Mocking Heaven's Web *with PeakPatches++*

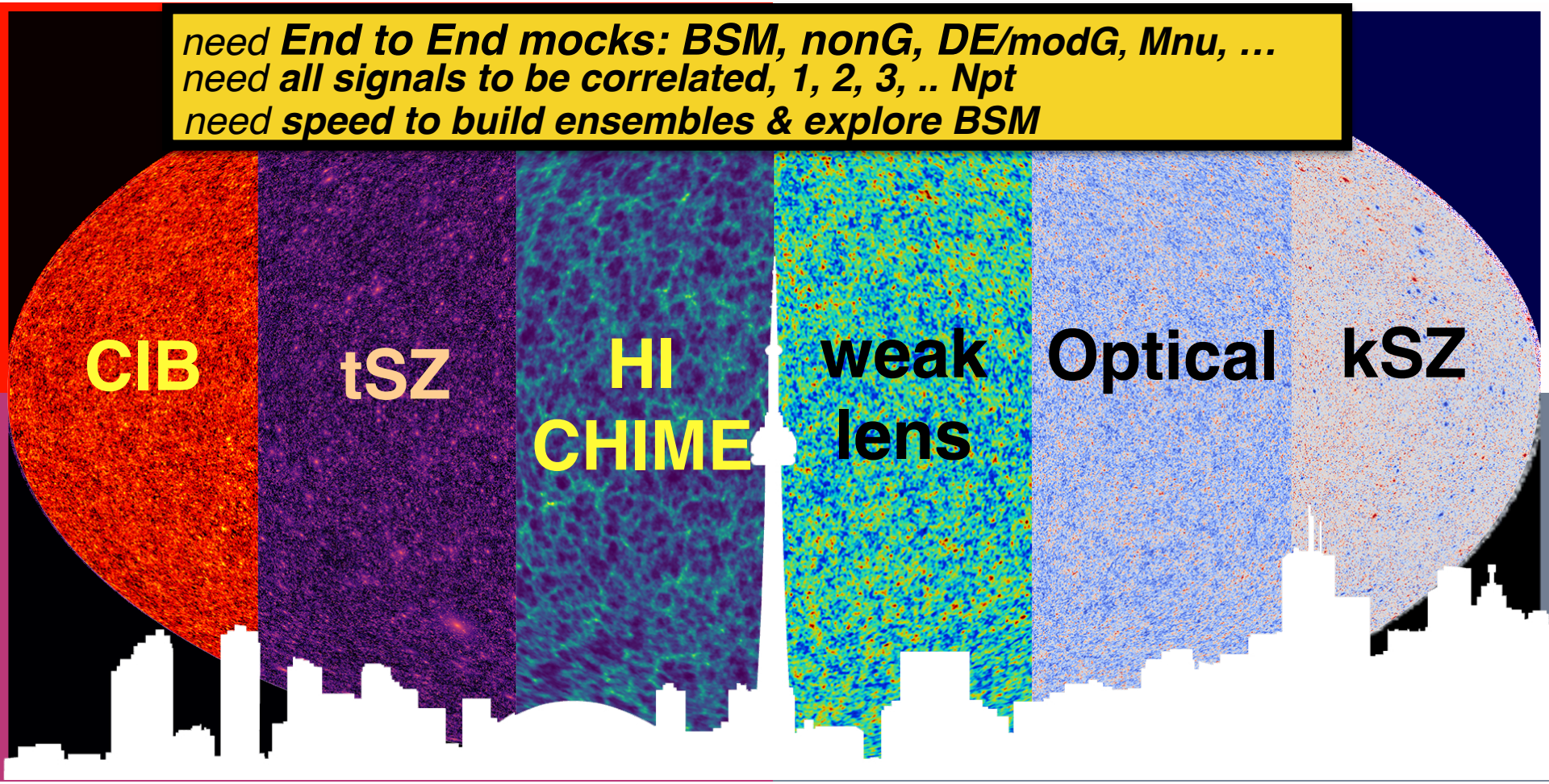
Bond @ UofT CosmicWebDay July 10, 2017

Planck, AdvACT, SO, CMB-S4, CCATp, EUCLID, LSST, CHIME, HIRAX, COMAP, ...SKA

Line Intensity Mapping and Line Absorption Mapping *fLIMfLAM*

CITA mini-industry: Marcelo Alvarez, Dick Bond, George Stein & Battaglia, Codis, van Engelen & FIRE: Lakhlani + Murray + Hopkins + Berger & Connor Bevington, Bruno Régaldo-Saint Blancard, Ronan Kerr, Louis Pham

need ***End to End mocks: BSM, nonG, DE/modG, Mnu, ...***
need ***all signals to be correlated, 1, 2, 3, .. Npt***
need ***speed to build ensembles & explore BSM***



Planck 2015 XII: Full Focal Plane Sims: FFP8 ensemble of 10K ***End****to****End*** *mission realizations in 1M maps. instrument noise + CMB + PSkyModel + .. (25M NERSC CPU hrs)*

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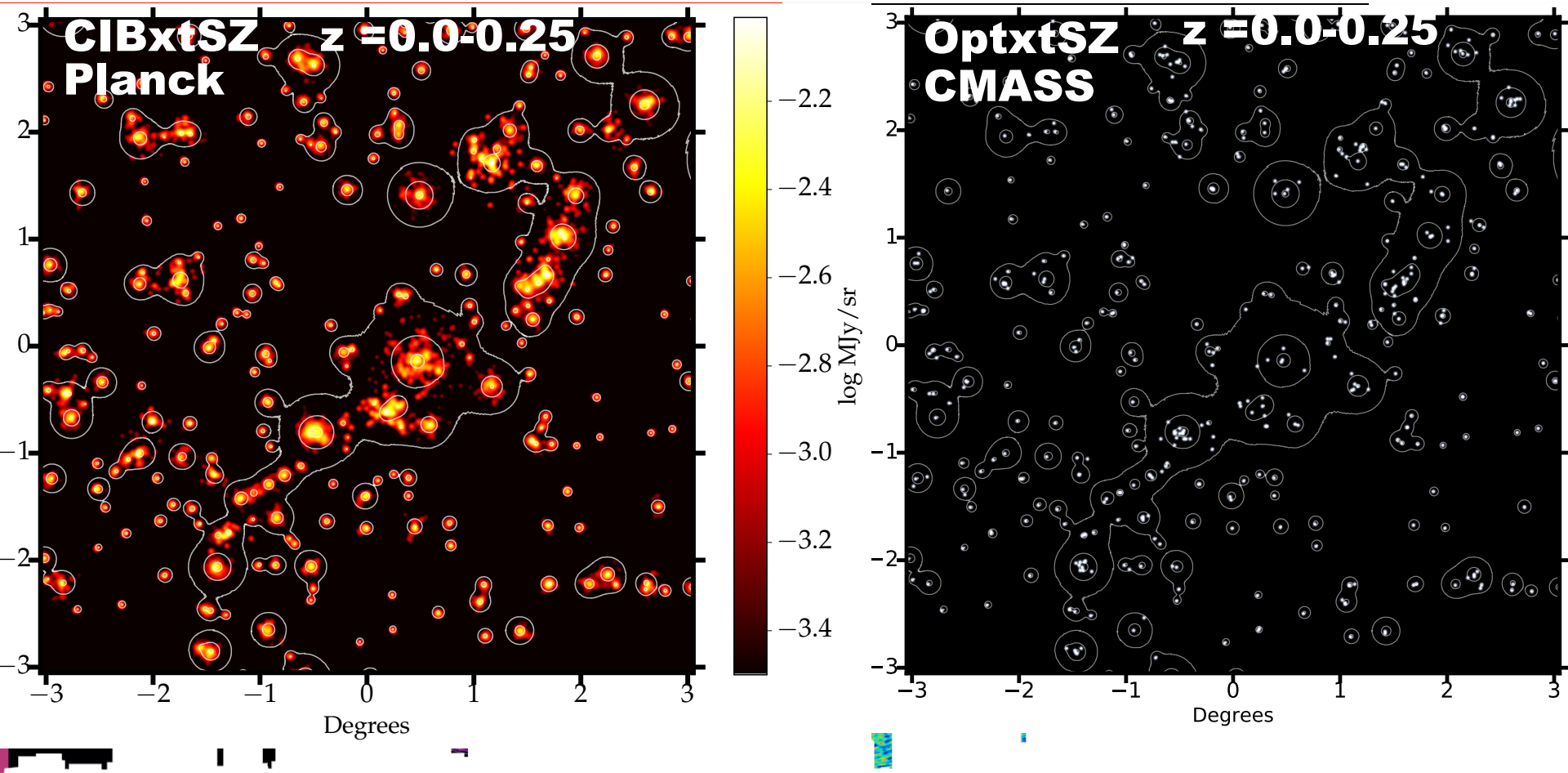

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Bond & Stein @ JHU IM17

Line Intensity Mapping and Line Absorption Mapping

radio: HI CO CII, … + optical Ly a, …

z=.8-2.5 z=2.4-3.4 z=6-8

Marcelo Alvarez, Bond, George Stein + FIRE: Lakhlani + Murray + Hopkins, Berger + Kerr

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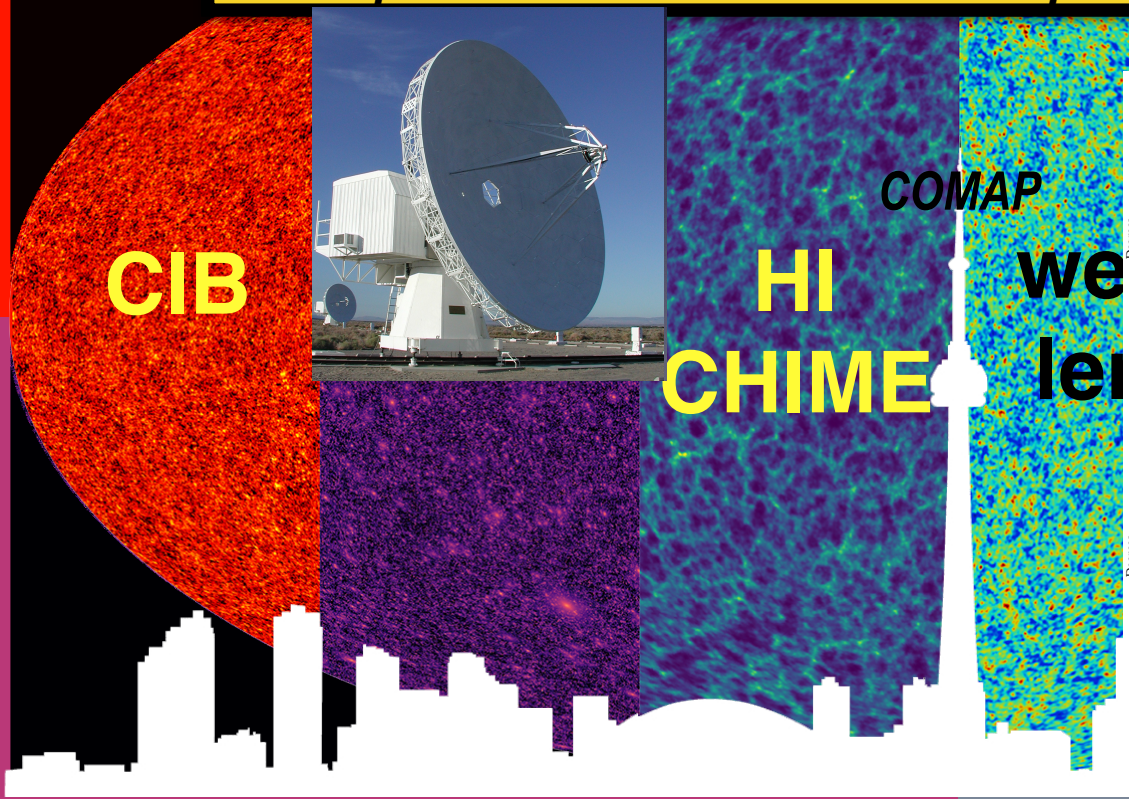
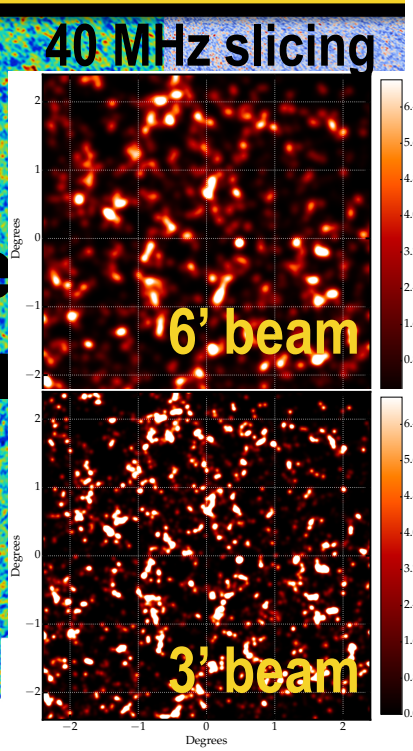
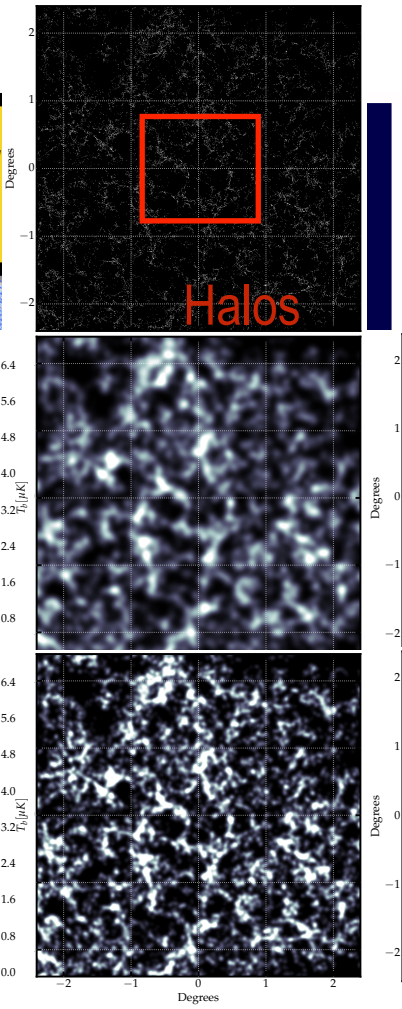




COMAP Survey Area



Planck, AdvACT, SO, CMB-S4, CCATp, EUCLID, LSST, CHIME, HIRAX, SKA, COMAP, …

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$_{adsley}$ 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

russian version of the web

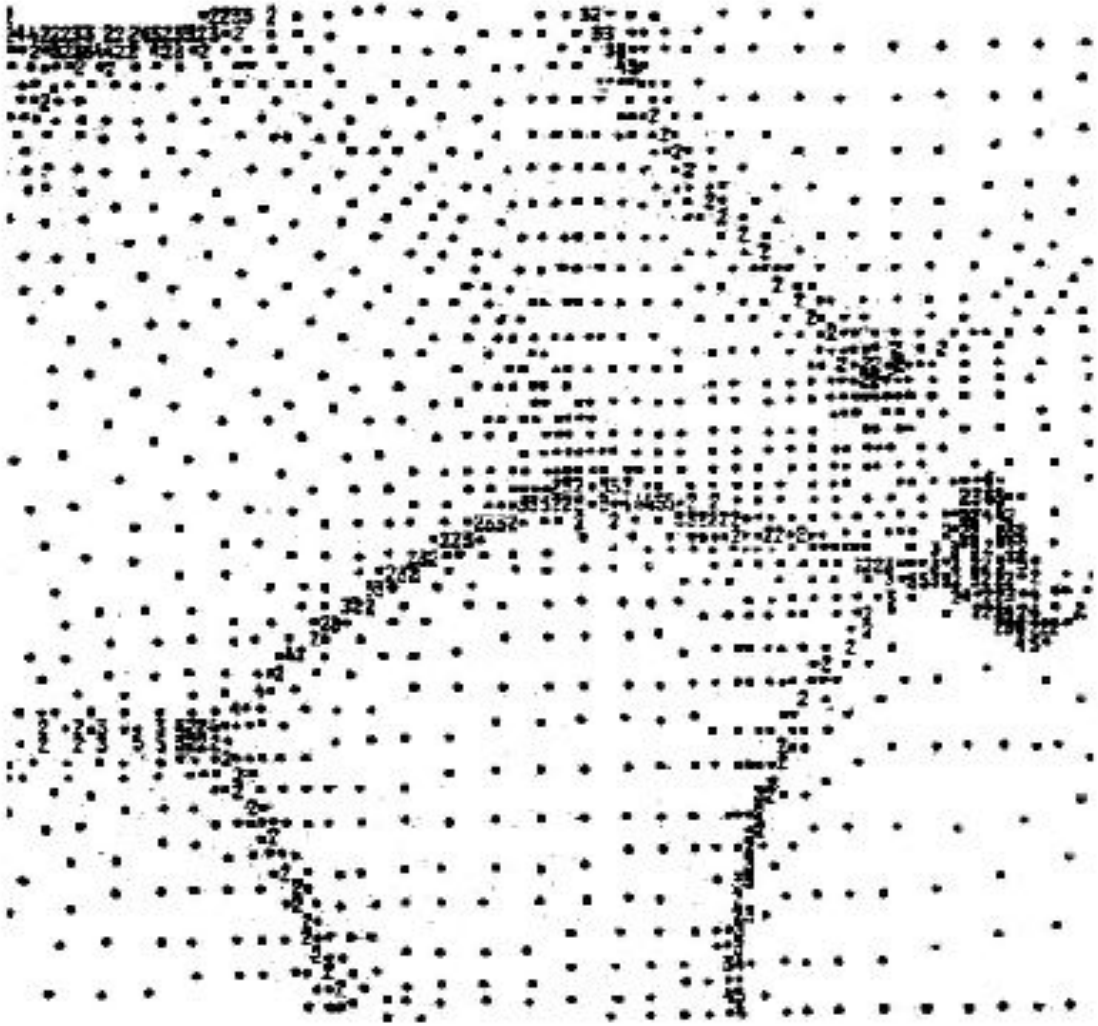
The first numerical simulation of the Zel'dovich (1LPT) Approximation - in 2D

Shandarin 1975

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

Later in Dorshkevich, Shandarin 1978

influential for Arnold, Shandarin Zeldovich 1982



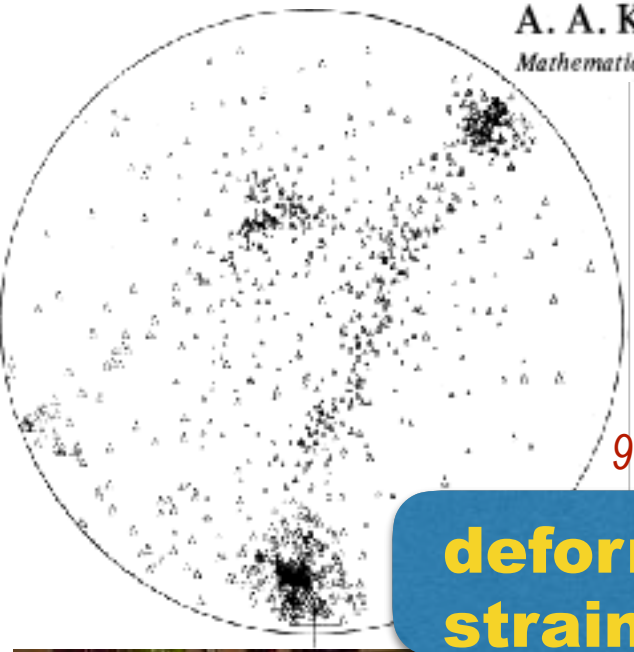
Made with alphanumeric printer

pancakes cf. BKP membranes

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

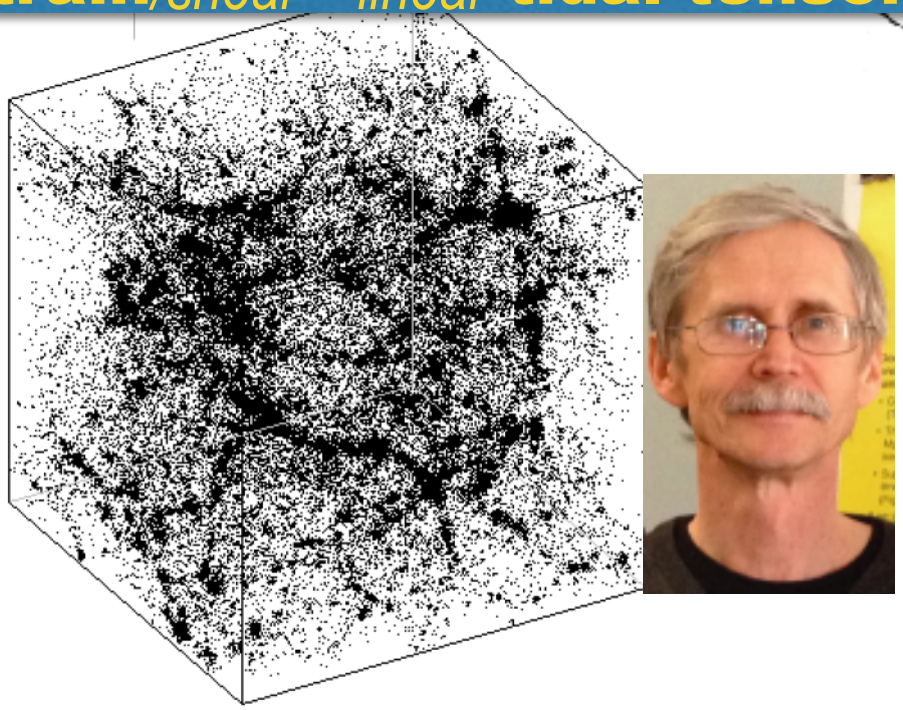


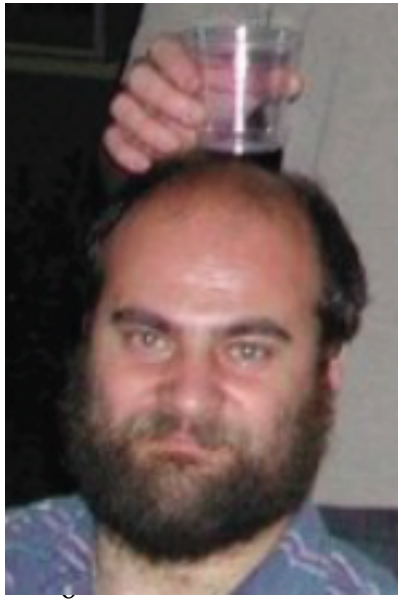
Klypin's vintage 82
160h^{-1}Mpc box 32^3 hDM

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

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

deformation tensor e_J^j
strain/*shear ~ linear* **tidal tensor**





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

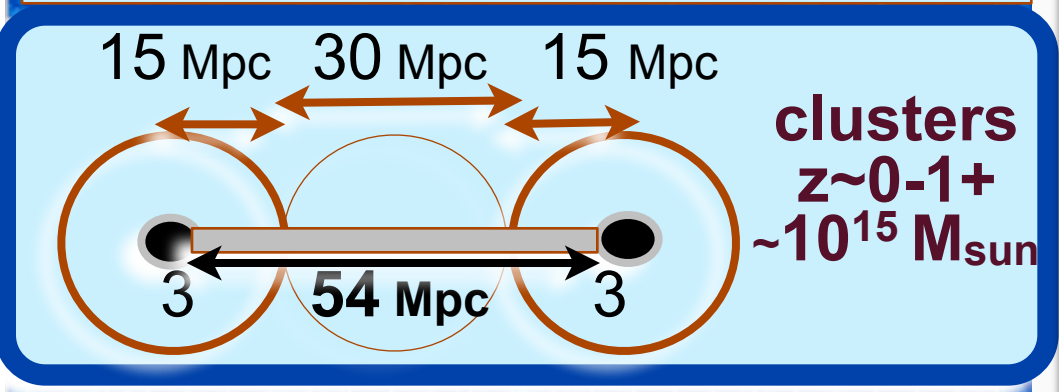
The Cosmic Web

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 (->2LPT+) flows of Lagrangian peak-patches agree with N-body Eulerian halo simulations => fast mock surveys



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

1 Mpc
2 Mpc
3.6 Mpc
1 Mpc

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

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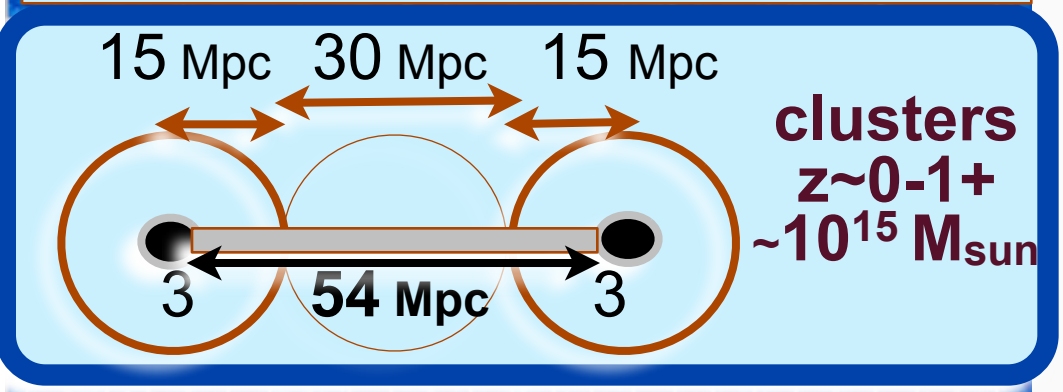
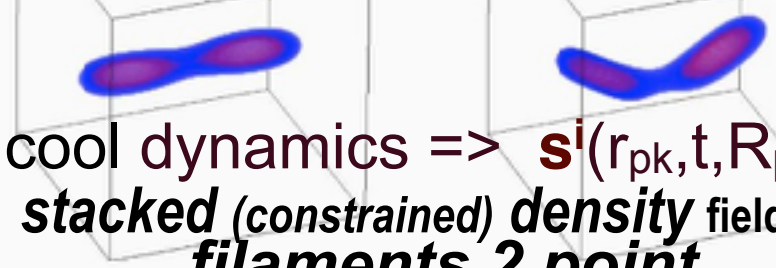


marriage of halos & Zeldovich

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

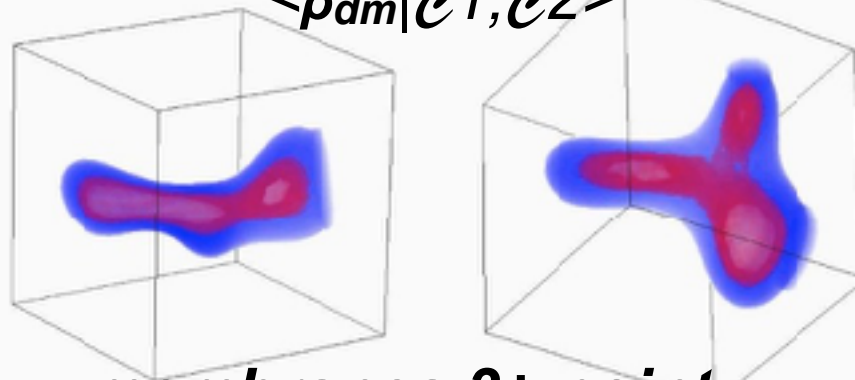


cool dynamics => $\mathbf{s}^i(r_{pk},t,R_{pk})$

stacked (constrained) density fields

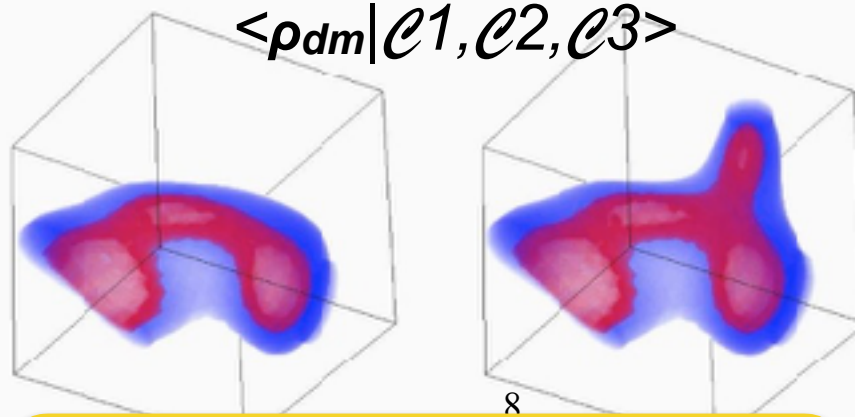
filaments 2 point

$\langle \rho_{dm} | \mathcal{C}1, \mathcal{C}2 \rangle$



membranes 3+ point

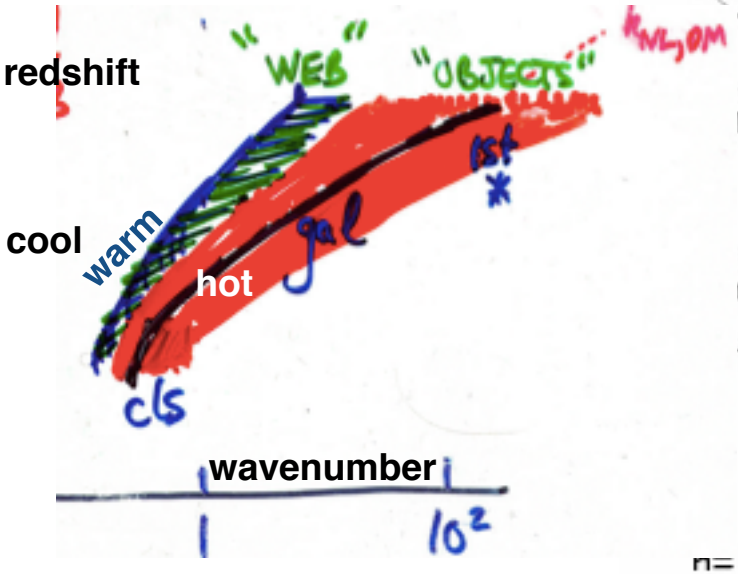
$\langle \rho_{dm} | \mathcal{C}1, \mathcal{C}2, \mathcal{C}3 \rangle$



1-point stack has better stats $\langle \rho_{dm} | \mathcal{C}1 \rangle$

Cosmic Web varies with initial density spectrum tilt

$d\sigma_{pL}^2/d\ln k \sim k^{(n_{eff}+3)}$



neff (k) *varies for 'standard' tilted* **Λ***CDM*

-1.3 cluster scale,

-2.3 galaxy scale,

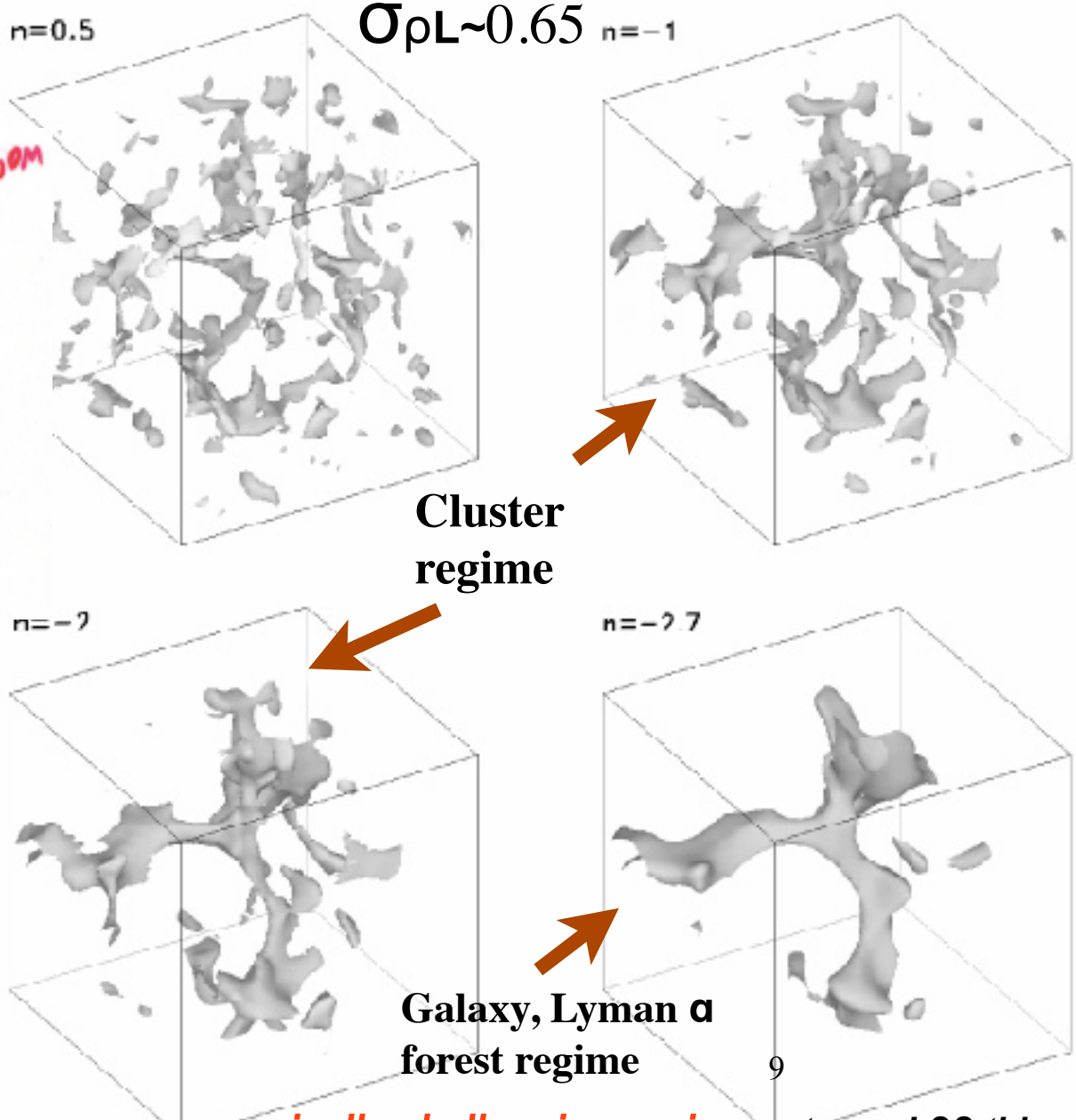
-2.8 Lyman α scale

-3.04 large k, 1st star

percolation threshold contour

smoothing

σ_{pL}~0.65



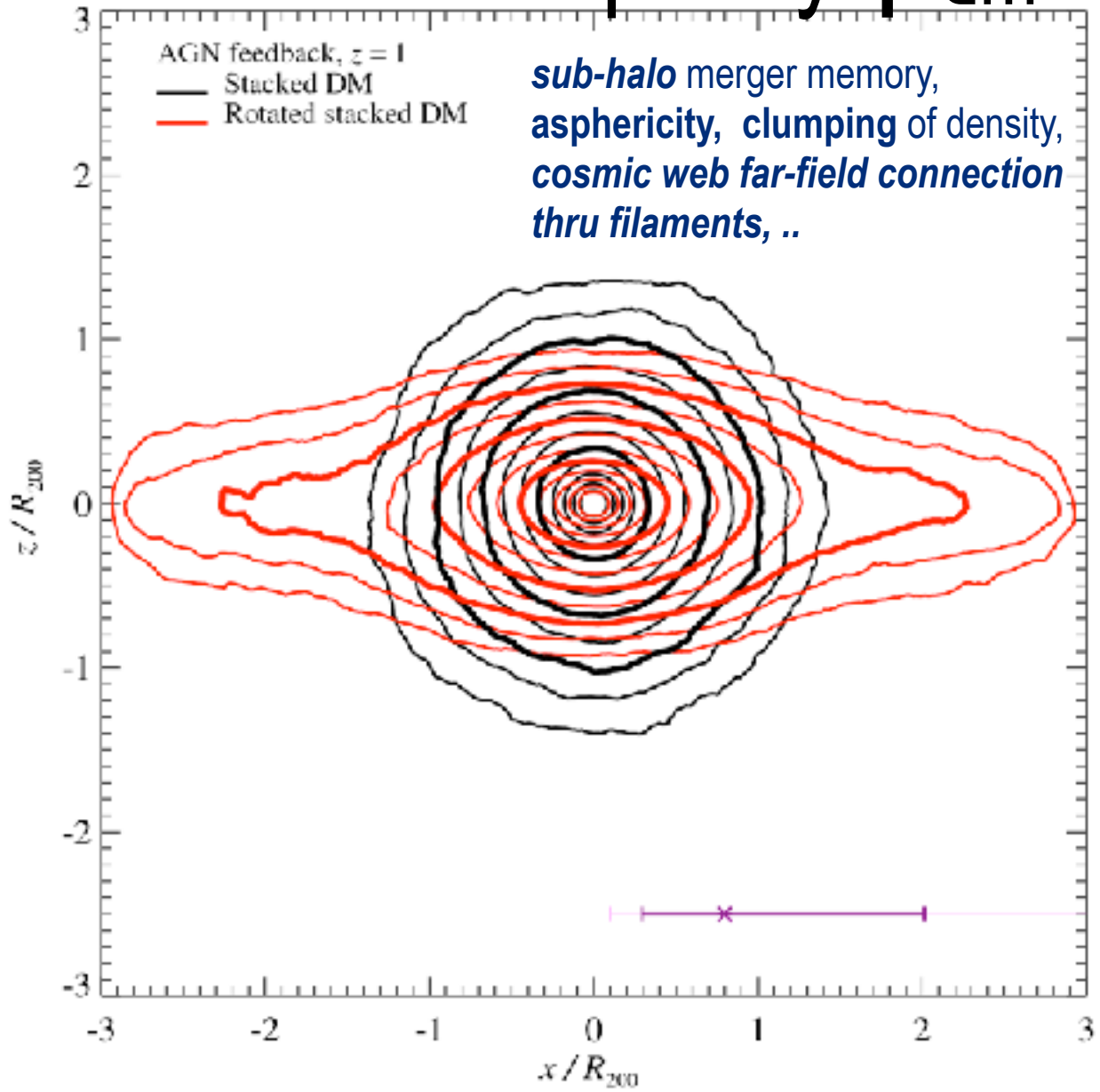
Cluster regime

Galaxy, Lyman α forest regime

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

Halos are Complex Systems

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

Battaglia, Bond, Pfrommer, Sievers 1,2,3,4 gasdynamical simulations with AGN feedback

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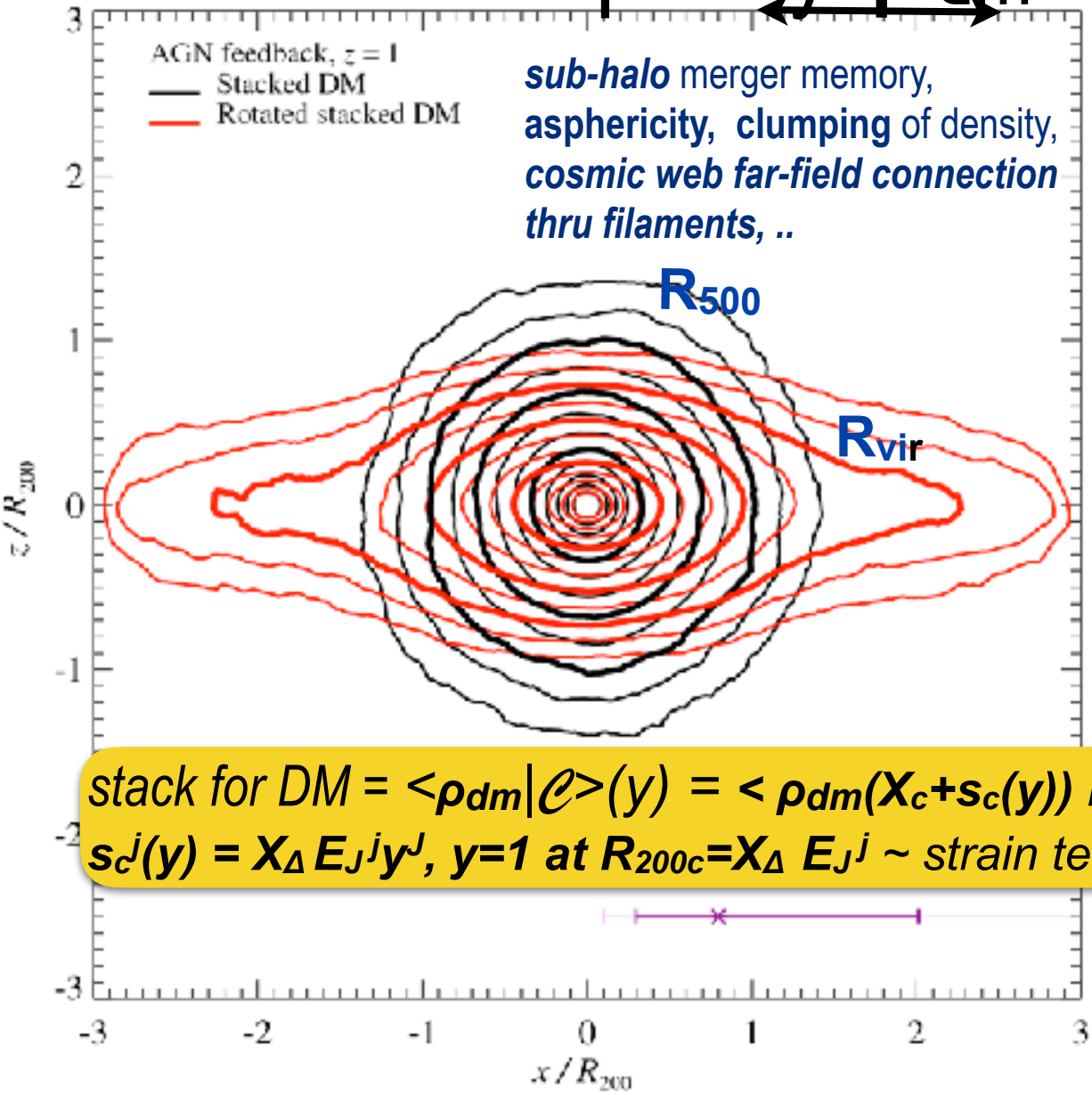

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stack for DM = $\langle \rho_{dm}|\mathscr{C}\rangle(y) = \langle \rho_{dm}(X_c+s_c(y))\, n_{\mathscr{C}}(X_c)\rangle / \langle n_{\mathscr{C}}(X_c)\rangle$,

$s_c^j(y) = X_\Delta E_J{}^j y^J$, $y=1$ at $R_{200c}=X_\Delta E_J{}^j$ ~ *strain tensor ~ (quadrupole tensor)*$^{-1}$

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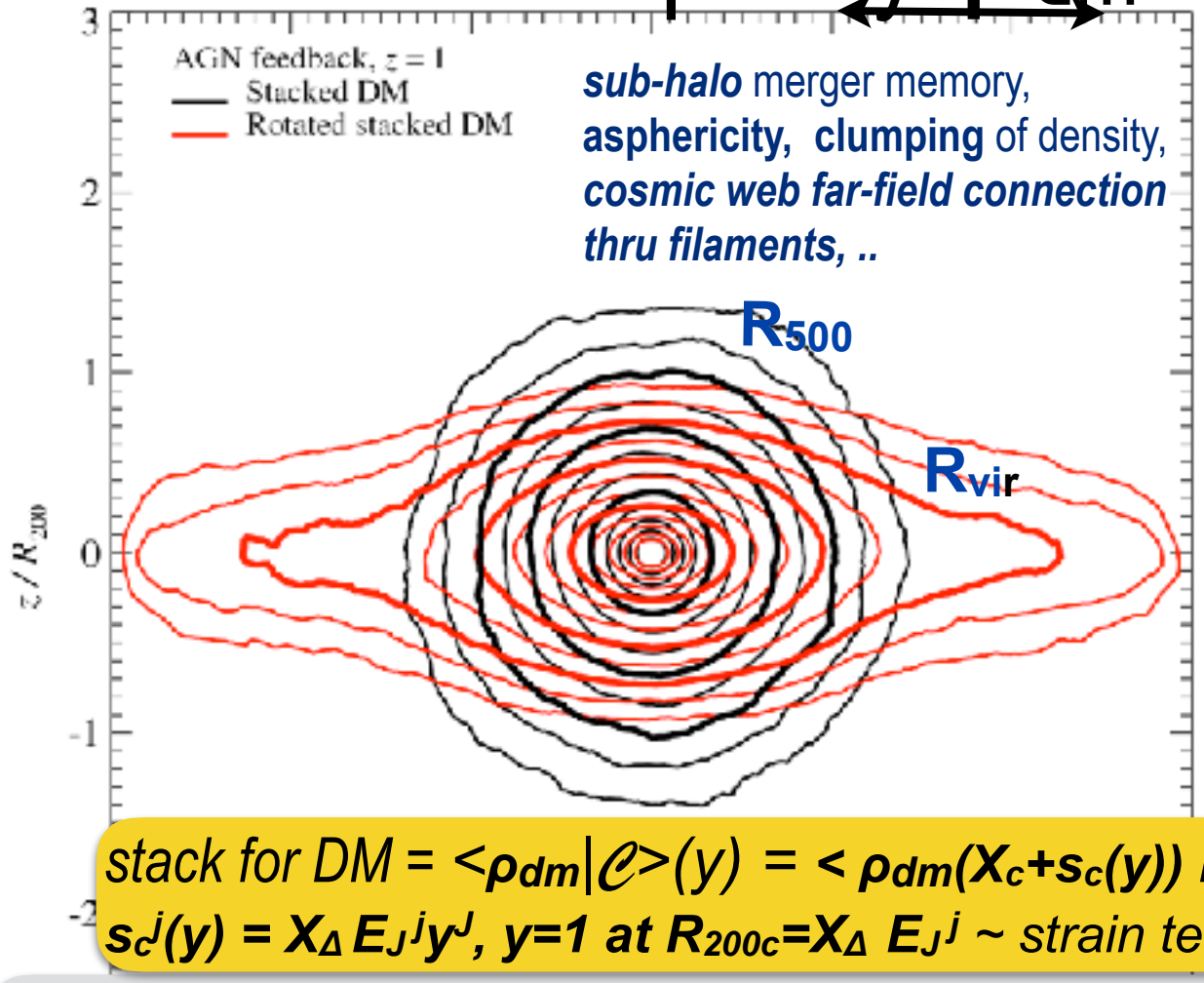

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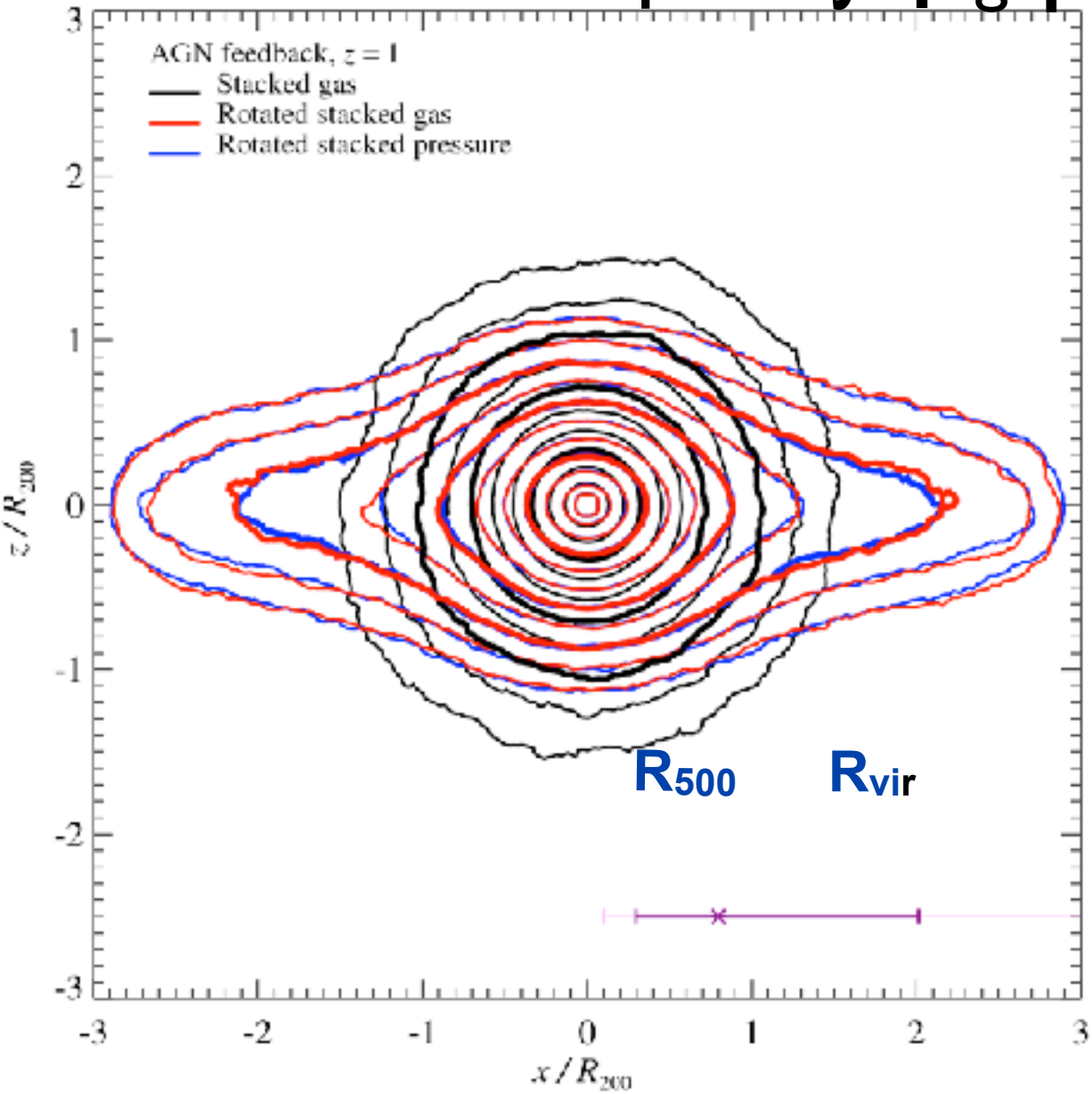
$\chi_{dm,c}$ *susceptibility(dm* $\mathscr{C}1$*)(y)=*$\langle [\rho_{dm}(X_c+s_c(y))/\rho_{\Delta c}]\, n_{\mathscr{C}}(X_c)\rangle \langle n_{\mathscr{C}}(X_c) n_{\mathscr{C}1}(X_{c1})\rangle^{-1}$

$\rho_{dm}(x)=\sum_c \chi_{dm,c}(x-x_c,R_{Ec}) M_{dm,c} \delta N_c(x_c,R_{Ec})$ *+inside/outside fluctuations*

Halo X-corr Ellipticity ρ_g ρ_g z=1



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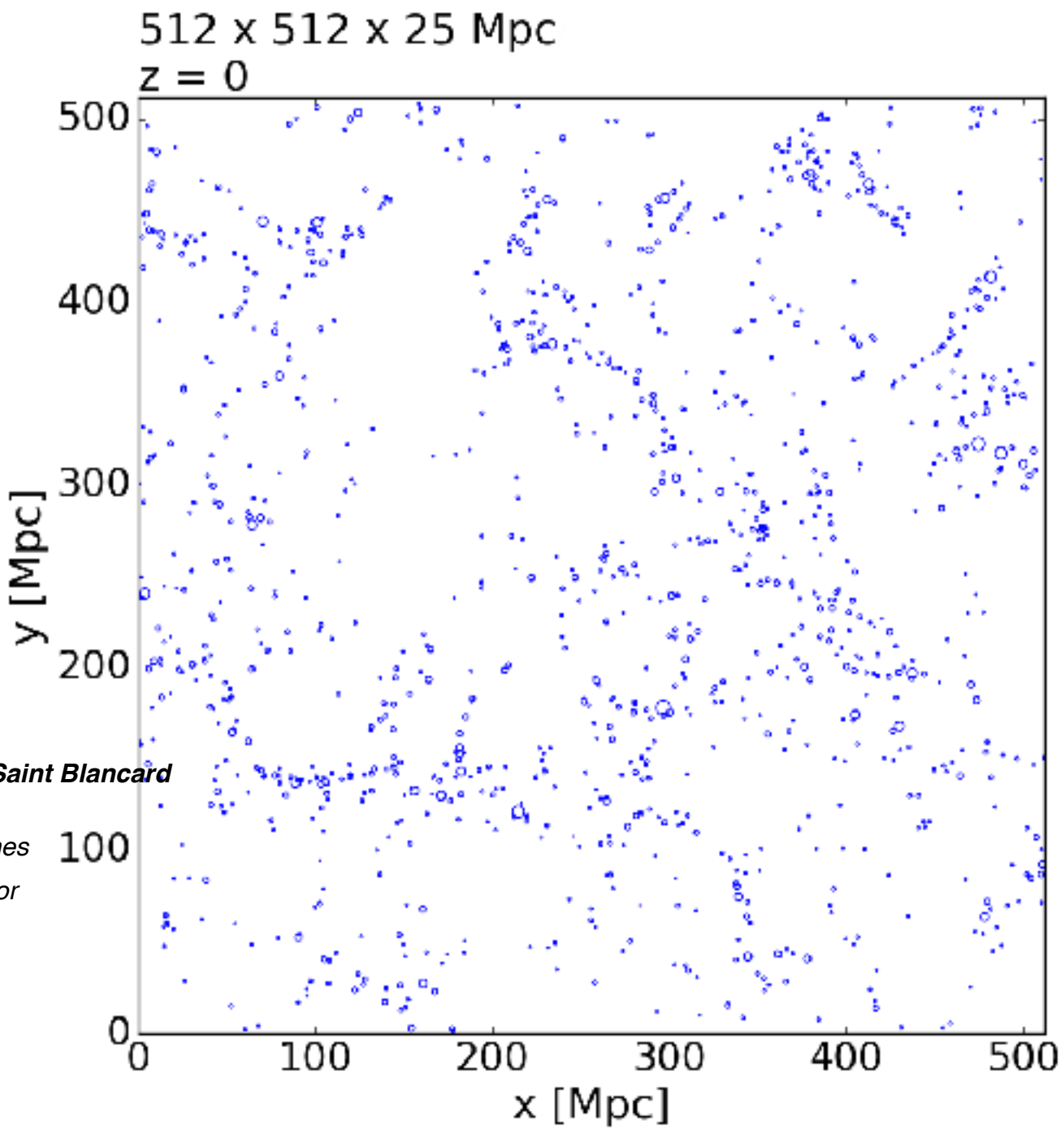
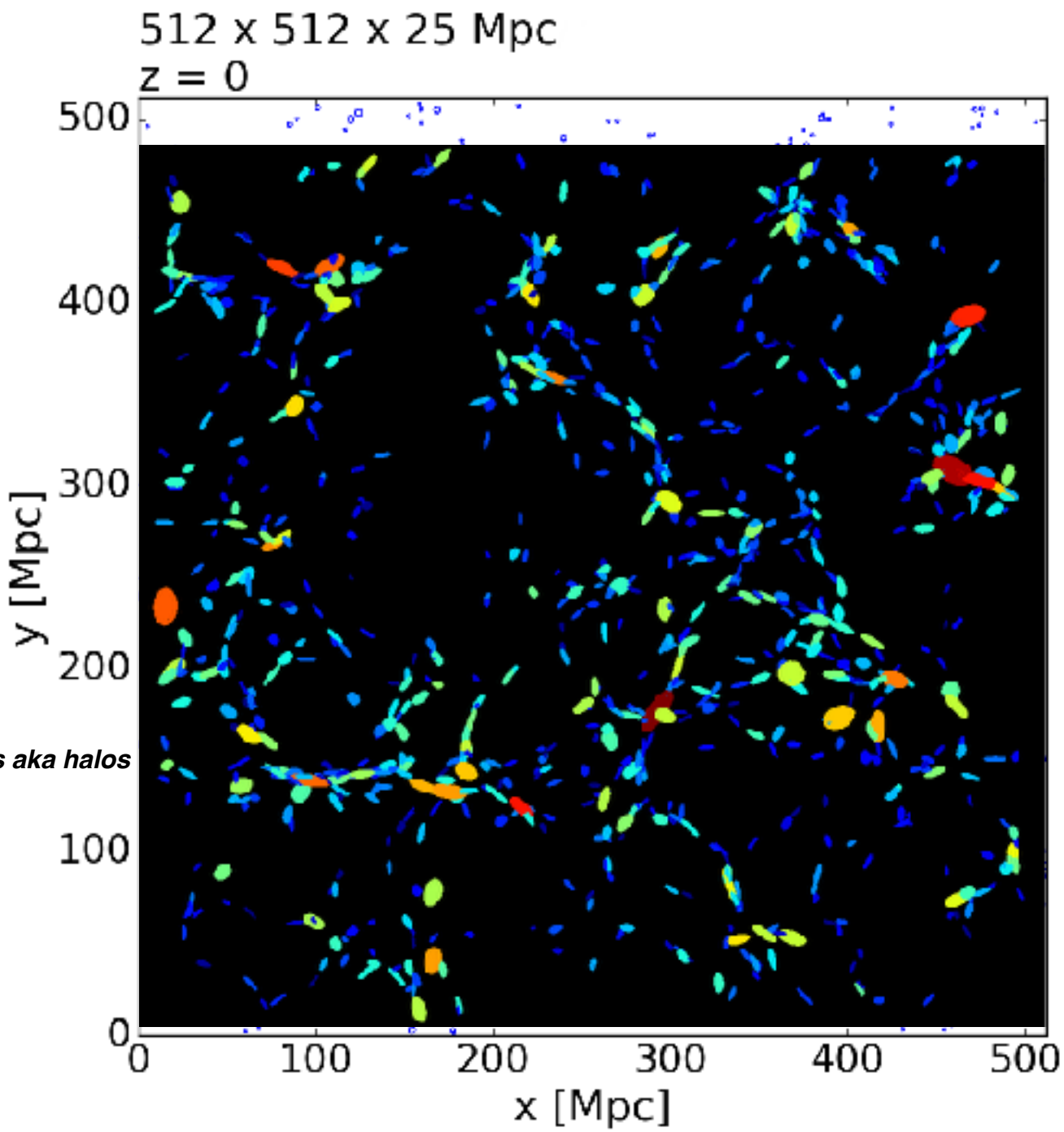


Alvarez, Bond, Stein, Codis +
Connor Bevington, Bruno Régaldo-Saint Blancard

the cluster class $\mathscr{C}$ *for the peak patches*

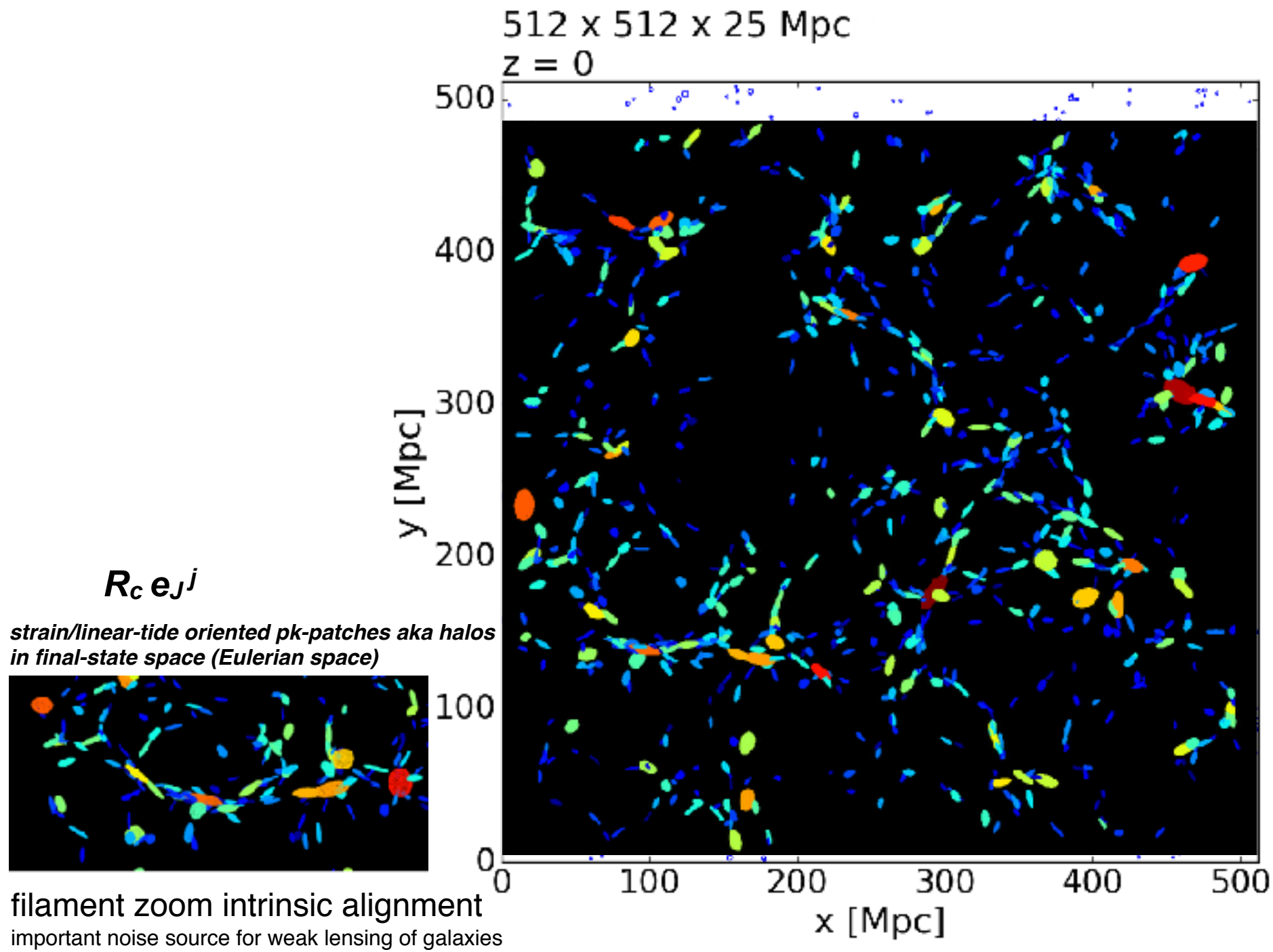
can orient according to the strain tensor (ellipsoidal symmetry) and can also have a direction (pk patch flow)

simulation examples



$R_c\, e_J{}^j$

strain/linear-tide oriented pk-patches aka halos in final-state space (Eulerian space)

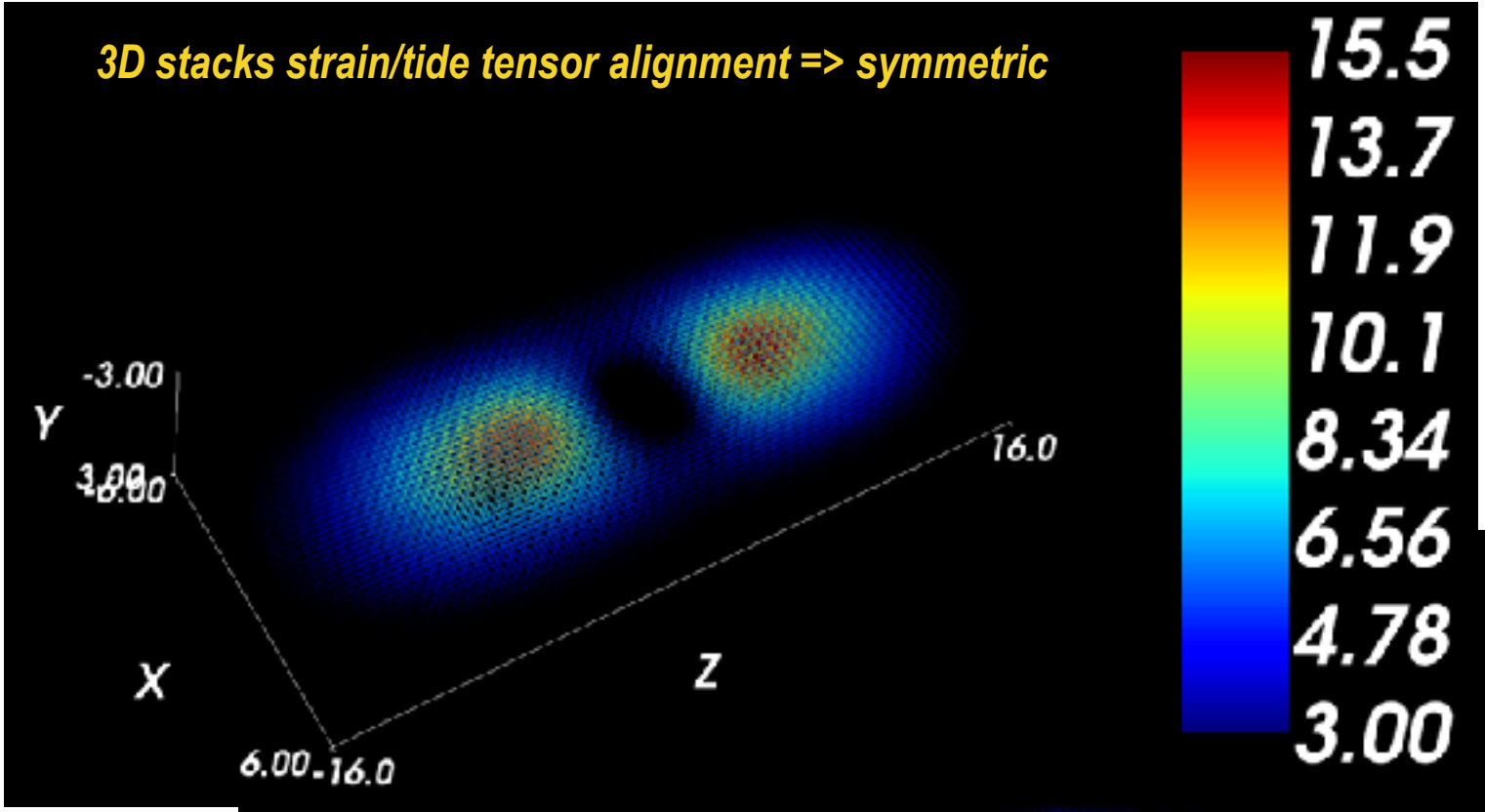


$R_c\, e_J{}^j$

strain/linear-tide oriented pk-patches aka halos in final-state space (Eulerian space)

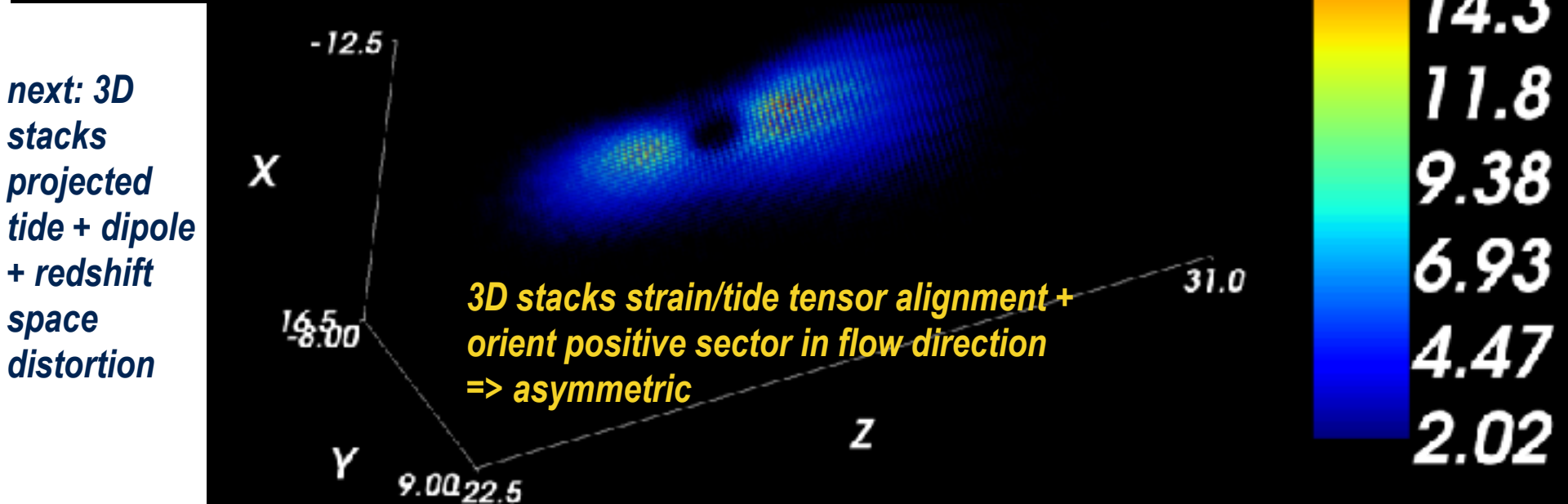
filament zoom intrinsic alignment

important noise source for weak lensing of galaxies



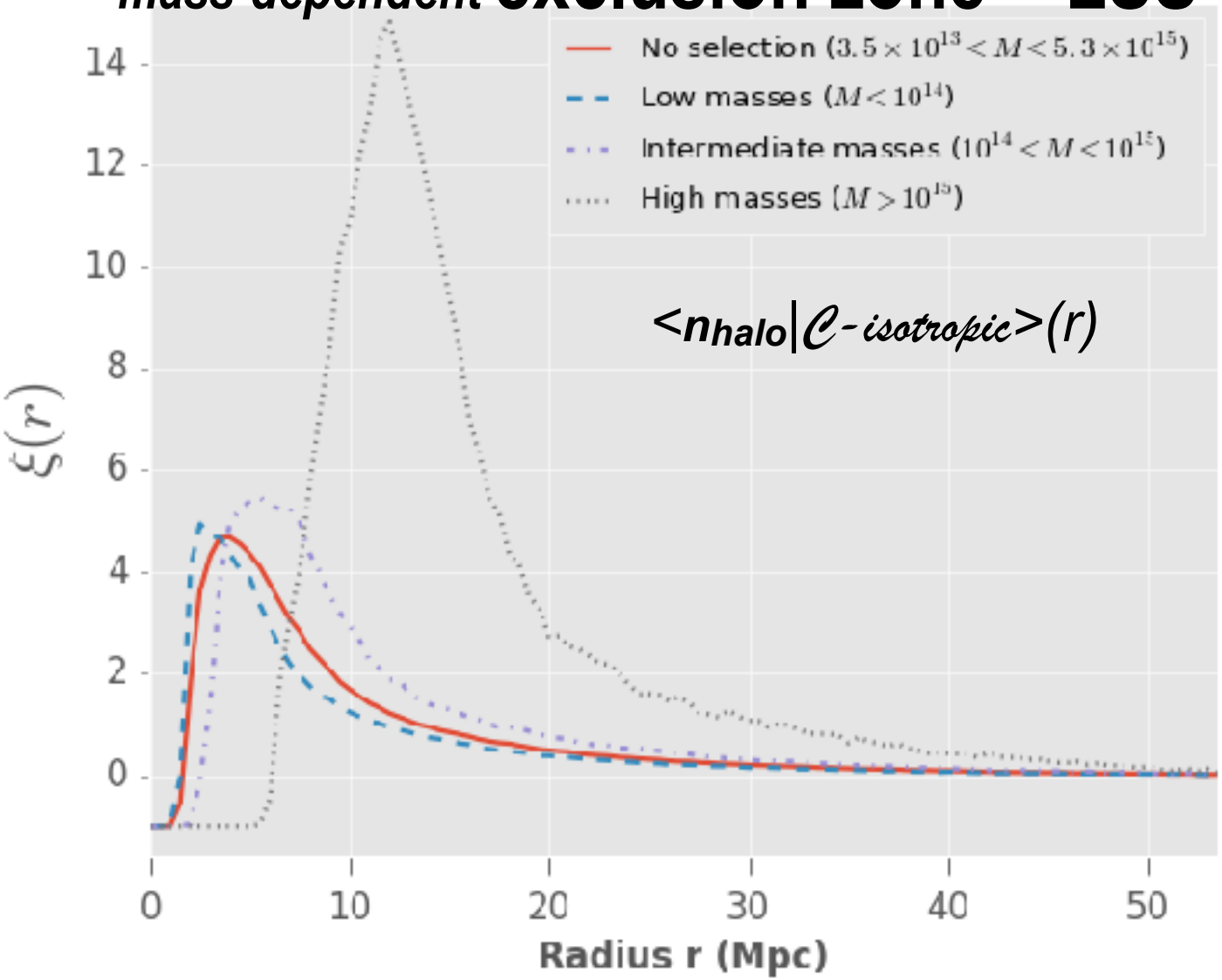
$\langle n_{halo} | \mathcal{C} \rangle (y)$

$s_c^j(y) = R_c \, e_J{}^j y^J$



next: 3D stacks projected tide + dipole + redshift space distortion

Halo Correlations: 1-halo self-correlation + *mass-dependent* exclusion zone + LSS biasing



$\langle n_{halo} | \mathcal{C}\text{-isotropic} \rangle (r)$

& decompose oriented stacked correlations into spherical harmonics

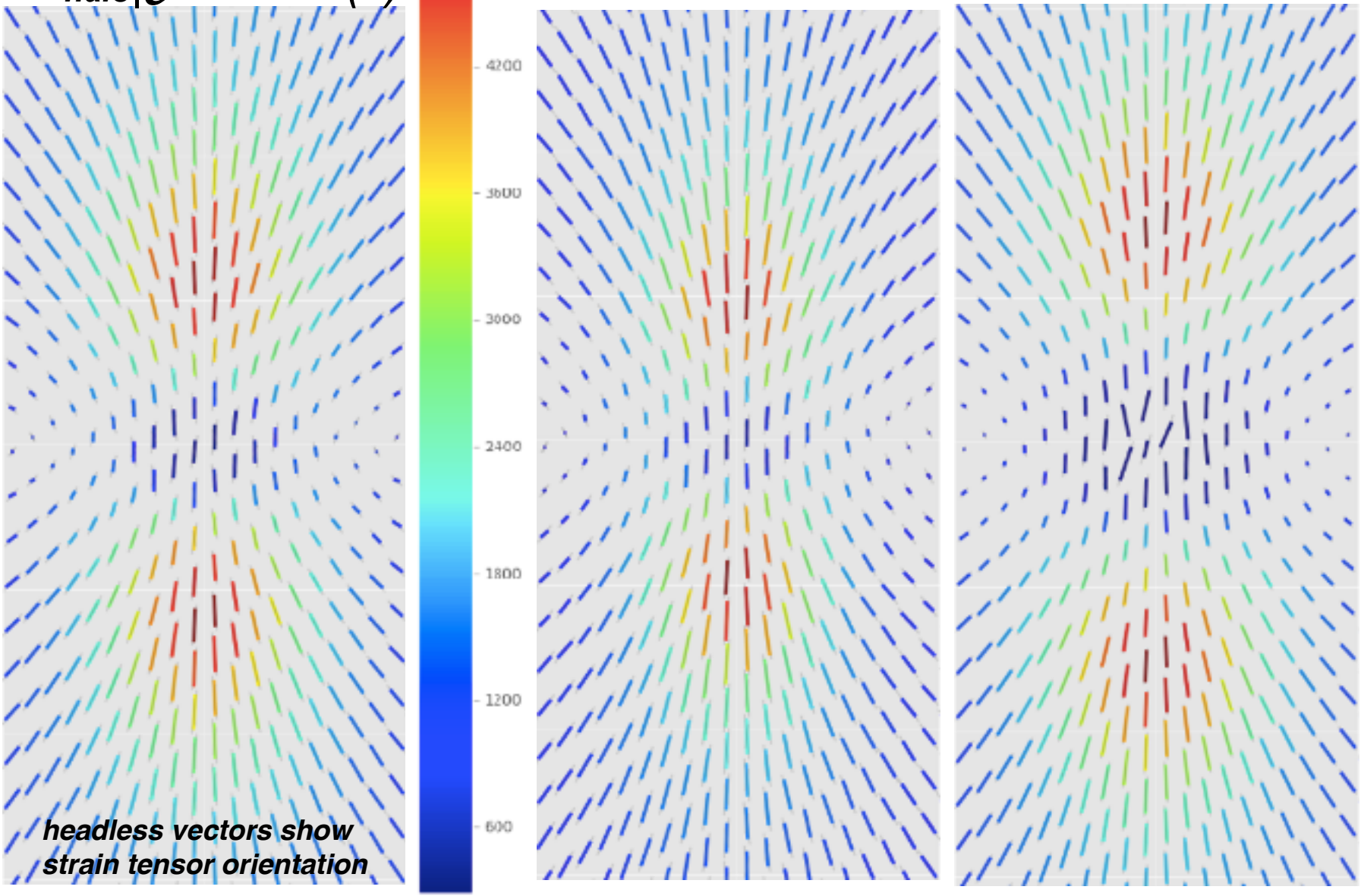
Projected-strain/tide 2D stacks

10Mpc X 30Mpc all masses

$\langle n_{halo} | \mathcal{C}\text{-oriented} \rangle (X)$

< 10^14 Msun

10^14 - 10^15 Msun



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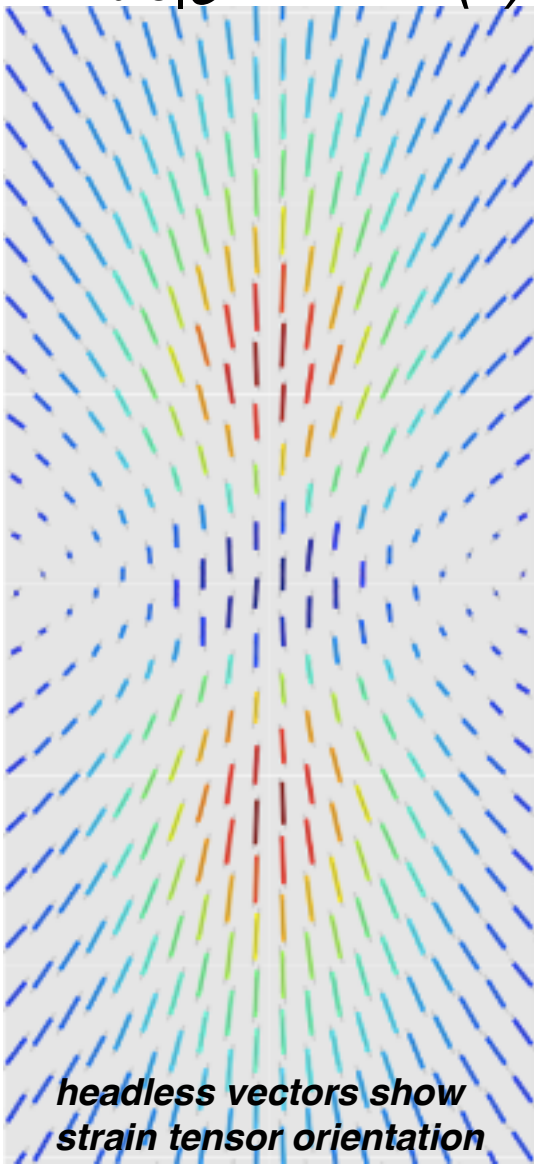
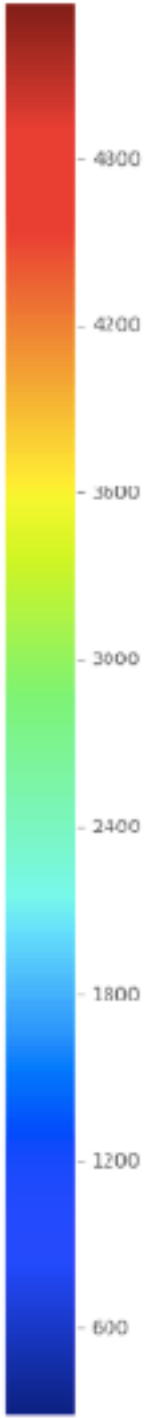
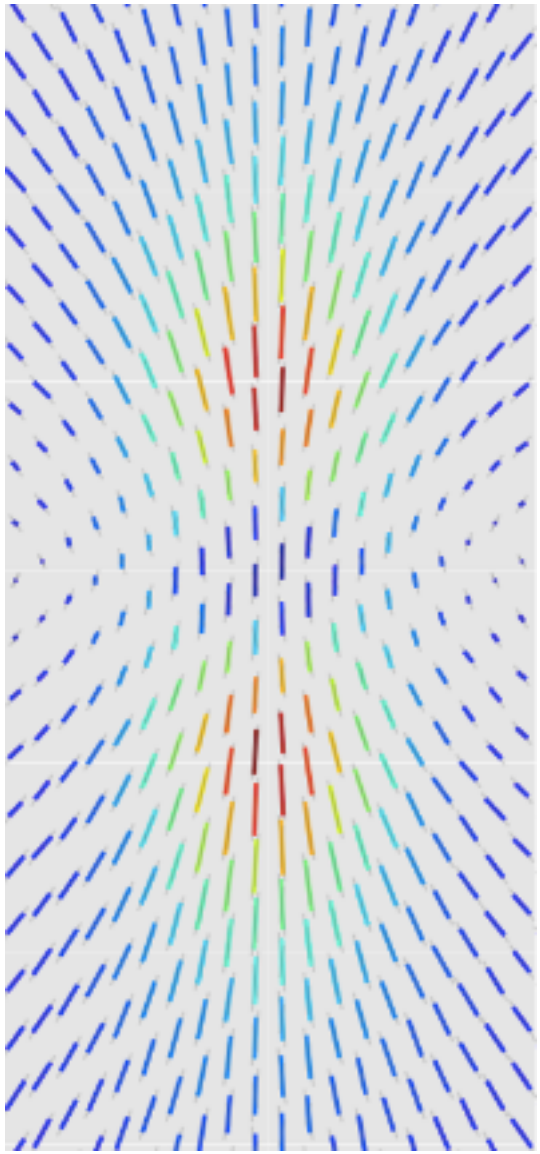




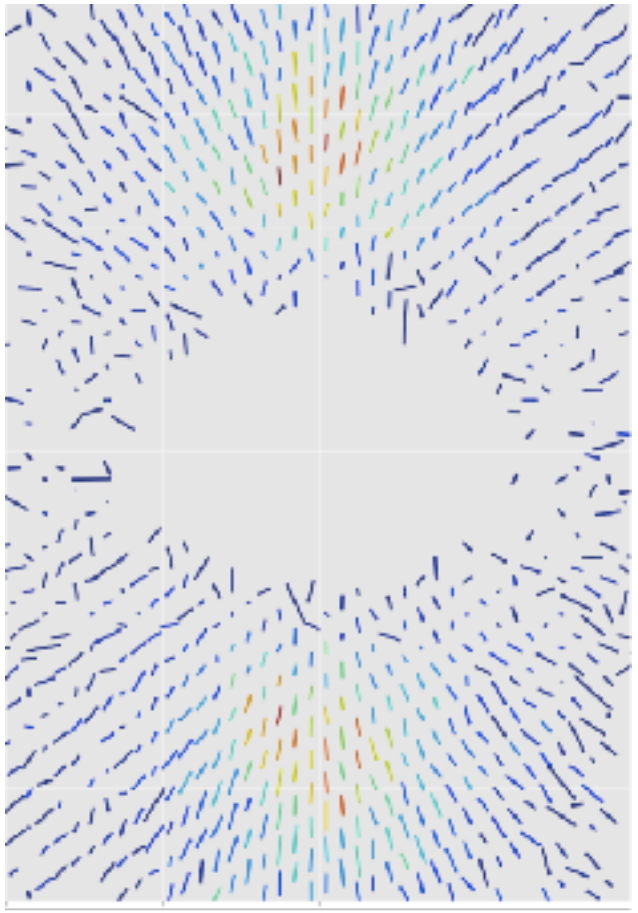
headless vectors show strain tensor orientation

< 10^14 Msun



> 10^15 Msun

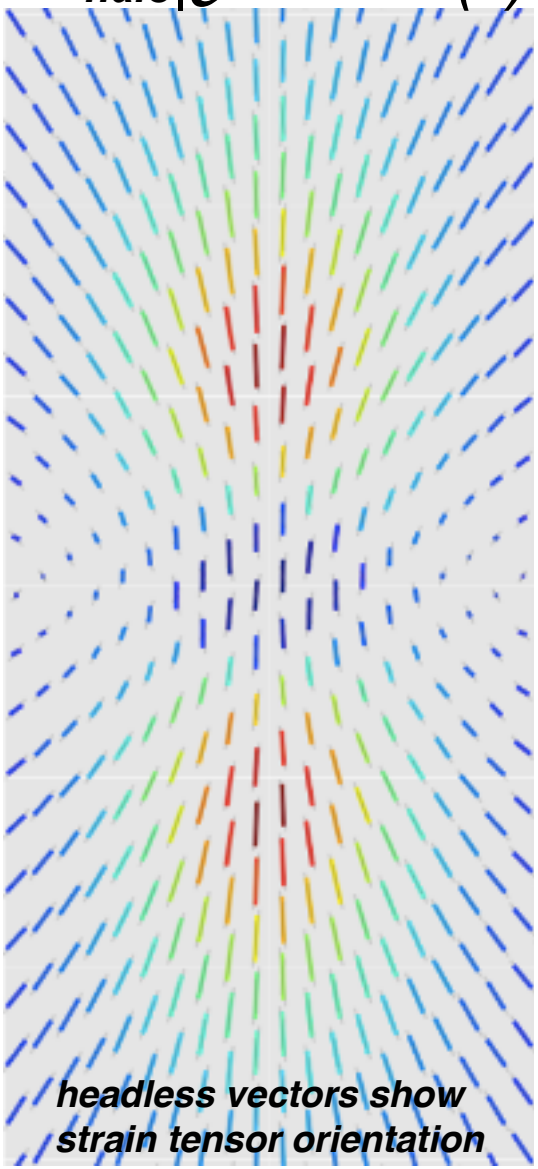
20Mpc X 40Mpc

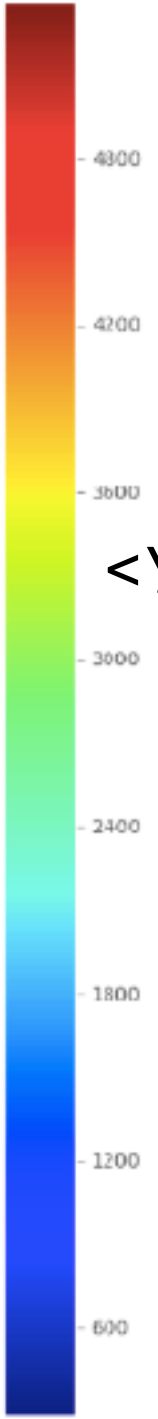


Projected-strain/tide 2D stacks, perfect resolution tSZ weighting

10Mpc X 30Mpc all masses

$\langle n_{halo} | \mathcal{C}\text{-oriented} \rangle (x)$

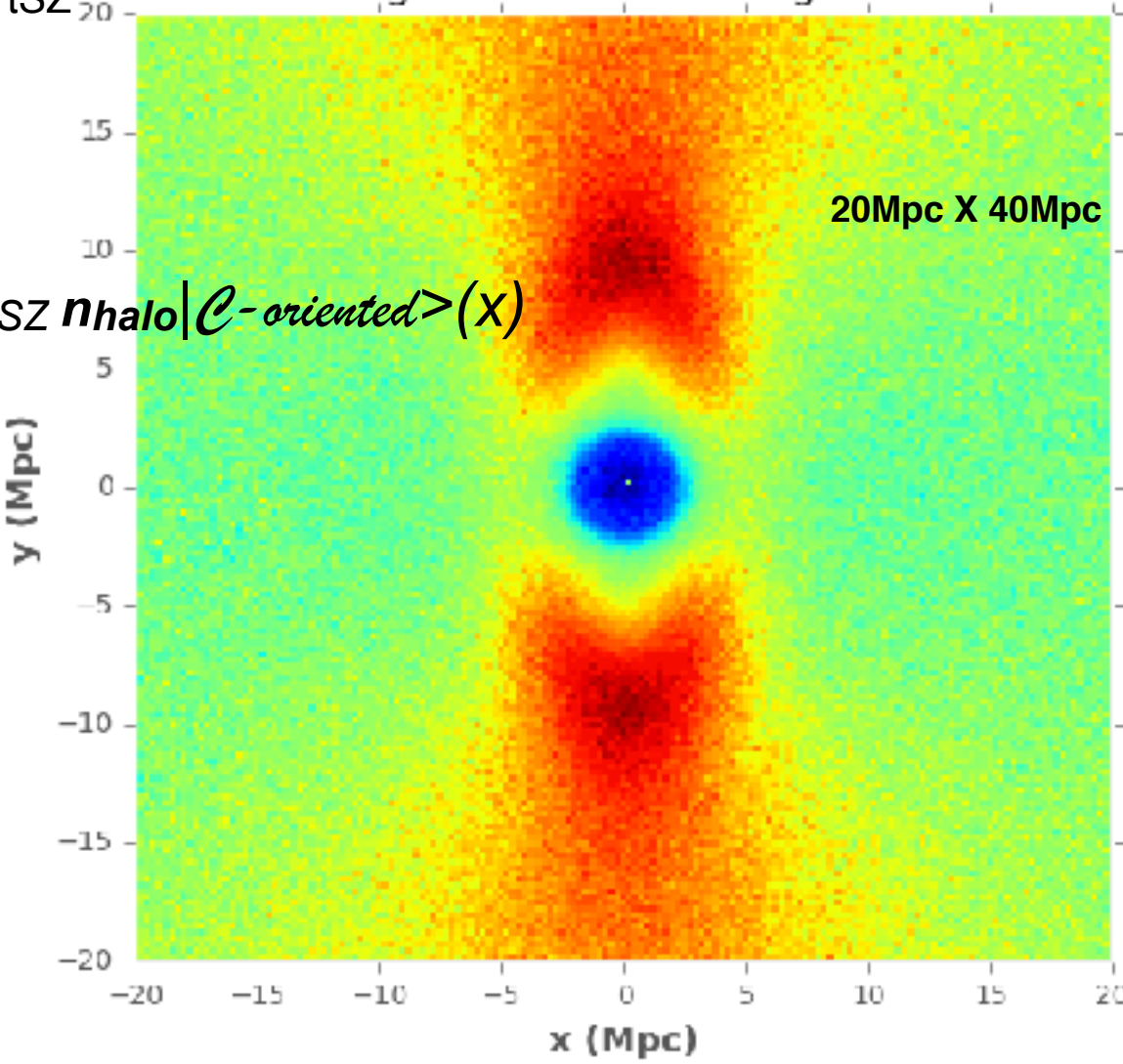


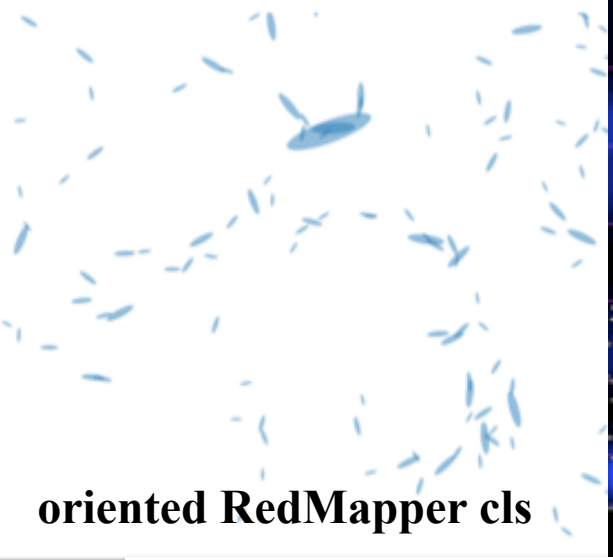


$Y_{tSZ} \sim M^{5/3}$ stacking. Median values. Logarithmic scale.

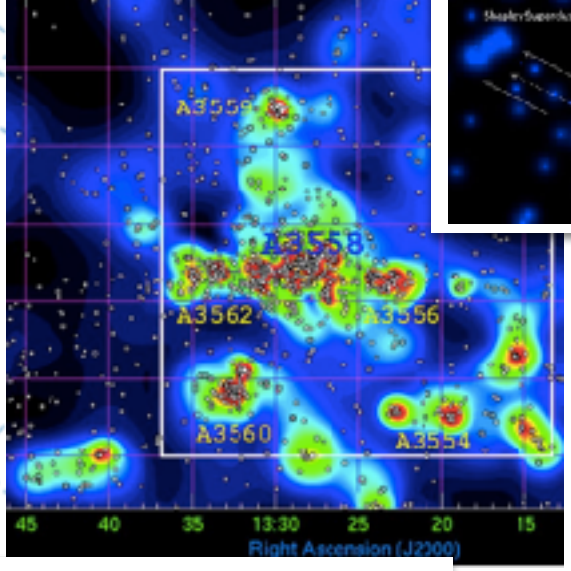
20Mpc X 40Mpc

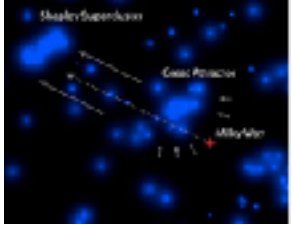
$\langle Y_{tSZ}\, n_{halo} | \mathcal{C}\text{-oriented} \rangle (x)$

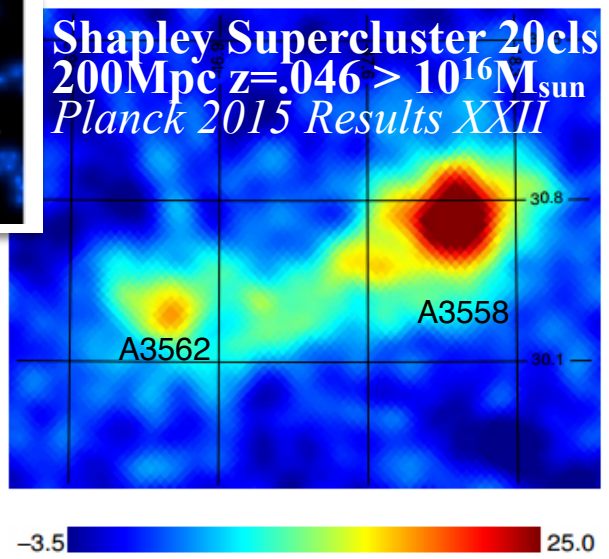




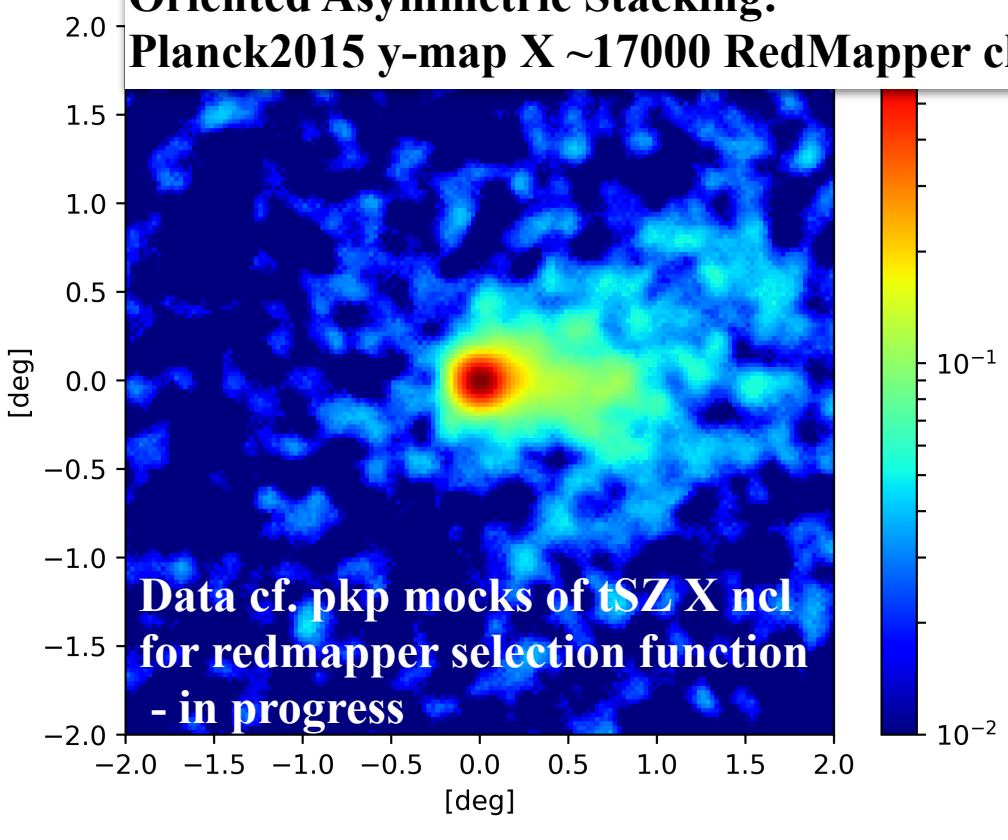
oriented RedMapper cls





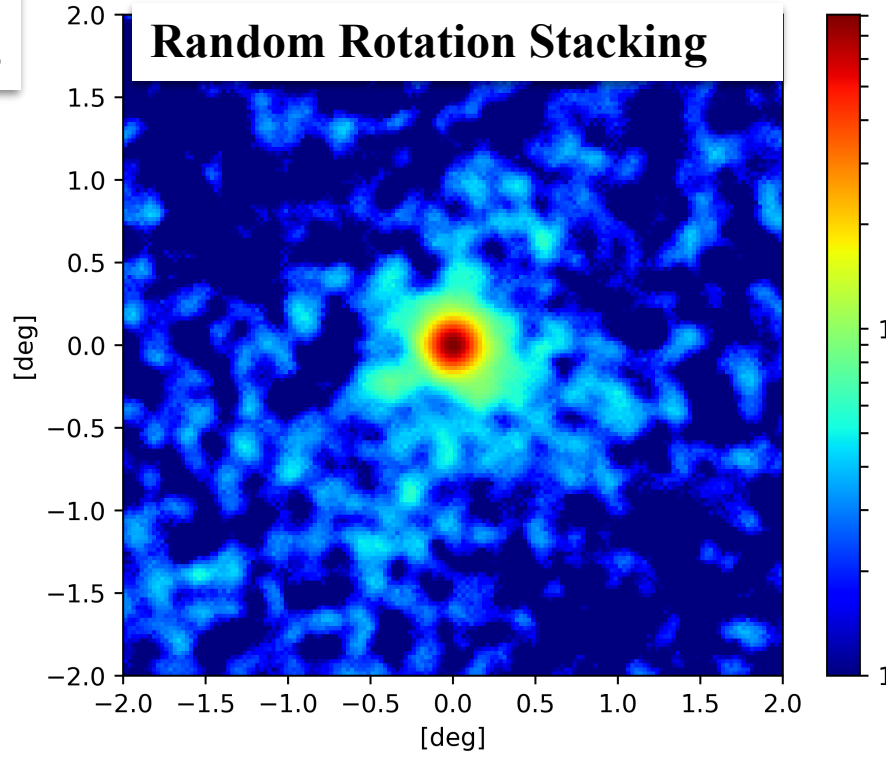


Oriented Asymmetric Stacking:
Planck2015 y-map X ~17000 RedMapper cls



Data cf. pkp mocks of tSZ X ncl for redmapper selection function - in progress

Random Rotation Stacking



pp+ ***for coarse-grained mapping of the cosmic web:***

fast halo finding for ensembles & BSMc - *works well BM, ABS+ tsts, Euclid tst*

halo interiors: measured mean-field stacked susceptibilities

2LPT for fluctuations external to halos (& unresolved biased halo-field)

"mocking heaven" apps: **tSZ, CIB, kSZ** *original CMB motivation => tSZxCIB*, **Lens**

optical galaxies **via HOD for CMASS, Euclid, LSST, .. DES, HSC, sphereX**

Line intensity mapping **of HI (CHIME, HIREX, ..,SKA) COmap, CII CCATp**

well suited: **to cross-correlation studies of all sorts**

well suited: **to characterize correlated/non-Gaussian errors**

well suited: **light cones** *automatic, no interpolation*

Physics: *beyond Lambda:* dynamical DarkEnergy, modified gravity

LSS *non-Gaussianity:* perturbative, intermittent, scale-dependent bias

CITA mini-industry: Marcelo Alvarez, Dick Bond, George Stein & Battaglia, Codis, van Engelen & FIRE: Lakhlani + Murray + Hopkins + Berger & Connor Bevington, Bruno Régaldo-Saint Blancard, Ronan Kerr, Louis Pham

much more TBD on generalized stacking:

how to measure strain/tide etc. analogues to orient, scale & symmetry-break in final state (Eulerian/observed) space?

use a coarse-grained tide & gravitational acceleration?

if no dynamical info, use halo/galaxy number density field e.g.,

$\Phi_{Nij} \sim \nabla_i \nabla_j \nabla^{-2} \sum_c M_c n_c \quad g_{Pi} \sim -\nabla_j \nabla^{-2} \sum_c M_c n_c \quad \psi_{Sij} \sim \nabla_i \nabla_j \nabla^{-2} ln \sum_c M_c n_c$

or mass-quadrupole/dipole tensors or … whatever works

stack on other non-peak point processes e.g., saddle points

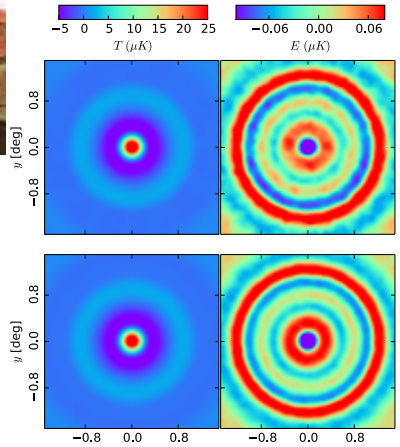
Topography of the y-web, n_{gal} -web, Φ_N -web, CMB Web, ISM Web, IQU/ E B, early Universe ζ = ln a(x,t) -web related to $\Phi_N \sim -3/5(D(t)/a(t))$ ln a(x,t) if linear

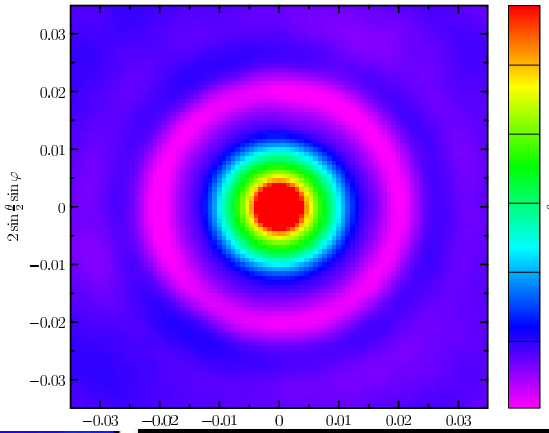
B+ Zhiqi Huang CITA => prof @SunYatSen U one of the thousand talents

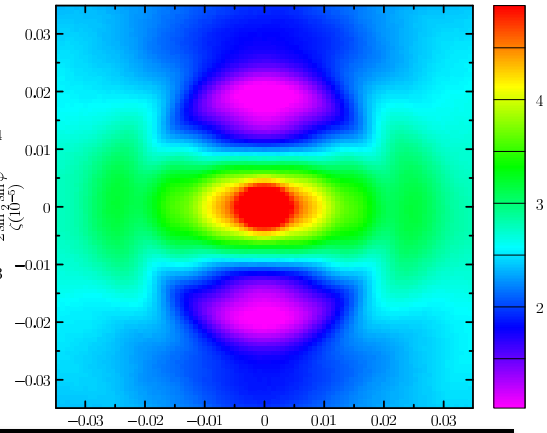
Topography of the CMB Web, ISM Web, y-web, IQU/ E B

oriented/symmetry-broken stacking on field points peaks saddles (cols, passes)

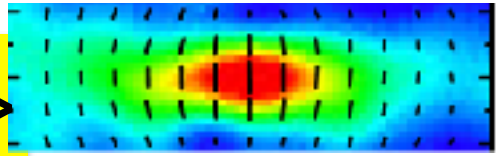
Louis+16
ACTPol *stack*
<T,E,B|T-field>







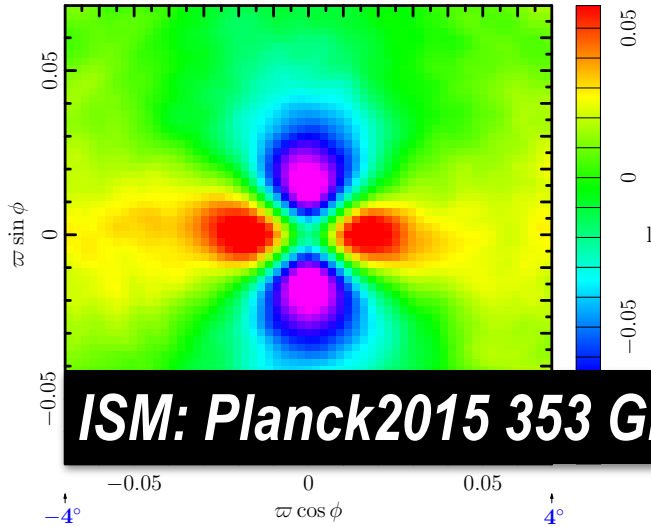
<Qr |oriented l-pk>

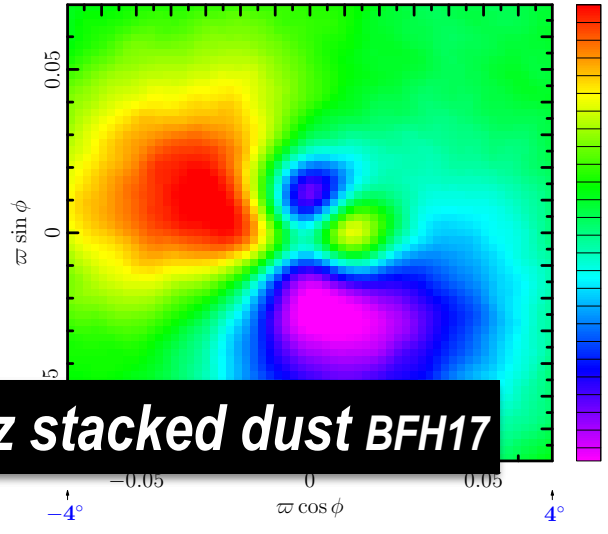


stacked on 7779 cols, Hessian oriented

earlyU SuperWeb map Planck2015 XVII
stacked ζ-map | ζ-pk TQU> BFH17

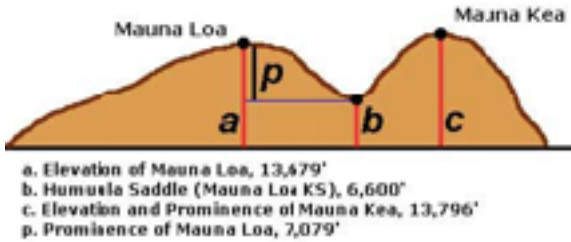
stacked on 7779 cols, Hessian oriented





ISM: Planck2015 353 GHz stacked dust BFH17

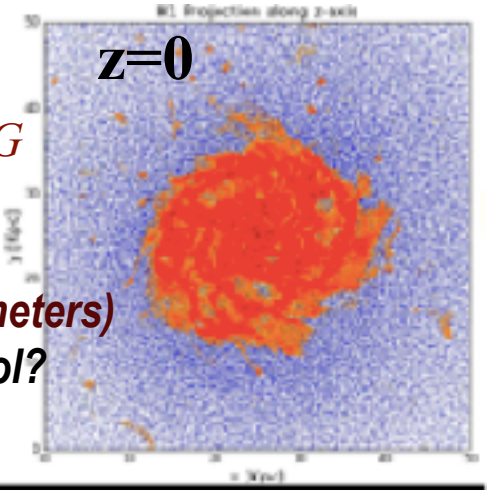
stacked + Hessian
+ direction info
<ln I | l-saddle
broken symm>



pp modus-operandi measure response functions to stimuli= susceptibilities

fluctuations inside controlled? outside 2LPT and subgrid halos adequate?

tSZ, kSZ ***in pp-control*** BBSP sims, PUPPY;



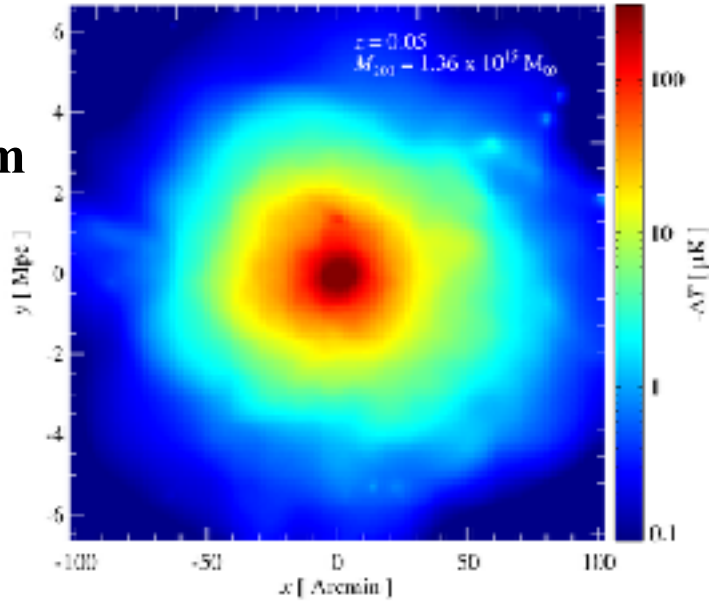
CO, HI, CIB via FIRE sims *ABS+Lakhkani+Murray+Ronan Kerr UG*

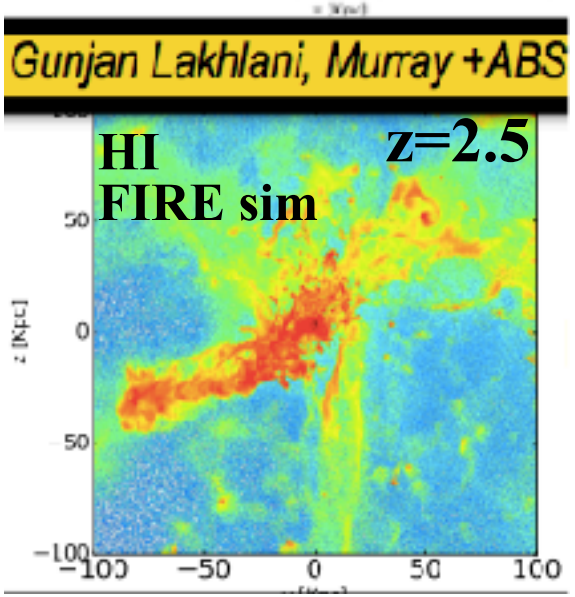
importance sampling: probabilistic control over an ensemble of sims constrained initial conditions via mean-fields + fluctuations or via zoom:

Prob(CO etal) = int Prob(CO etal| control parameters) dProb (control parameters)

galaxy assembly = out of control? e.g. CO ~ dM*/dt, how to FIRE-sim-control?

tSZ
BBPS sim





Lensing of CMB, CIB & LIM & cls underway *ABS+ LouisPham UG +van Engelen*

why do LIMLAM? just understand galactic weather / storms

theorist hope: component-separate gastrophysics to reveal fundamental BSMc physics

e.g., use LSS to further develop the map of the early universe from CMB ***(stacked)***

END