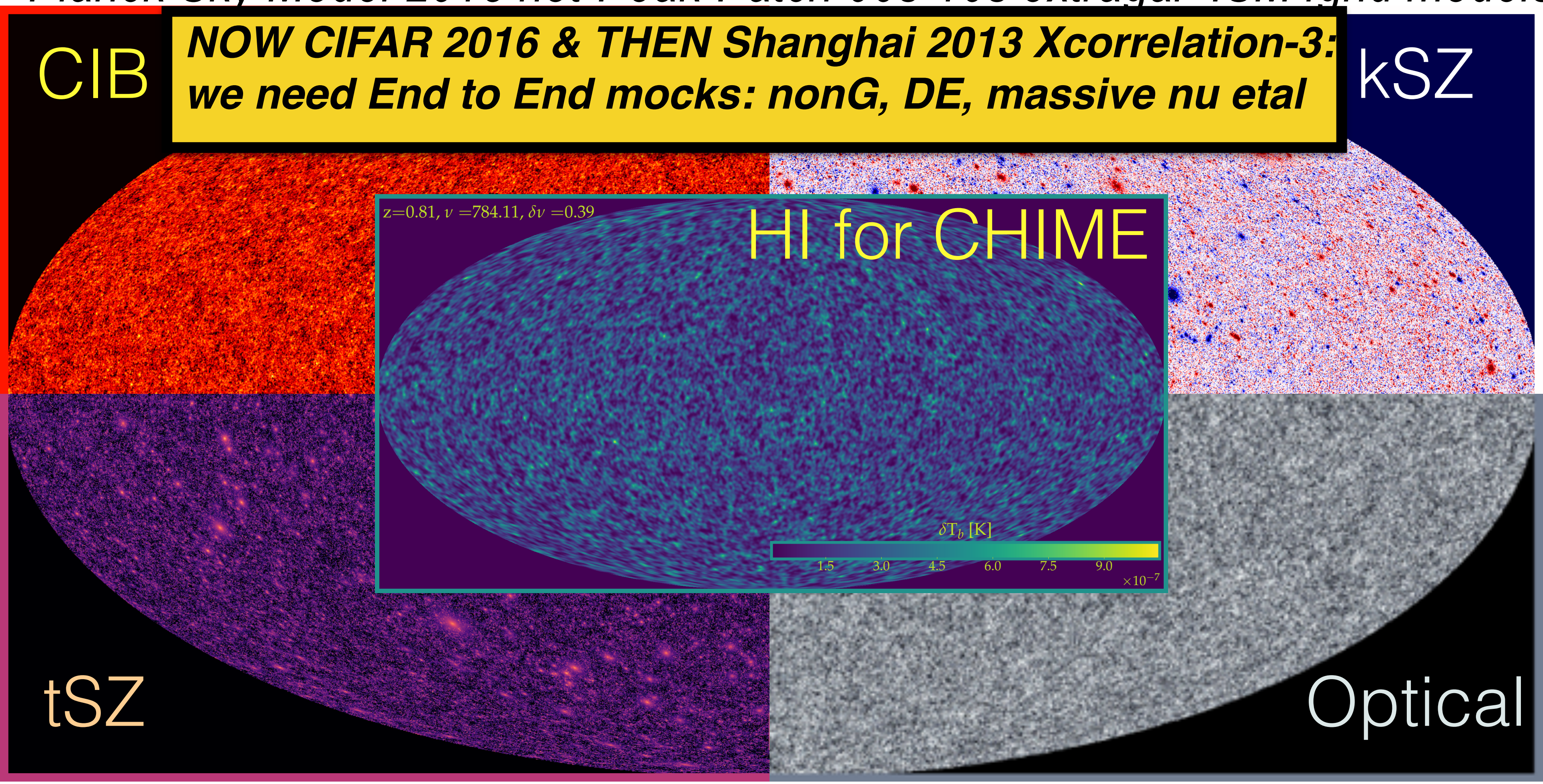
Mocking Heaven @ *CIFAR16* **Dick Bond**

Peak Patch Full Sky Models: @CIFAR1991 tSZ,CIB

Peak Patch tSZ,kSZ in Planck 90s Bouchet-Gispert the cosmic sandwich

Planck Sky Model 2015 not-Peak-Patch 00s-10s extragal+ISM fgnd models



*Planck 2015 XII: Full Focal Plane Sims (Nov): FFP8 ensemble of10K **End**to**End** mission realizations in 1M maps. instrument noise + CMB + PSM + .. (25M NERSC CPU hrs)*

$u_q(x)=\sum_c \chi_{qc}(x-x_c,R_{Ec})\,q_c\,\delta N_c(x_c,R_{Ec})+u_{qf}(x)\Theta_{VE}+u_{qf}(x)(1-\Theta_{VE})$

inside = $\Theta_{VE}(x)$, 1 or 0 outside = $1-\Theta_{VE}(x)$ = complement

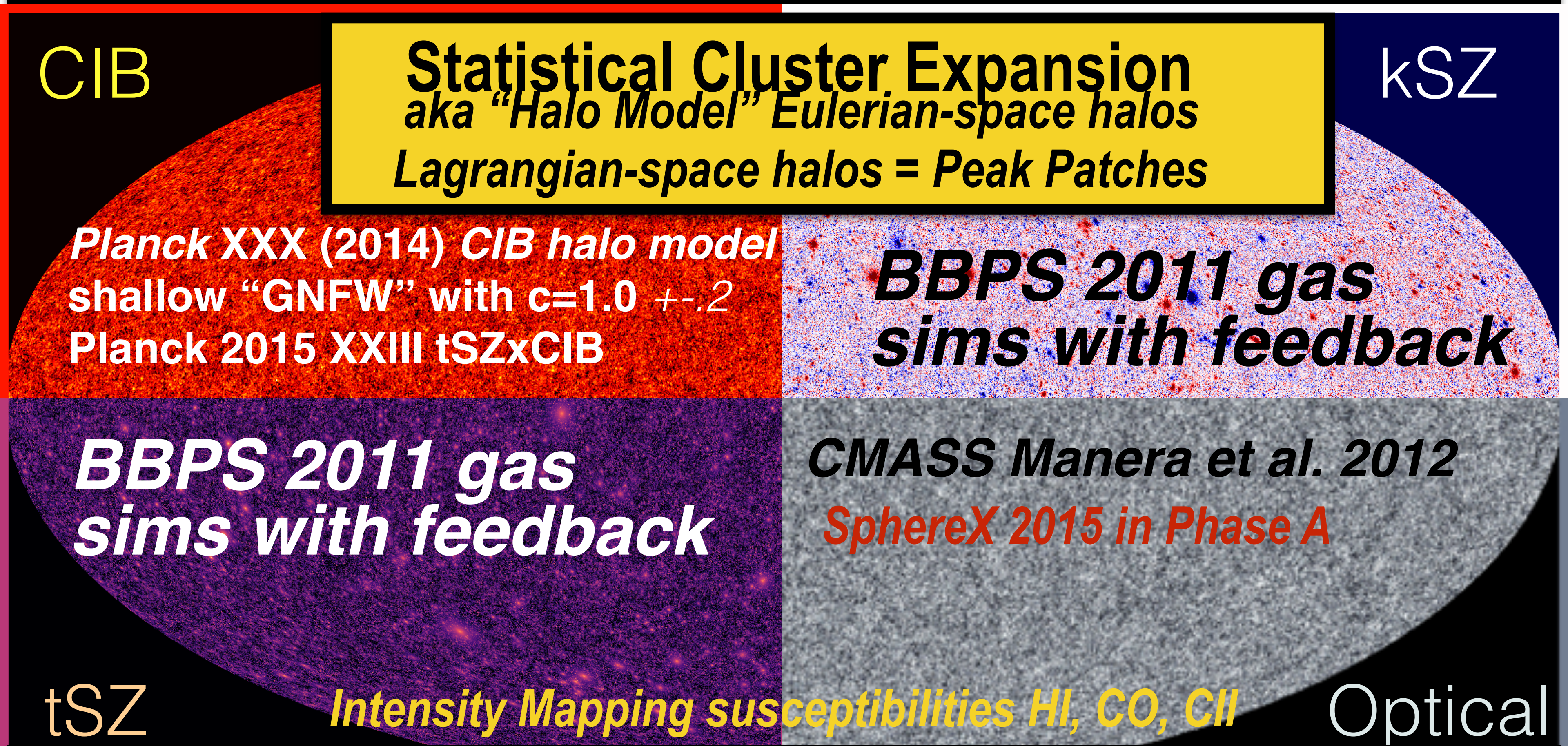
χ_{qc} **susceptibility** of u_q to the "charge" q_c the art of halo models

$q=M_{tot}$, M_{dm}, M_{gas}, PV, V_E, K_{dm}, S, S_{conf} … measure: obs, gas sims

Statistical Cluster Expansion

aka "Halo Model" Eulerian-space halos

Lagrangian-space halos = Peak Patches



Eulerian <= **Lagrangian** map: 1LPT s_{Lc}, 2LPT & beyond the art of s_{NLc}

$x_c(t)=x_c(t_i)+s_{NLc}\,(t|x_c(t_i),t_i)$ $\quad$ $x_c(t_i)=r_c$ initial Lagrangian position

THEN: an historical flow from 70s western ‘halos’ & russian pancakes thru BBKS & BCEK to BM peak-patches = E^3 to BKP cosmic web & pk/void-patch mean fields to BW shearing patches & importance sampling

in ``A Pan-Chromatic View of Clusters of Galaxies and the Large-Scale Structure'', (Berlin/Heidelberg: Springer)

Clusters and the Theory of the Cosmic Web

Rien van der Weygaert & J.Richard Bond, 2008, Lecture Notes in Physics 740, 335-408

http://www.astro.rug.nl/~weygaert/tim1publication/weybondgh2005.paper1.pdf

Observations and Morphology of the Cosmic Web

Rien van der Weygaert & J.Richard Bond, 2008, Lecture Notes in Physics 740, 409-468

http://www.astro.rug.nl/~weygaert/tim1publication/weybondgh2005.paper2.pdf

brief history of understanding objects and their distribution in the cosmic web

50s Neyman&Scott point process of galaxies - Poissonian ideas

70s Peebles etal: dark matter to stabilize spirals, search for a faint **halo** of low mass stars (or Jupiters or black holes VMOs or .. particle relics)

hence **spherical halo** as home for dissipative / condensing baryons White & Rees, Gunn, …

HALOS hierarchy, small round objects => large round objects

spherical **2-pt** correlation functions in angular Shane-Wirtanen galaxy catalogue & **3-pt**

50s-80s Abell cluster catalogue & 2-point cg and cc 'extra power' => **xCDM**

BUT 70s adiabatic east, Einasto confirming Zeldovich pancake picture

70s: Doroshkevich, Shandarin, Zeldovich: 1st order Lagrangian dynamics, statistics of 1D collapsing entities (caustics & pancakes) in a GRF; 80s: Arnold, Shandarin & Zeldovich: influential picture of 1st order catastrophes;1D⇒2D⇒3D pancake⇒filament⇒cluster flows

80s: **superclusters are real**, large voids exist. **Oort**'s last astro passion

3D redshift surveys CfA ⇒ 2dF, SDSS,COSMOS

80s APM catalogue Efstathiou etal 2-point gg also 'extra power' => **xCDM**

На здоровье
Terviseks

Z70,ZES82
AZS82
e_J^j

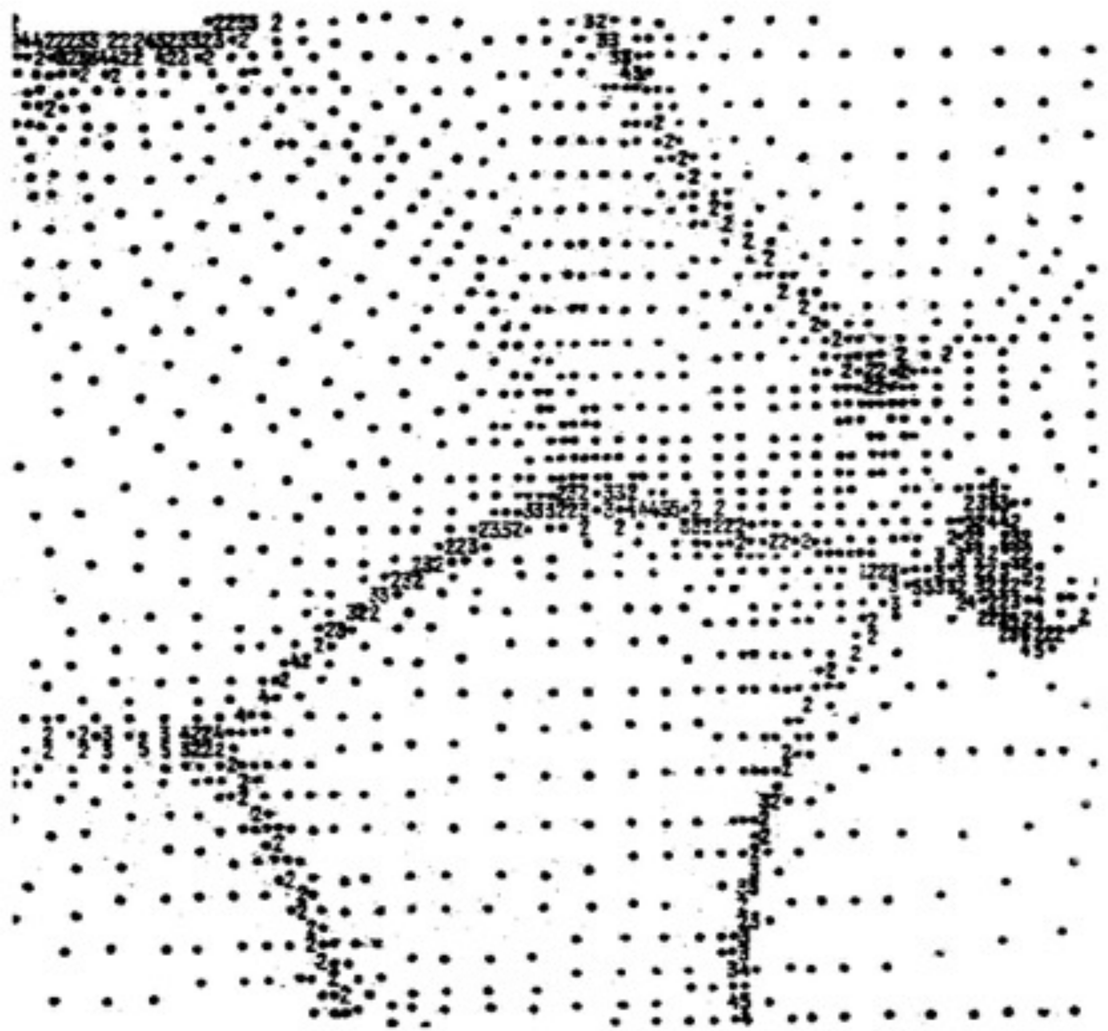
The first numerical simulation of the Zel'dovich Approximation in 2D

Shandarin 1975

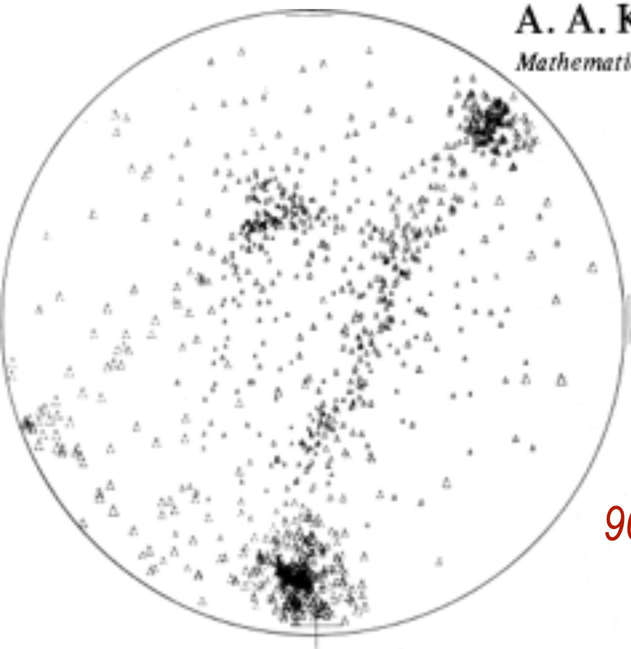
published in review
by Doroshkevich
Zeldovich
Sunyaev 1975
(in Russian)

Later in
Dorshkevich,
Shandarin 1978

influential for Arnold,
Shandarin Zeldovich 1982



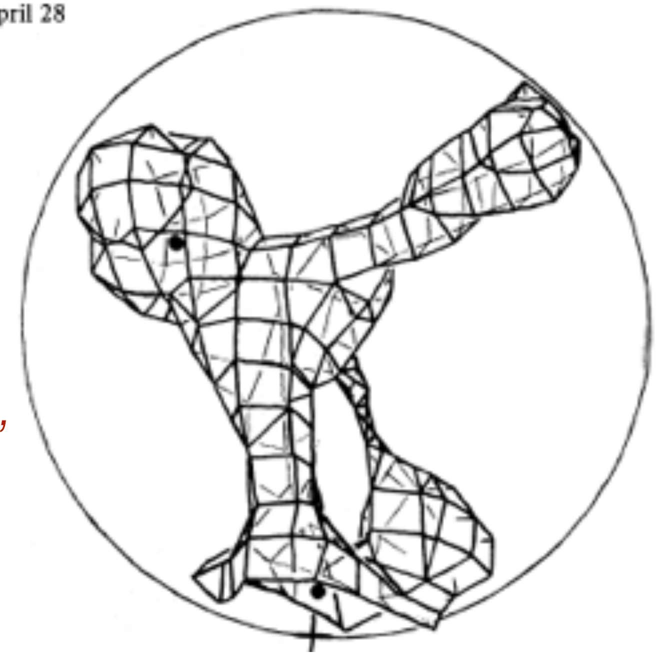
Made with alphanumeric printer



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

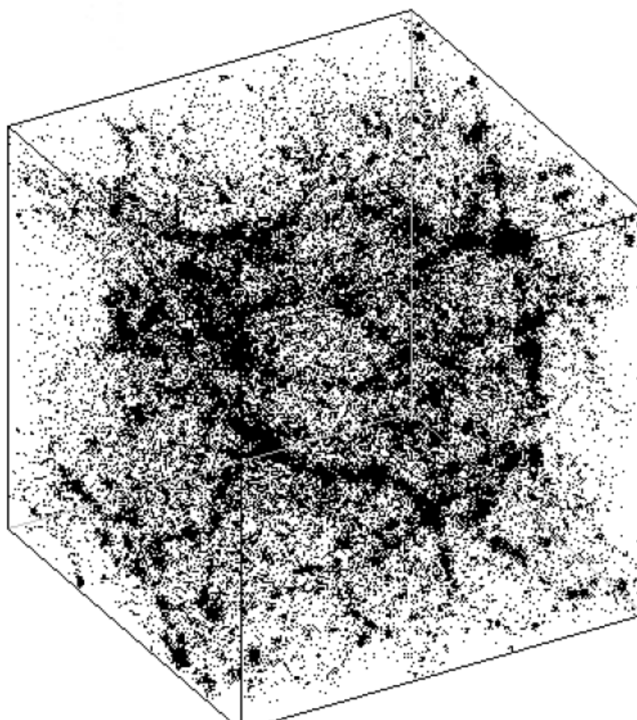
3D numerical model of the Universe

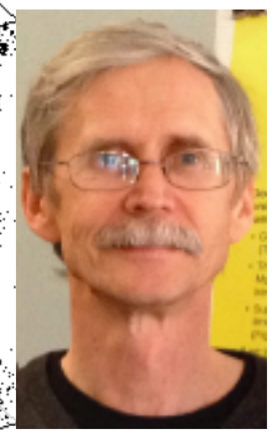


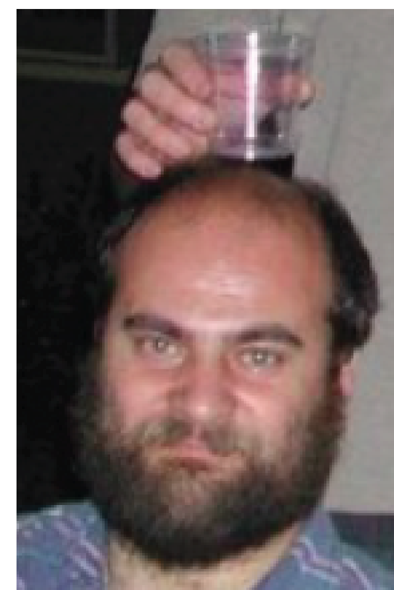
Klypin's vintage 82
$160h^{-1}$Mpc box 32^3 hDM

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

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

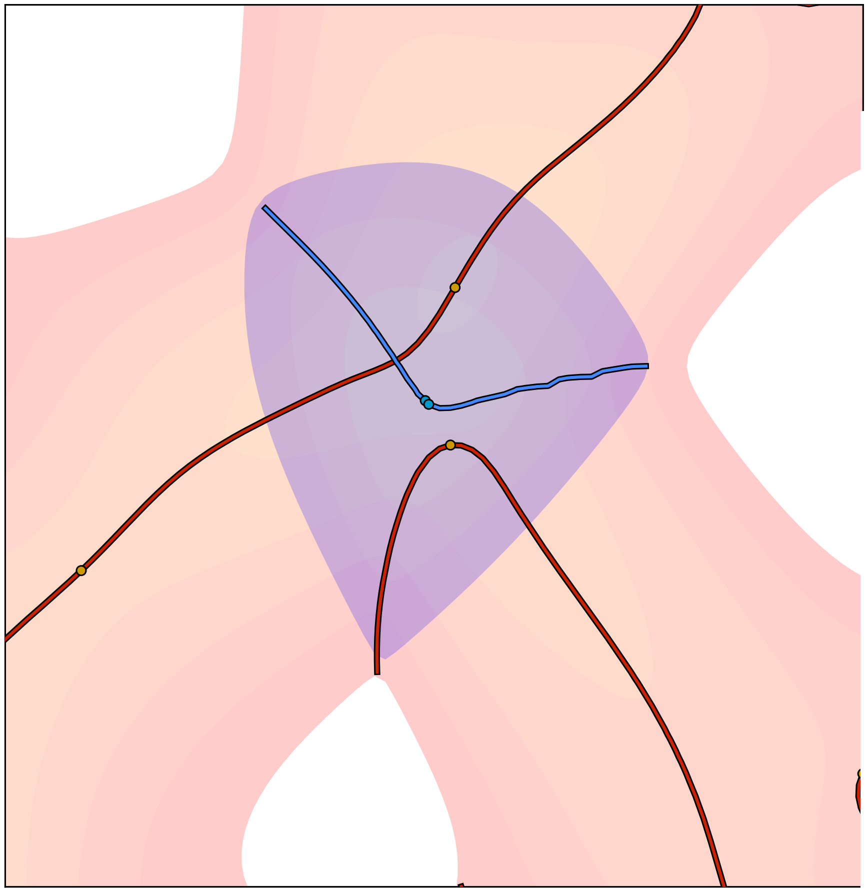






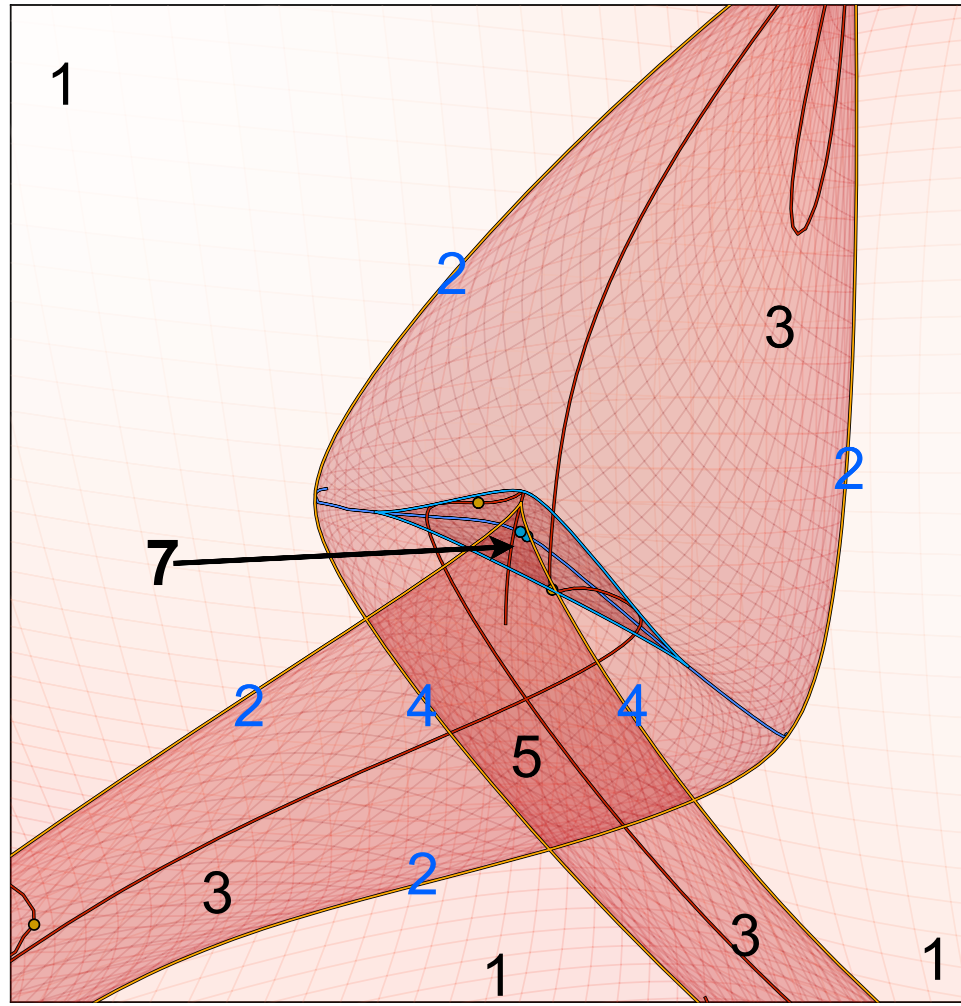
Klypin's vintage 93 $50h^{-1}$Mpc box 128^3 sCDM = BKP98 web workhorse, Couchman's 128^3 for BM91-96

Complexity of caustics



Lagrangian space

Number of streams
in Eulerian space



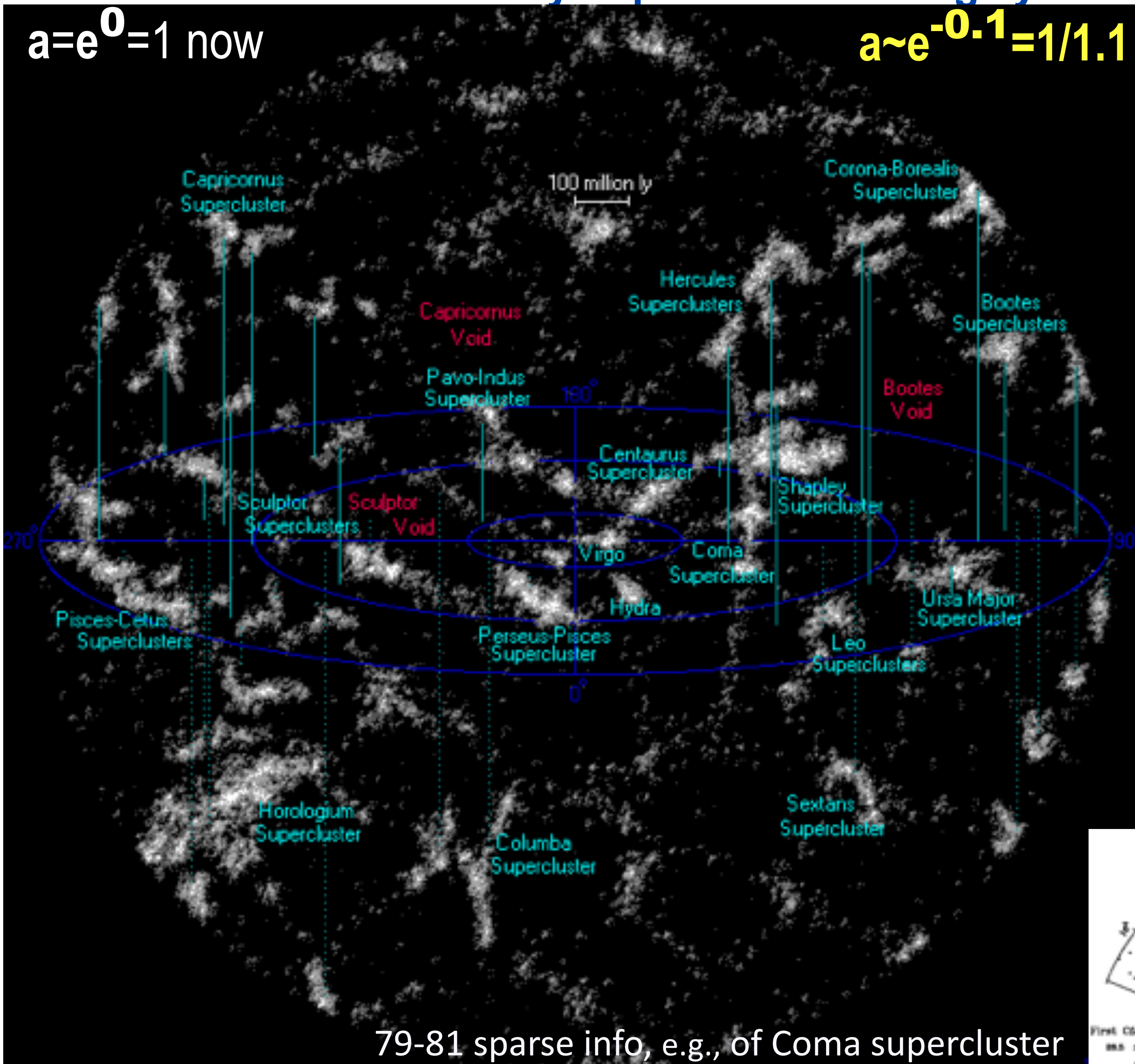
Hidding,
Shandarin,
van de Weygaert
2014

to **a ~ 0.9 via 3D maps** "local" **COMPLEXITY**

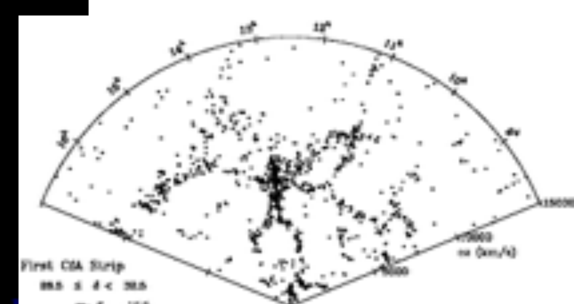
cosmic web of **nearby superclusters < *Gigalyr***

$a=e^0=1$ now

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



79-81 sparse info, e.g., of Coma supercluster



70s adiabatic pancake (physical filter)
Doroshkevich, Zeldovich
cf.
70s isoc B/BH (power law CorrFn)
Basko

miracle of CDM = grand unification of east & west ideas with ~ HSZ spectrum

emergence of superclusters

Peebles vs.
70s Einasto+..
80 + Oort +

brief history of understanding objects and their distribution in the cosmic web

80s: M **scale space** *ln*R_f 3+1D => 4+1D our ADS to CRFT => 9+1D **ε**

80s: objects=**peaks** of filtered GR initial linear **density** field BBKS..; **clustered shots & bias**

B88a,b,89.. BM91,93a,b,c,94,B96, big unpublished 'preprints' BM93-97,BKP98a,b,BKPW98,BW01

~~90s: **threshold-based excursion sets** & 1-pt statistics of "dark matter" halos BCEK,...~~

lnR_f => resolution as pseudo-imaginary-time $\sigma_{\rho L}^2$

imported ***Stochastic Inflation*** ideas of Bond +Salopek 90, 91 into LSS *Langevin, Smoluchowski, Fokker-Planck, barriers, ..*

90s: the **peak-patch picture of cosmic catalogues** BM96a,b,c: tidal/strain fields $\varepsilon^j{}_J(r_{pk},t,R_{pk})$ fundamental in evolution; ***accurate mass & spatial structure determination cf. SP-O gps***; shearing patch simulations BW96-99-02, BWKP99

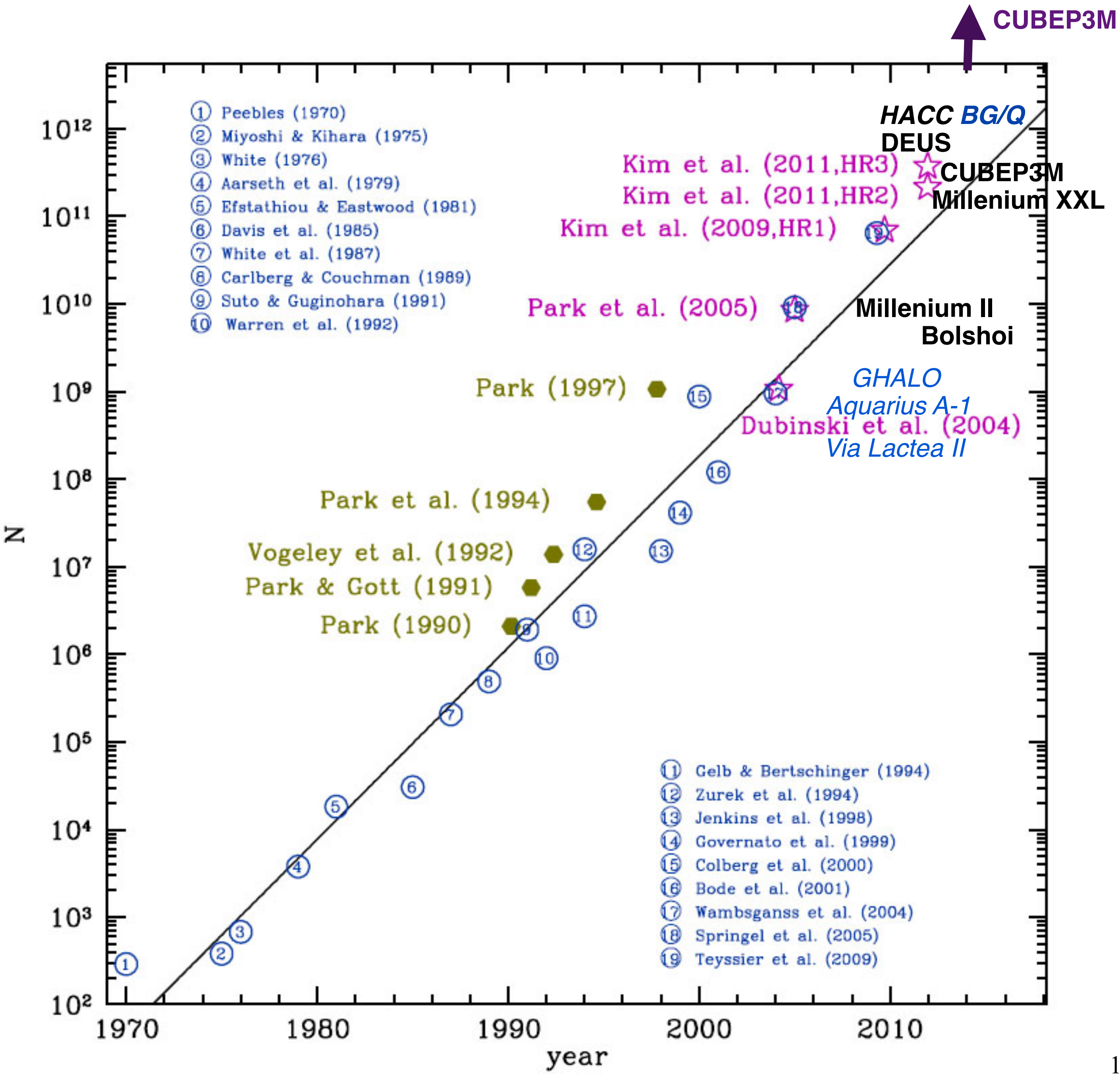
1. INTRODUCTION BM96a =BM93 preprint

One might wonder why we put effort into approximate descriptions of cosmic structure formation given the tremendous recent and promised advances in computing power. Surely the not very distant future will bring computations of arbitrarily large simulation volumes with arbitrarily high resolution using arbitrarily adaptive hydrodynamical and *N*-body techniques. That will be so. But even so, we need a physical language to discuss the outcomes.

For the all important rare events in the medium, such as massive clusters now and bright galaxies at high redshift, the appropriate idiom is the flowing peak patch at which grand constructive interferences in density and velocity waves mark out the sites of collapse. And radiating outward from the peak-patch core are filaments and sheets that too are rare. The structure may finally fade into the root-mean-square fluctuations in the medium as coherence in the phases fades into randomness. Or the structure may blend into another peak patch, for rare constructive interferences tend to be clustered. No image from the cosmology of the 1980s was as powerful as the CfA picture of Coma and its Great Wall, the paradigm for a peak patch and its environs.

90s: the **cosmic web** of interconnected filaments, membranes & voids, with $\varepsilon^j{}_J$-oriented peak-patches playing a determining role BKP98 ⇒ **"molecular" picture** of large scale structure

all collapses in a hierarchy are warm not cold, becoming hotter as phase space tubes further wind. vs AZS82 & pro BKP98



(Juhan Kim et al. 2011)

THEN

BBKS/BCEK scale-space filters & threshold hypersurfaces & critical pts

442 BOND ET AL. Vol. 379

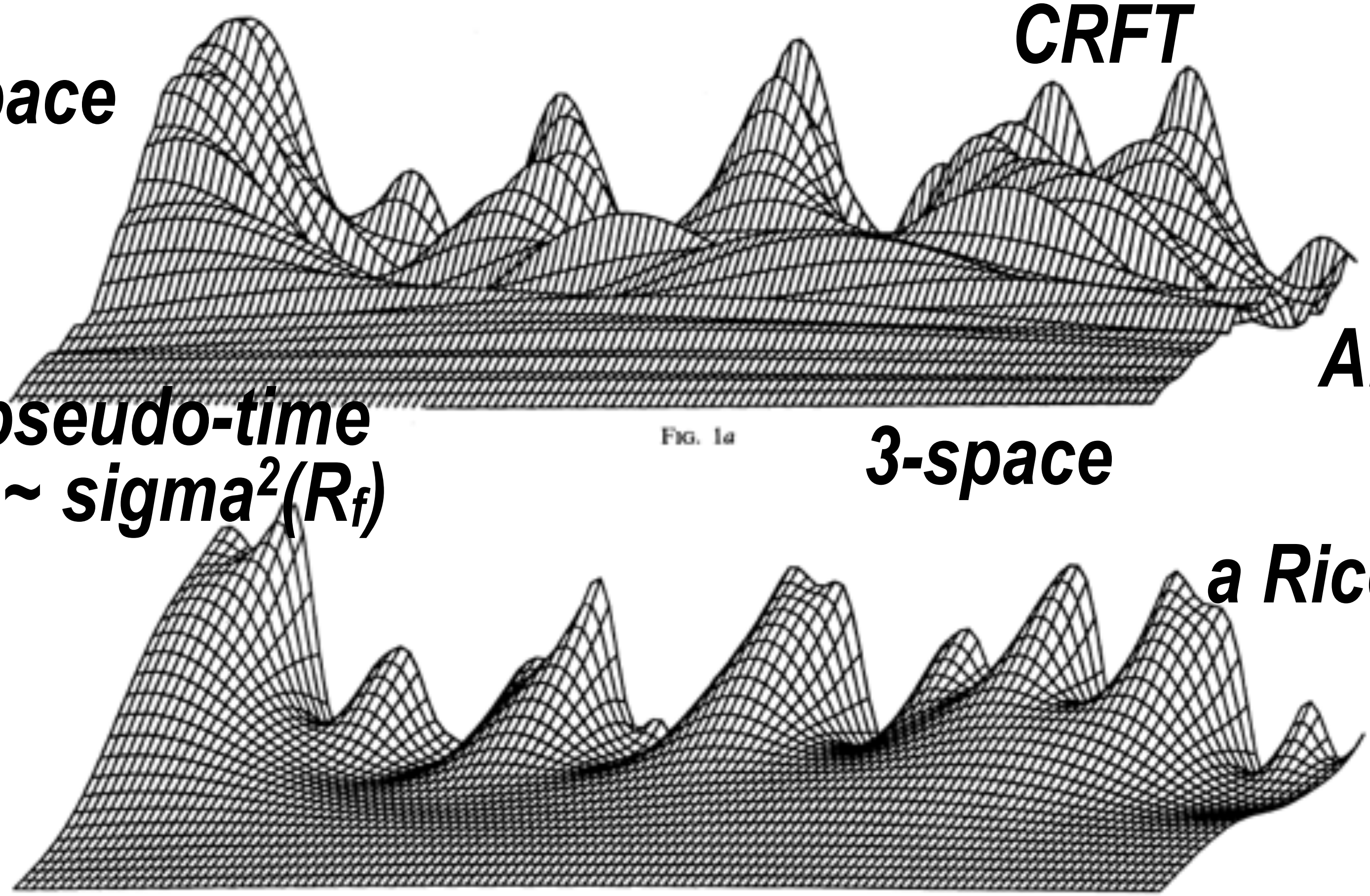


FIG. 1a

FIG. 1b

FIG. 1.—Topographical maps of one-dimensional Gaussian random density fields $F(r, \Lambda)$ as a function of position and resolution for (*a*) sharp *k*-space filtering

THEN

1991 EXCURSION SET MASS FUNCTIONS

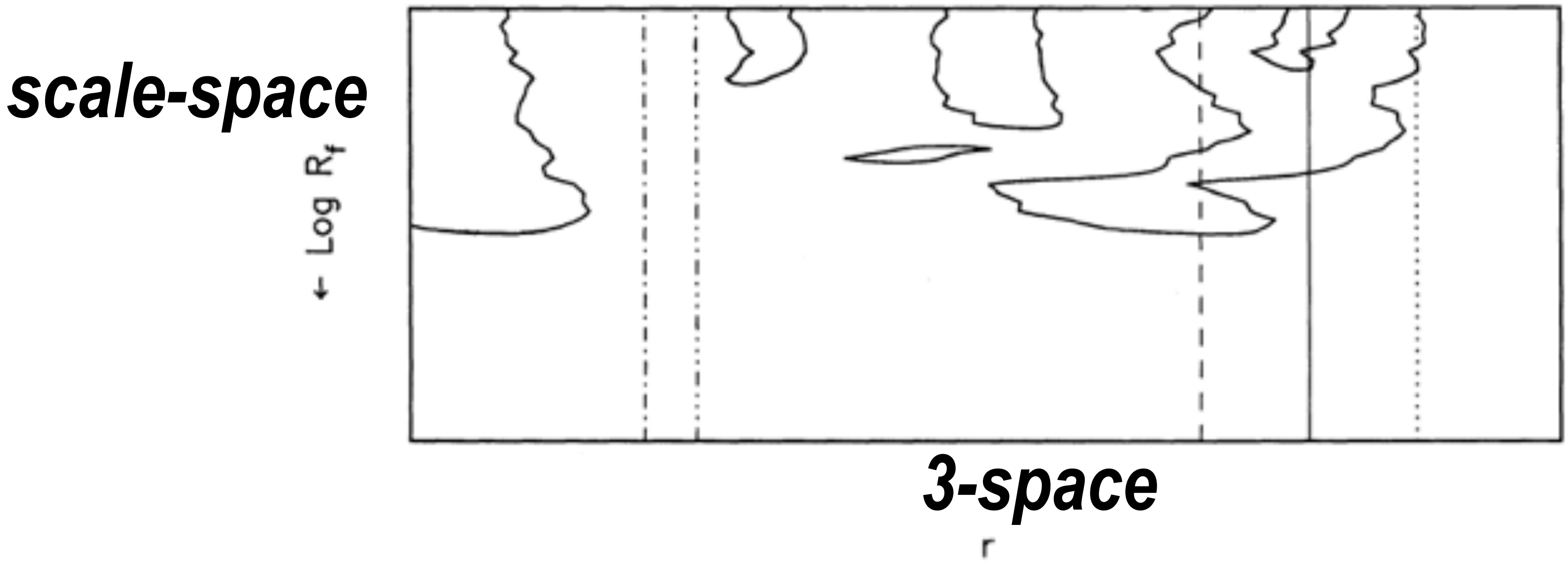
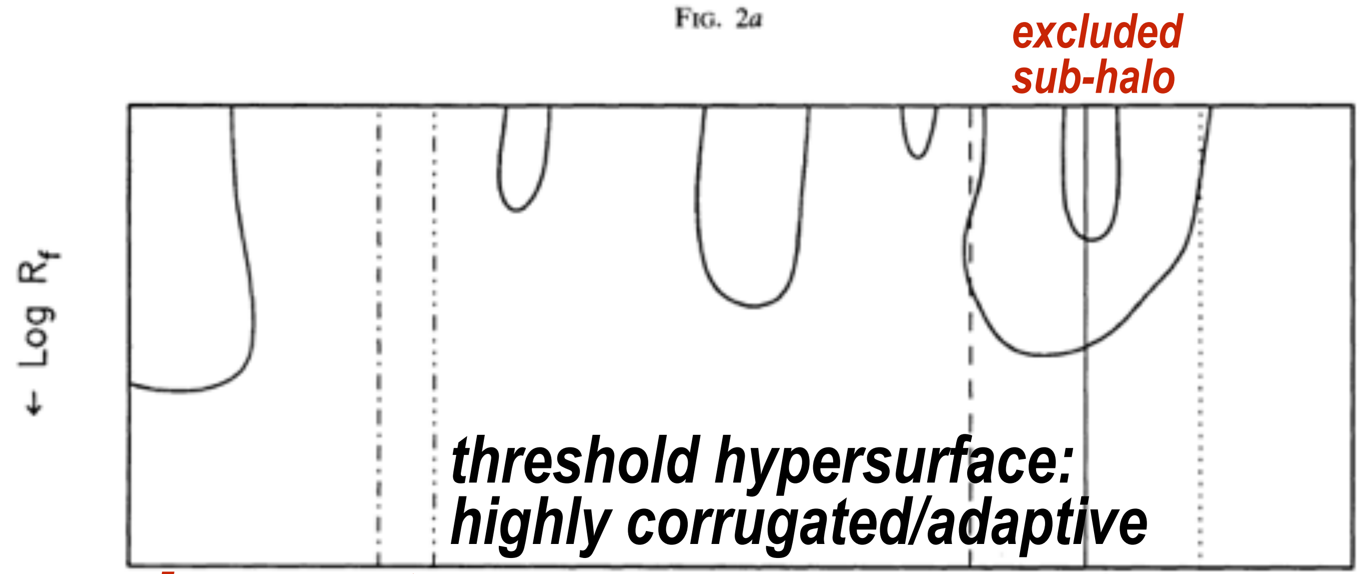


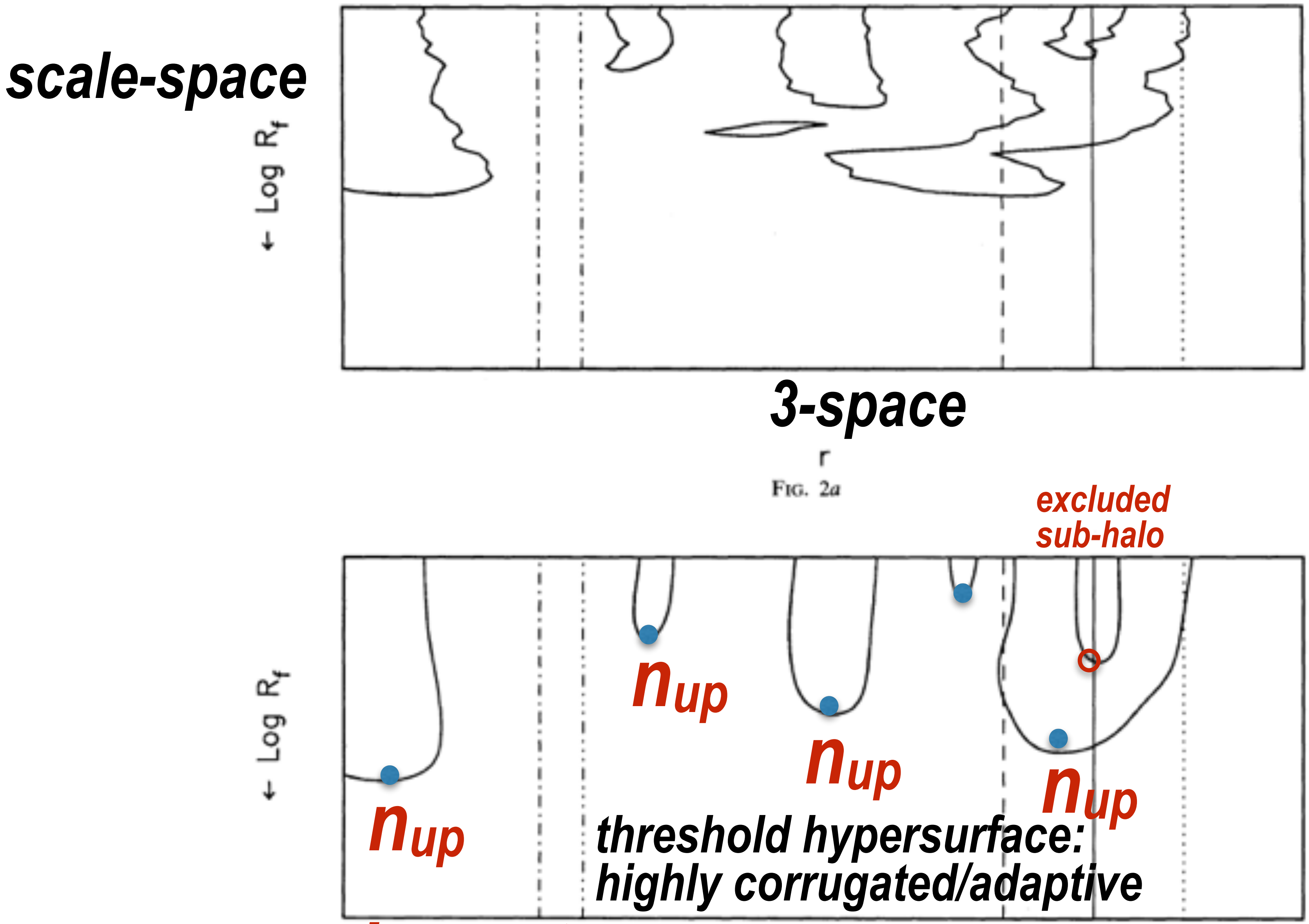
Fig. 2a



b88, b89 ***upcrossing rate*** thru threshold for mass function ***n_{up}***

THEN

1991 EXCURSION SET MASS FUNCTIONS



b88, b89 ***upcrossing rate*** thru threshold for mass function n_{up}

THEN

1991 EXCURSION SET MASS FUNCTIONS

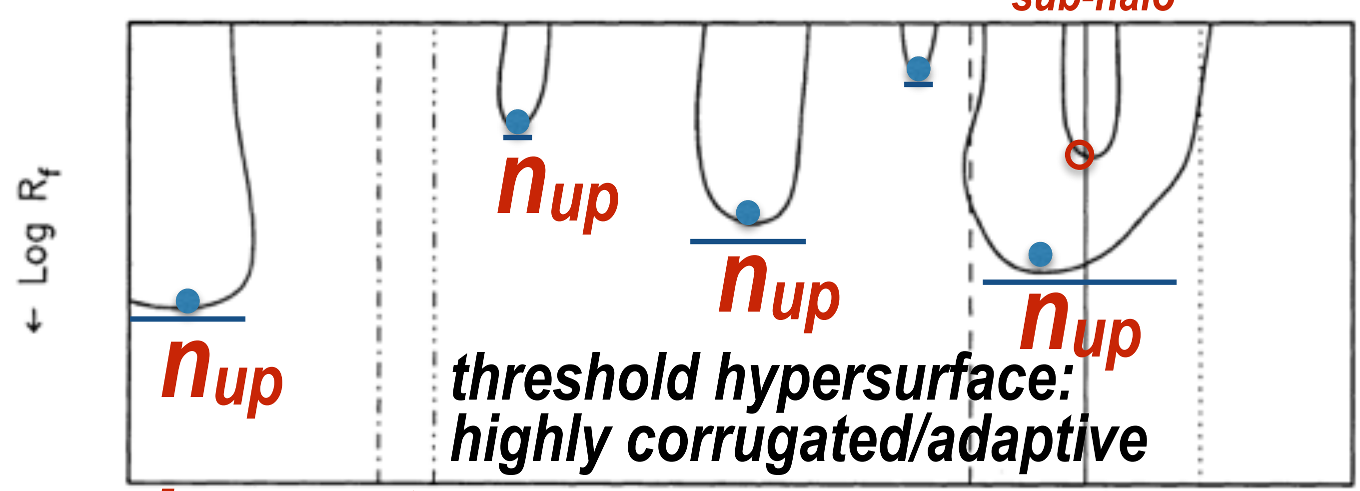
scale-space

3-space

r

FIG. 2a

Excluding Ellipsoidal Excursions **E^3**
aka Hierarchical Peak Patches **hpk**



b88, b89 ***upcrossing rate*** thru threshold for mass function n_{up}

THEN

1991 EXCURSION SET MASS FUNCTIONS

BM1 96: Excluding Ellipsoidal Excursions E^3 aka Hierarchical Peak Patches hpk is what EPS with ellipsoidal collapse should have done to be physically correct. and that is what BM did THEN, and what ABS+ is doing NOW.

What the PS method should do is this: take all points. For each point, start at a large radius and come inwards until the volume-averaged linear overdensity $= f_c$. If so, assign that point the top-hat mass associated with the critical radius. Take the candidate points to be those which have pierced the f_c line. *Now apply to the candidate points the full exclusion algorithm* of the last subsection. Most candidate points are excluded and the surviving points with their nonoverlapping spherical Lagrangian patches about them are precisely our hierarchical peaks. We shall see that the end result for the mass function is not very different from the standard Press-Schechter result, with a slightly modified mass assignment, but there are no fudges, the mass assignment is natural and one can do spatial structure, including correlations. More important, the peaks picture is physically correct.

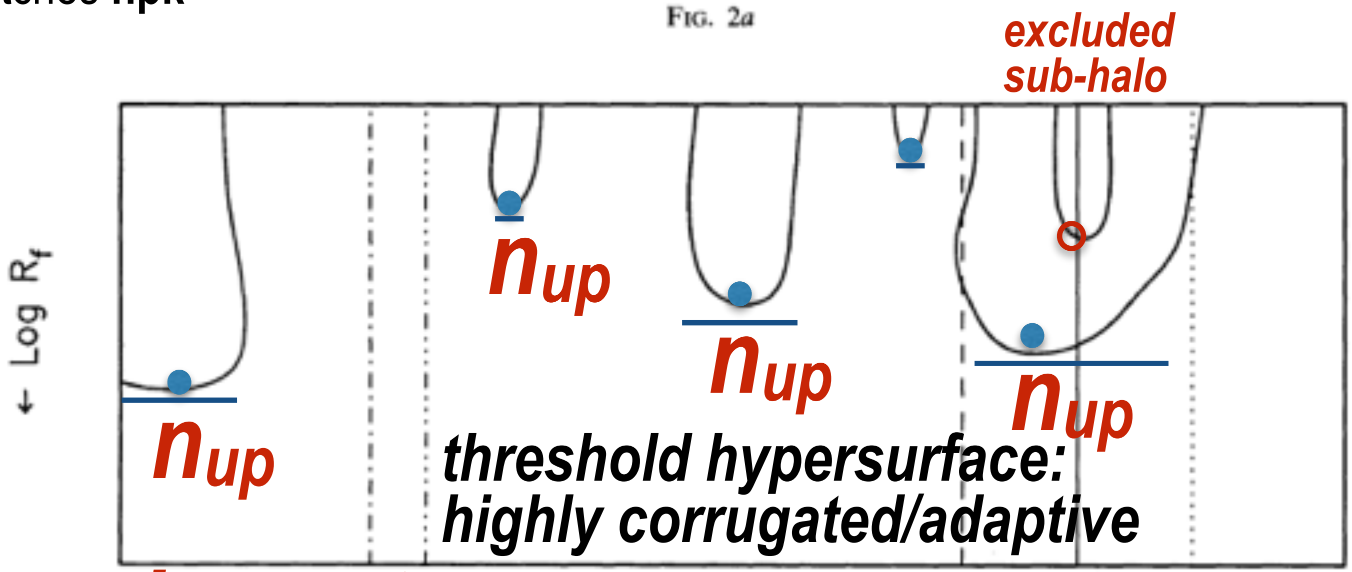
Excluding Ellipsoidal Excursions **E^3**
aka Hierarchical Peak Patches **hpk**

hpk

3-space

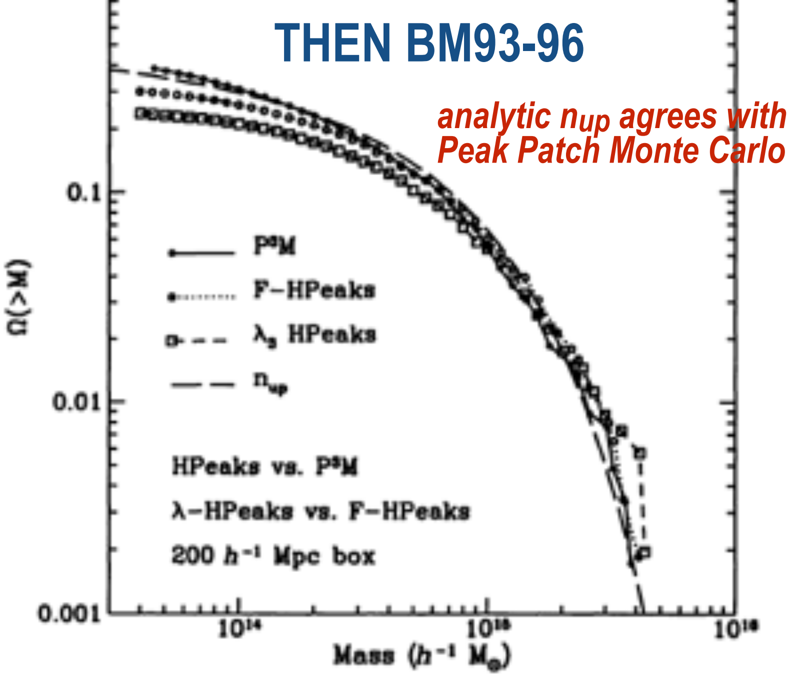
r

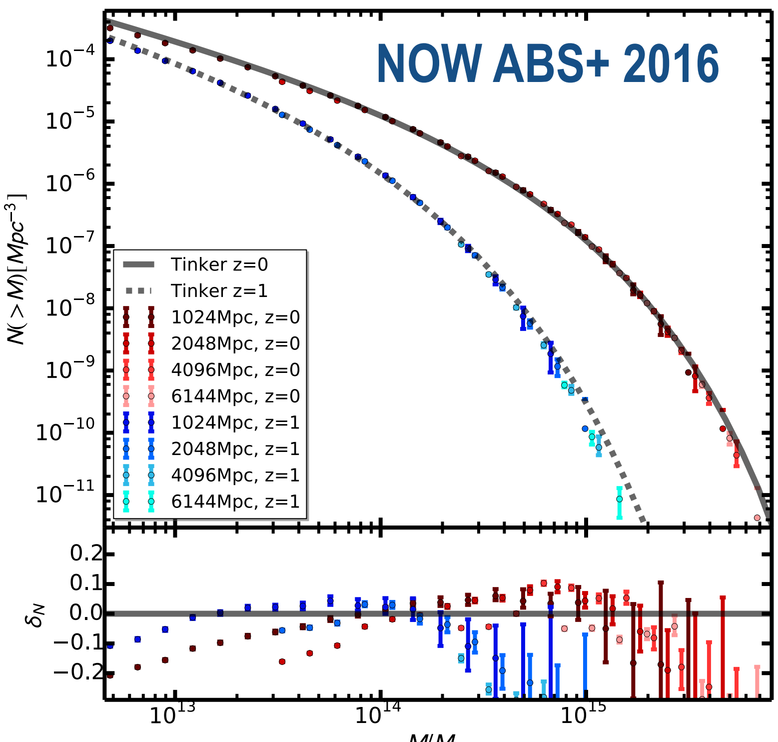
FIG. 2a



b88, b89 ***upcrossing rate*** thru threshold for mass function n_{up}

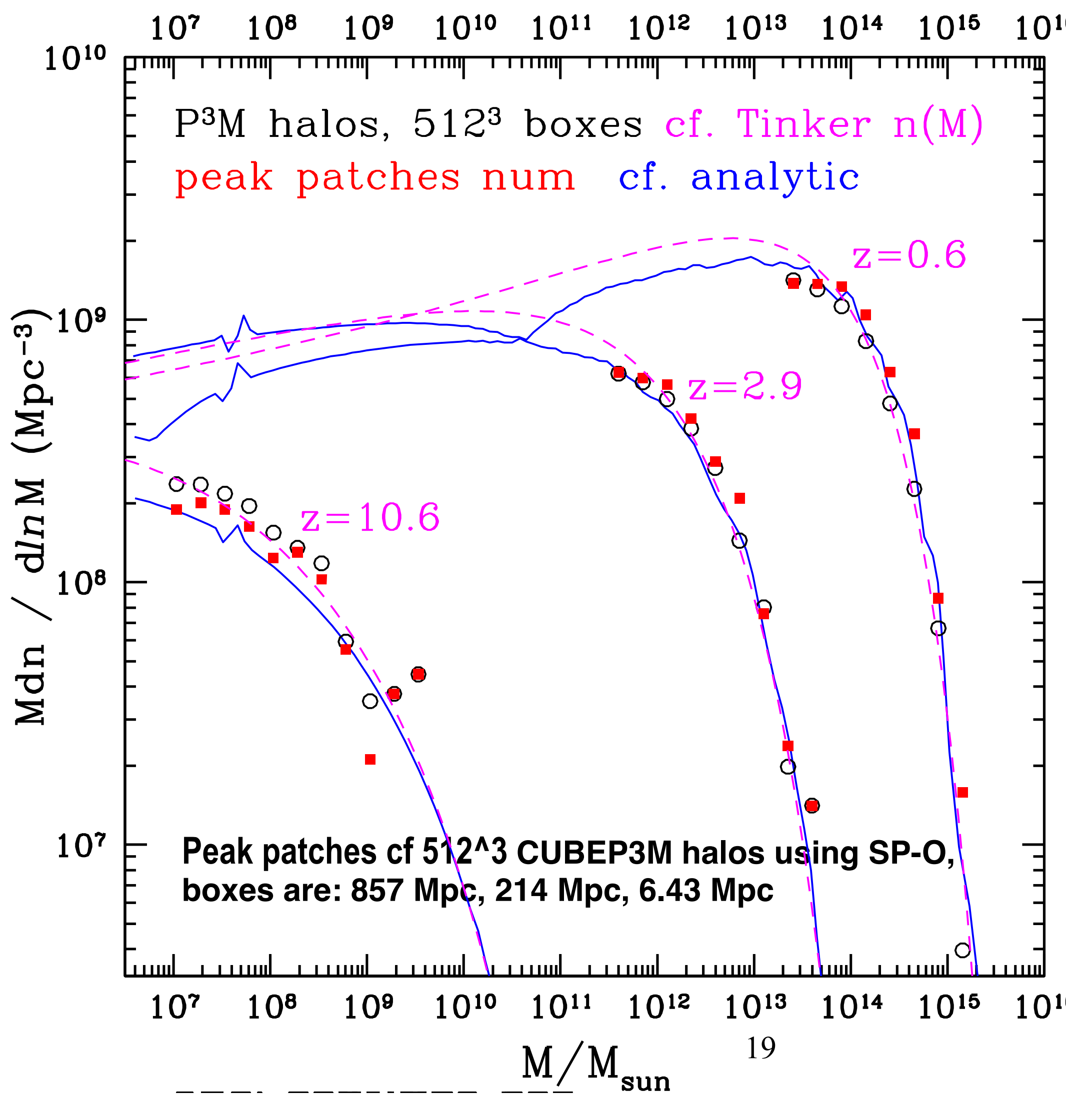
mass function 1-pt tests => halo abundances *understood*



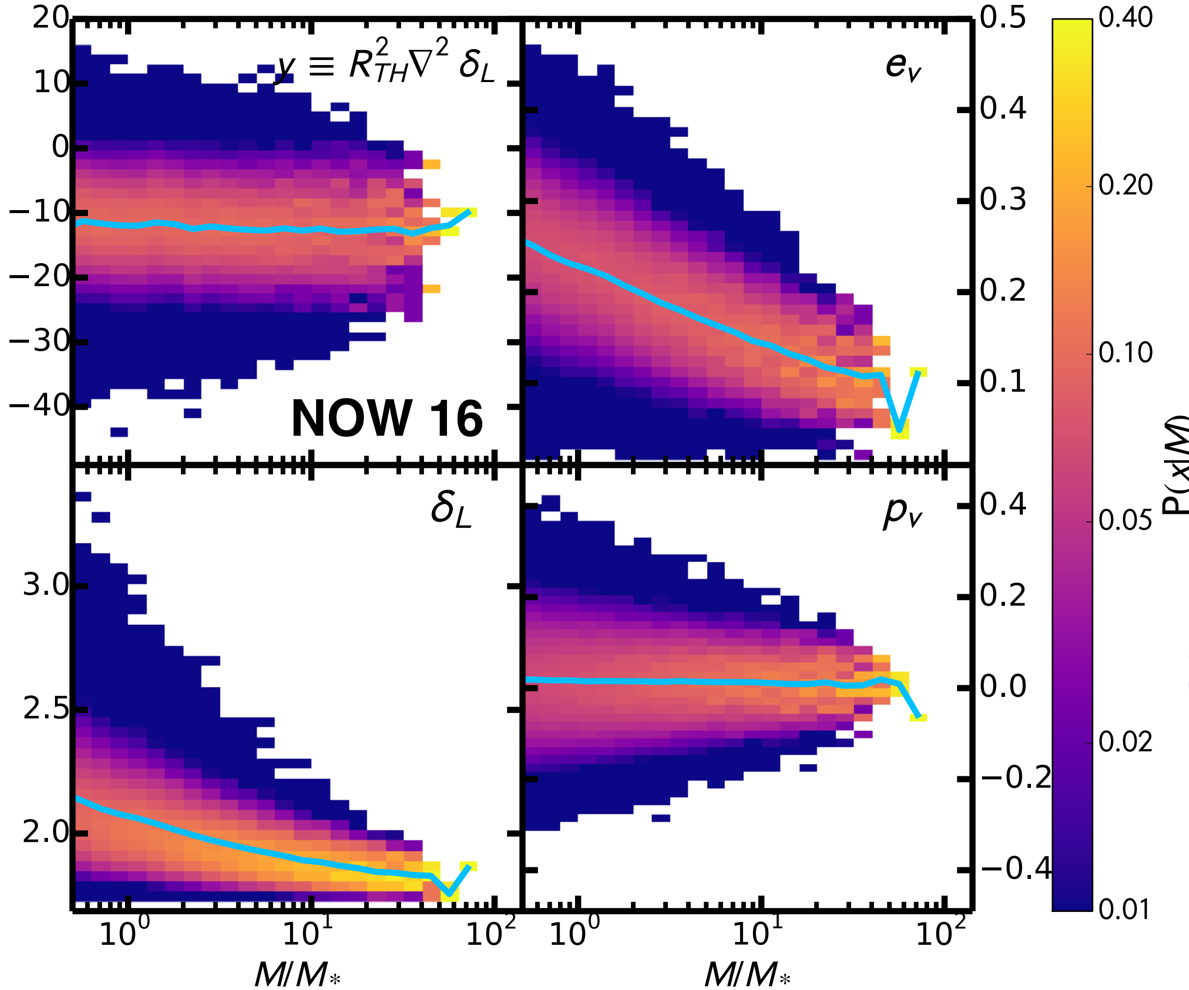


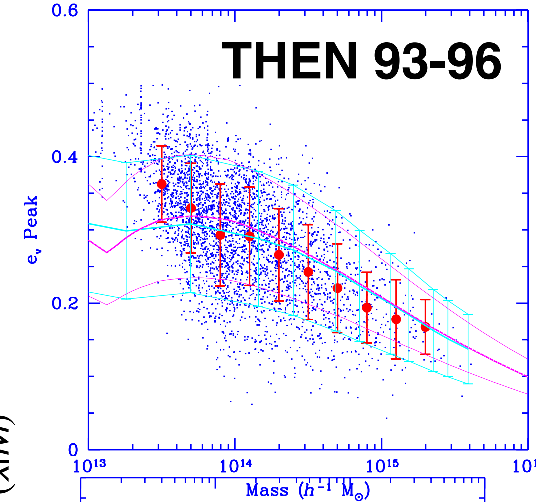
SP-O Halos are exactly **Eulerian-space** Peak Patches

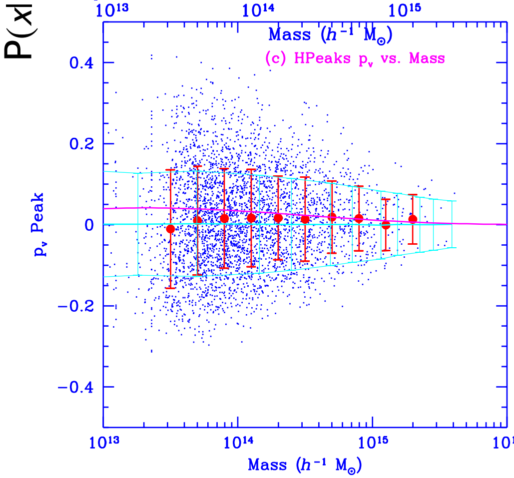
NOW ish @IAU 2014

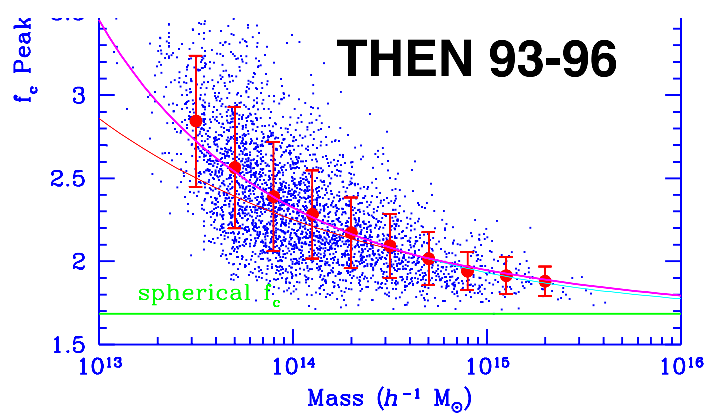


Alvarez, Bond, Hajian, Stein, Emberson 2013

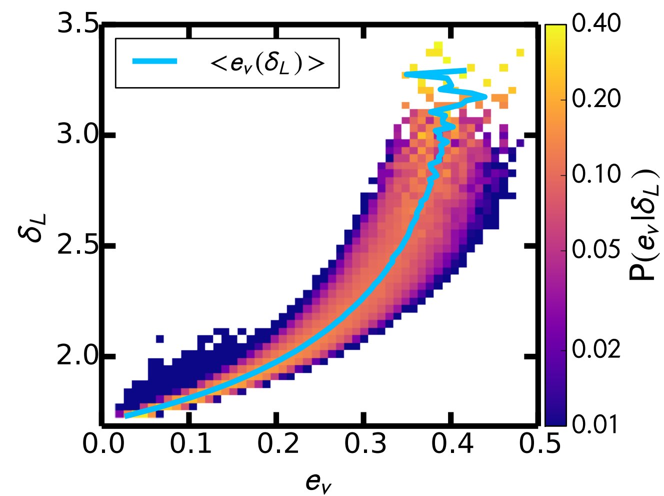








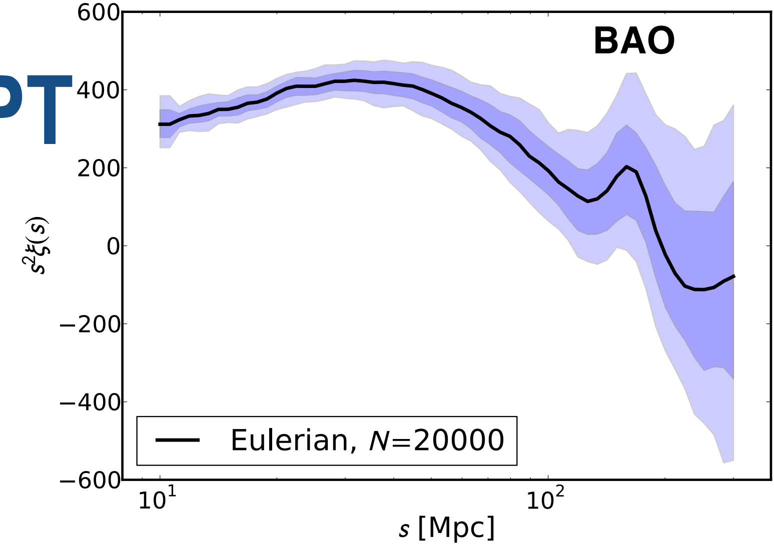
<e$_v$|F> was the key to successful B-analytics using mean fields THEN. NOW needs the full distributions, i.e., Monte Carlo ish 'analytics'



BIAS & 2-point clustering of halos is understood numerically & analytically:

move via *ADAPTIVE* 1LPT+2LPT

stop overshoor > 2LPT

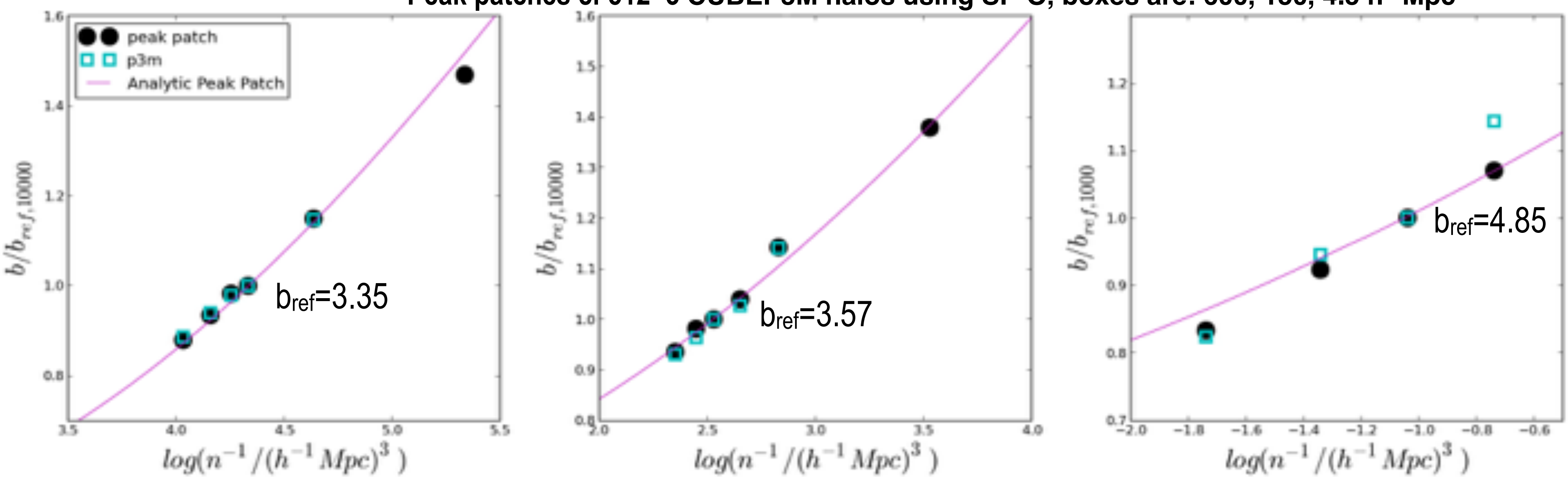


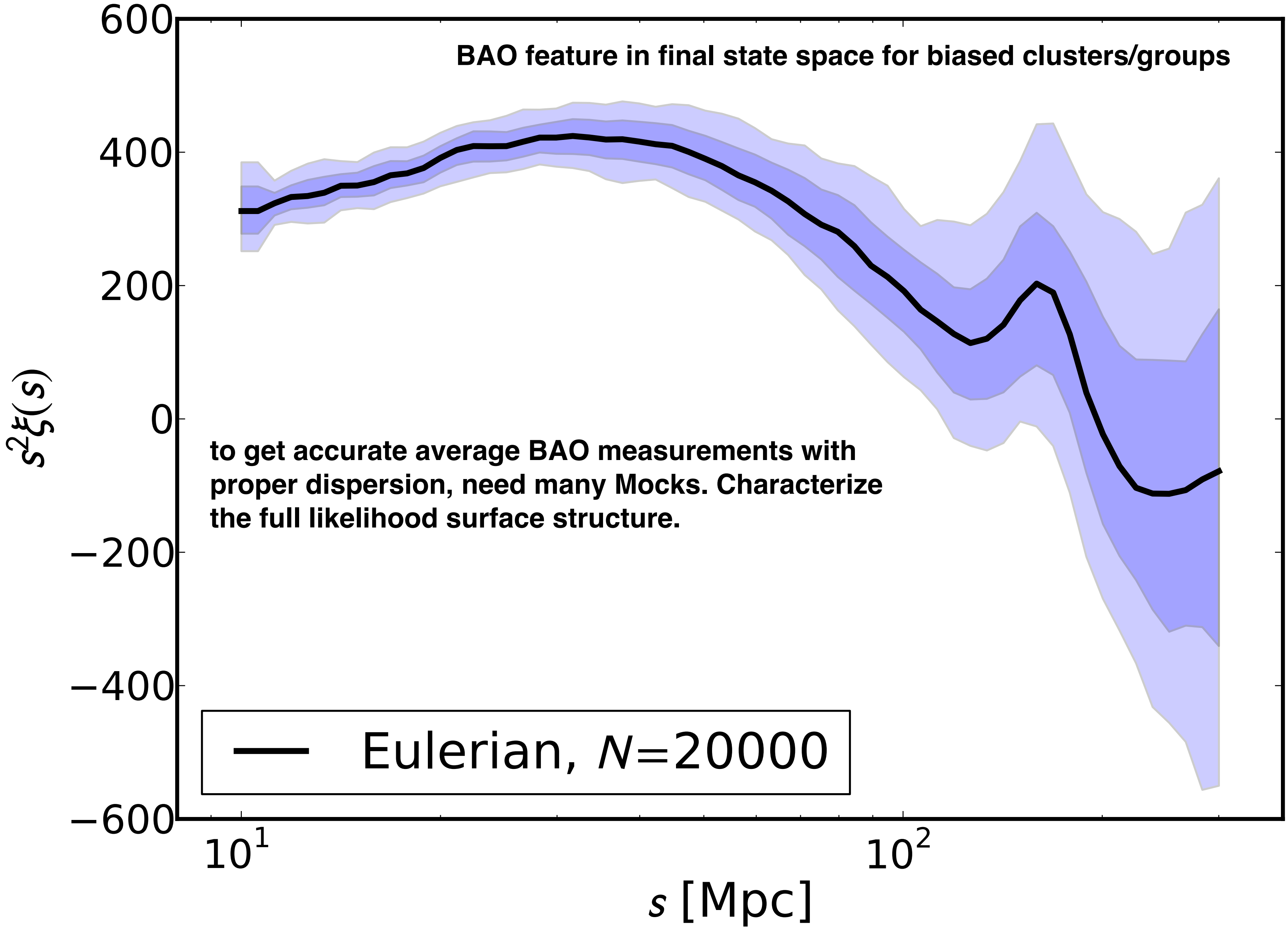
THEN 93-96 analytic bias cf.

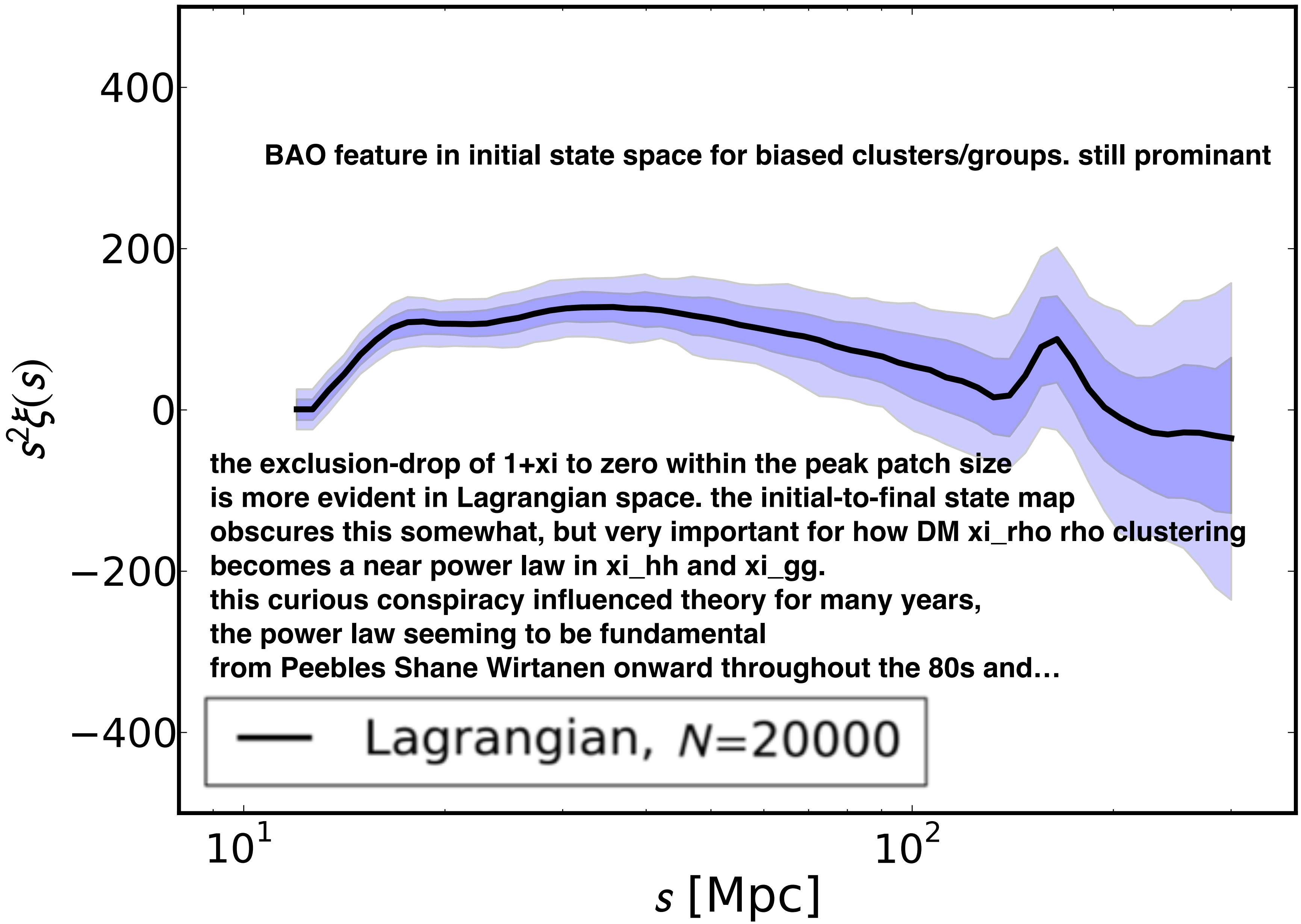
'NOW 14' measured bias in pp (L-halos) and p3m (E-halos)

IAU jun 2014 …Alvarez, Bahmanyer, Bond, Hajian 2014

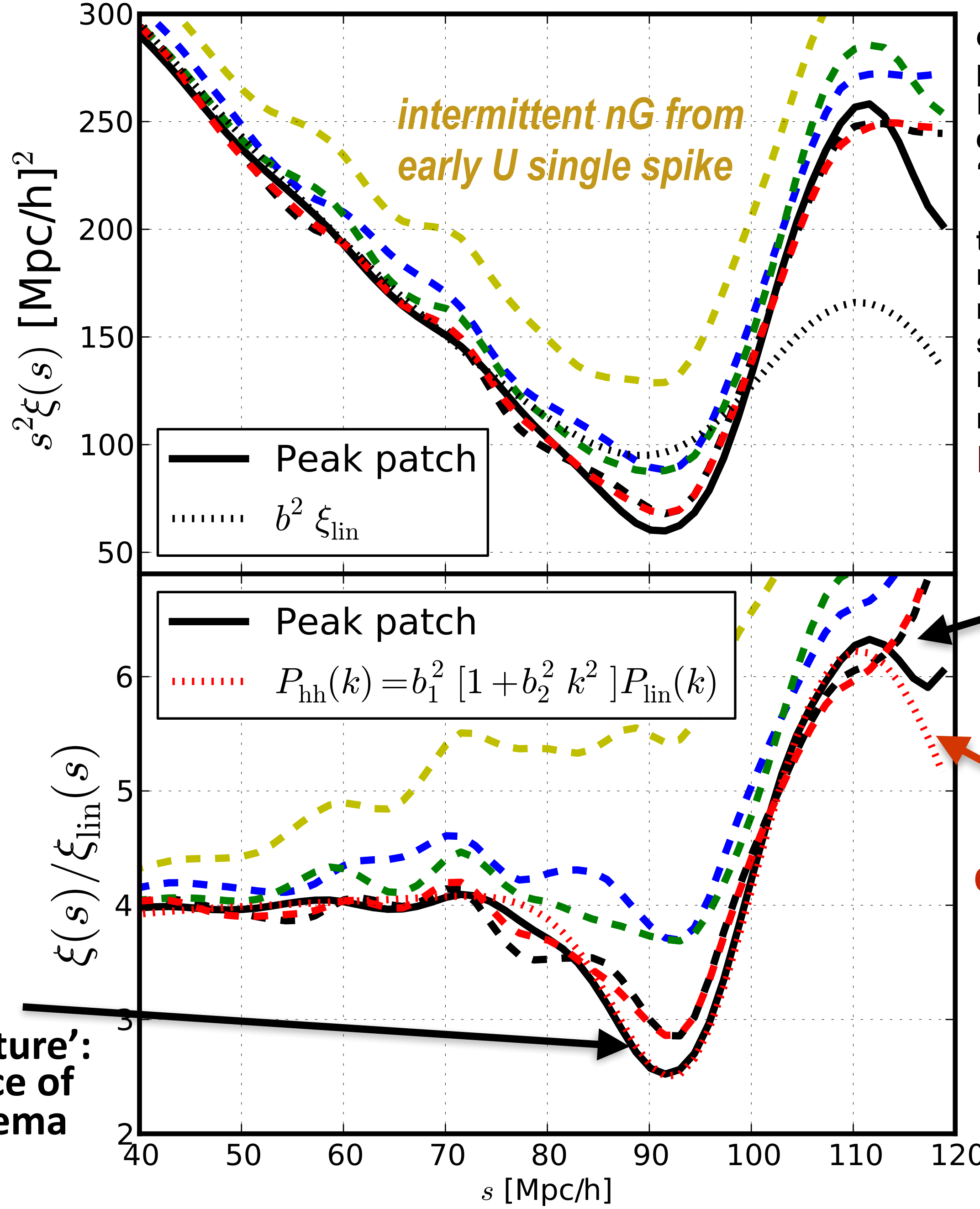
Peak patches cf 512^3 CUBEP3M halos using SP-O, boxes are: 600, 150, 4.5 h^{-1}Mpc




BAO feature in final state space for biased clusters/groups
to get accurate average BAO measurements with
proper dispersion, need many Mocks. Characterize
the full likelihood surface structure.
Eulerian, N=20000
600
400
200
0
−200
−400
−600
$s^2\xi(s)$
10^1
10^2
s [Mpc]


BAO feature in initial state space for biased clusters/groups. still prominant
the exclusion-drop of 1+xi to zero within the peak patch size
is more evident in Lagrangian space. the initial-to-final state map
obscures this somewhat, but very important for how DM xi_rho rho clustering
becomes a near power law in xi_hh and xi_gg.
this curious conspiracy influenced theory for many years,
the power law seeming to be fundamental
from Peebles Shane Wirtanen onward throughout the 80s and...
Lagrangian, N=20000
400
200
0
−200
−400
$s^2\xi(s)$
10^1
10^2
s [Mpc]

Incorporating multiple biases important for interpreting any found primordial nonG in LSS



THEN linear-response bias depends on second … peak/halo parameters BBKS96.. eg Laplacian F, curvature. "Assembly Bias" NOW-THEN

there are also many linear response biases B97.., mostly subdominant at large scales in the neff<-1 ish regime, but not for steep neff >0 and - **not in the BAO regime NOW**

Positive 'Curvature': Overabundance of Negative Extrema

cf. fit to N-body results: without any tuning it comes out from peak patches naturally

Positive 'Curvature': Overabundance of Negative Extrema

N-body / Eulerian halos - spheres in final state space *full exclusion*

SP-O (overdensity M/V) cf. FoF (surface-density 1st gp)

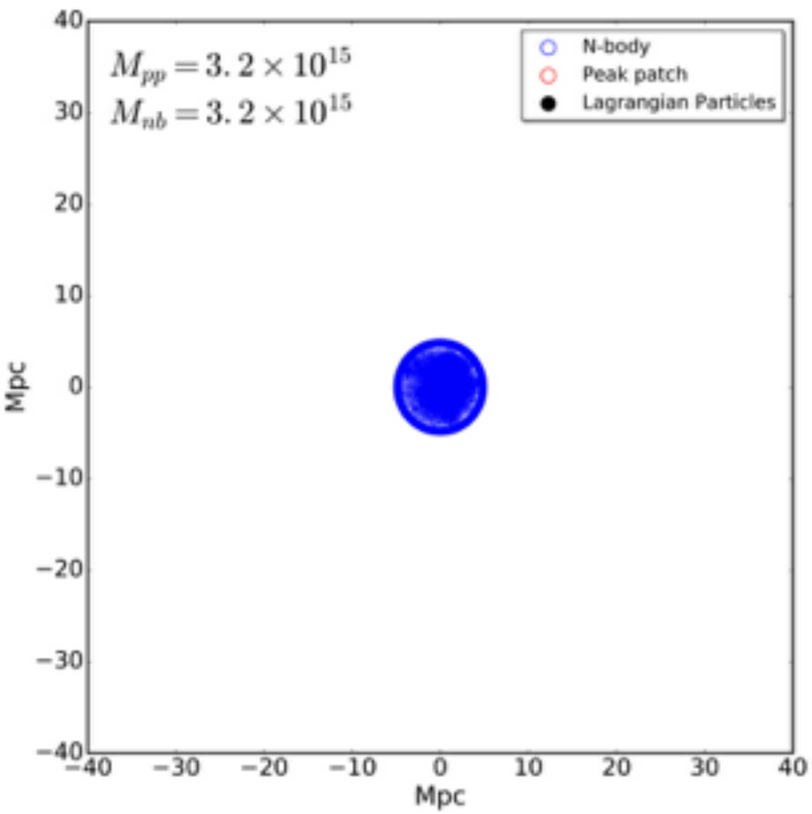
Peak-patch /Lagrangian halos - spheres in initial state space

- *half-exclusion* then *binary-exclusion (breaks sphere)* - *full exclusion an option*

Object-by-object

Eulerian to Lagrangian map: $P(x_f t_f | x_i t_i)$ = SUM_branches exp[-Trace ln e (r,t)]

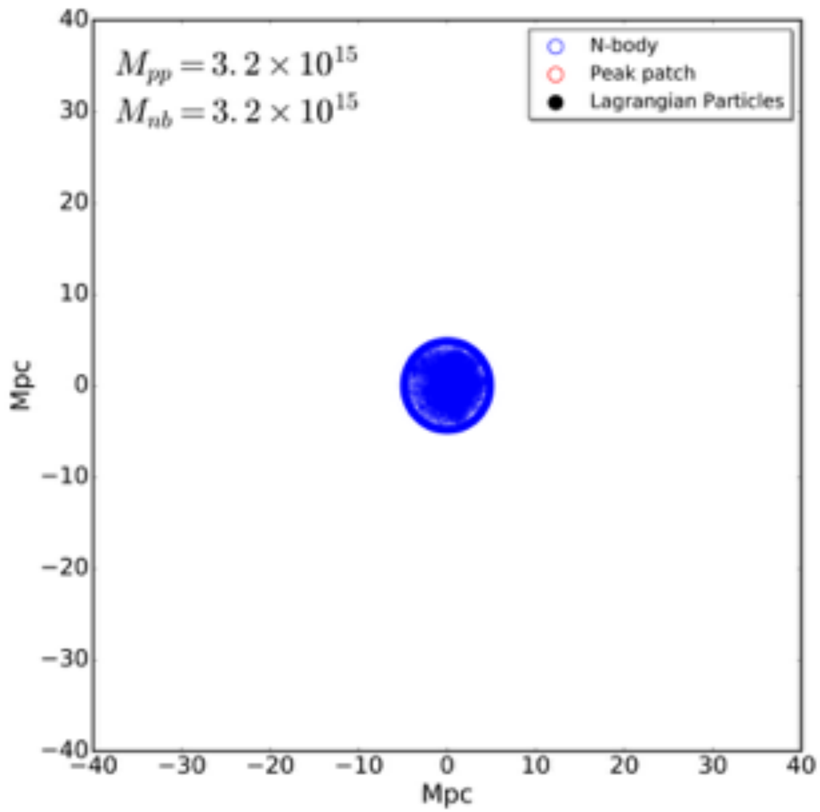
$$d\mathbf{x}_f = \mathbf{e}(\mathbf{x}_i, \mathbf{t}|\mathbf{t}_i)d\mathbf{x}_i$$



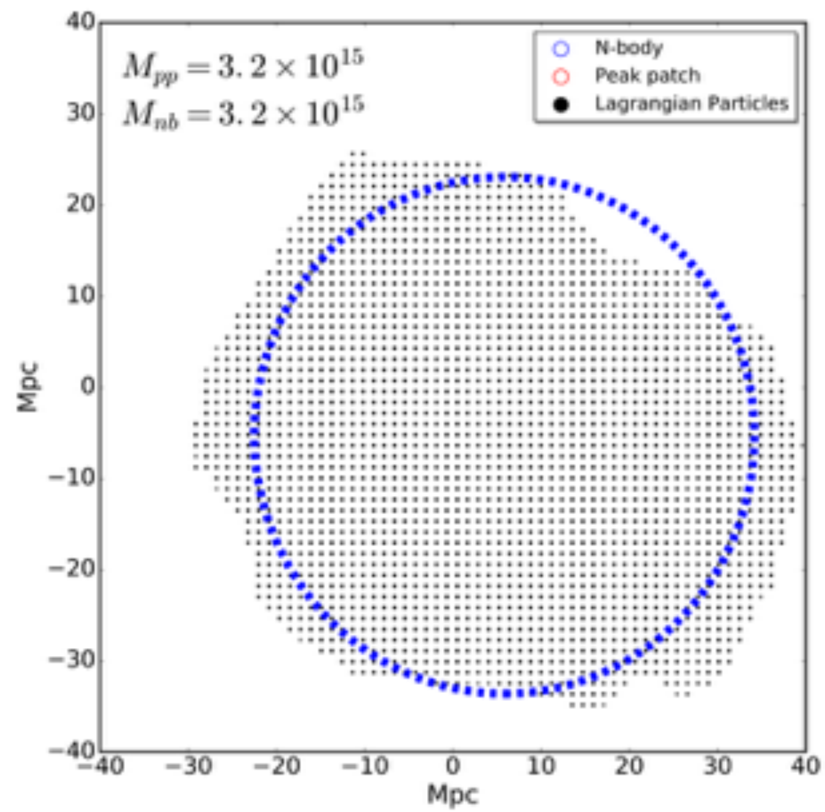
1. Identify N-body halo in Eulerian Coordinates
2. Trace back all the particles to their Lagrangian positions

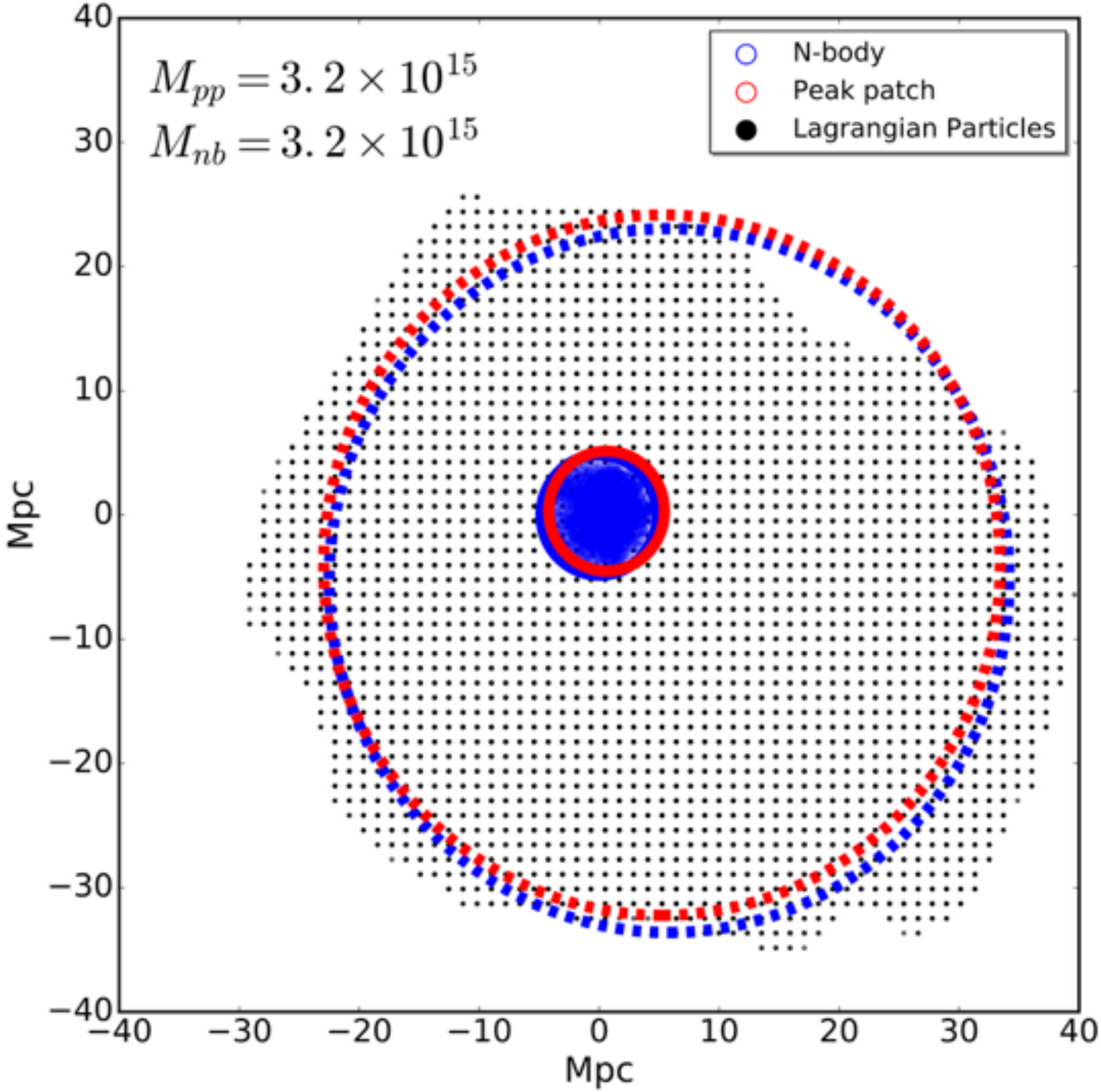
N-body vs. Peak-patch: Object-by-object

Eulerian

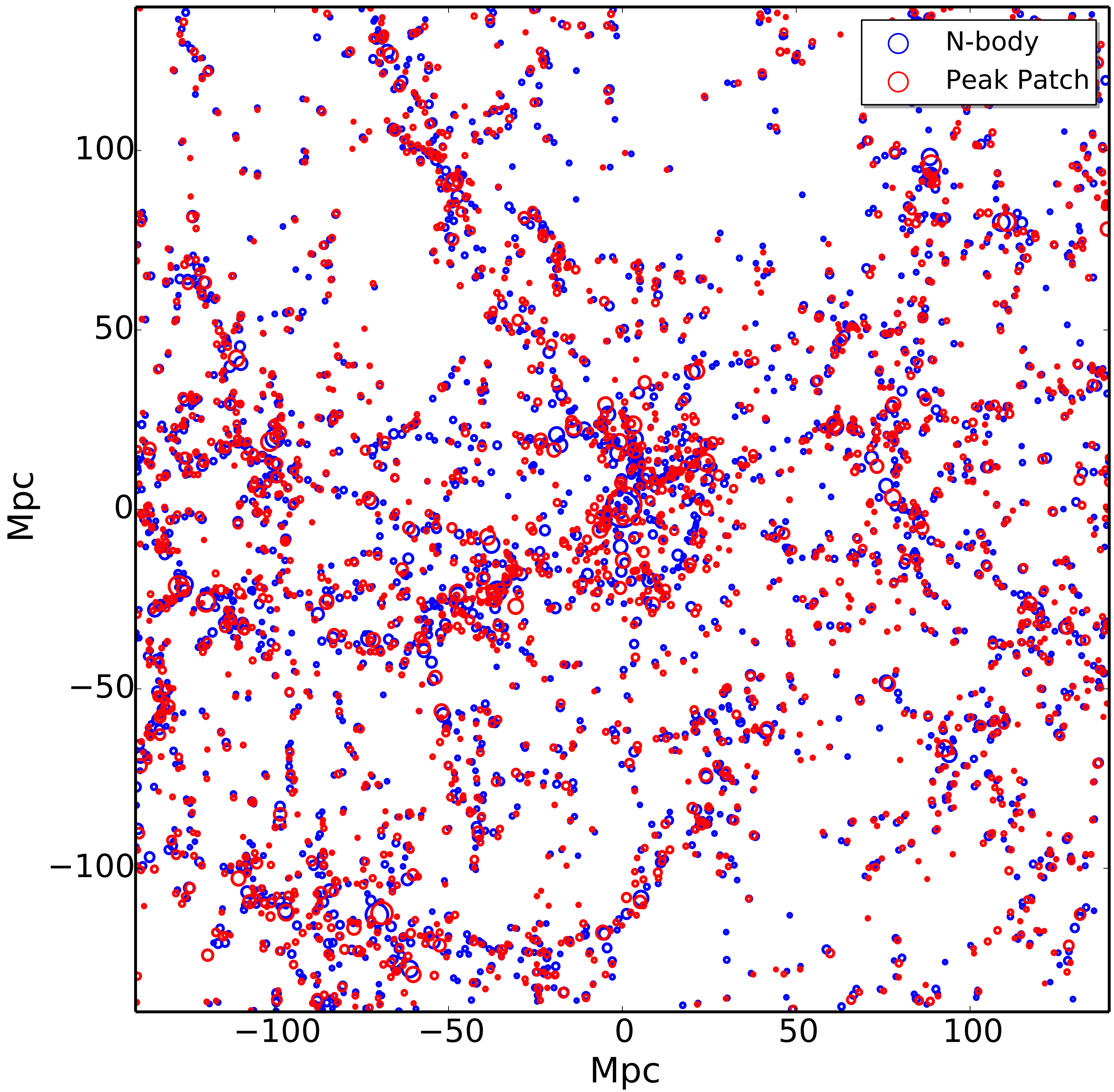


Lagrangian

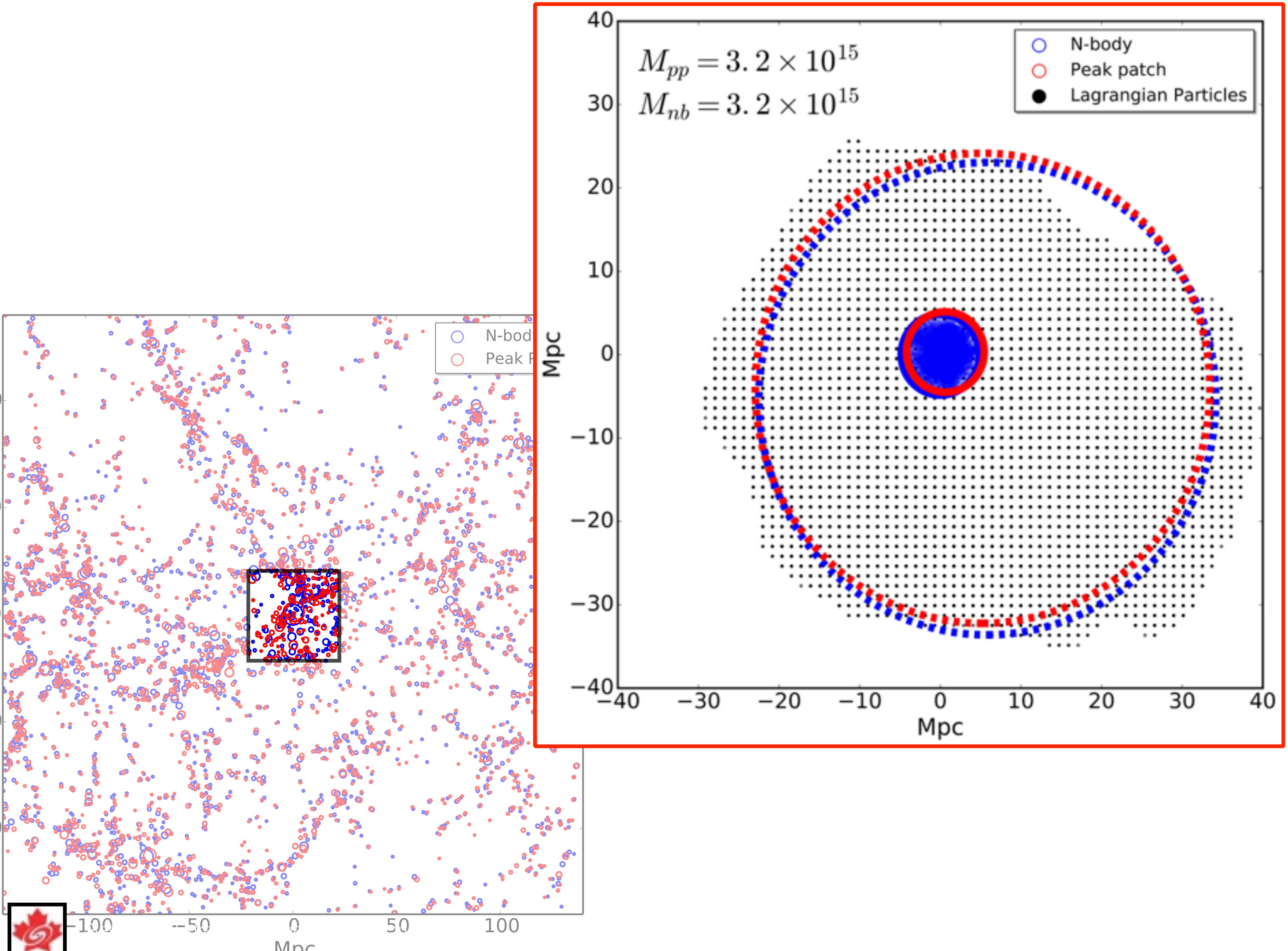




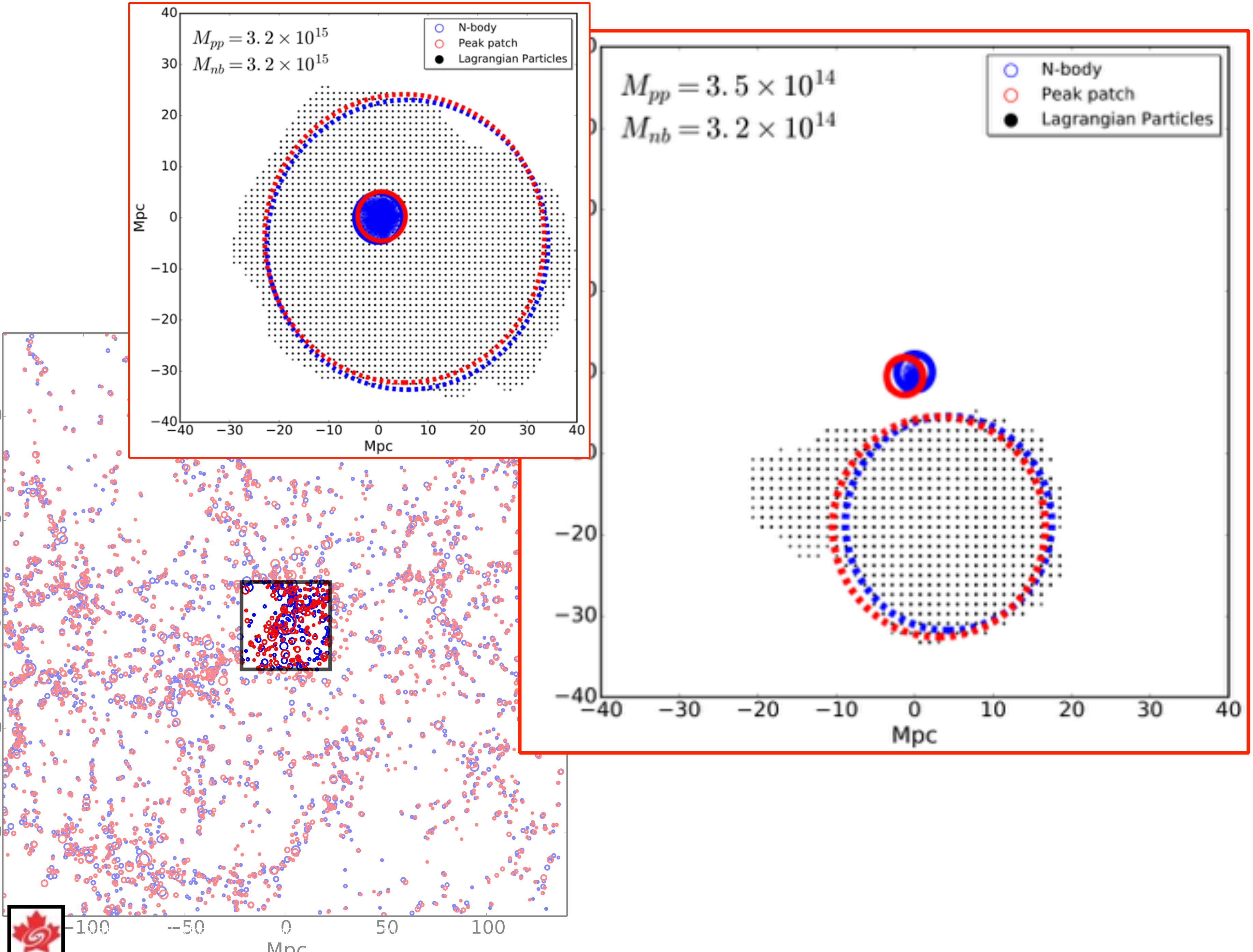
$M_{pp} = 3.2 \times 10^{15}$
$M_{nb} = 3.2 \times 10^{15}$
N-body
Peak patch
Lagrangian Particles
Mpc
Mpc
40
30
20
10
0
−10
−20
−30
−40
−40
−30
−20
−10
0
10
20
30
40



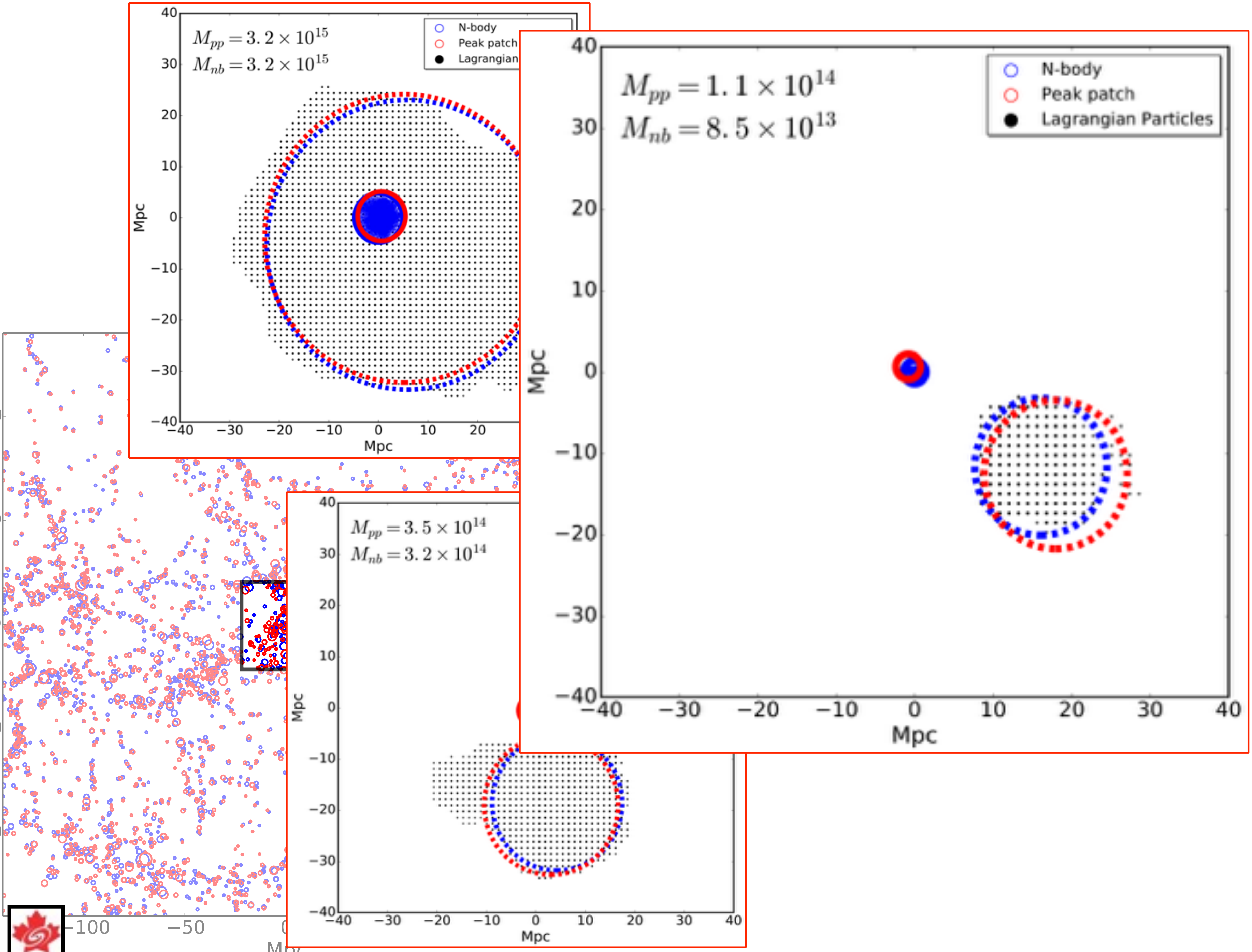
N-body
Peak Patch
Mpc
Mpc
100
50
0
−50
−100
−100
−50
0
50
100



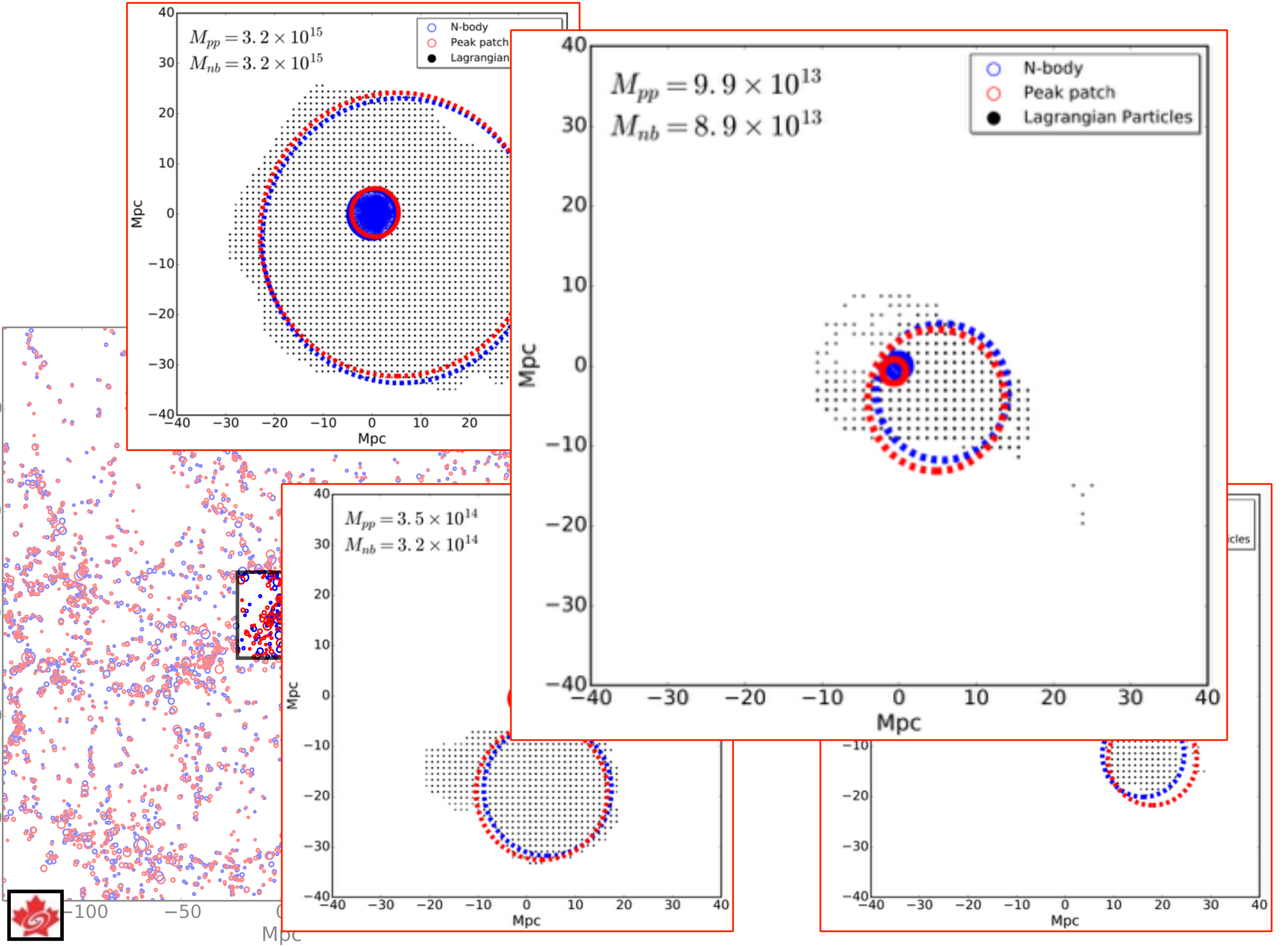
$M_{pp} = 3.2 \times 10^{15}$
$M_{nb} = 3.2 \times 10^{15}$
N-body
Peak patch
Lagrangian Particles
40
30
20
10
0
−10
−20
−30
−40
−30
−20
−10
0
10
20
30
40
Mpc
Mpc
−100
−50
0
50
100
Mpc



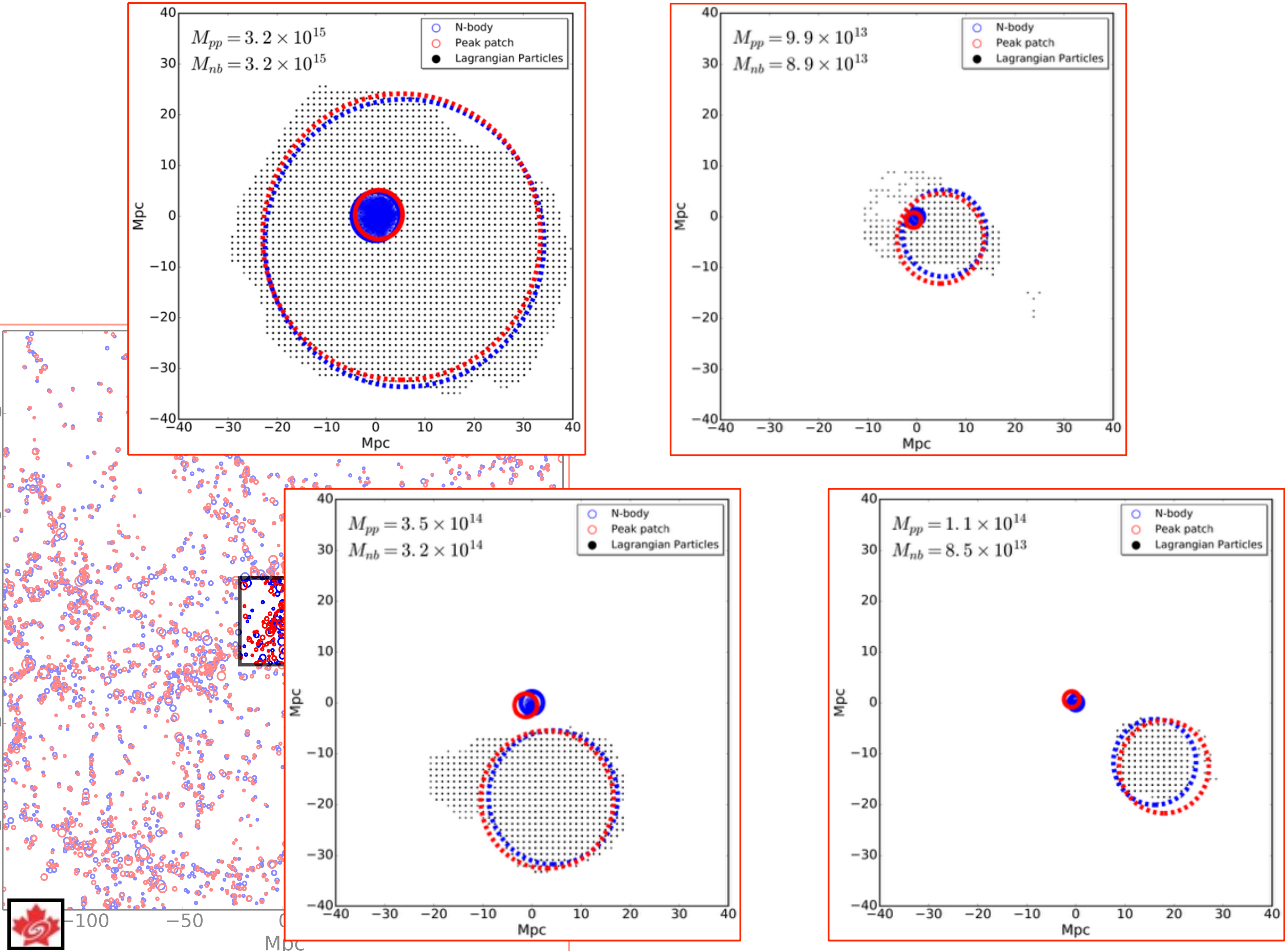
$M_{pp} = 3.2 \times 10^{15}$
$M_{nb} = 3.2 \times 10^{15}$
N-body
Peak patch
Lagrangian Particles
Mpc
$M_{pp} = 3.5 \times 10^{14}$
$M_{nb} = 3.2 \times 10^{14}$
N-body
Peak patch
Lagrangian Particles
Mpc
Mpc



$M_{pp} = 3.2 \times 10^{15}$
$M_{nb} = 3.2 \times 10^{15}$
N-body
Peak patch
Lagrangian
Mpc
$M_{pp} = 3.5 \times 10^{14}$
$M_{nb} = 3.2 \times 10^{14}$
Mpc
$M_{pp} = 1.1 \times 10^{14}$
$M_{nb} = 8.5 \times 10^{13}$
N-body
Peak patch
Lagrangian Particles
Mpc



$M_{pp} = 3.2 \times 10^{15}$
$M_{nb} = 3.2 \times 10^{15}$
N-body
Peak patch
Lagrangian
Mpc
$M_{pp} = 9.9 \times 10^{13}$
$M_{nb} = 8.9 \times 10^{13}$
N-body
Peak patch
Lagrangian Particles
Mpc
$M_{pp} = 3.5 \times 10^{14}$
$M_{nb} = 3.2 \times 10^{14}$
Mpc
Mpc



$M_{pp} = 3.2 \times 10^{15}$
$M_{nb} = 3.2 \times 10^{15}$
N-body
Peak patch
Lagrangian Particles
Mpc
$M_{pp} = 9.9 \times 10^{13}$
$M_{nb} = 8.9 \times 10^{13}$
N-body
Peak patch
Lagrangian Particles
Mpc
$M_{pp} = 3.5 \times 10^{14}$
$M_{nb} = 3.2 \times 10^{14}$
N-body
Peak patch
Lagrangian Particles
Mpc
$M_{pp} = 1.1 \times 10^{14}$
$M_{nb} = 8.5 \times 10^{13}$
N-body
Peak patch
Lagrangian Particles
Mpc
−100
−50
Mpc

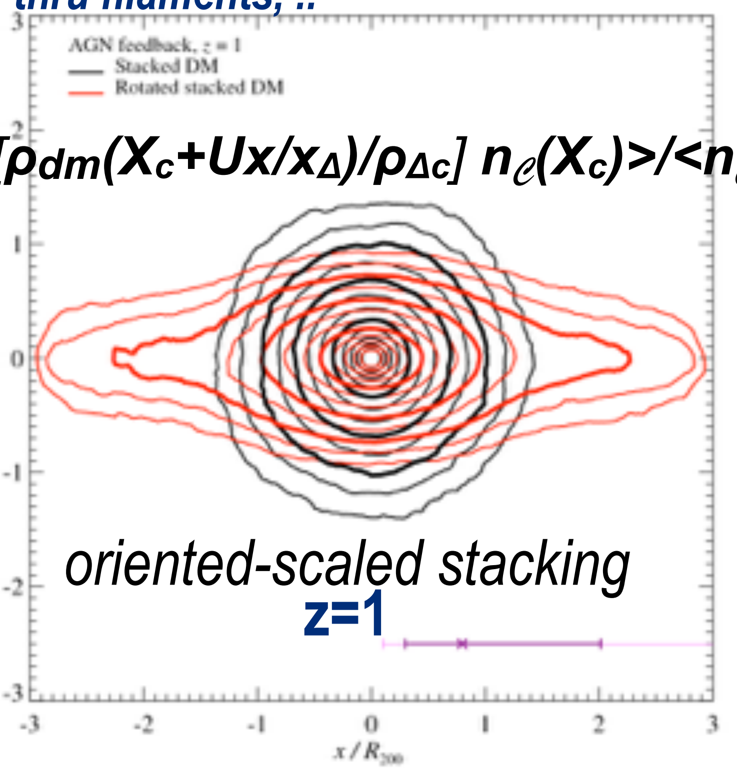
HALOs in the Web(z)

the CLUSTER SYSTEM example

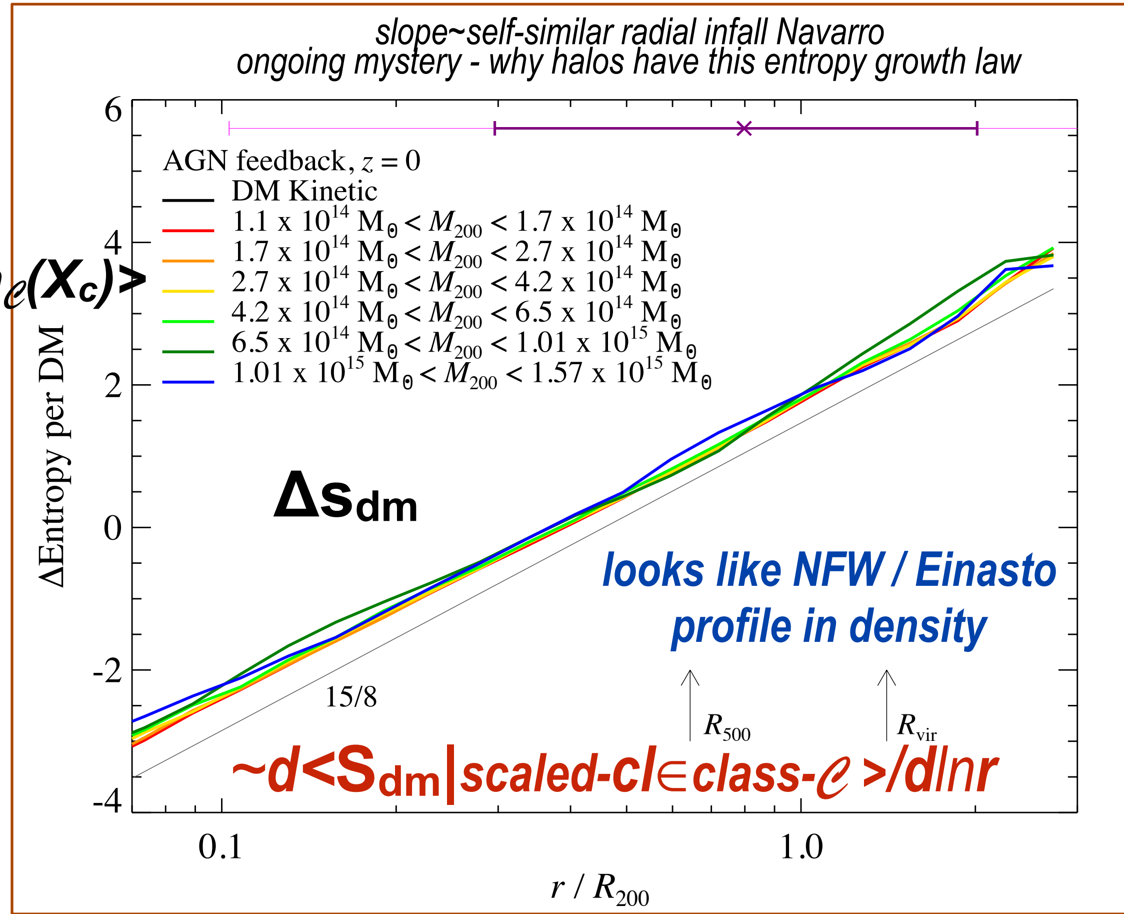
Halos are Complex Systems

sub-halo merger memory,
asphericity, clumping of density,
cosmic web far-field connection thru filaments, ..

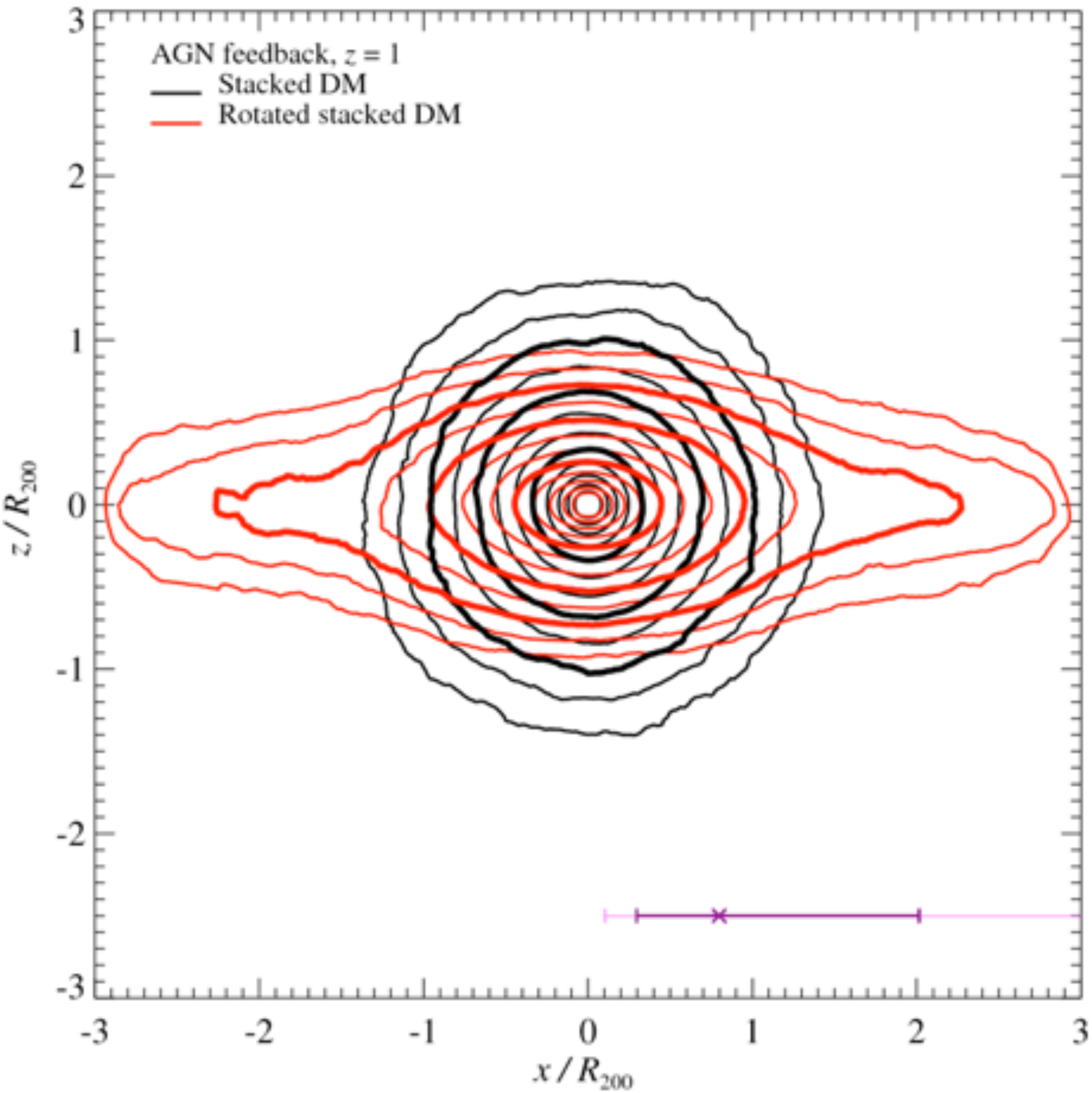
$< [\rho_{dm}(X_c+Ux/x_\Delta)/\rho_{\Delta c}]\ n_{\mathscr{C}}(X_c)>/<n_{\mathscr{C}}(X_c)>$



Universal dark matter Entropy Profile? yes!!



Halo X-corr Ellipticity ρ_{dm} z=1



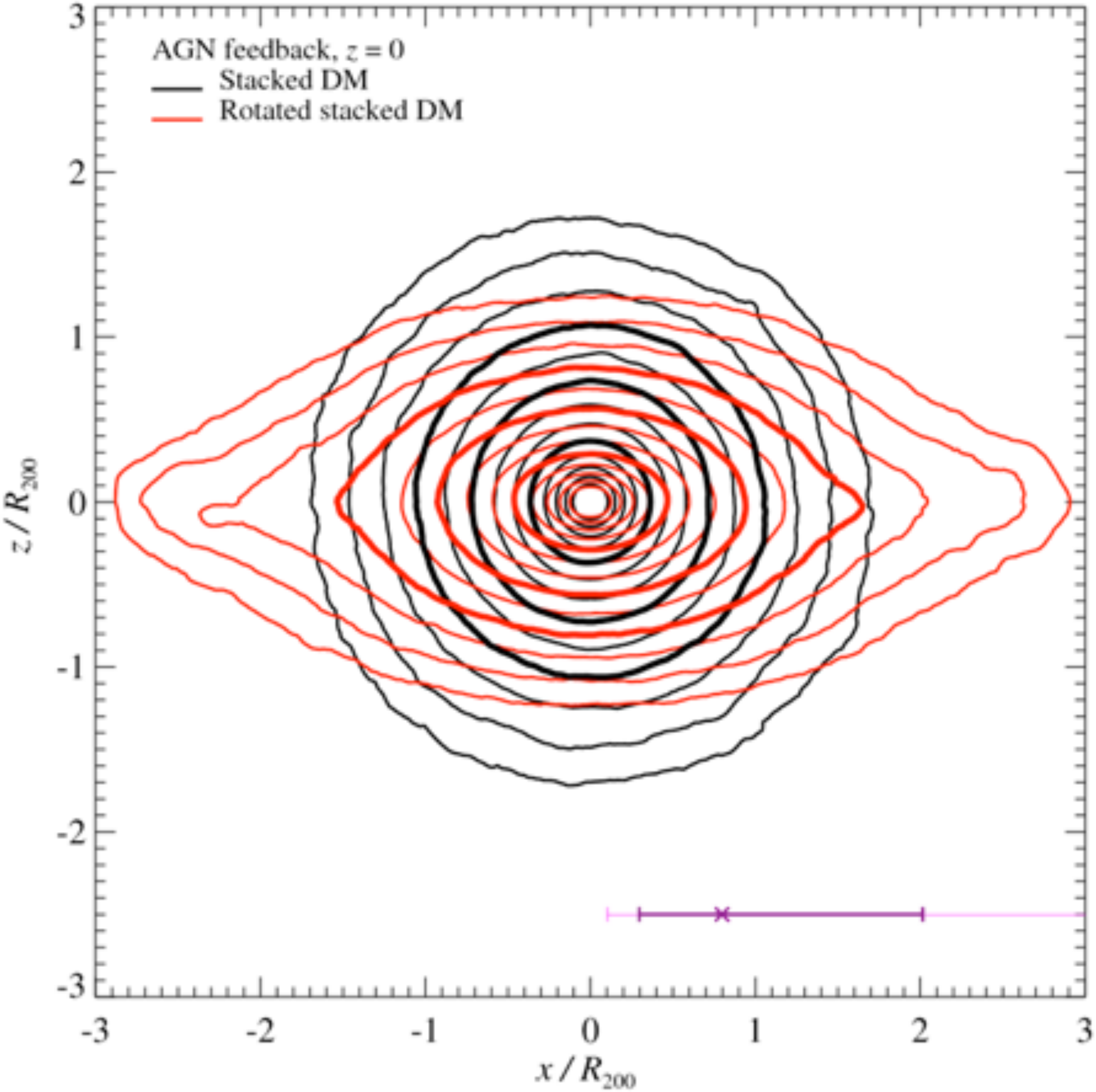
DM in cluster-Y_{SZ} “far-field” is increasingly elongated: a little near-field filament penetration

e(gas) < e(DM) /2

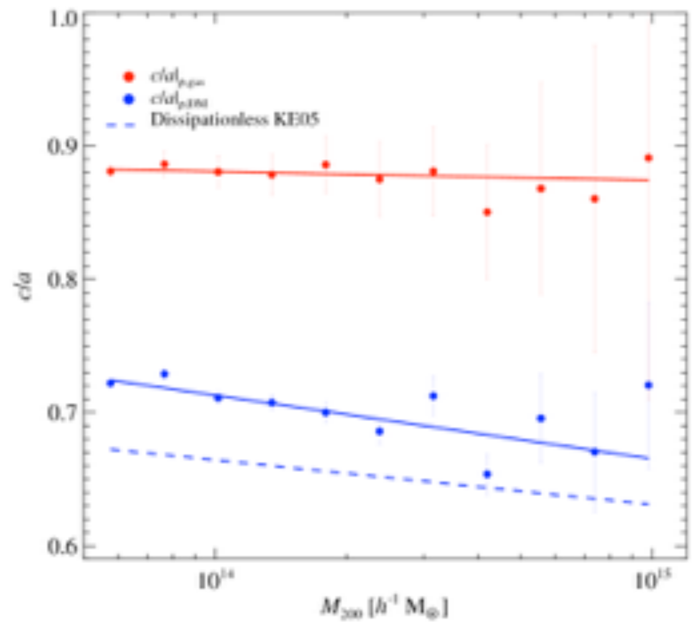
z=1 extreme cf. z=0

Halo X-corr Ellipticity ρ_{dm} z=0

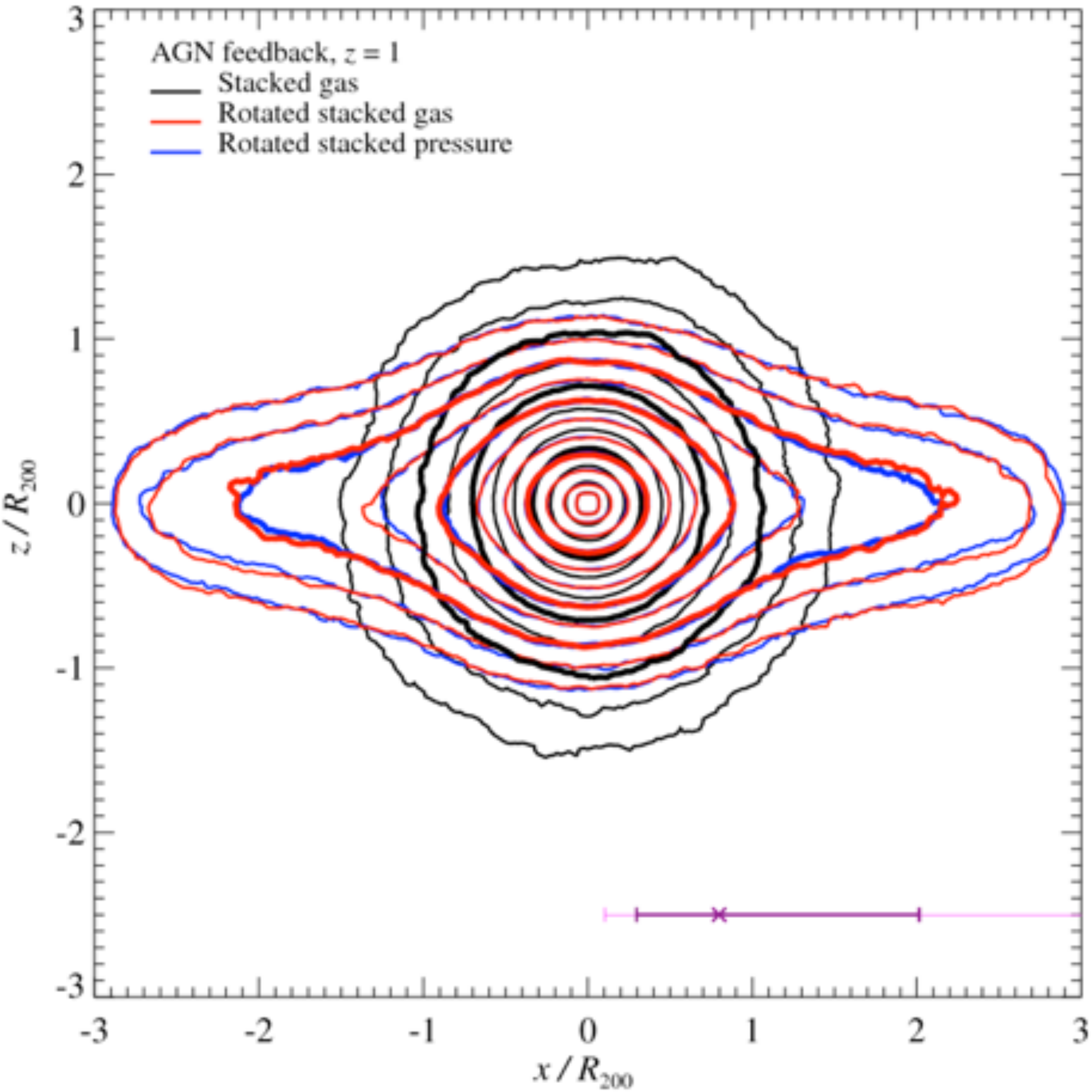
DM in cluster-Y_{SZ} "far-field" is more elongated: a little near-field filament penetration



e(gas) < e(DM) /2



Halo X-corr Ellipticity ρ_g p_g z=1

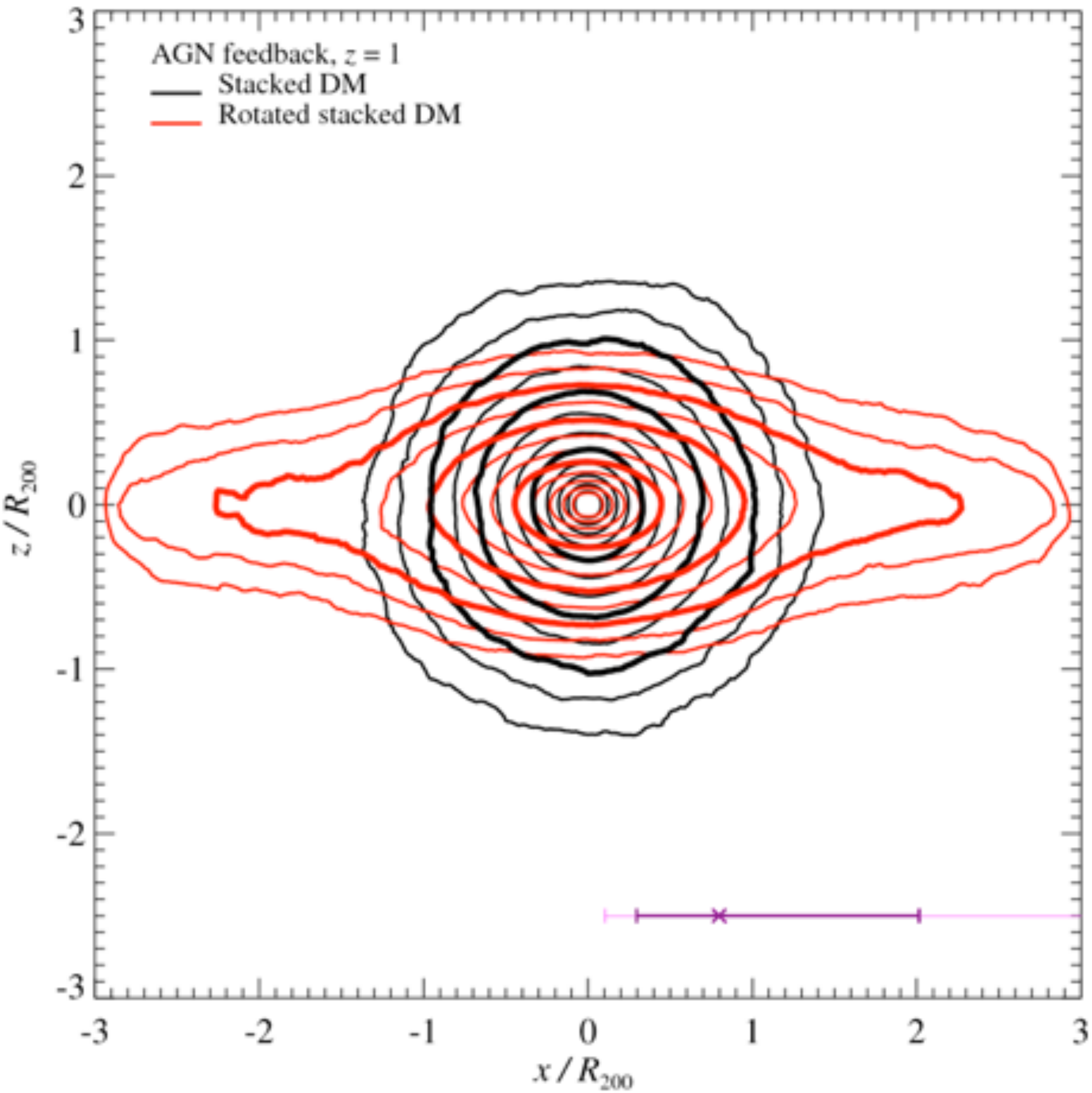


gas in cluster-Y_{SZ} "far-field" is increasingly elongated: a little near-field filament penetration

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

generalized random field 'cluster-expansion' aka halo expansion for a **q-charge density** in Eulerian space: e.g., M_{tot}, PV, Vol_E

$\mathbf{u_q(x)} = \sum_c \chi_{qc}(\mathbf{x}-\mathbf{x}_c, R_{Ec})\, q_c \delta N_c(\mathbf{x}_c, R_{Ec}) + u_{qf}(x)\Theta_{VE} + u_{qf}(x)(1-\Theta_{VE})$

inside = $\Theta_{VE}(x)$ BM's $\mathcal{E}_{hpk}$, 1 or 0 outside $= 1-\Theta_{VE}(x)$=complement

Eulerian collapse fraction $\Theta_{VE}(x) = \sum_c \Theta_c(x-x_c, R_{Ec})\, \delta N_c(x_c, R_{Ec})$

q-charge current:

$\mathbf{J_q(x)} = \sum_c \chi_{qc}(\mathbf{x}-\mathbf{x}_c, R_{Ec})\, \mathbf{v}_c q_c \delta N_c(\mathbf{x}_c, R_{Ec}) + \mathbf{J}_{qf}(x)\Theta_{VE} + \mathbf{J}_{qf}(x)(1-\Theta_{VE})$

Eulerian <= **Lagrangian** map: 1LPT s_{Lc}, 2LPT & beyond the art of s_{NLc}

$\mathbf{x_c(t) = x_c(t_i) + s_{NLc}(t|x_c(t_i), t_i)}$ $\quad x_c(t_i) = r_c$ initial Lagrangian position

Lagrangian cluster expansions v. similar to Eulerian,
except initial proximity cf. final proximity ie mass spheres cf. volume spheres

collapse fraction $\Theta_M(r) = \Theta_{VL} = \rho_{Lcoll}/\rho_{m0} = \sum_c \Theta_c(r-r_c, R_{Lc})\, \delta N_c(r_c, R_{Lc})$

evolves to $\rho_{Ecoll}/\rho_{m0} = \sum_c \chi_{Mc}(x-x_c, R_{Ec})\, M_c\, \delta N_c(x_c, R_{Ec})$ NFWish χ_{Mc}

χ_{qc} **susceptibility** of u_q to the "charge" q_c the art of halo models

χ_{qc} ***susceptibility*** *of u_q to the "charge" q_c the art of halo models*

$q = M_{tot}, \sim Vol_L$ M_{dm}, M_{gas}, PV, Vol_E, K_{dm}, BE, S, S_{config}, S_{dm}…

N_{HI} L_{CO} L_{opt} L_{IR} L_X Y_X Y_{SZ} ..

via measurement: hi res ***gas sims*** *BBPS, n-body sims,* ***observations***

$M_C \sim R_{Lc}^3$, $Vol_E \sim R_{Ec}^3$, BE_c from the peak patch algorithm

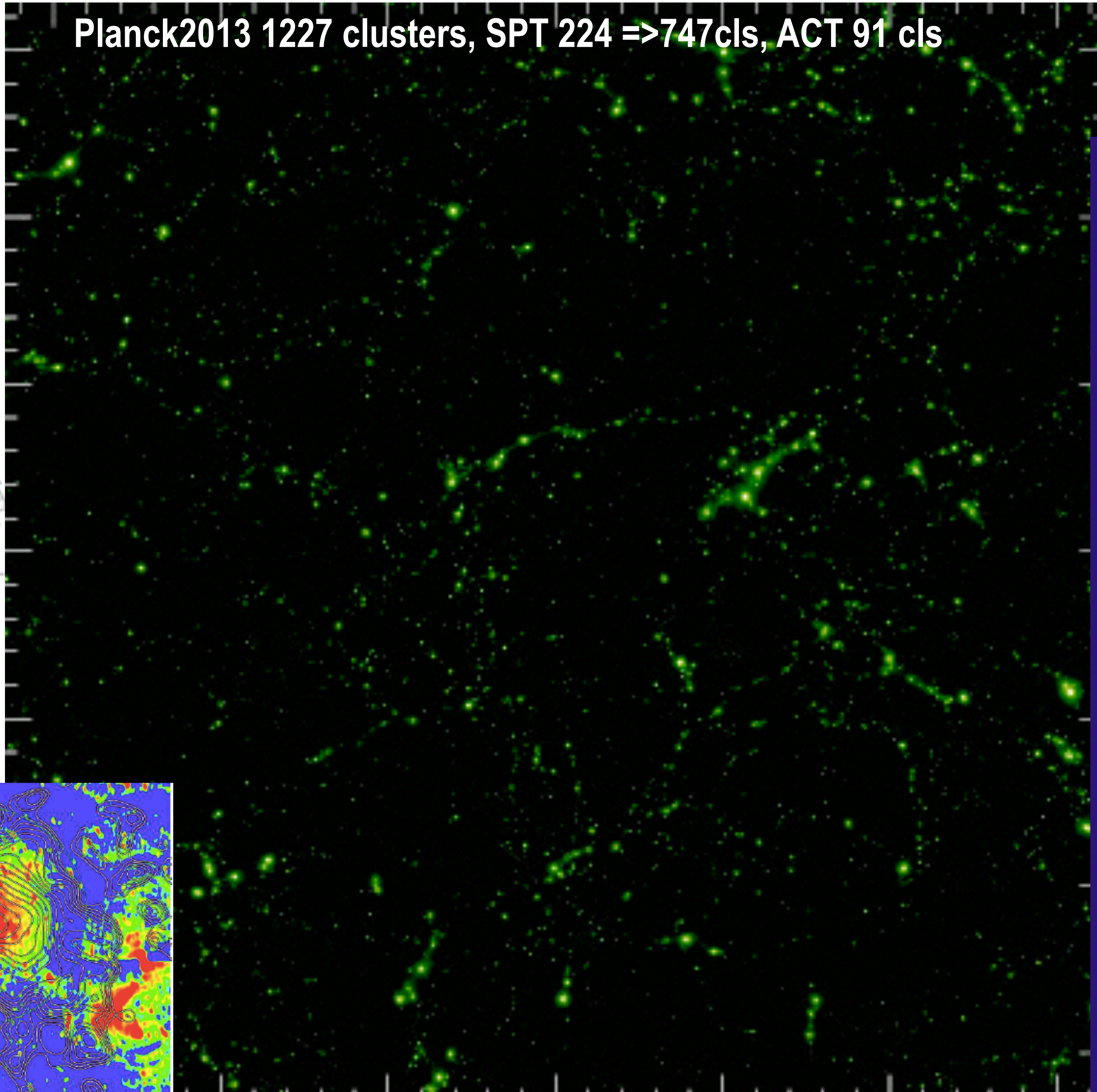
shearing/tidal patches of BW/BKP: tensor 'charges' $\mathbf{e}_J^{\ j}$

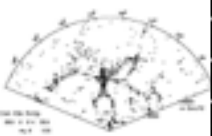
susceptibility = (linear) response function = form factor = mean internal q-density in a cluster

Let there be HEAT/LIGHT/ENTROPY: susceptibilities measure entanglement of baryons, dark matter, … in cosmic-web clusters (in the statistical sense) aka patches of high entropic entanglement

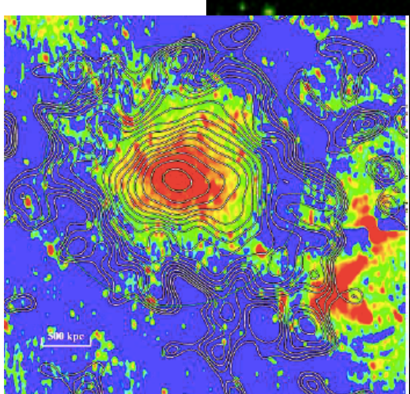
pressure intermittency *in the cosmic web, in cluster-group concentrations probed by* **tSZ**

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





Planck's
Coma



$p_e(x,t)$

the thermal Sunyaev Zeldovich Probe

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

Compton cooling of hot cosmic web gas

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

$y = \sigma_T \int p_e \, d$*line-of-sight*

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

$x = h\nu/T_\gamma$

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

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

$\rho_g(x,t)$

a~1

400 Mpc

ΛCDM

WMAP5

gas density

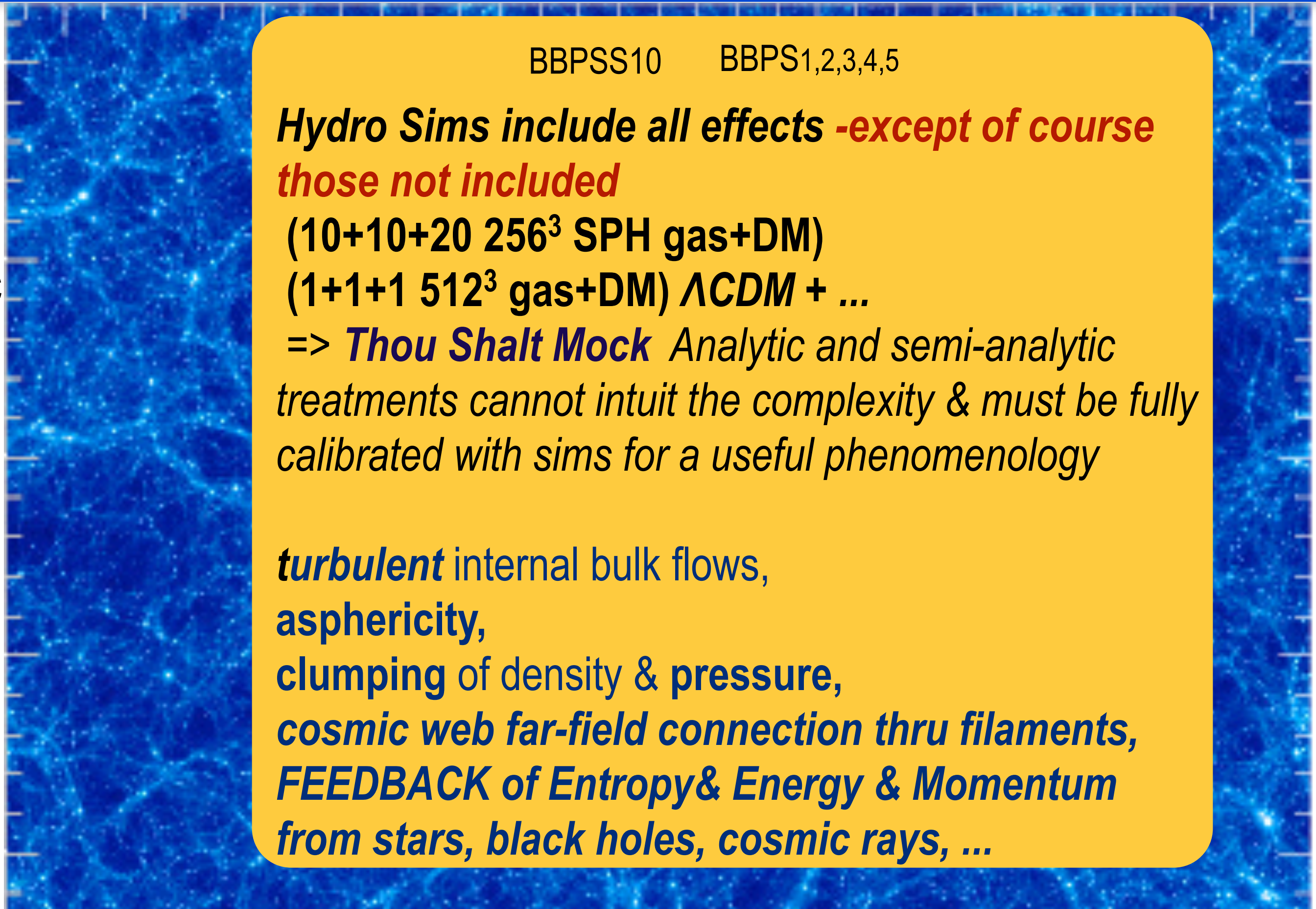
Gadget-3

SF+ SN E+ winds +CRs

512^3

BBPSS10

BBPS1,2,3,4,5



BBPSS10 BBPS1,2,3,4,5

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

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

(1+1+1 512^3 gas+DM) *ΛCDM* + ...

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

turbulent internal bulk flows,

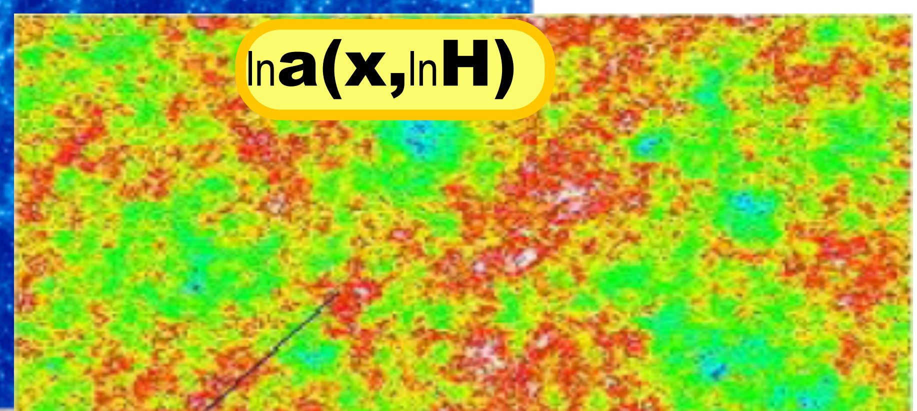
asphericity,

clumping of density & **pressure,**

cosmic web far-field connection thru filaments,

FEEDBACK of Entropy& Energy & Momentum from stars, black holes, cosmic rays, ...

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

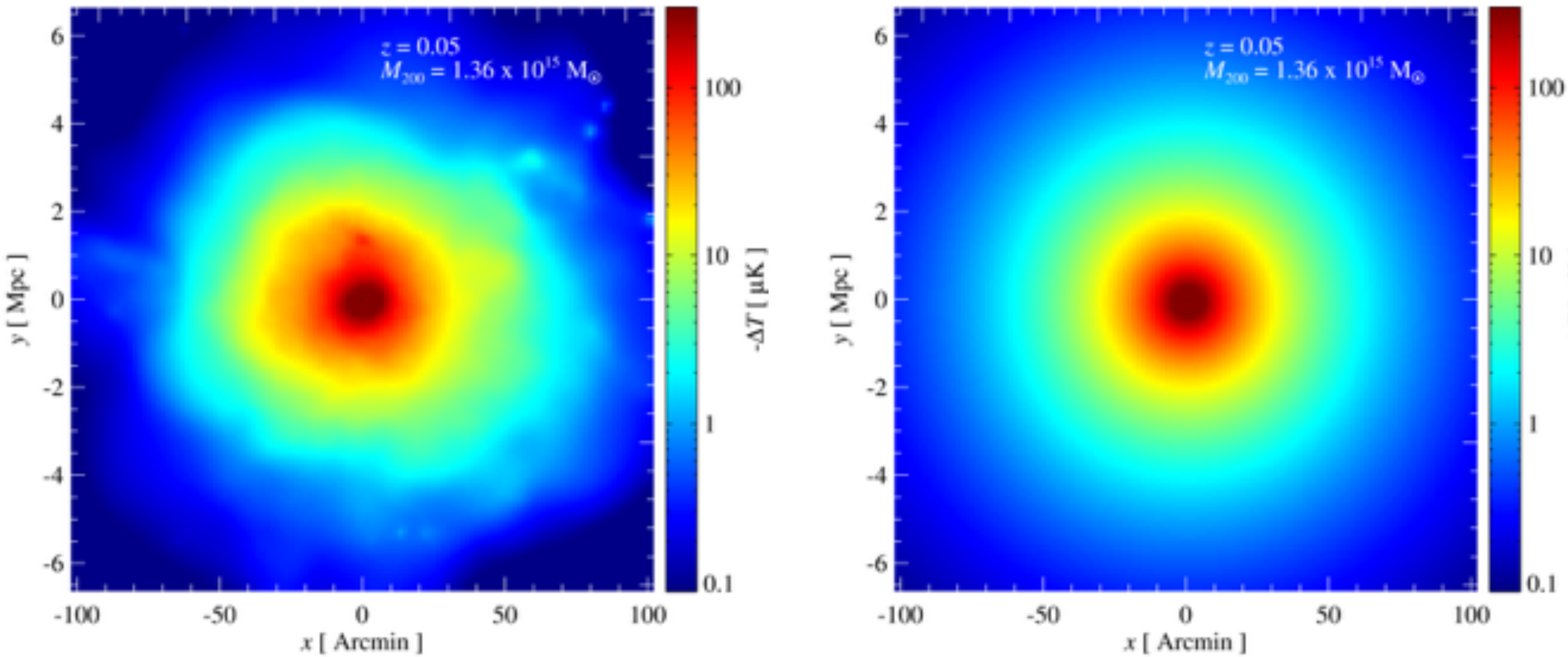


2D pressure exact vs. fit ⇨ pressure sub-structure

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

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

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

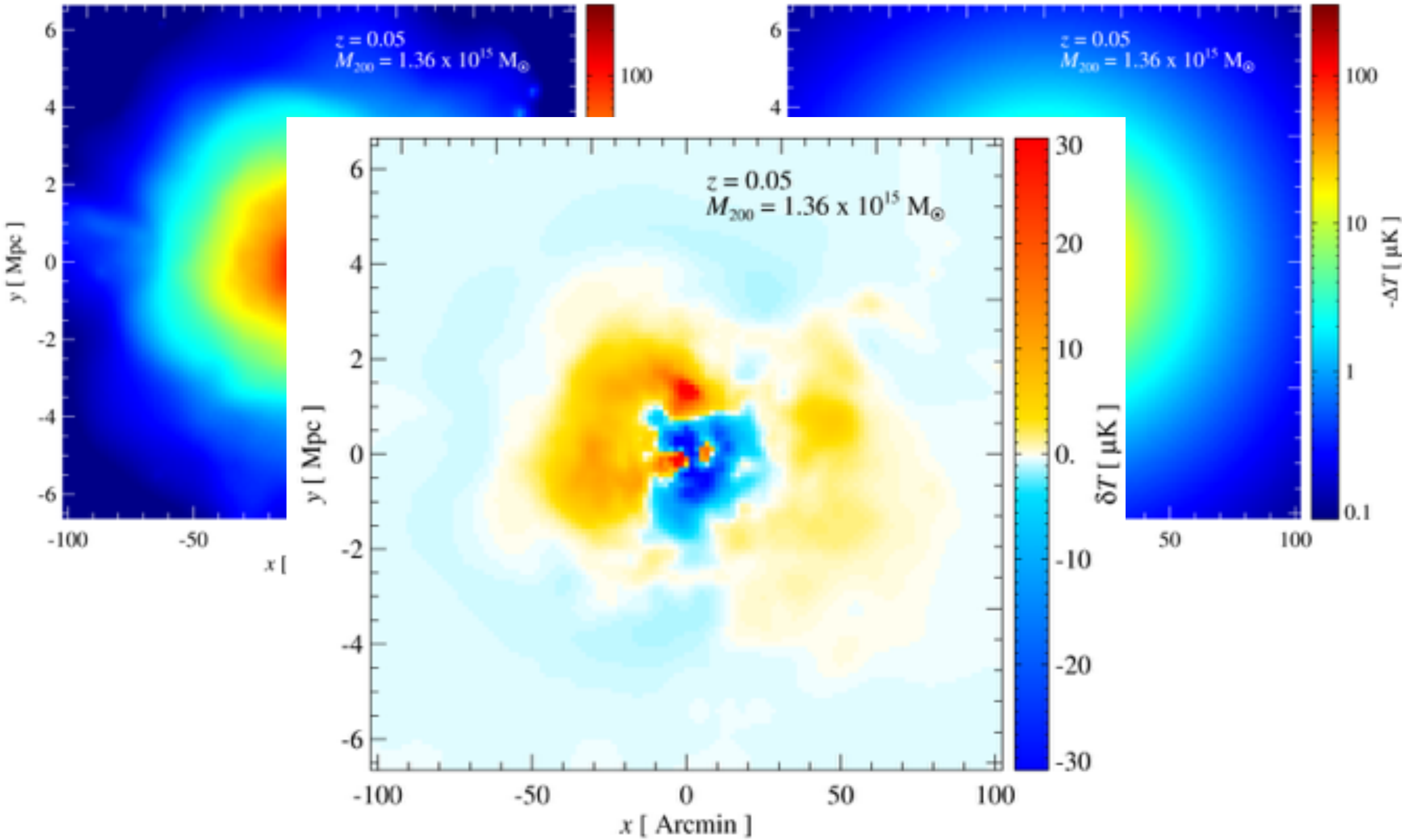


Same cluster (pasted on GNFW according to mass)

@ 30 GHz, z = 0.05 Mass ~10^{15} M_{sun}

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

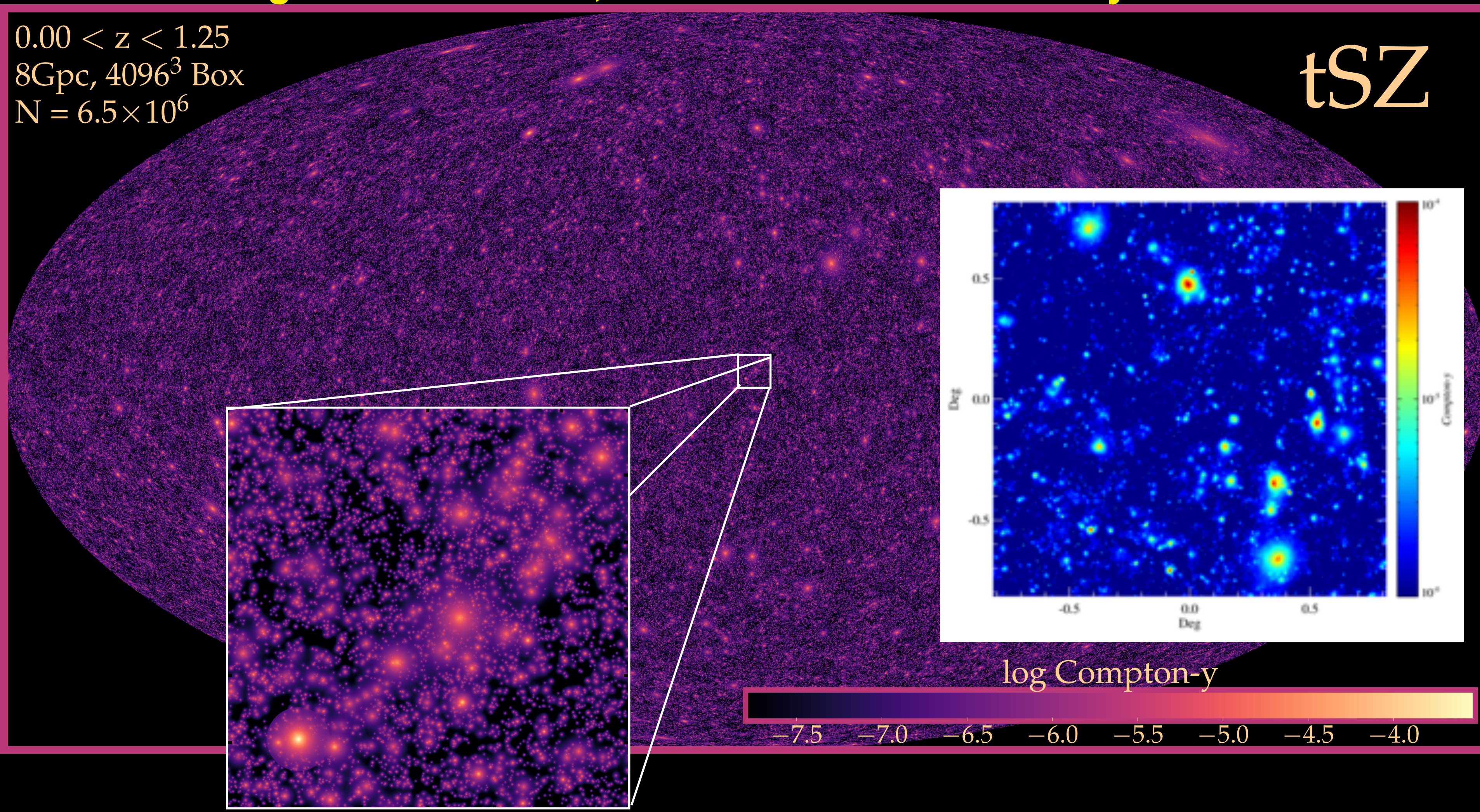
p_f *(residual "noise")*



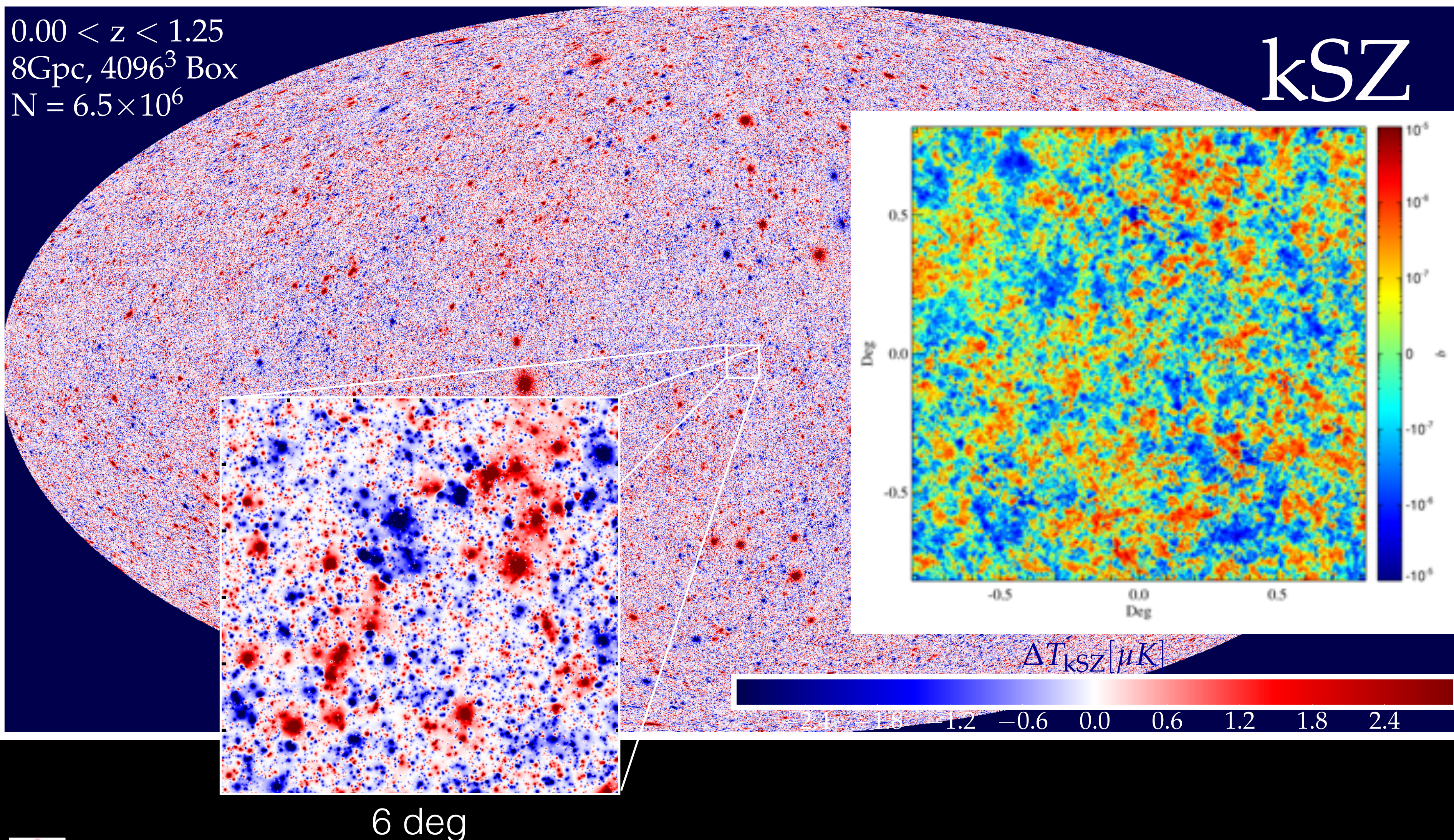
BBPS 1,2,3,4,5,.. Pressure Susceptibilities and ‘Charges’ PV_{gas}

Observational Pressure Susceptibilities: Arnaud ‘Universal’ Profile from Stacked X-ray clusters

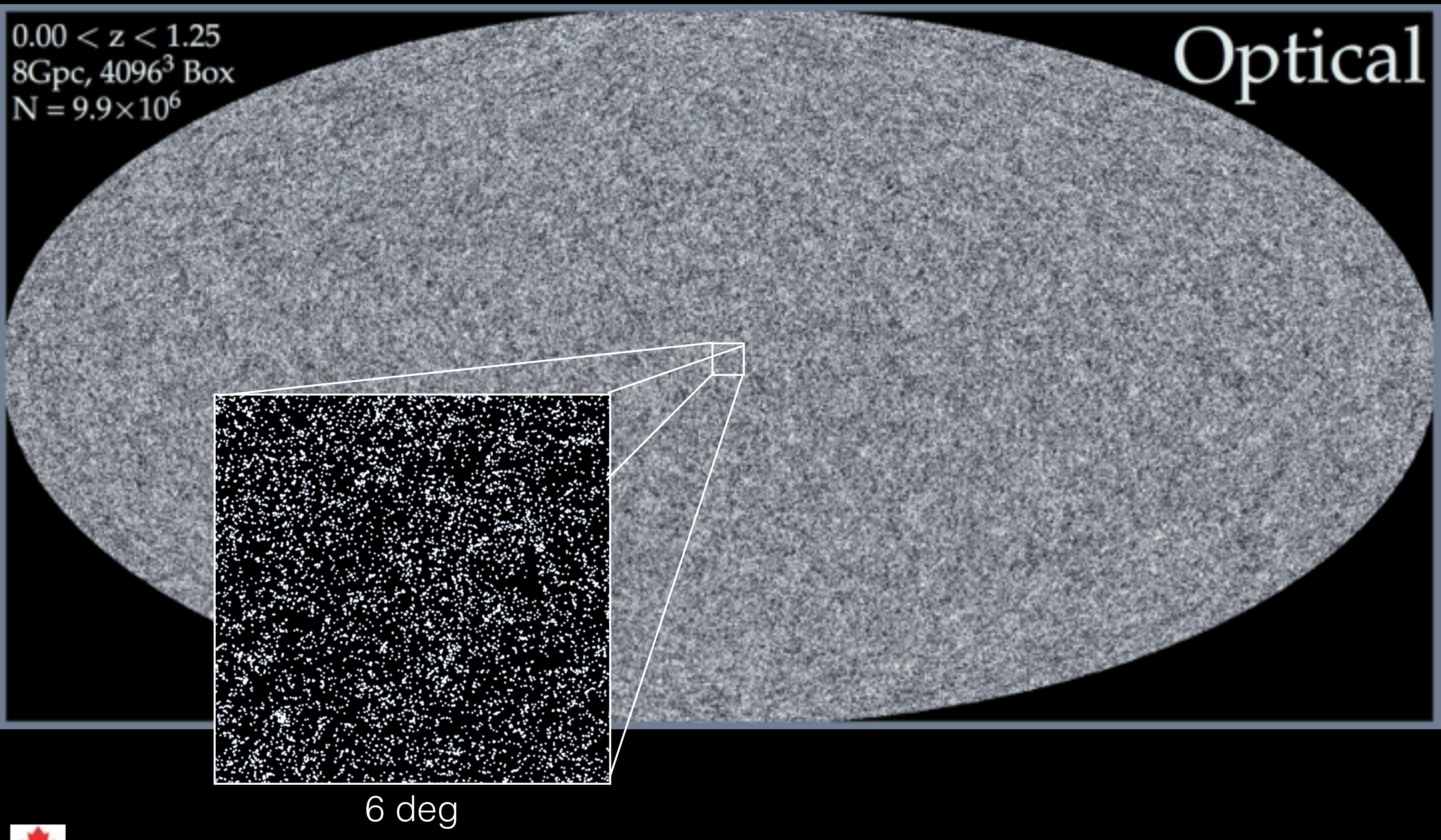
our **PUPPY:** Planck 2013 **Universal pressure Profile?**
agrees with BBPS, who show z/M-universality is broken



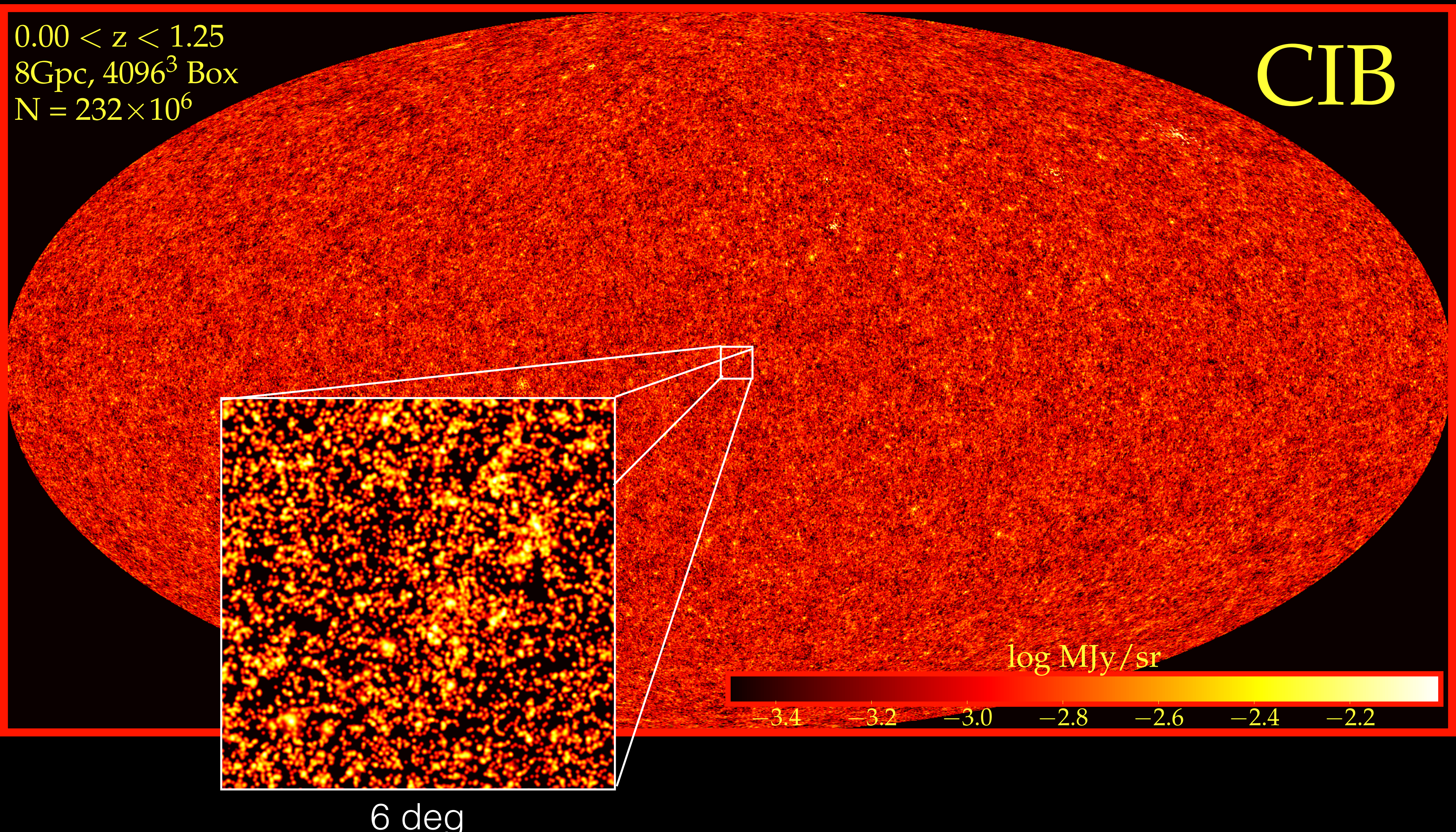
BBPS 1,2,3,4,5,.. ionized Gas Density Susceptibilities and 'Charges' M_{gas}



Manera et al. (2012) CMASS HOD susceptibility Model, following NFW DM profile



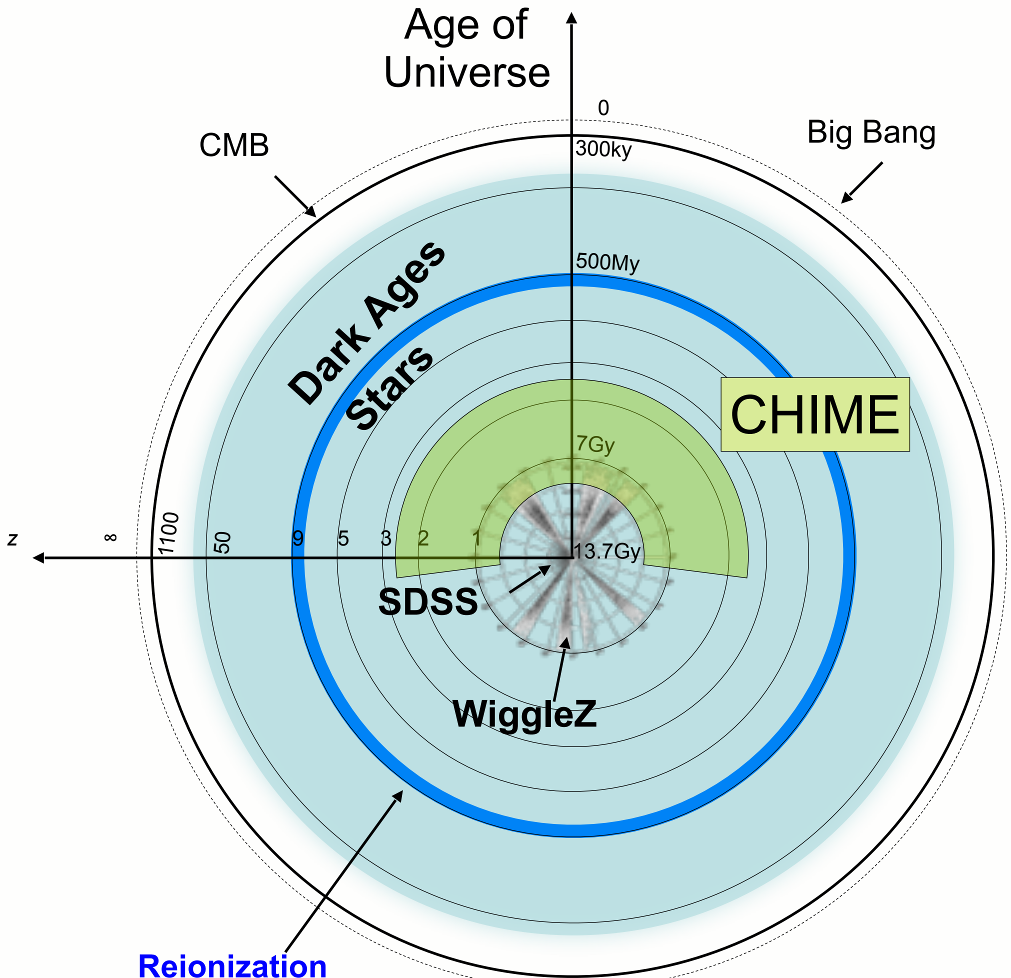
Planck 2015 CIB susceptibility model aka Shang et al. (2012) DSFG HOD + Dust SED Model



HI Intensity Mapping: Huge Volume

Existing and upcoming surveys:

BINGO, BAOBAB, LOFAR, PAPER, HERA, HIRAX, MWA, SKA and pathfinders, Tianlai, **CHIME, …**

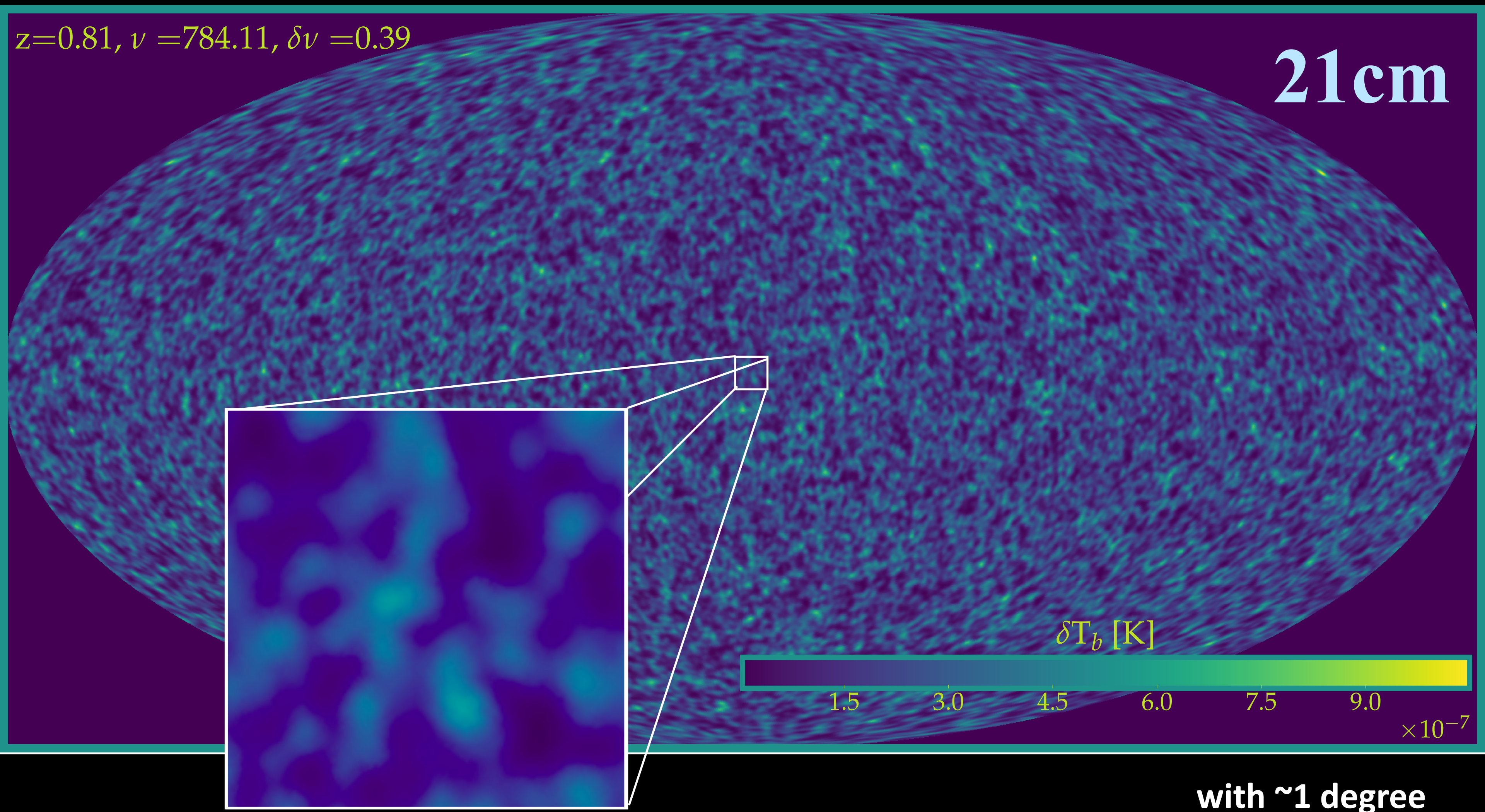


z=0.8-2.5, ~(8 Gpc)^3

3D tomographic in z => k-parallel modes, but truncated k-perpindicular modes (degree scale reconstructed beam)

HI Susceptibilities and ‘Charges’ N_{HI}

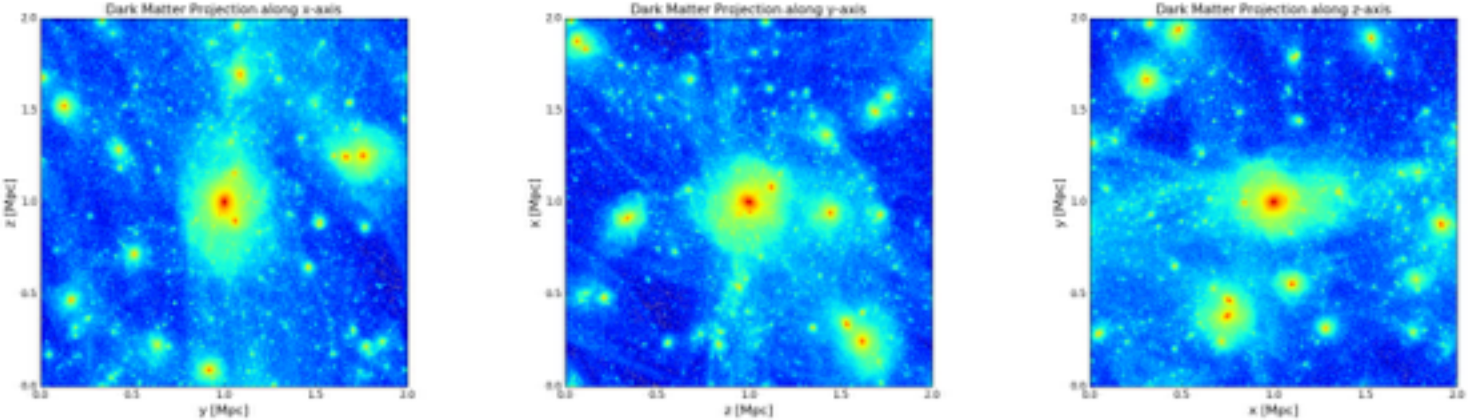
ABBS for CHIME mocks Subgrid halos + interior HOD
only a little GBT data to anchor susceptibilities on, now trying FIRE sims



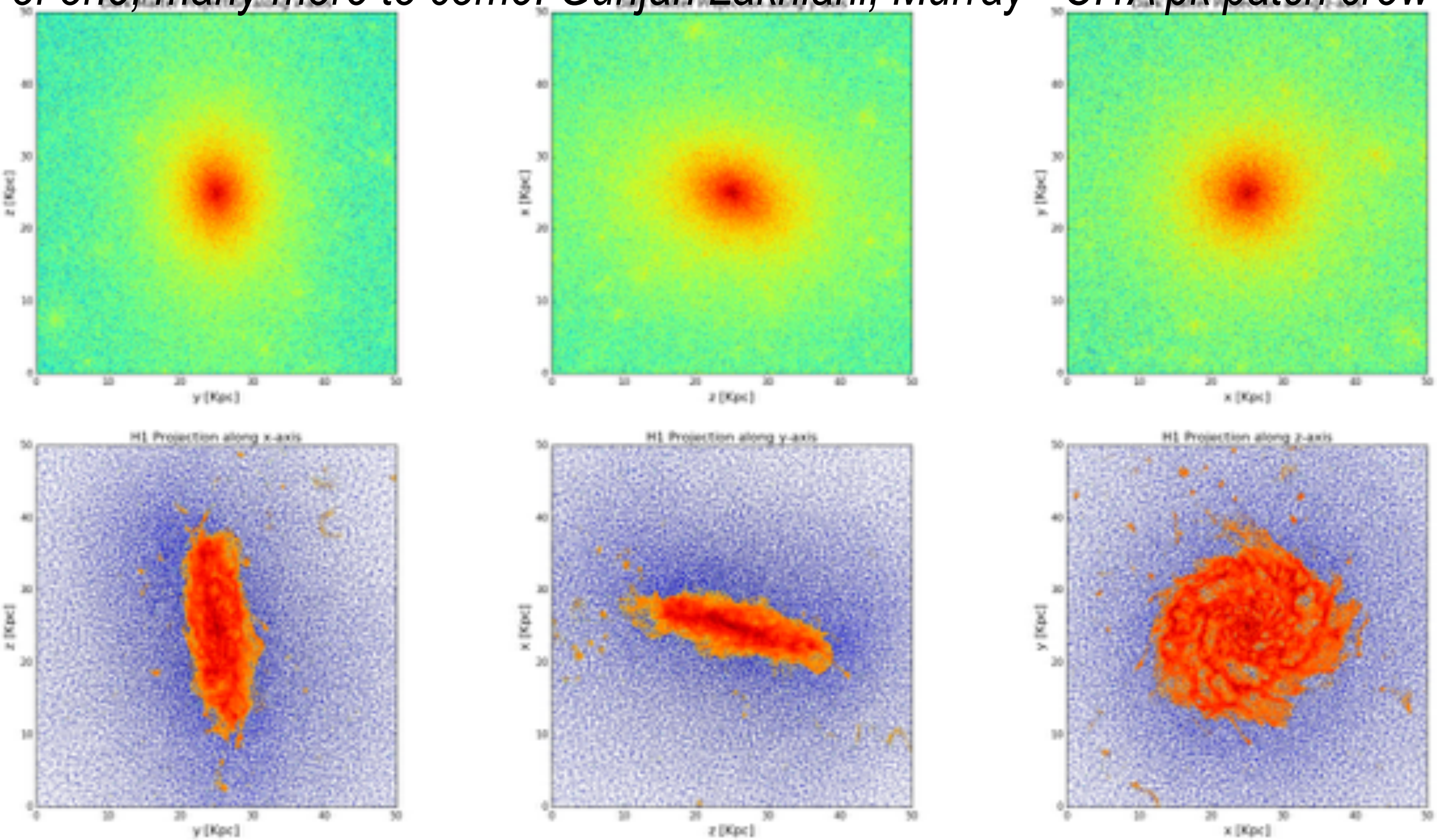
6 deg

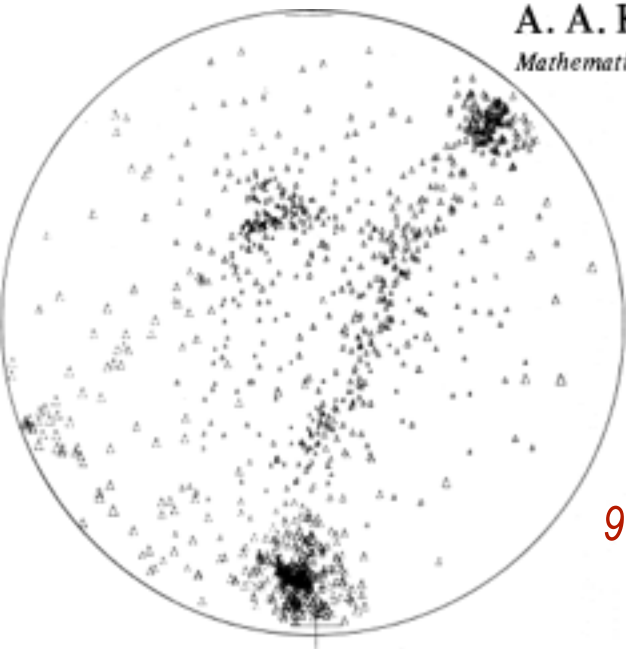
with ~1 degree CHIME beam

only a little GBT data to anchor susceptibilities on, now trying FIRE sims



hi res FIRE hydro (Hopkins+) for galaxy formation susceptibilities: a first measurement - ensemble of one, many more to come: Gunjan Lakhlani, Murray +CITA pk patch crew





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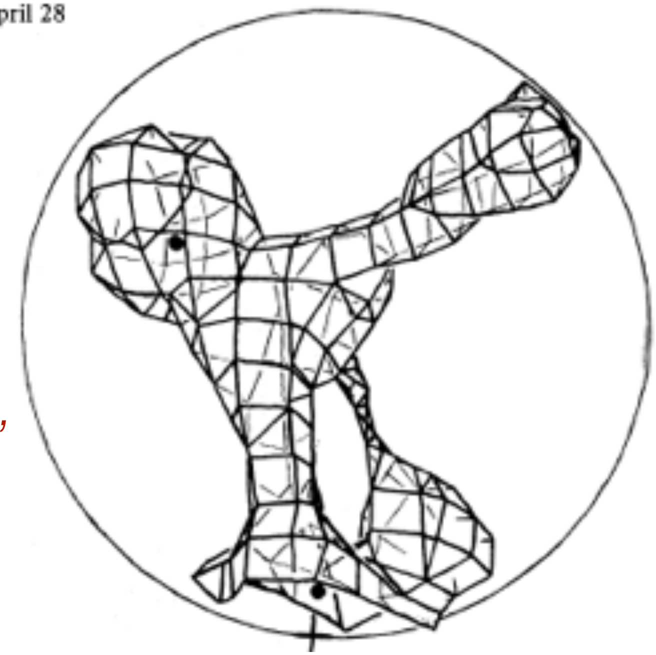
Received 1982 November 15; in original form 1982 April 28

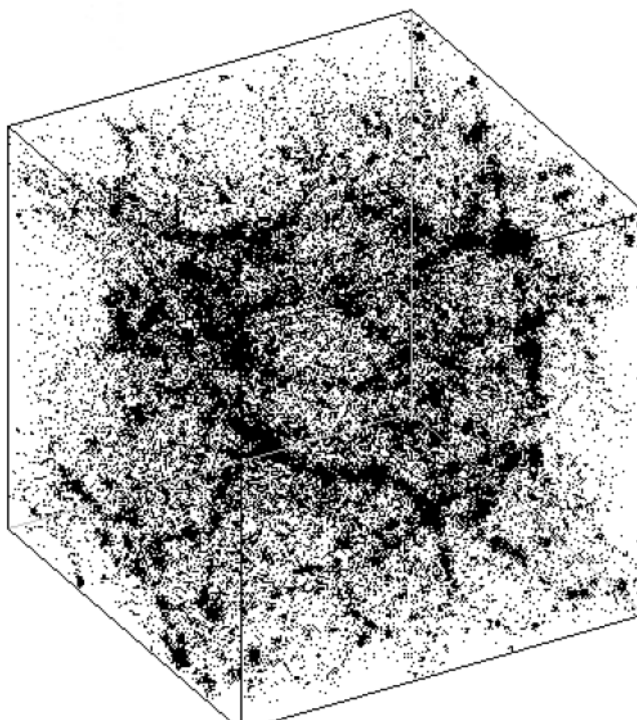
3D numerical model of the Universe

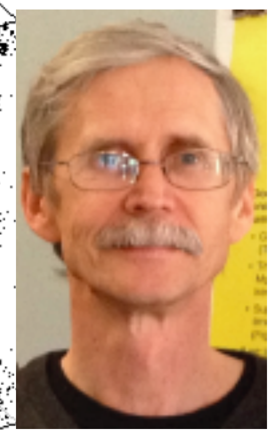


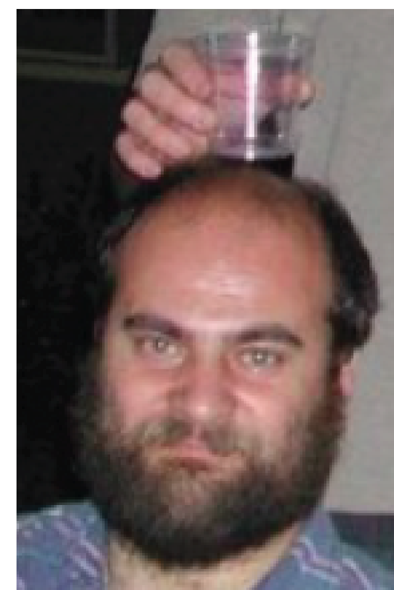
Klypin's vintage 82
160h^{-1}Mpc box 32^3 hDM

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

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







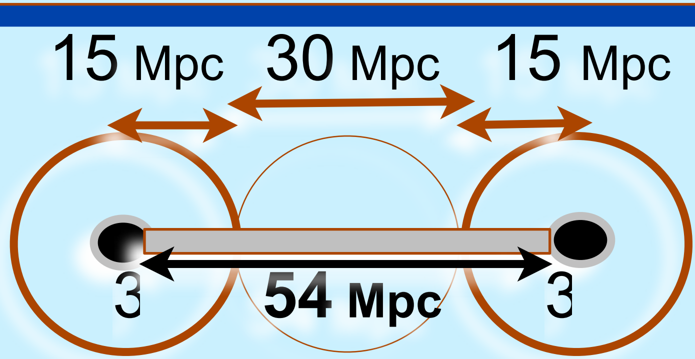
Klypin's vintage 93 50h^{-1}Mpc box 128^3 sCDM = BKP98 web workhorse, *Couchman's 128^3 for BM91-96*

Peak-patches = “hot” halos
B+Myers 91-96; BBKS 83-86

The ***Cosmic Web***
B+Kofman+Pogosyan 96-99

“Molecular” Picture of LSS Filaments & Membranes

HALOS are dynamically HOT, the hierarchical standard model, ΛCDM, => scale space (3+1D => 4+1D)
adaptive coarse-grain Zeldovich flows of Lagrangian peak-patches agree with N-body Eulerian halo simulations => fast mock surveys



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

1 Mpc 2 Mpc 1 Mpc
3.6 Mpc

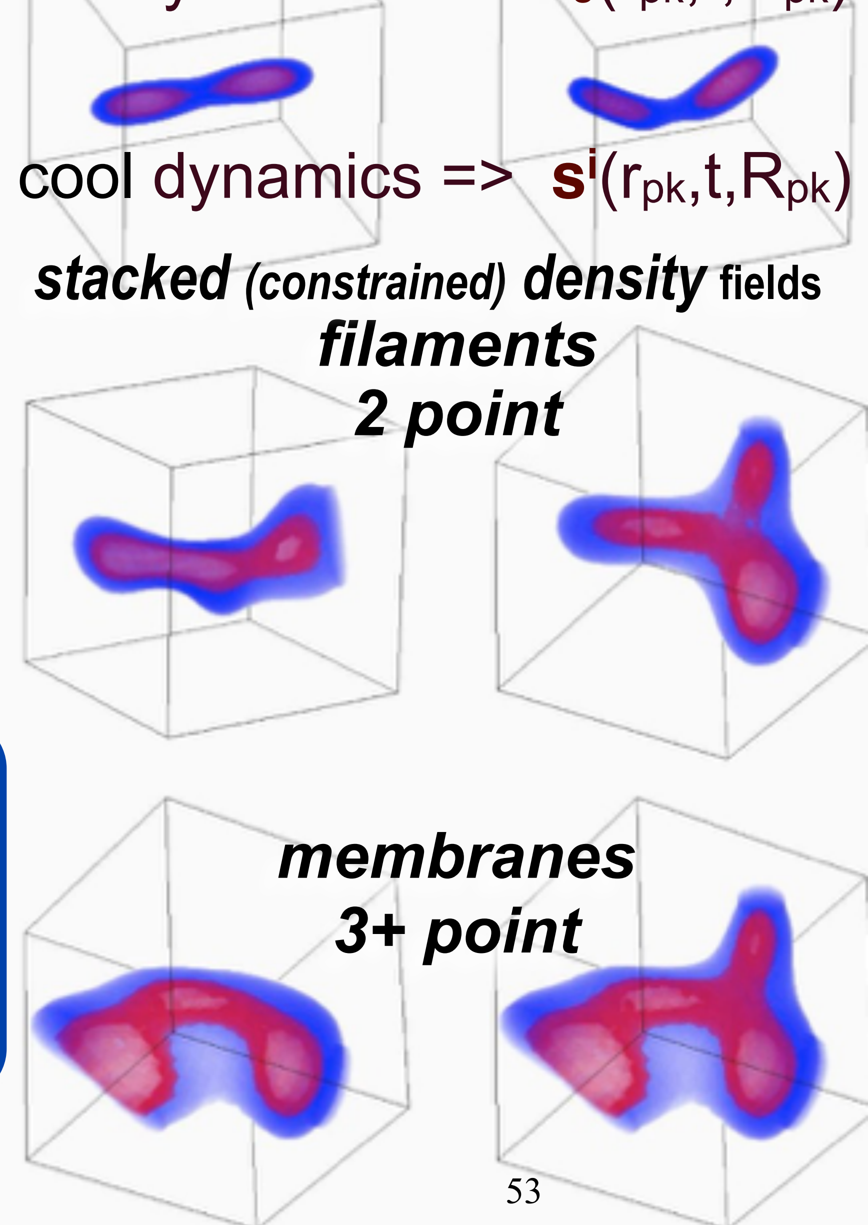
galaxies
z~2-5
$\sim 10^{11.5}$ M_{sun}

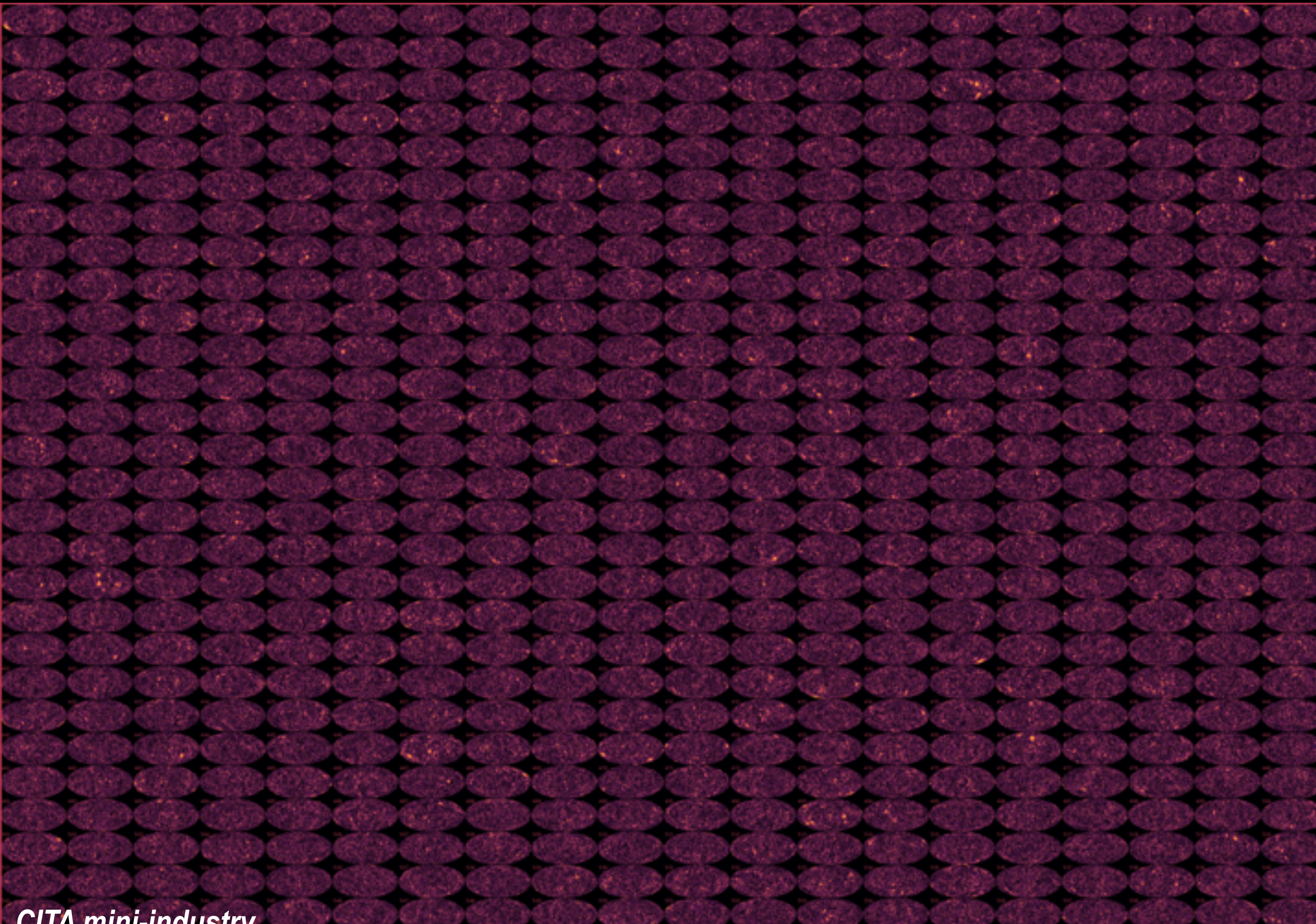
marriage of halos & Zeldovich

hot dynamics => $\mathbf{e^i}_J(r_{pk},t,R_{pk})$

cool dynamics => $\mathbf{s^i}(r_{pk},t,R_{pk})$

***stacked** (constrained) **density** fields*



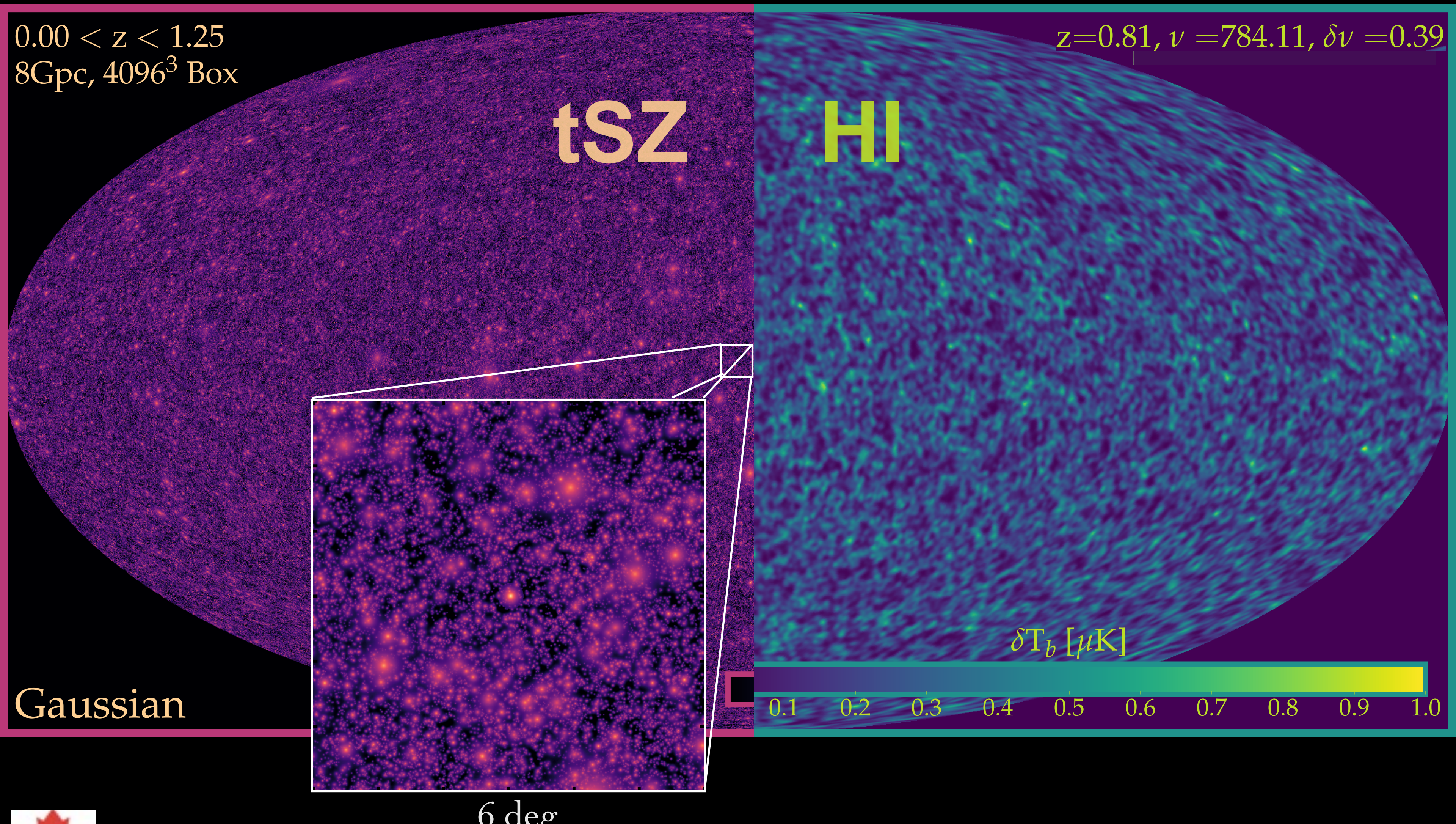


CITA mini-industry

Alvarez, Berger, Bond, Stein, Bahmanyer, Battaglia,..Huang, Frolov 2016

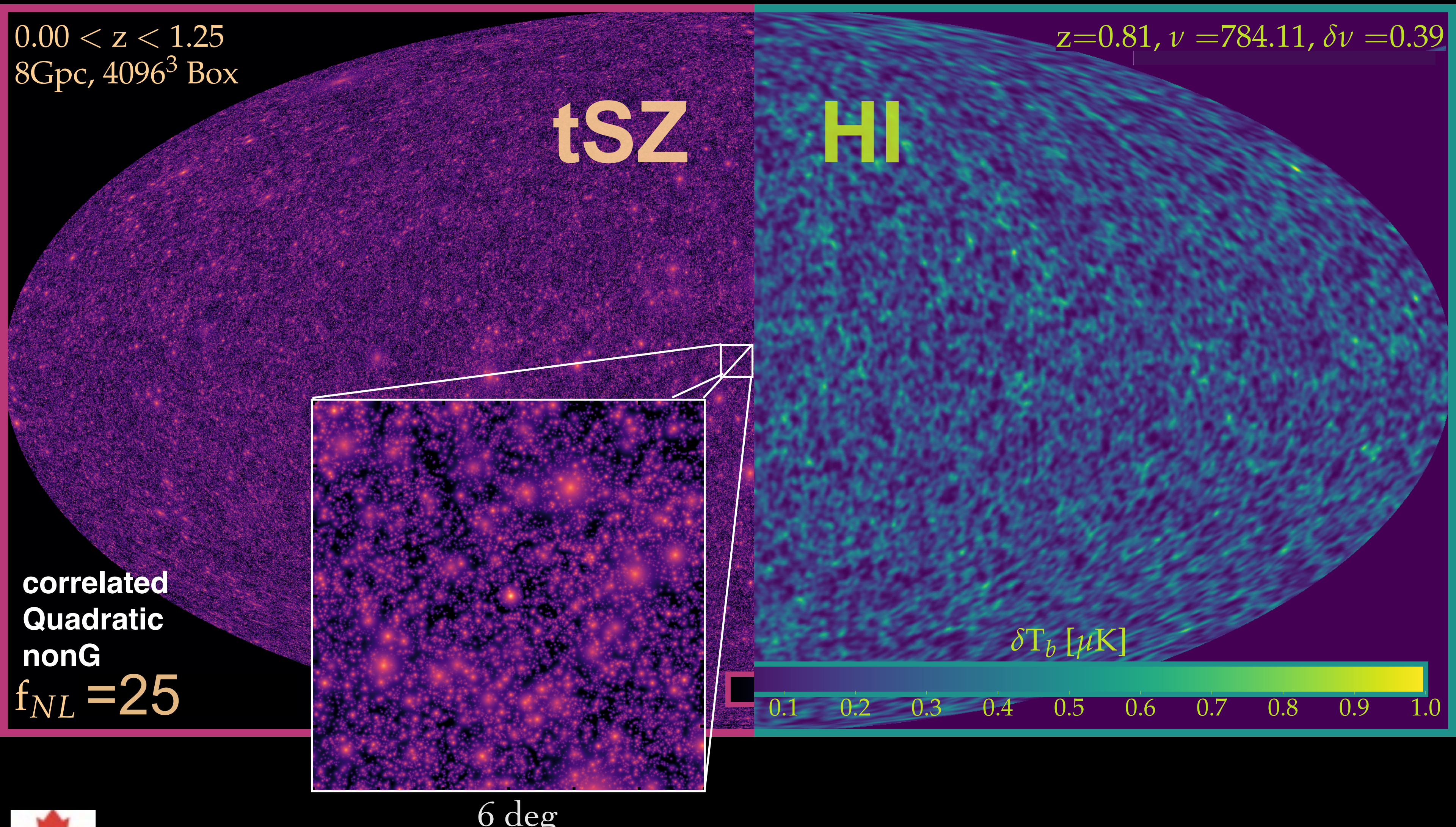
BBPS 12345 2012+
Pressure Susceptibilities

Subgrid Halos + Neutral
Hydrogen Prescription



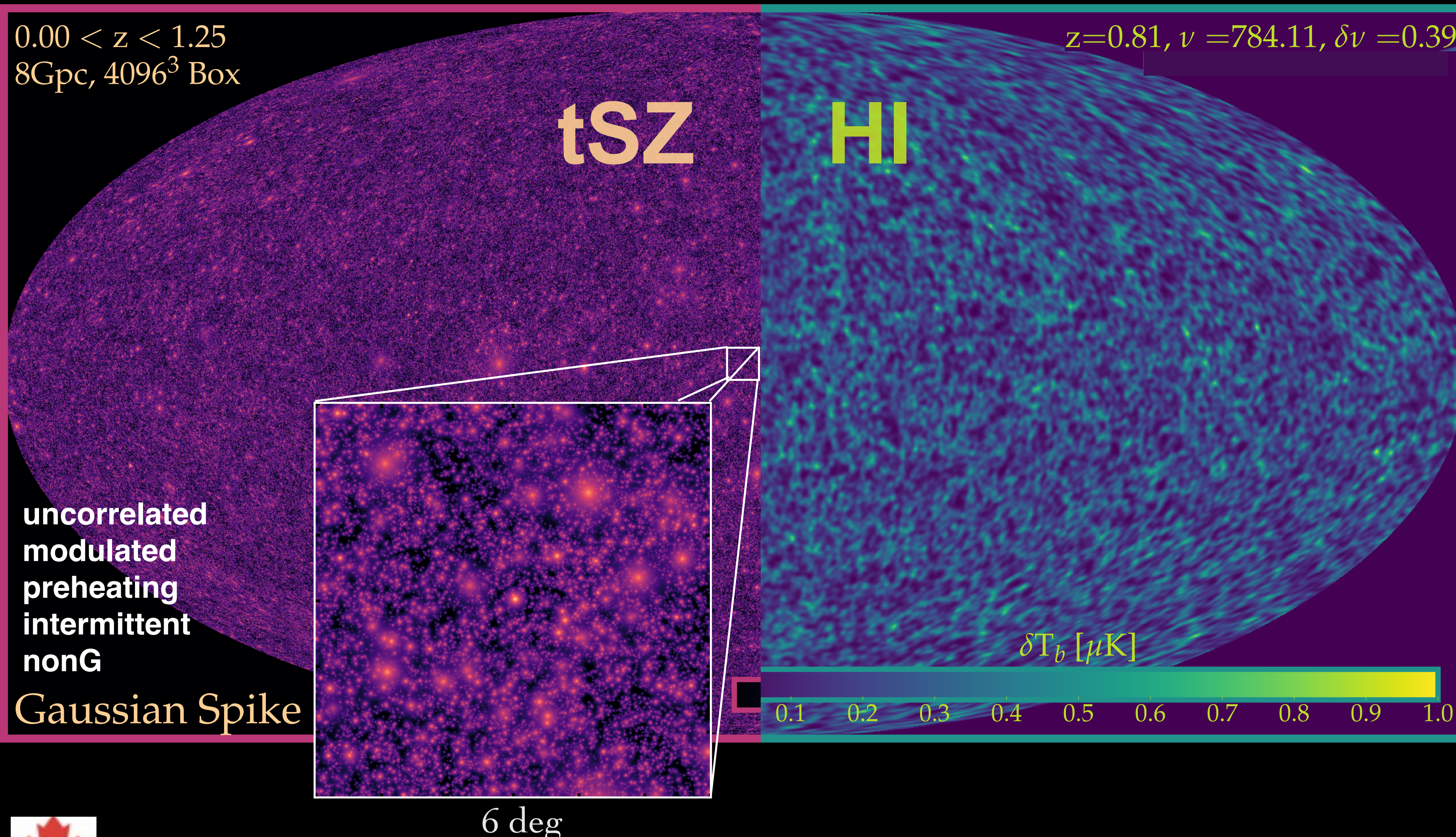
BBPS 12345 2012+ Pressure Susceptibilities

Subgrid Halos + Neutral Hydrogen Prescription



BBPS 12345 2012+ Pressure Susceptibilities

Subgrid Halos + Neutral Hydrogen Prescription



END