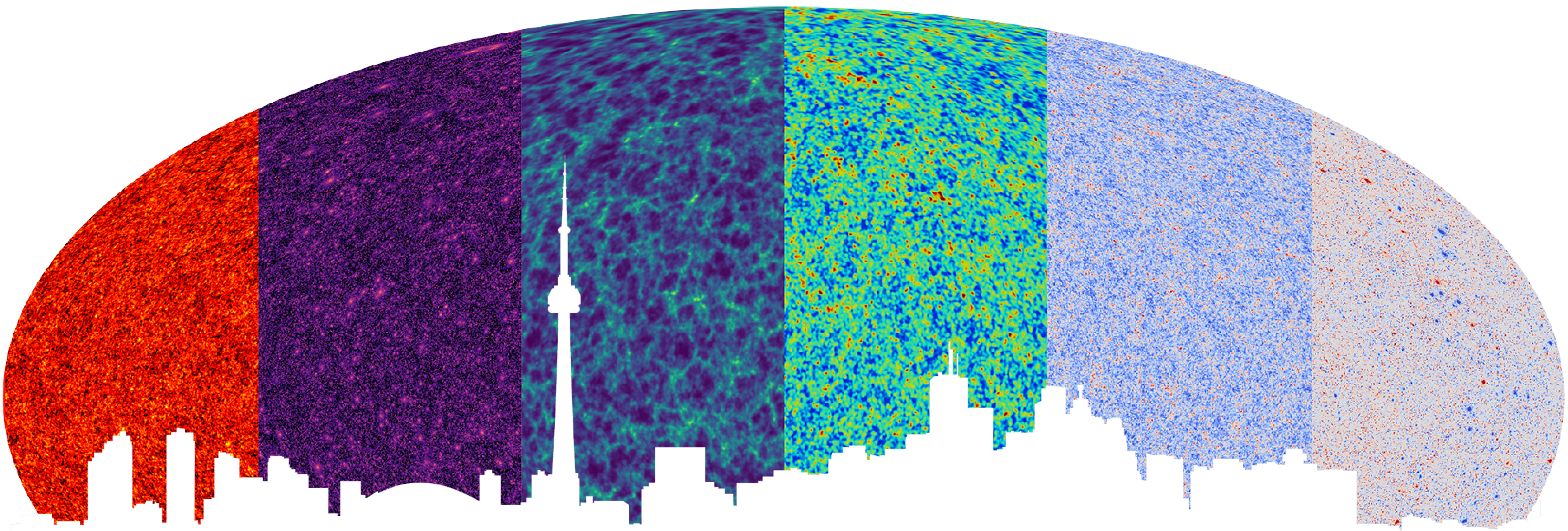
Covariance Estimation & Sky Maps with the Peak Patch Approach

George Stein, Dick Bond, Marcelo Alvarez, Sandrine Codis,
Alex van Engelen, Nick Battaglia, Phil Berger



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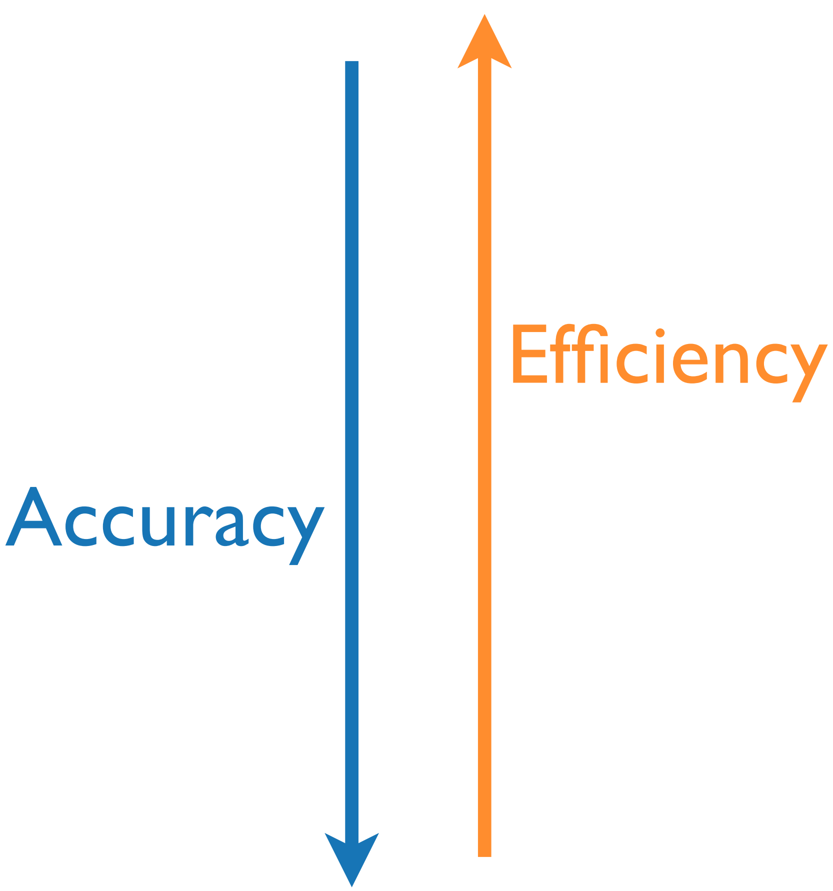
Differing Approaches for LSS Sims



Linear theory

Works only on large scales, fastest

Lagrangian perturbation theory

More realistic non-Gaussianity, only slightly slower

Direct halo finding (e.g. peak patch, pinocchio, …)

As fast as LPT
Realistic halo statistics and exclusion

N-body for DM only

Gas dynamics, galaxy formation and feedback added by hand

Hydrodynamics, Galaxy Formation and Feedback

Very expensive
Complexity reduces predictive power

Differing Approaches for LSS Sims

Combining LPT and Peak Patches "good enough" for covariance & mocks?

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Approximate Methods

Bold = Euclid Collaborators

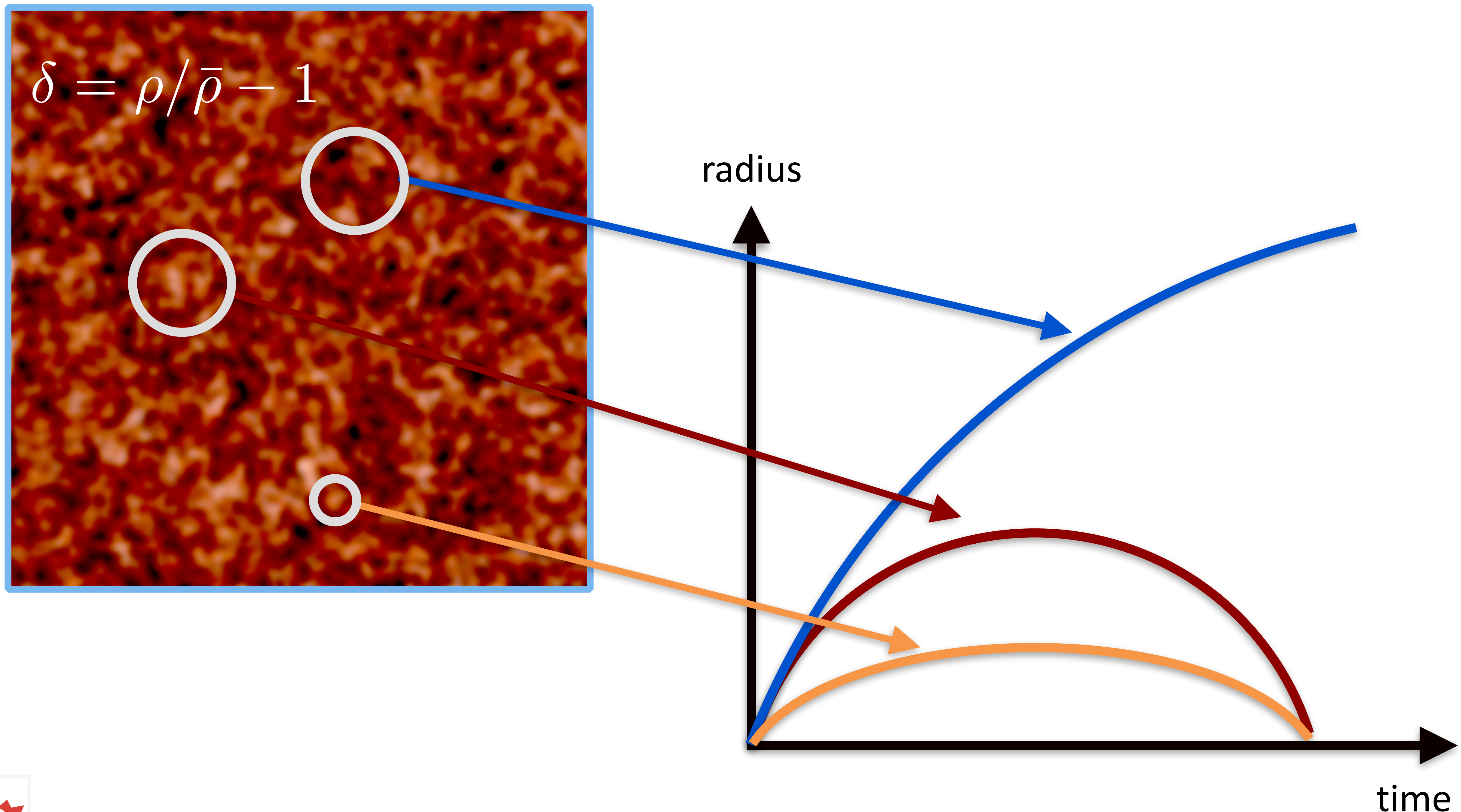
1. **Peak Patch (1993,++) - Bond, Myers**
   - Homogeneous ellipsoid collapse + LPT
2. **PINOCCHIO (2002,++) - Monaco et al.**
   - PINpointing Orbit Crossing-Collapsed HIerarchical Objects
   - Inverse collapse time for particles + fragmentation criteria to create distinct halos
3. **HALOGEN (2014,++) - Avila et al.**
   - Combination of 2LPT, analytical mass functions, and a single-parameter stochastic model for halo bias to position halos
4. **COLA (2013, ++) - Tassev, Zaldarriaga, Eisenstein**
   - COmoving Lagrangian Acceleration
   - Nobody in frame co-moving with 2LPT observers

   ★ L-PICOLA, ICE-COLA
5. FastPM (2016) - Feng, Chu, Seljak
   - PM + broadband correction at each timestep to enforce correct linear evolution
6. "Conditional HMF" (2013) - Torre, Peacock
   - populating with halos of mass below the resolution limit
   - stochastically sampling a field derived from the density field of the halo catalogue + use constraints from the conditional halo mass function
7. APT (2013) - Kitaura, Heß
   - Augmented LPT
   - 2LPT + Spherical Collapse
8. PATCHY (2013,++) - Kitaura, Yepes, Prada
   - PerturbAtion Theory Catalog generator of Halo and galaxY distributions
   - APT + nonlinear stochastic biasing
   - 5 parameter model with poisson distribution in intermediate regime & negative binomial in high density regime
9. PThalos (2001, ++) - Scoccimarro, Sheth
   - 2LPT + $n(m,\delta \mid z)$ assignment using merger tree + NFW particle placement

   ★ Manera et al. (2012)
   - 2LPT + fof (linking length = 0.38) + HMF

The Peak Patch Approach as an Explicit Forward Model For Halos

= Non-Linear Ellipsoidal Collapse + LPT



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The Peak Patch Approach as an Explicit Forward Model For Halos

= Non-Linear Ellipsoidal Collapse + LPT

$$\frac{\ddot{x}_i}{x_i} = \frac{\ddot{a}}{a} - \frac{1}{2}\Omega_m H^2 \left[b_i \bar{\delta} + c_i \bar{\delta}_{\rm lin} \right]$$

← Evolve each axis according to strain

$$\bar{e}^{(1)}_{ij} \equiv \quad (\partial \bar{\mathbf{s}}^{(1)}_i / \partial q_j + \partial \bar{\mathbf{s}}^{(1)}_j / \partial q_i)/2$$

$$\bar{e}_{ij} = \sum_k \lambda_k \hat{n}^i_k \hat{n}^j_k$$

$$\lambda_i = -(\bar{\delta}^{(1)}/3)(1 + c_i)$$

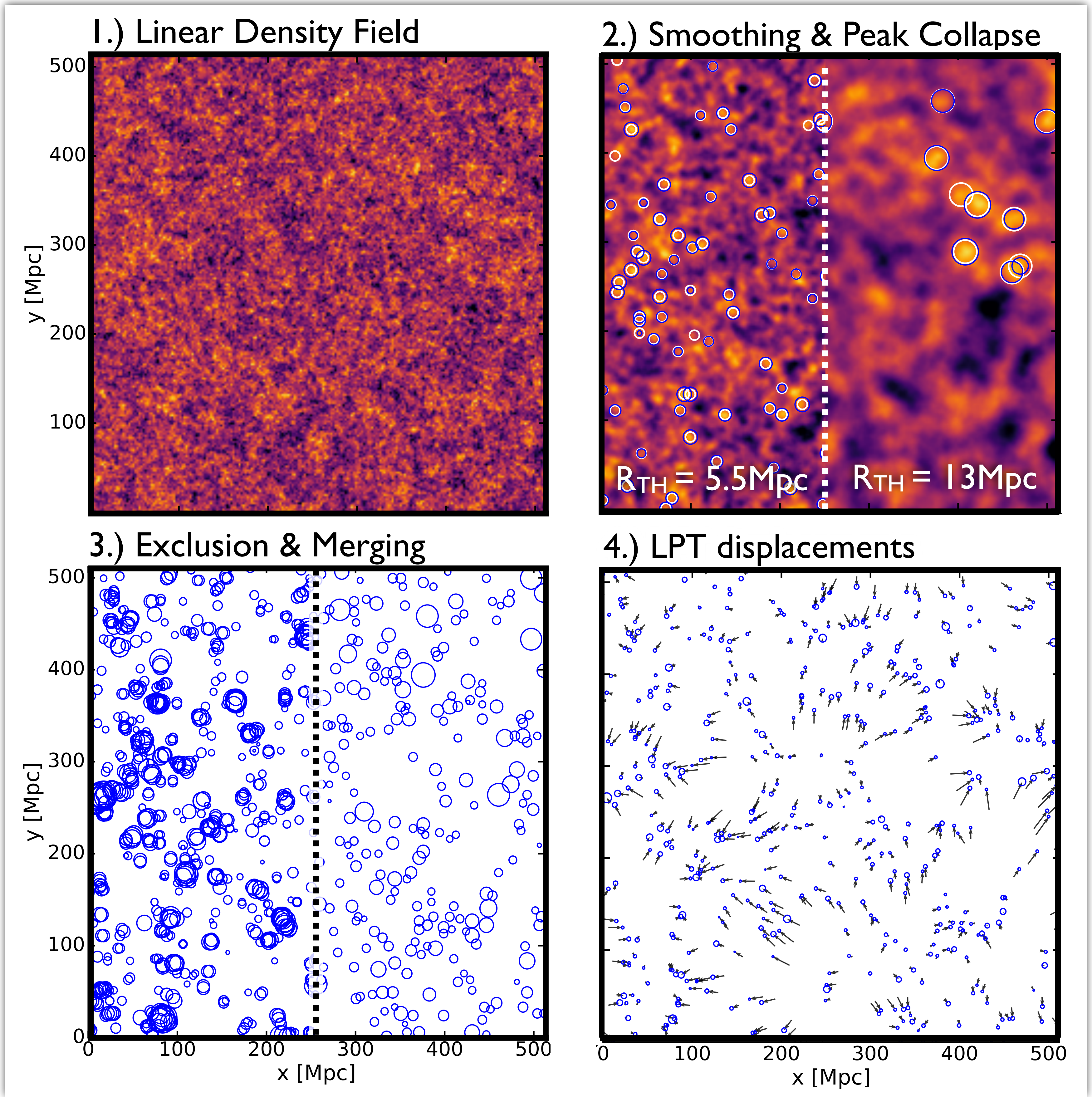
$$b_i(t) \equiv \frac{3}{2} \int_0^\infty d\tau \, [\tilde{x}_i^2 + \tau]^{-1} \prod_j [\tilde{x}_j^2 + \tau]^{-1/2}$$

The Peak-Patch Picture of Cosmic Catalogs. I. Algorithms
Bond, Myers, 1993

The Peak Patch method:

For Halo Catalogue
Monte Carlos

Alvarez, Bond, Stein, et al. in prep



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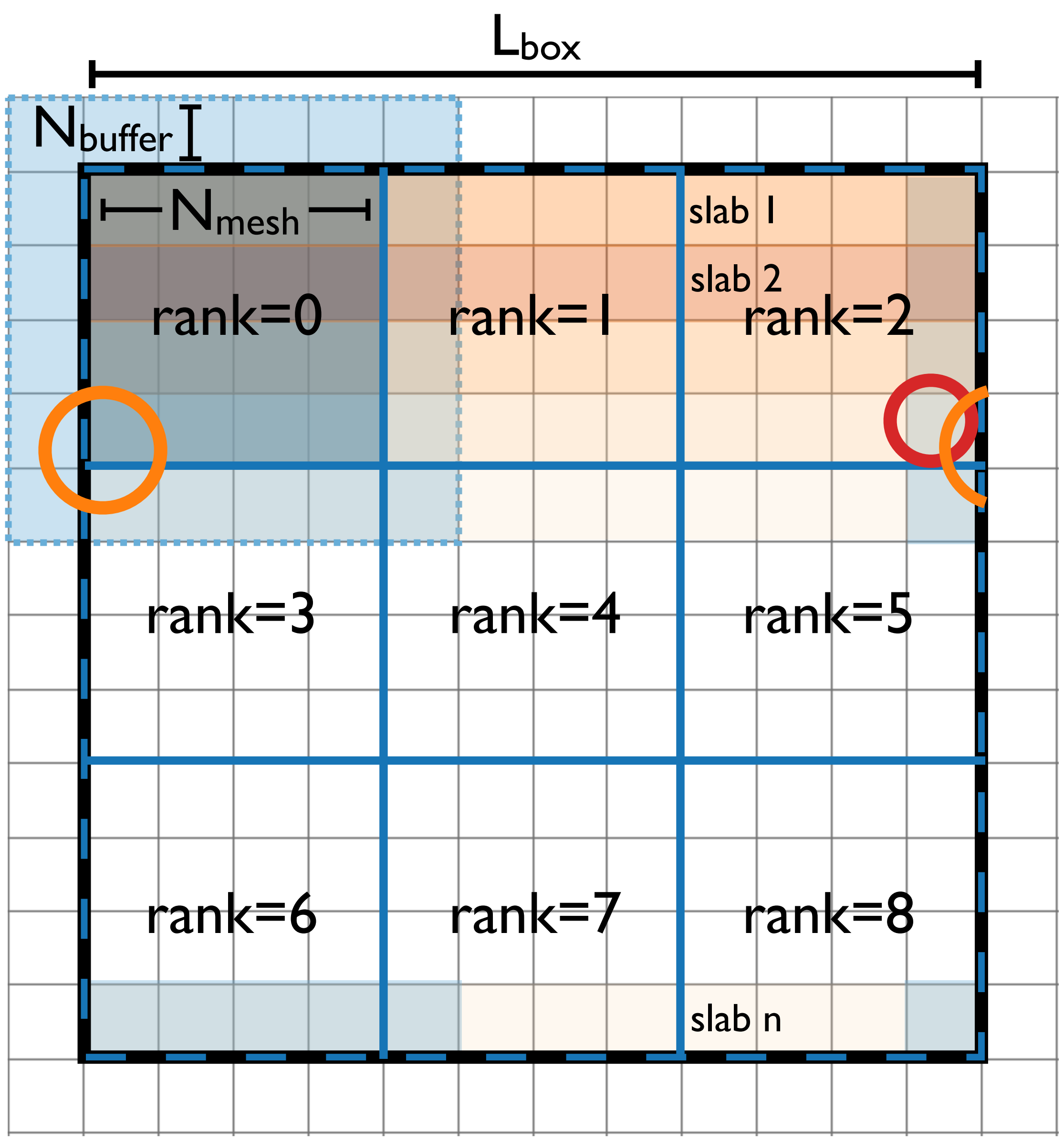
Where the Speed Comes From:

"Easily" Parallel

1. Generate ICs
2. Rearrange to cubic volumes
   - Include buffers to deal with boundaries
3. Run each "tile" completely independently

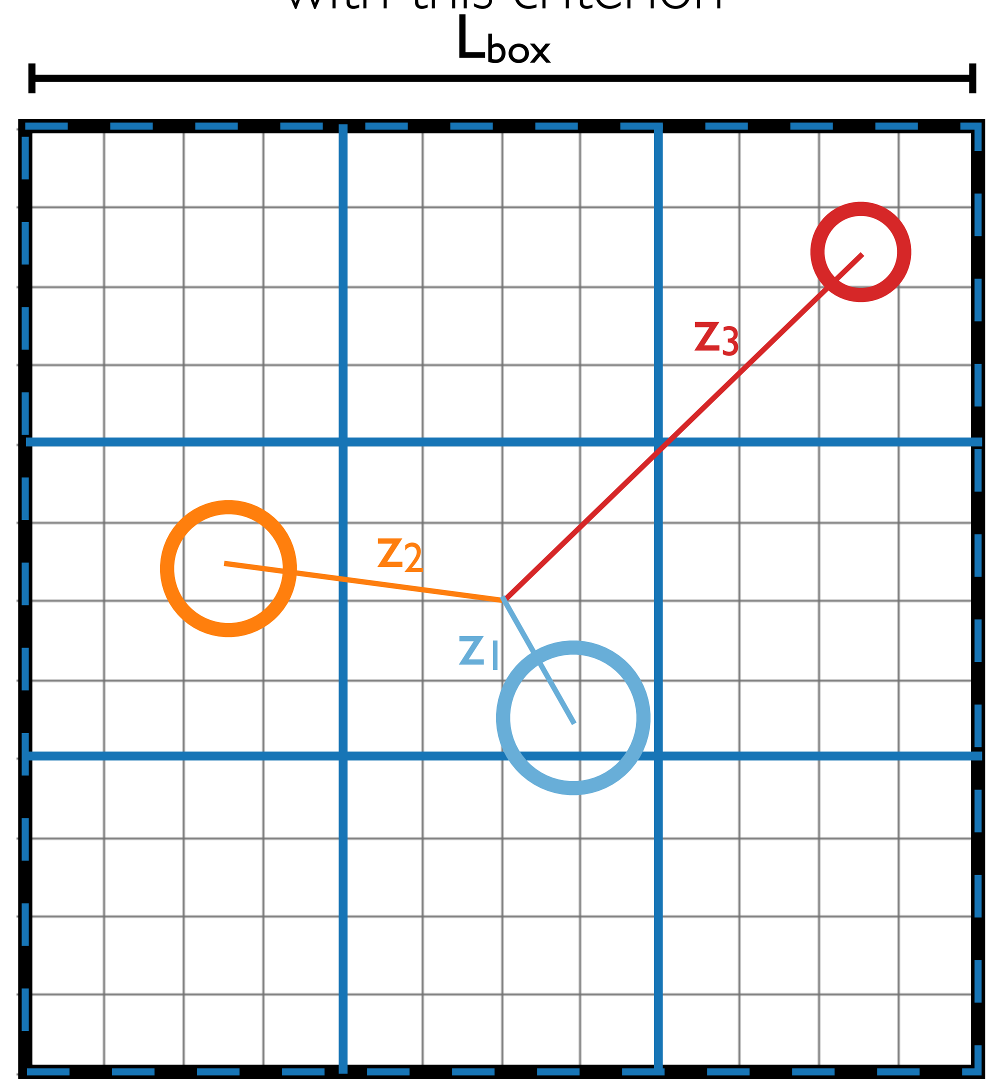


Small Memory Footprint

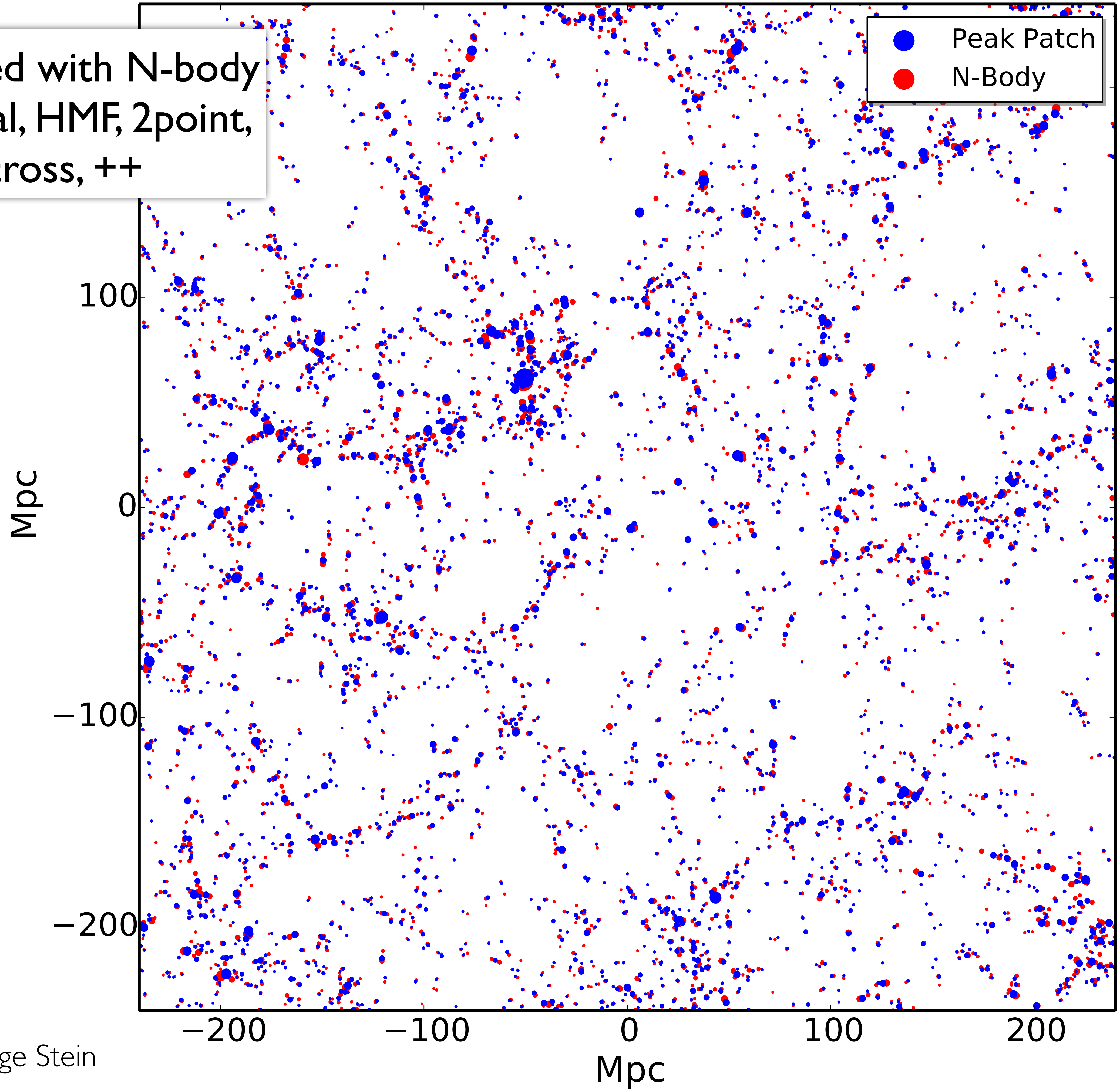
- 7 floats per cell (ICs)
- 7 floats per halo
- + small additional arrays

On the Fly Lightcones

Redshift at each halo location is known
⟶ calculate Ellipsoidal Collapse with this criterion



Validated with N-body at visual, HMF, 2point, cross, ++



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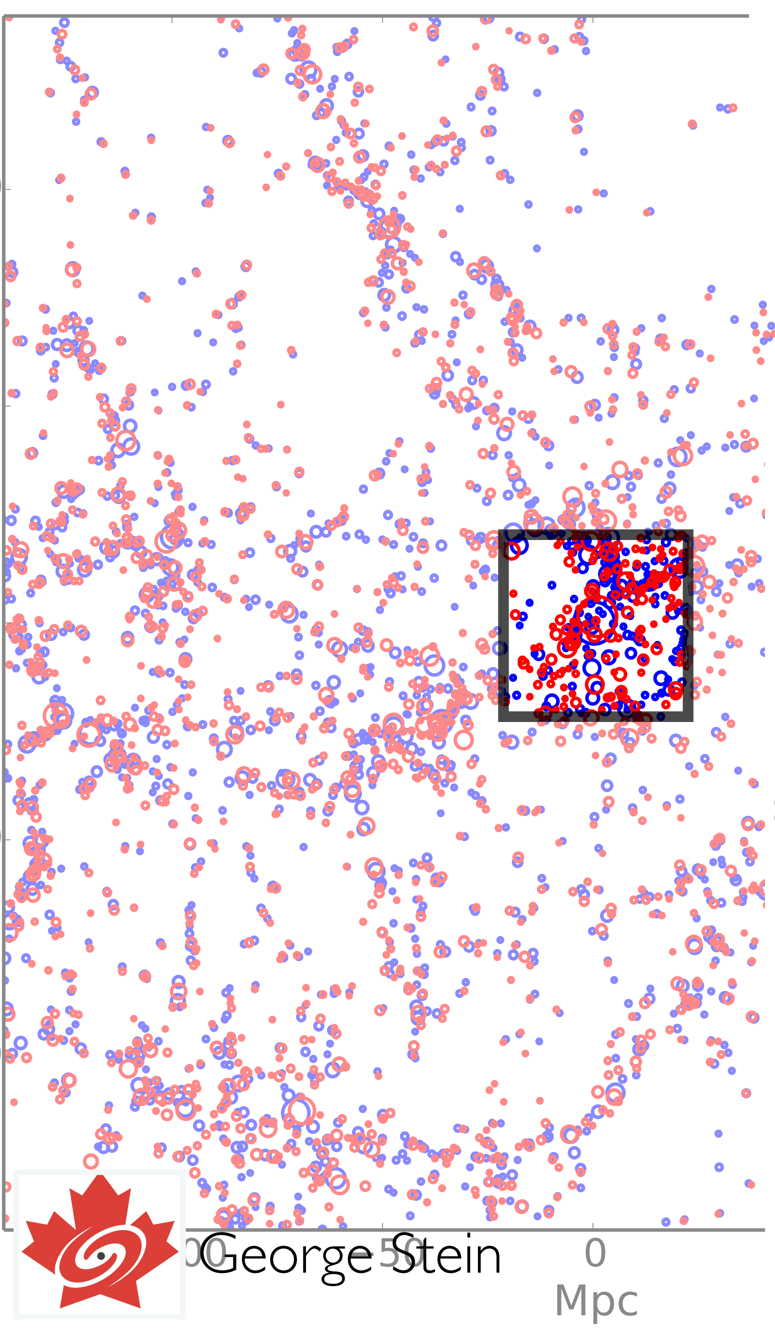
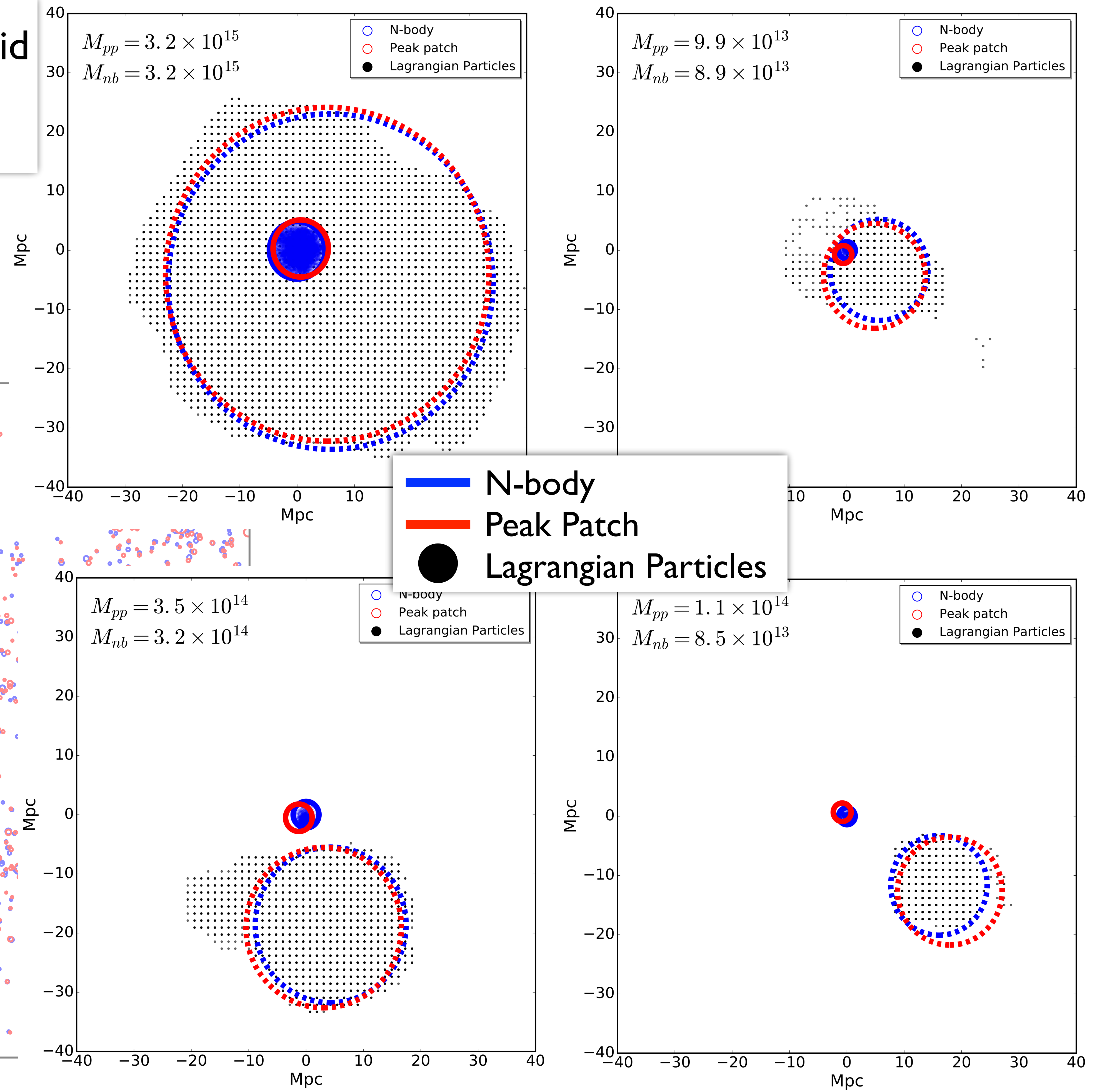
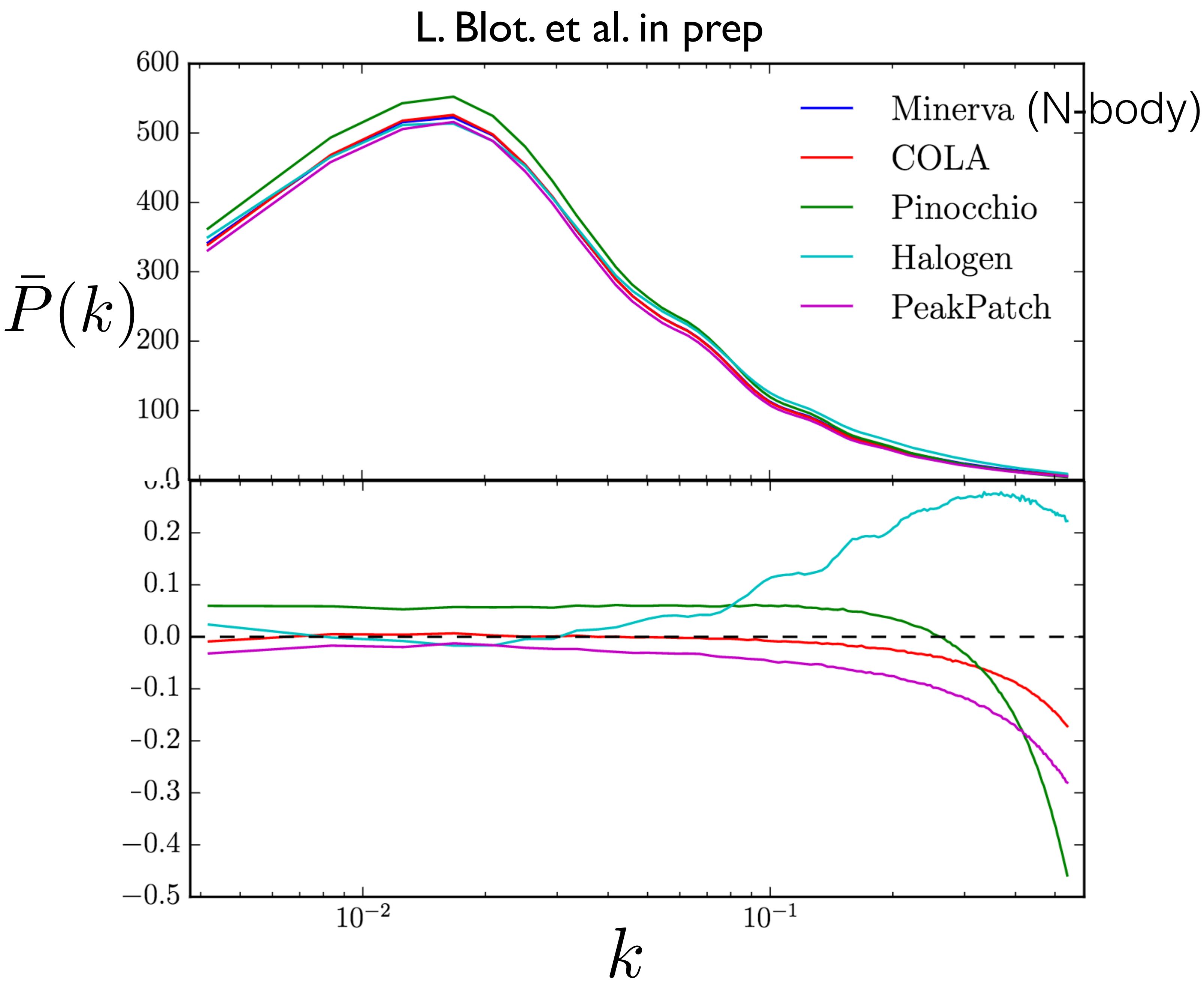
Homogeneous ellipsoid for non-spherical Lagrangian patches?

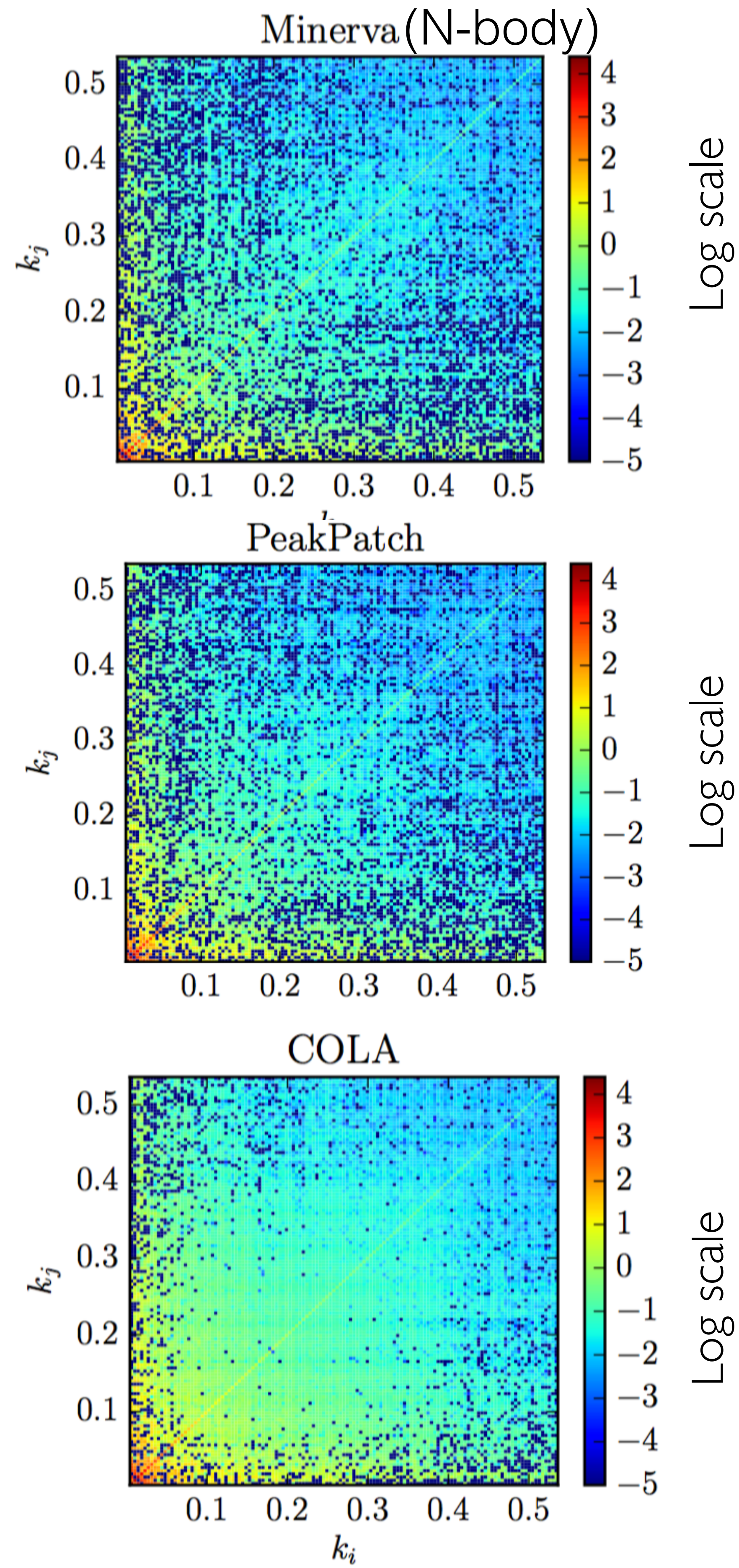




Euclid Covariance Matrix comparison project



300 simulations with matching seeds
$n_{part} = 1024^3$, 1500Mpc/h
number cut to N-body at $M = 100M_{cell}$



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Peak Patch = more than a “black box” for fast sims
- allows for theoretical understanding

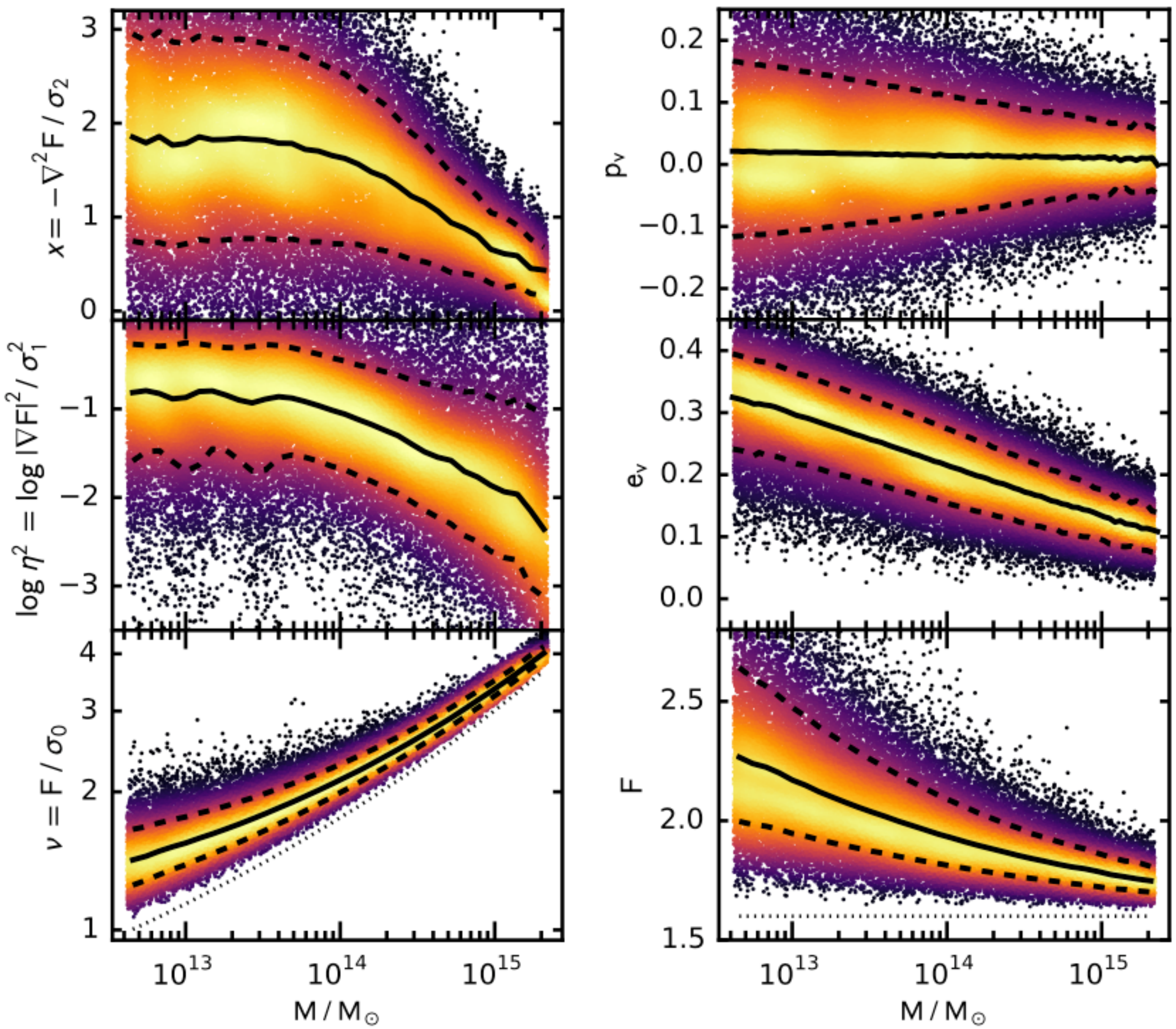
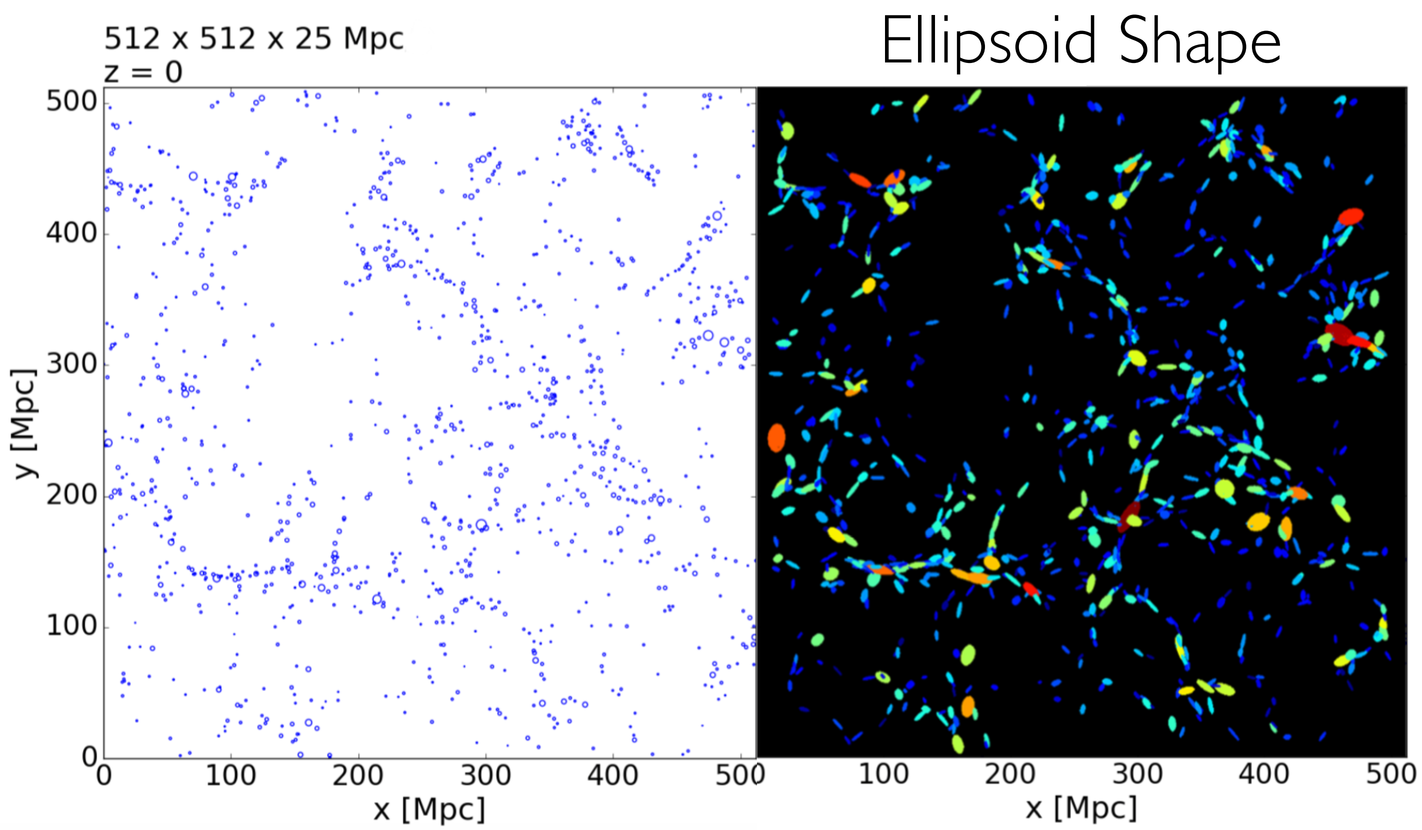


Figure 3. *Left* – Scatter plots, versus halo mass, of scaled density contrast $\nu \equiv F/\sigma_0(M)$ (bottom), square of gradient, $\eta^2 \equiv |\nabla F|^2/\sigma_1^2$ (middle), and curvature $x- \equiv \nabla^2 F/\sigma_2(M)$ (top), averaged over the Lagrangian volume of each halo. Also shown are the mean (solid) and 1-σ contours of the distribution (dashed). Contrary to the expectation for density peaks, halos gnerally originate in regions with non-negligible density gradients, with the effect increasing towards lower mass. *Right* – Same as left panel, but for the shear prolaticity, p_v (top), shear ellipticty, e_v (middle), and density contrast, F (bottom). The dotted line in the lower panels indicates the relation expected for spherical collapse with $\Delta = 200$, $F_c = 1.6$.

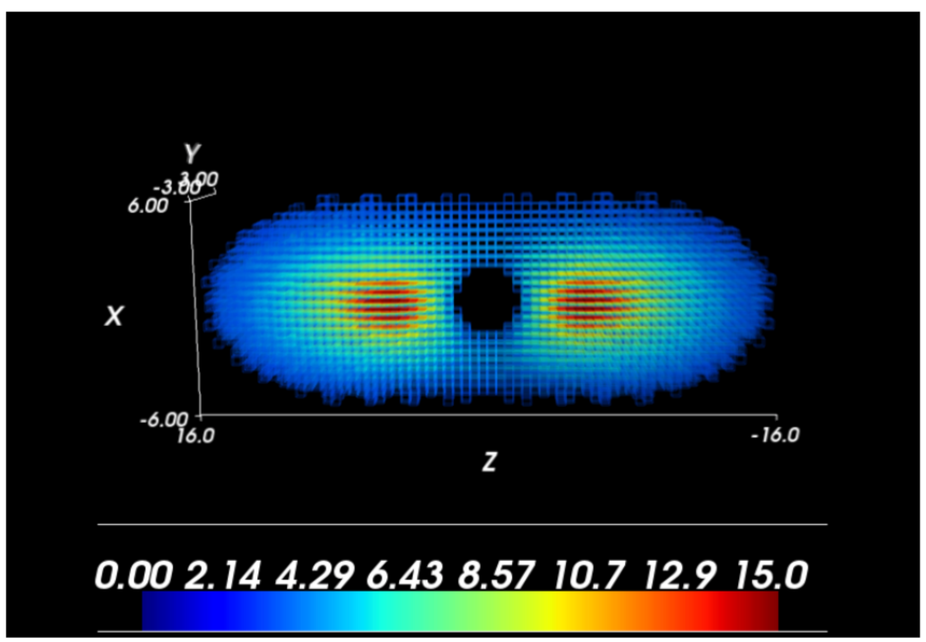
Peak Patch = more than a "black box" for fast sims
- allows for theoretical understanding



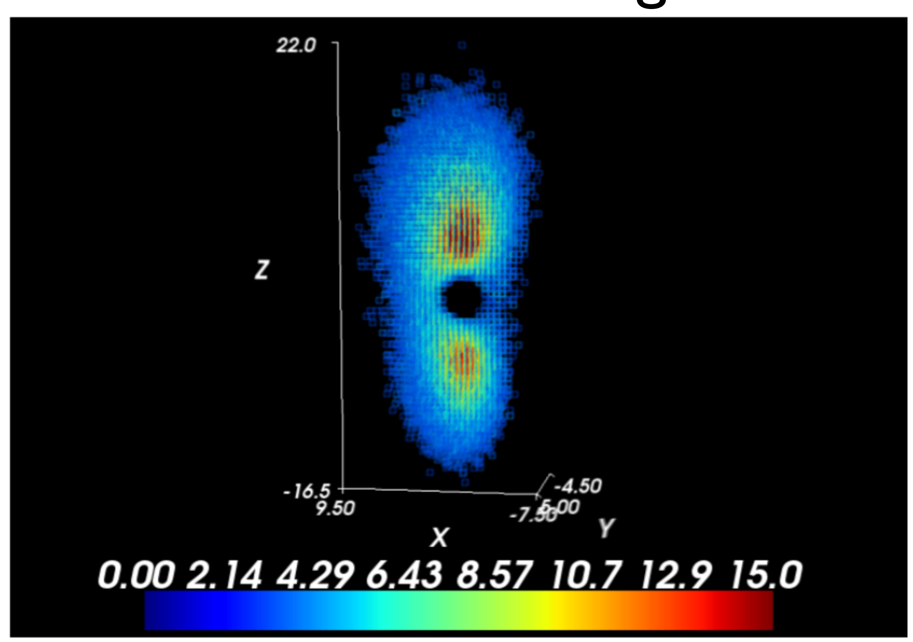
w/ Bruno Régaldo-Saint Blancard, Sandrine Codis

Technology allows for oriented stacking, ++

Strain tensor oriented stacking of halos

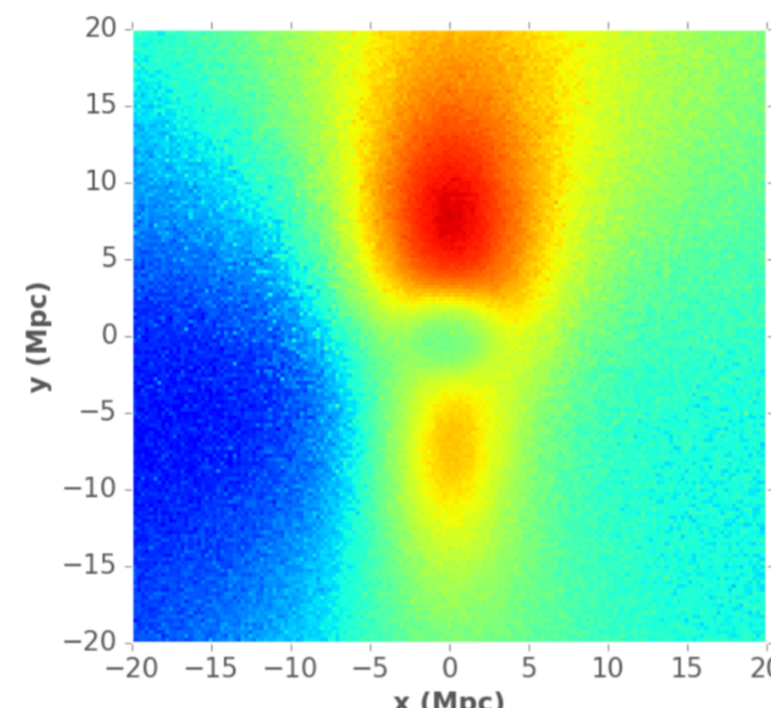


(c) $\xi^{\mathcal{E}}_{\delta\delta}(\boldsymbol{r}) > 3$ display.



(d) $\xi^{\mathcal{E}/\mathbf{s}}_{\delta\delta}(\boldsymbol{r}) > 3$ display.

with flow symmetry breaking



Oriented stack on tSZ

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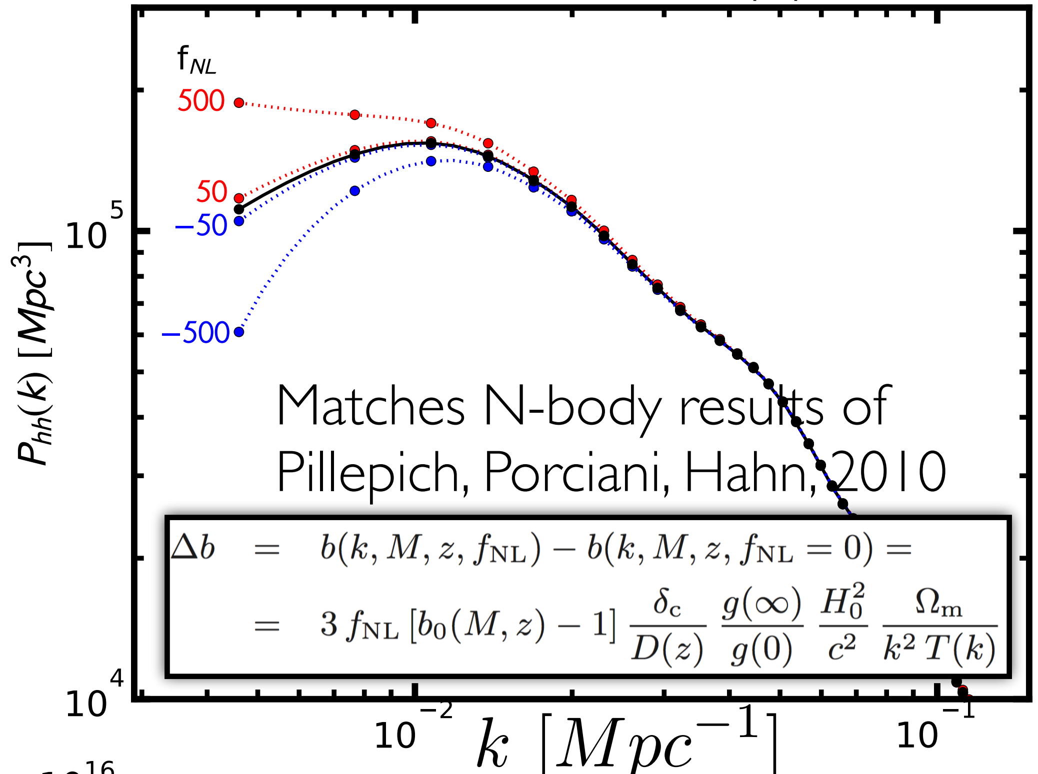
Add in:

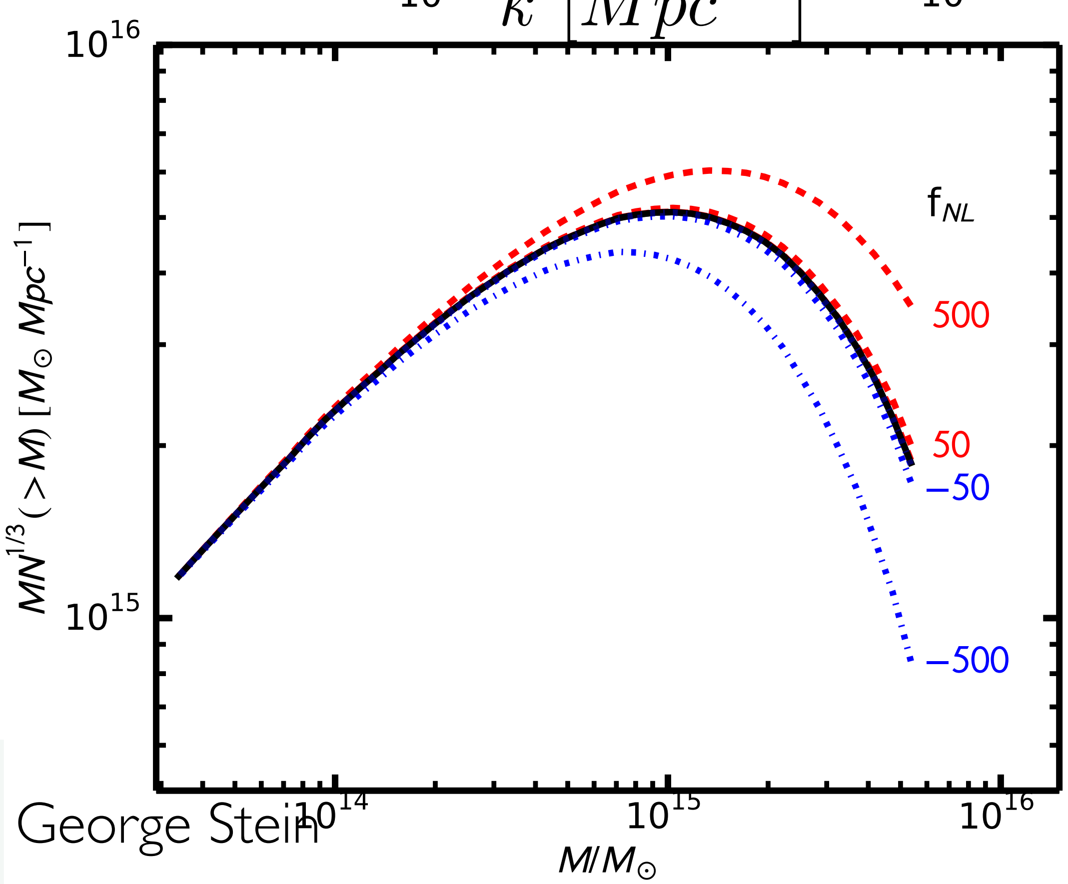
Primordial Non-Gaussianity & Modified Gravity

the Peak Patch method accurately reproduces the effects of primordial Non-Gaussianities
⟶Add to full mock pipeline

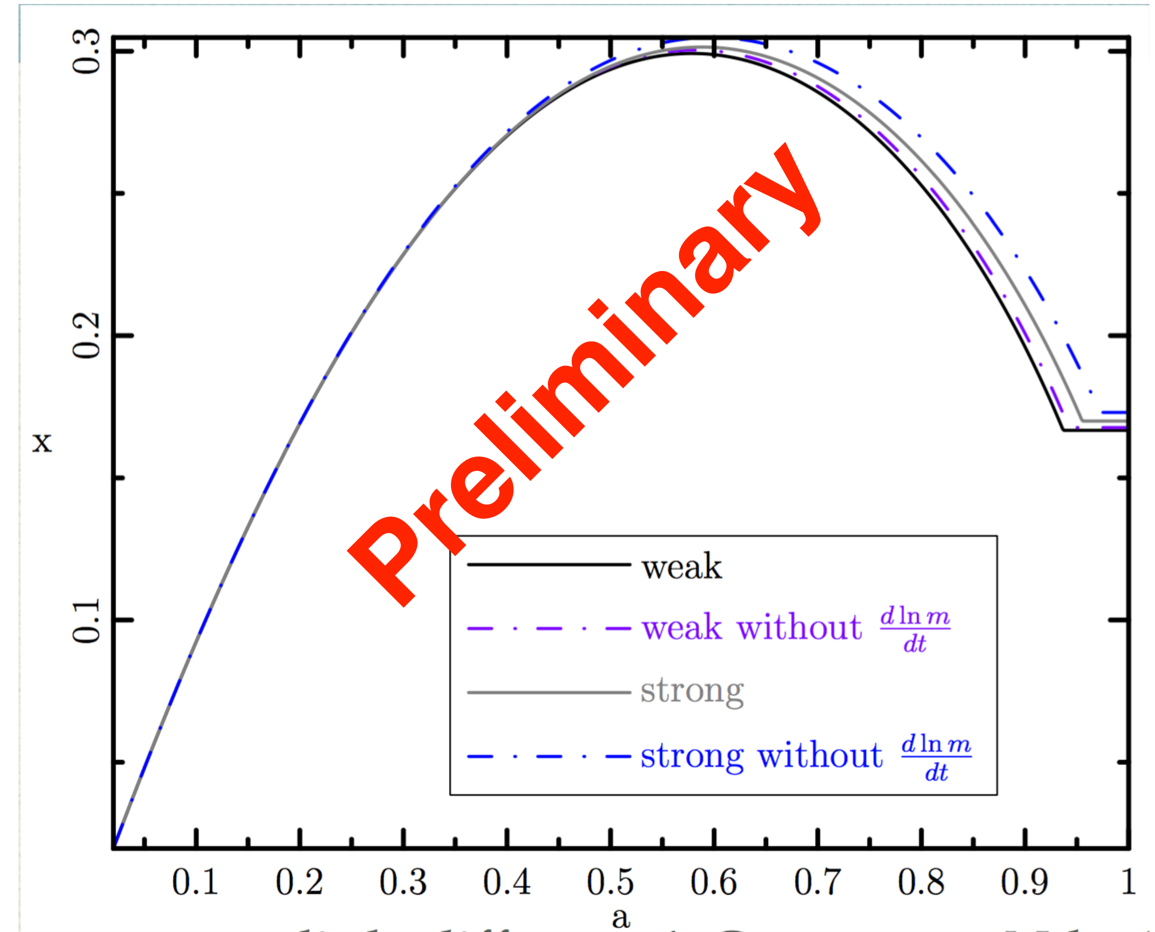


Matches N-body results of Pillepich, Porciani, Hahn, 2010

$$\Delta b = b(k, M, z, f_{\rm NL}) - b(k, M, z, f_{\rm NL}=0) = 3\, f_{\rm NL}\, [b_0(M,z)-1]\, \frac{\delta_c}{D(z)}\, \frac{g(\infty)}{g(0)}\, \frac{H_0^2}{c^2}\, \frac{\Omega_m}{k^2\, T(k)}$$



The Effect of chameleon-like f(R) gravity
On the dynamics of ellipsoidal collapse



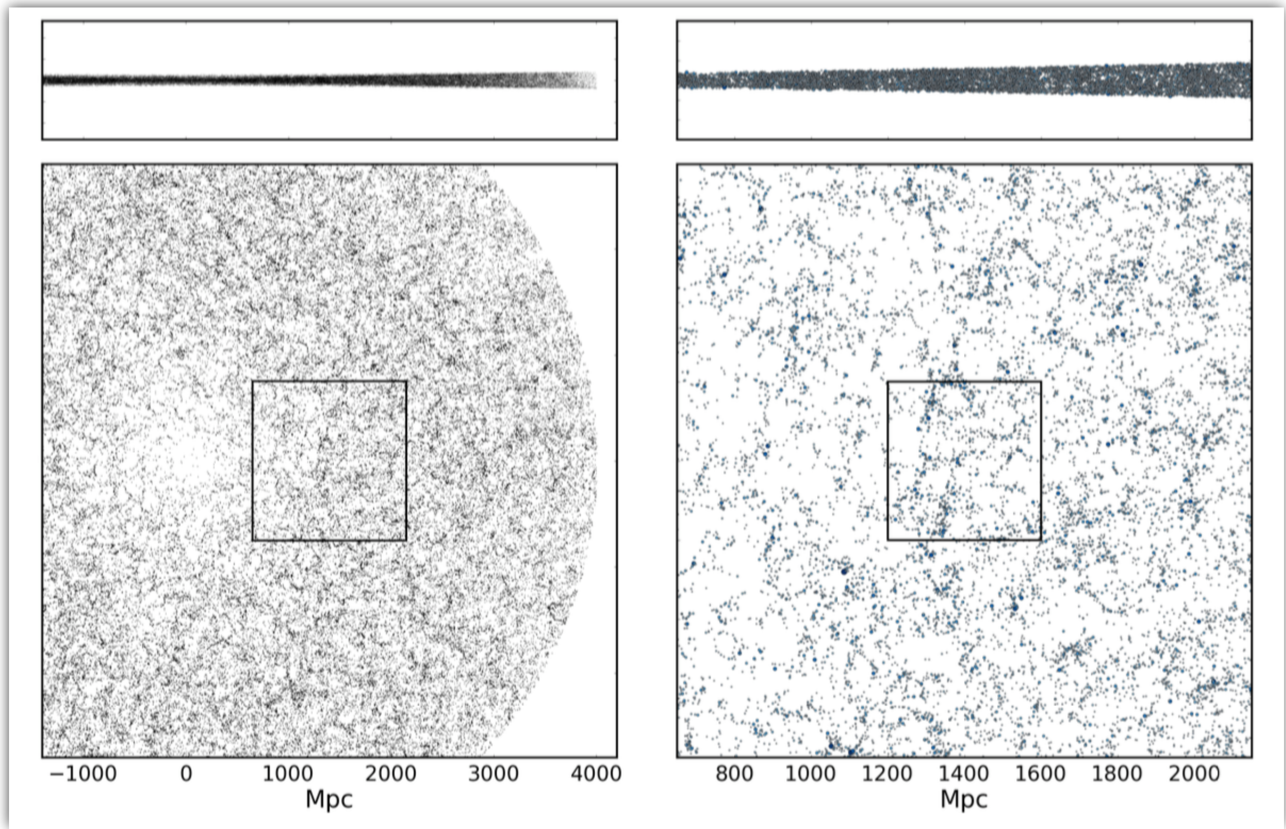

Emma Platts, Zhiqi Huang, Alex Lague

Halo Catalogue $\longrightarrow$ Sky Mocks

*Independent of Approximate Halo Finding method

Halo Catalogue

* Many Peak Patch Full-sky catalogues available



Validated with N-body at HMF+2point+x+visual

$z<4.6$ light cone, $8*4096^3$ resolution

= 8000 core hours

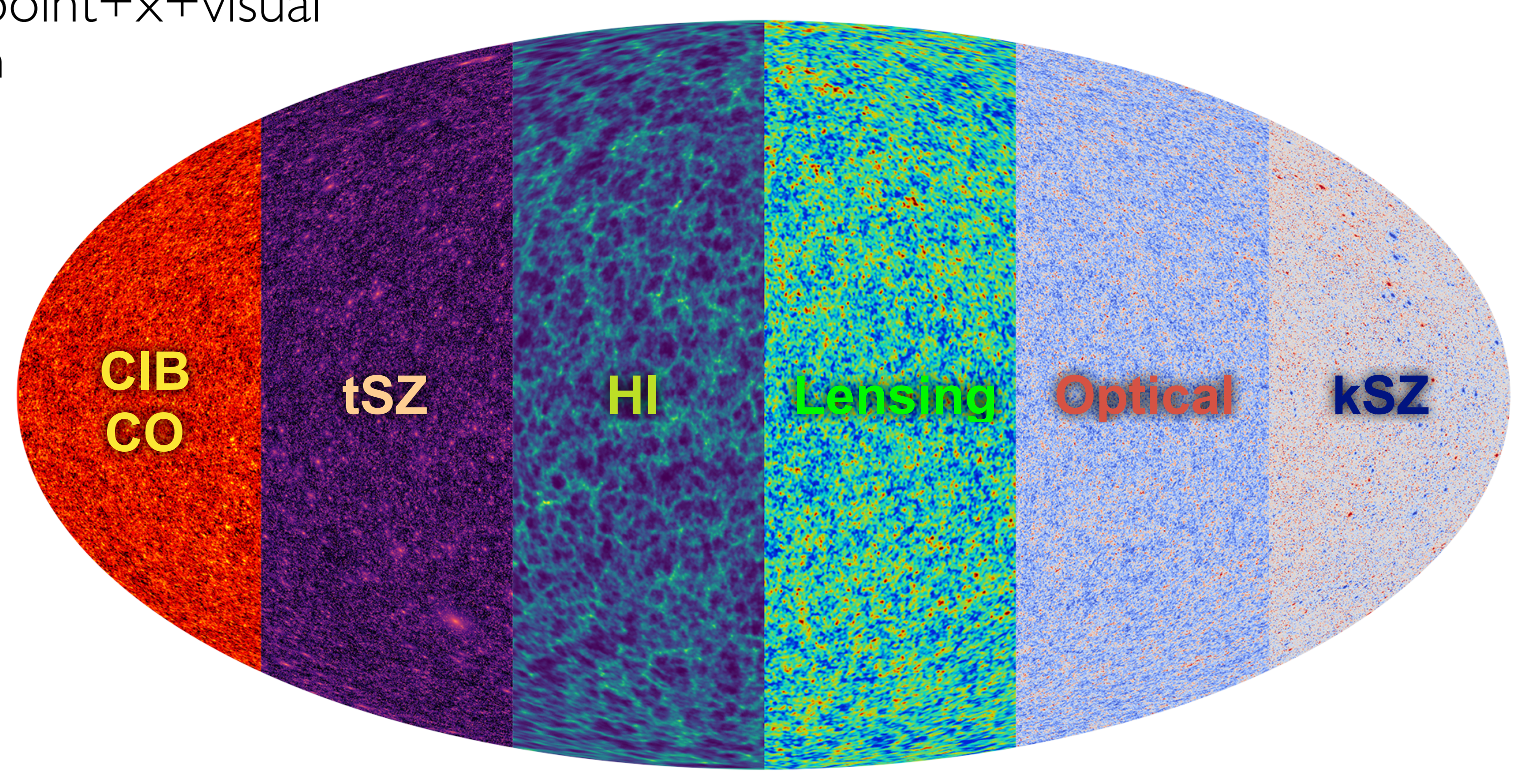
+

Mapmaking Code

Profile Paste/"Susceptibilities"

- put in sub halo physics "by hand"

=



cross correlations automatically included!

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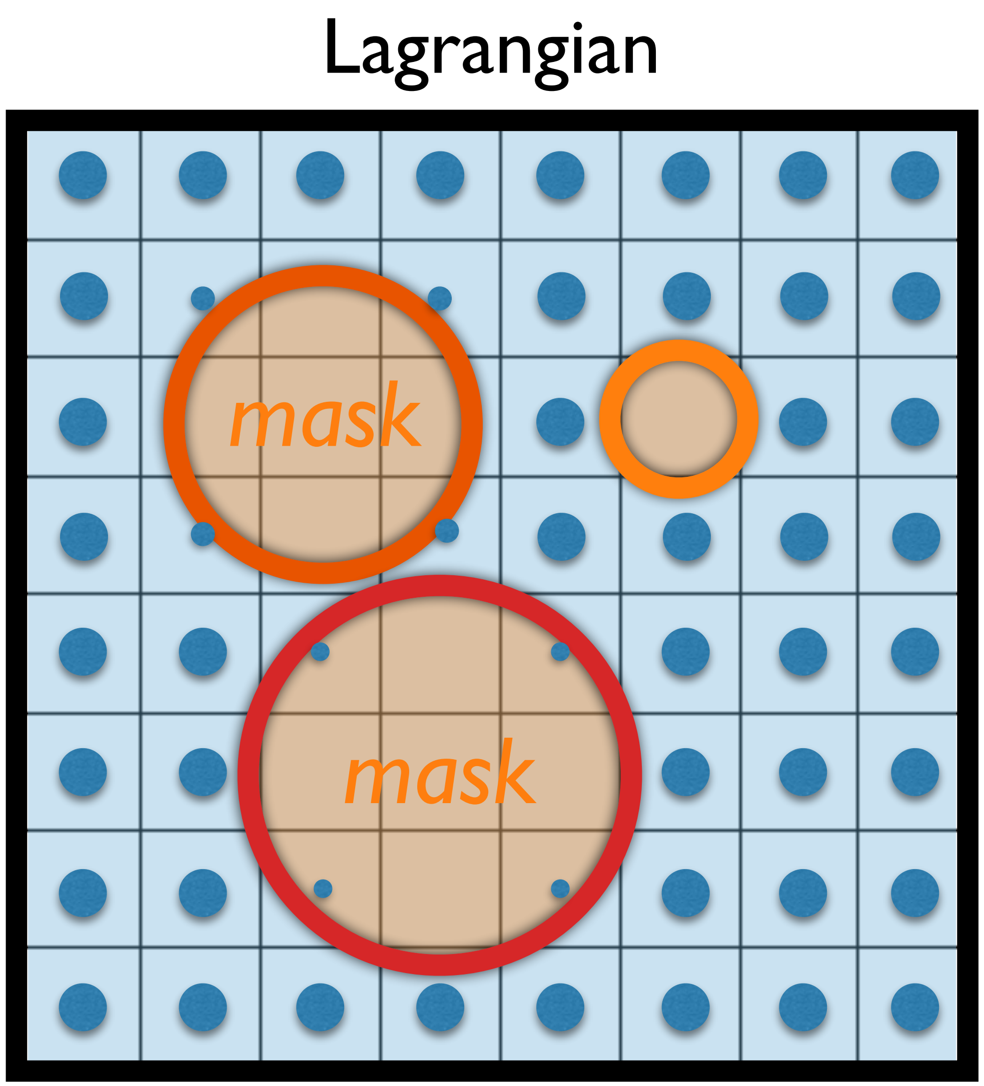
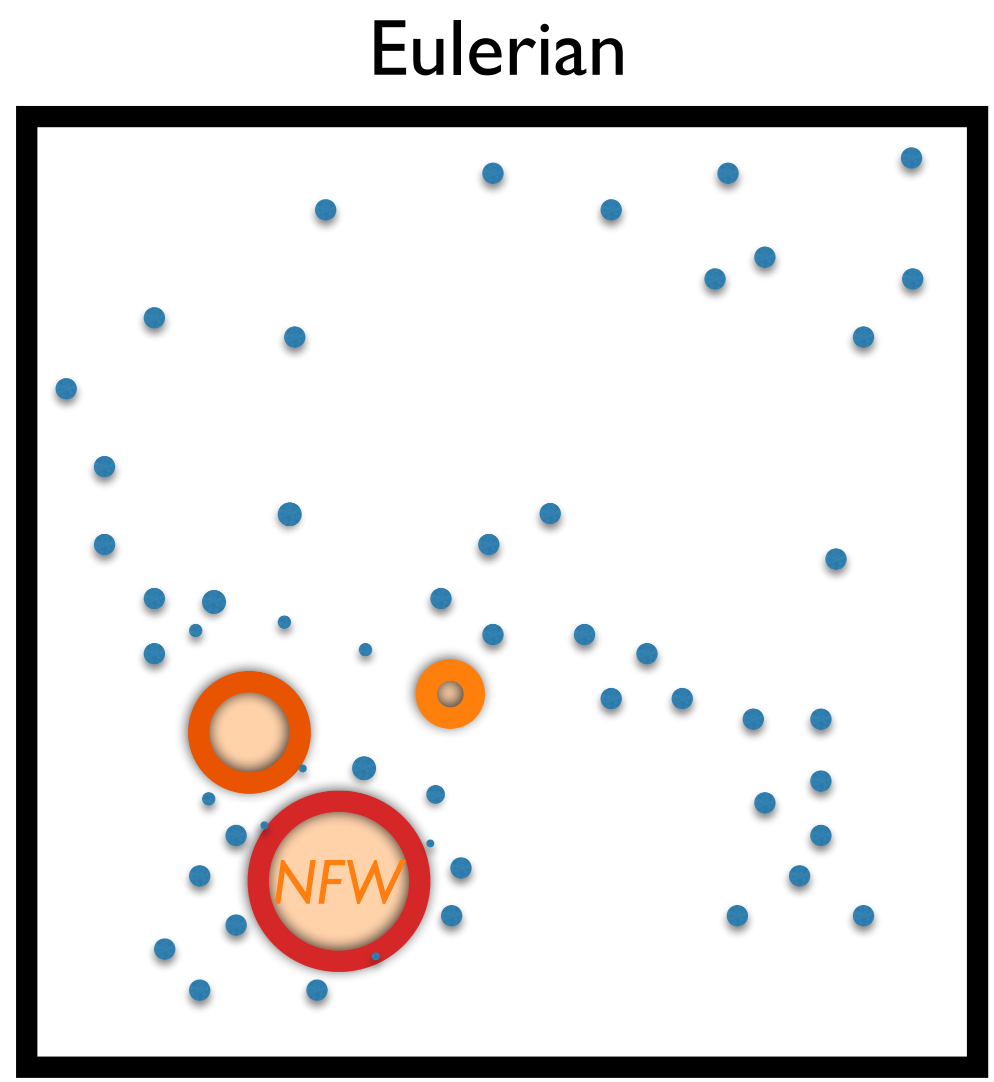
Weak Lensing with Peak Patch

2 components

1. Paste (g)NFW on Halos
2. 2LPT for "field" particles

"Swiss Cheese + Meatballs"
-Marcelo Alvarez

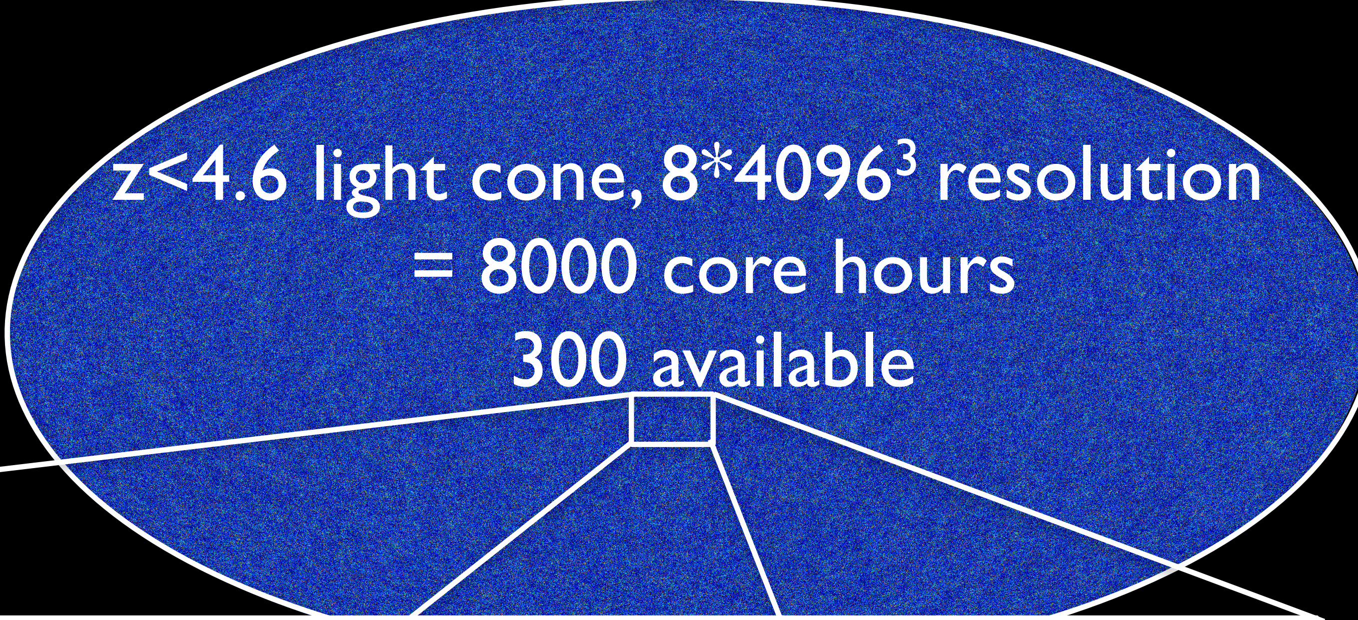


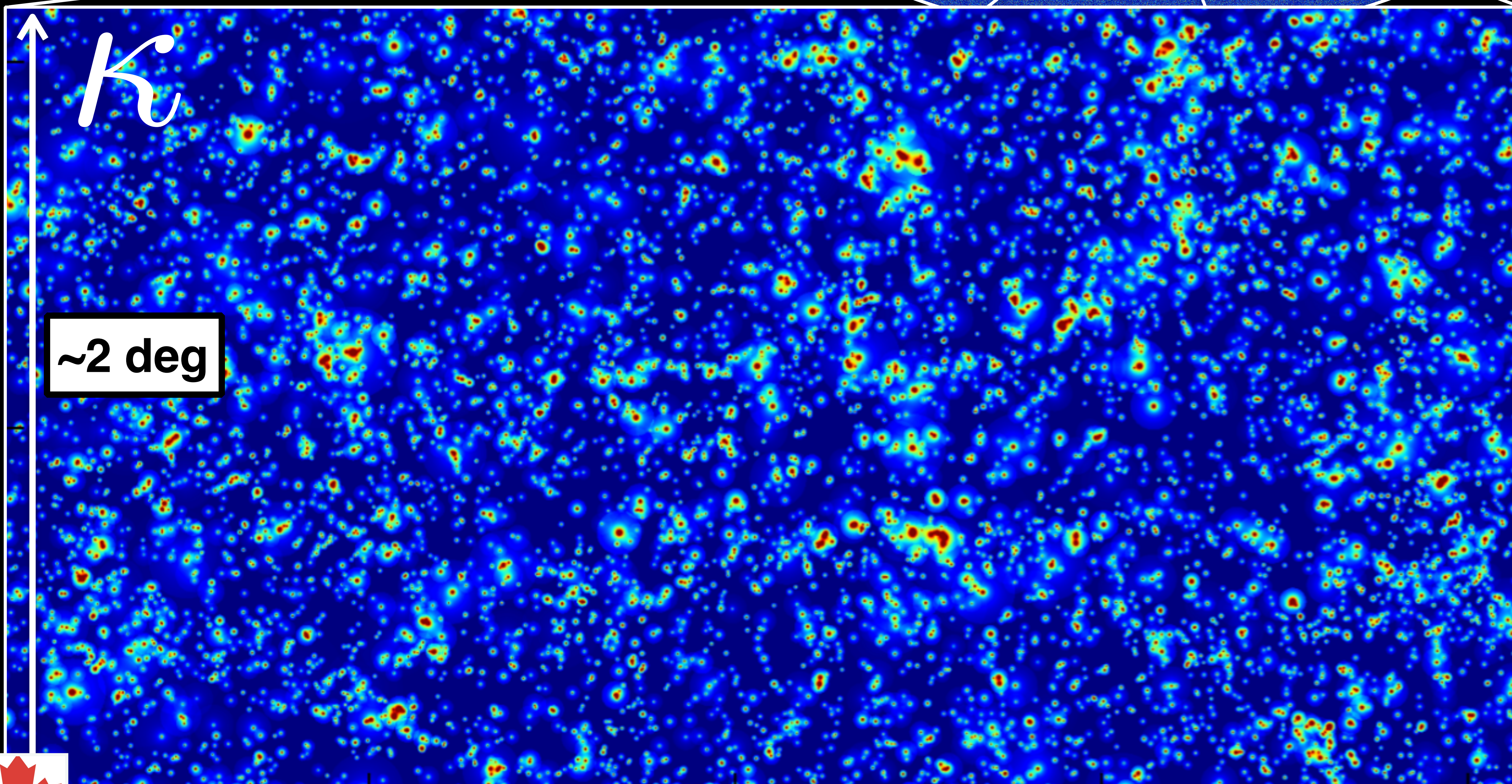


Combining LPT and Peak Patches "good enough" for lensing?

CMB

"Paint on" NFW + 2LPT Field = Lensing Convergence Map

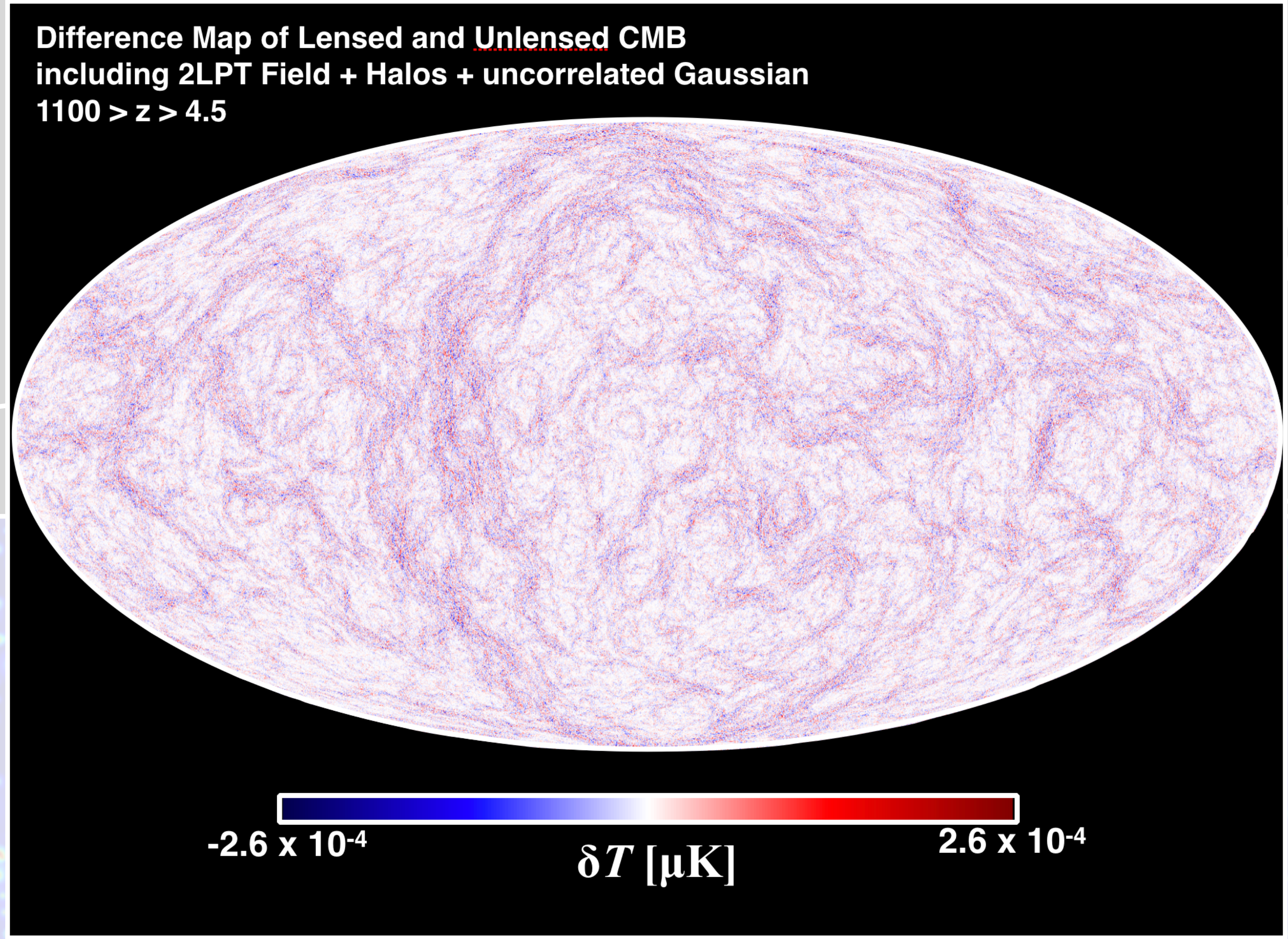


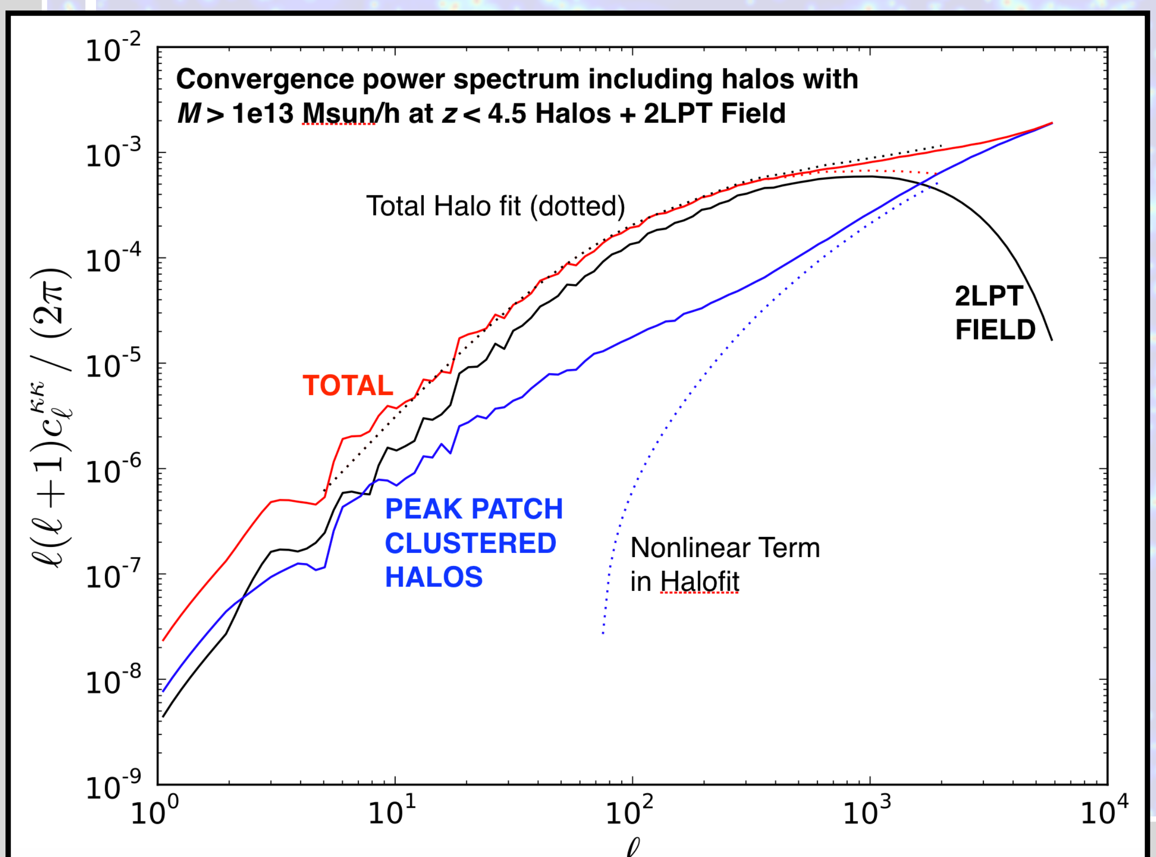


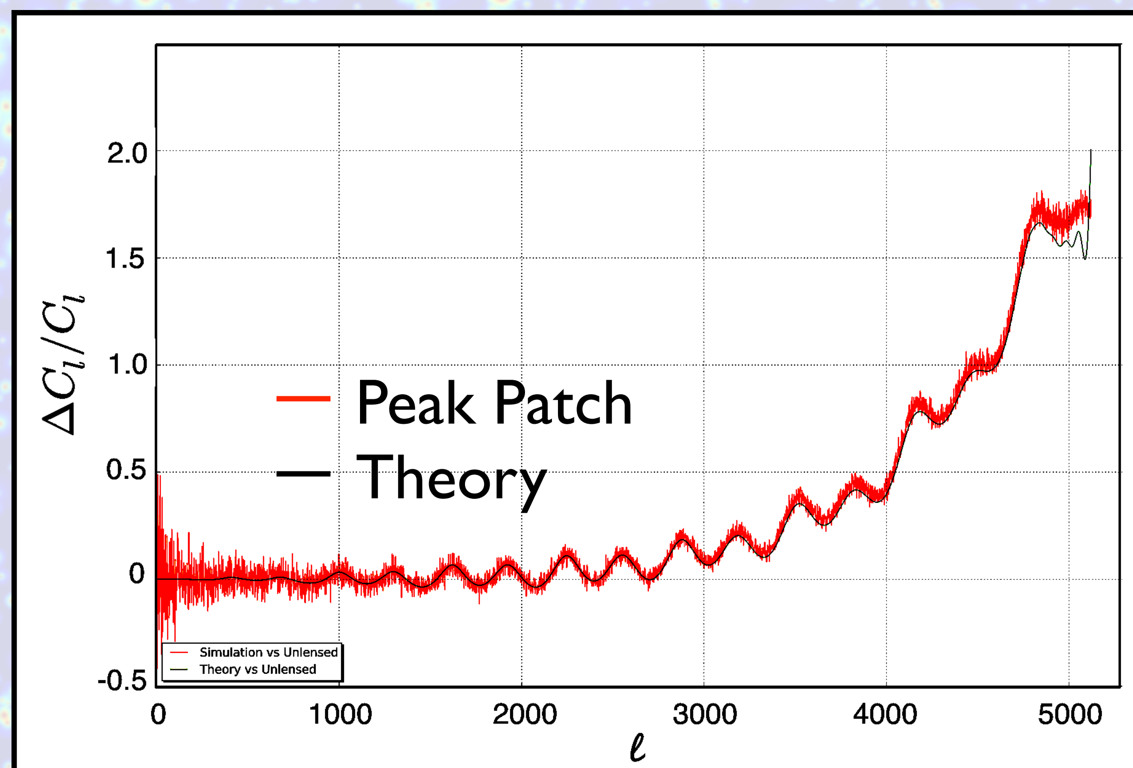
Combining LPT and Peak Patches "good enough" for lensing?

CMB

Modified Lenspix to read in our non-Gaussian Kappa maps



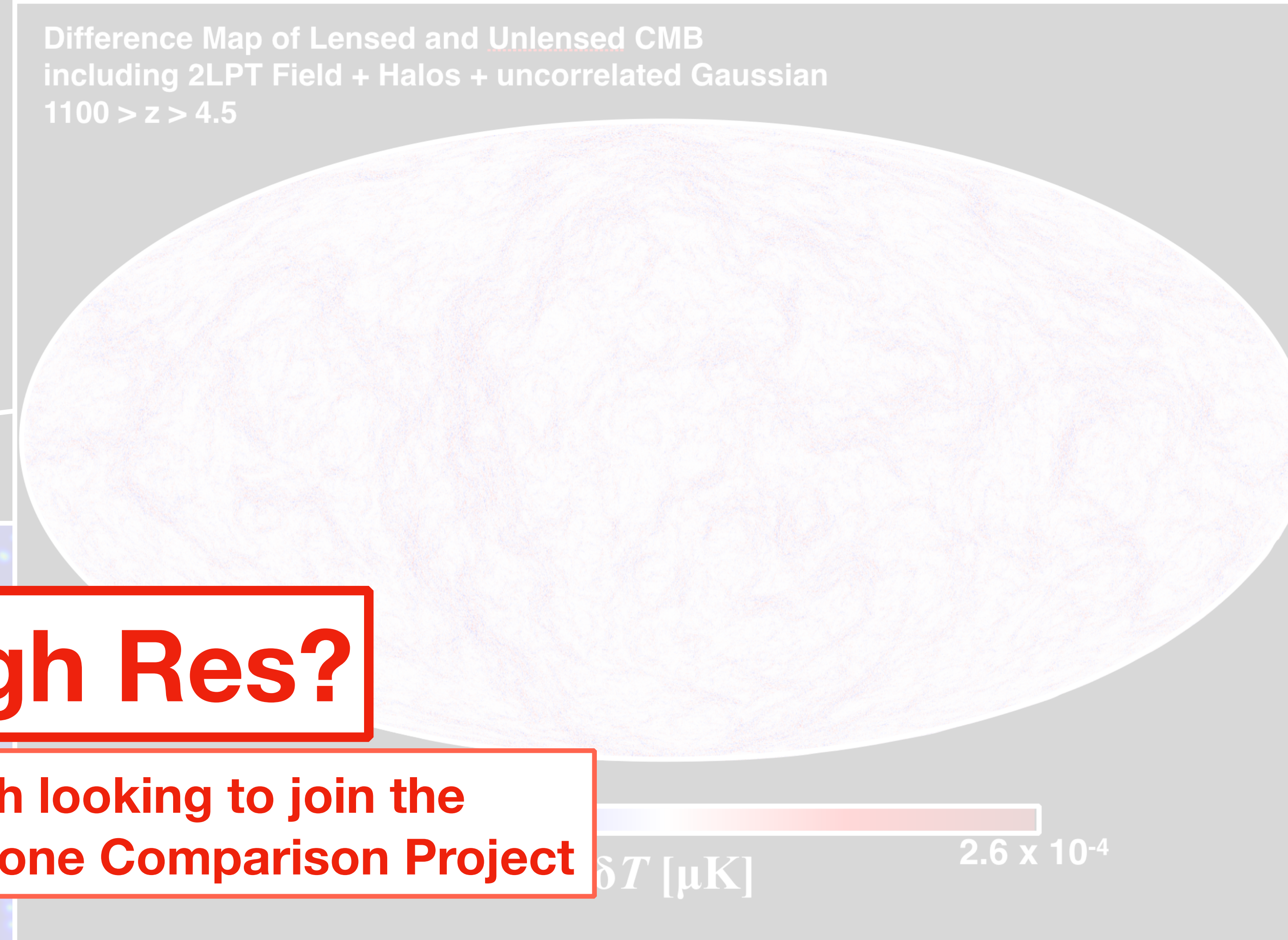




Alvarez, Bond, Stein, van Engelen, Pham

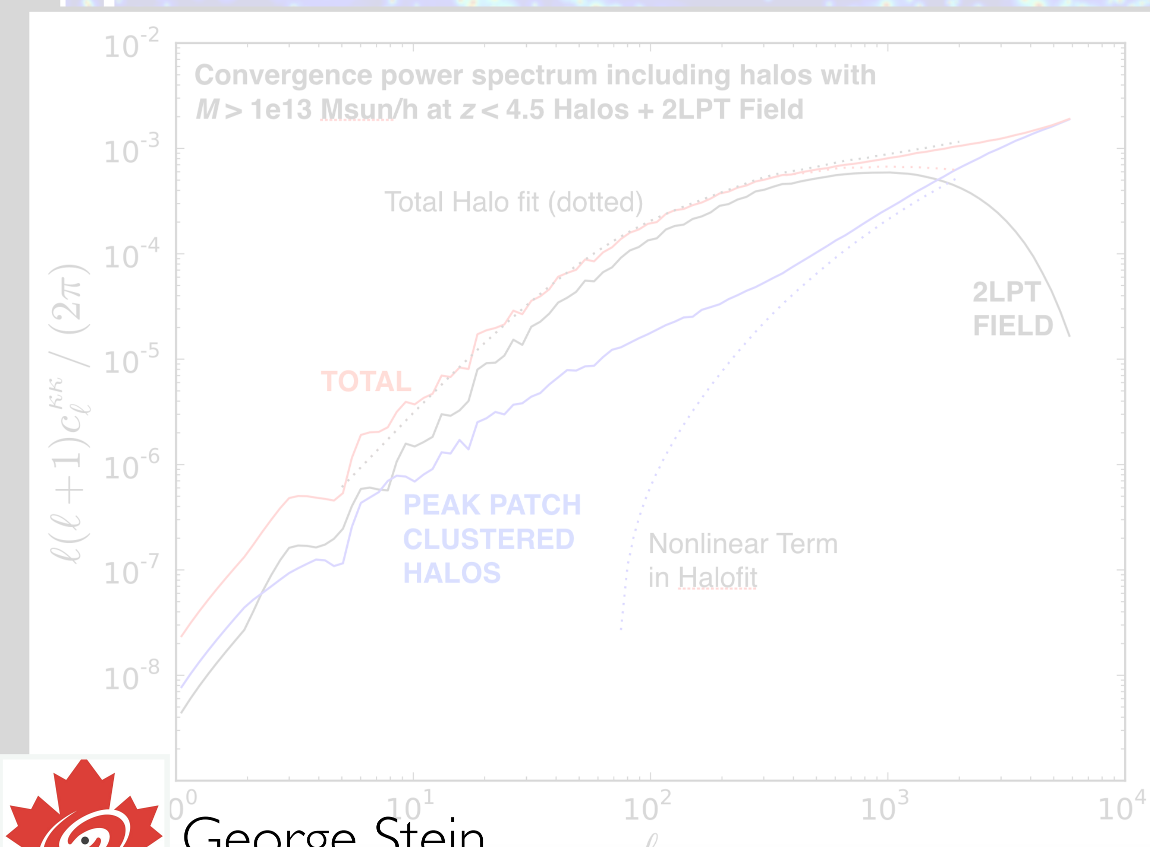
Combining LPT and Peak Patches "good enough" for lensing?

CMB



High Res?

Peak Patch looking to join the Lensing Lightcone Comparison Project



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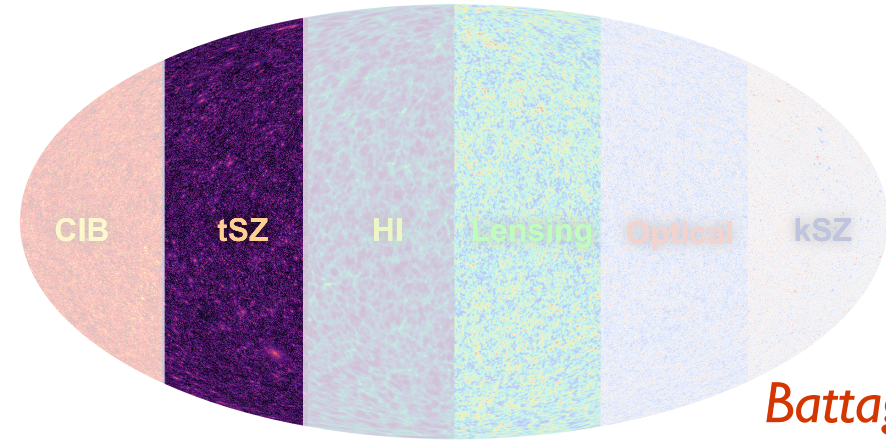
Alvarez, Bond, Stein, van Engelen, Pham

Has been applied to other LSS tracers + CMB secondaries

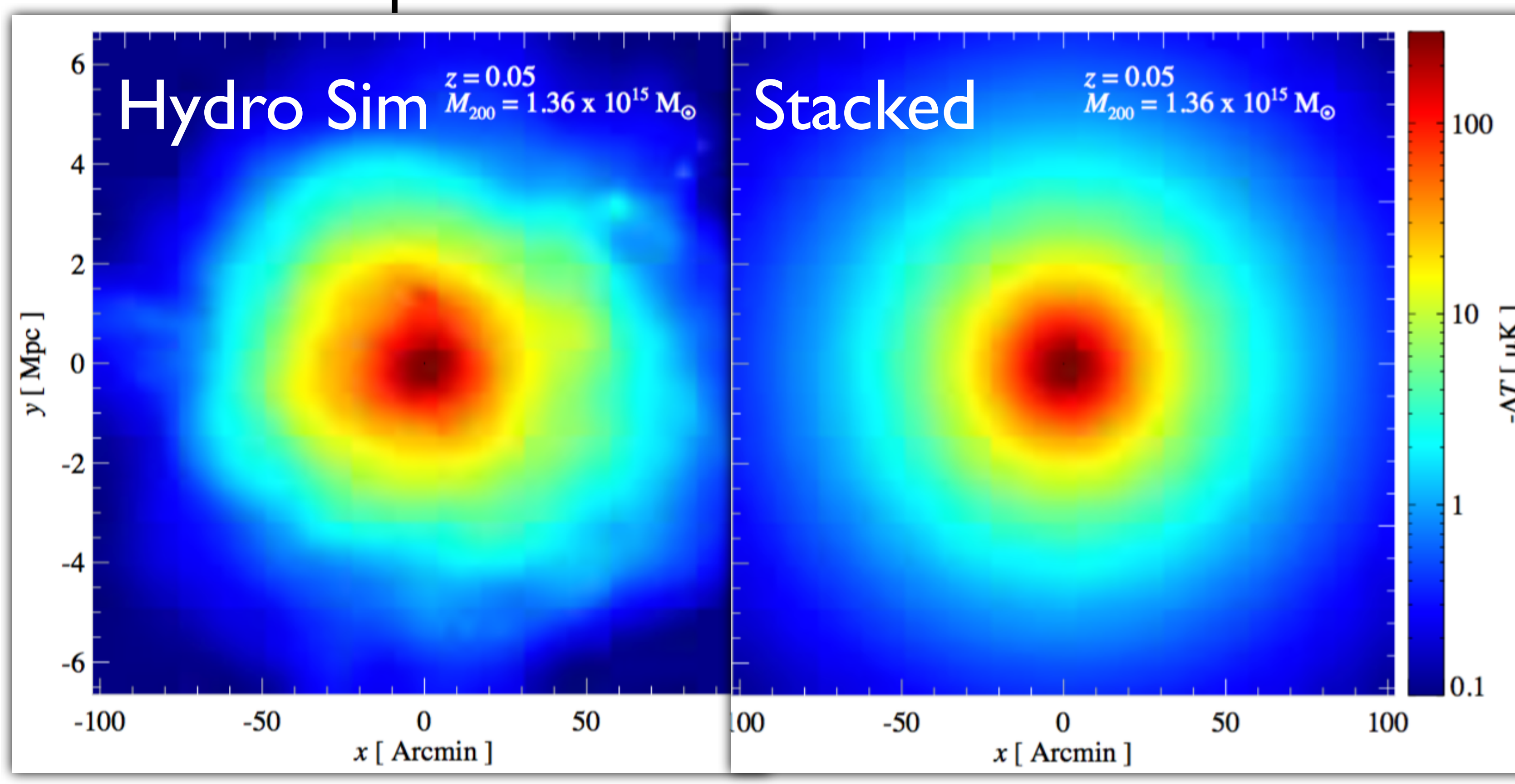
- tSZ, kSZ
- CIB
- Optical



Battaglia, Bond, Pfrommer, Sievers (2012)

tSZ

Temperature decrement at 30GHz



- Stack clusters in M, z, ++
- Fit observable f(x|M,z,++) to generalized NFW profile

  ie. f(x) = Pressure, gas, mass
- Need to explore stochastic fluctuations

$$f(x|M,z) = f_0(M,z)\left(\frac{x}{x_c}\right)^{\gamma}\left[1+\left(\frac{x}{x_c}\right)^{\alpha}\right]^{-\beta}$$

$$x \equiv r/R_{\Delta}$$

Covariance For Intensity Mapping Experiments

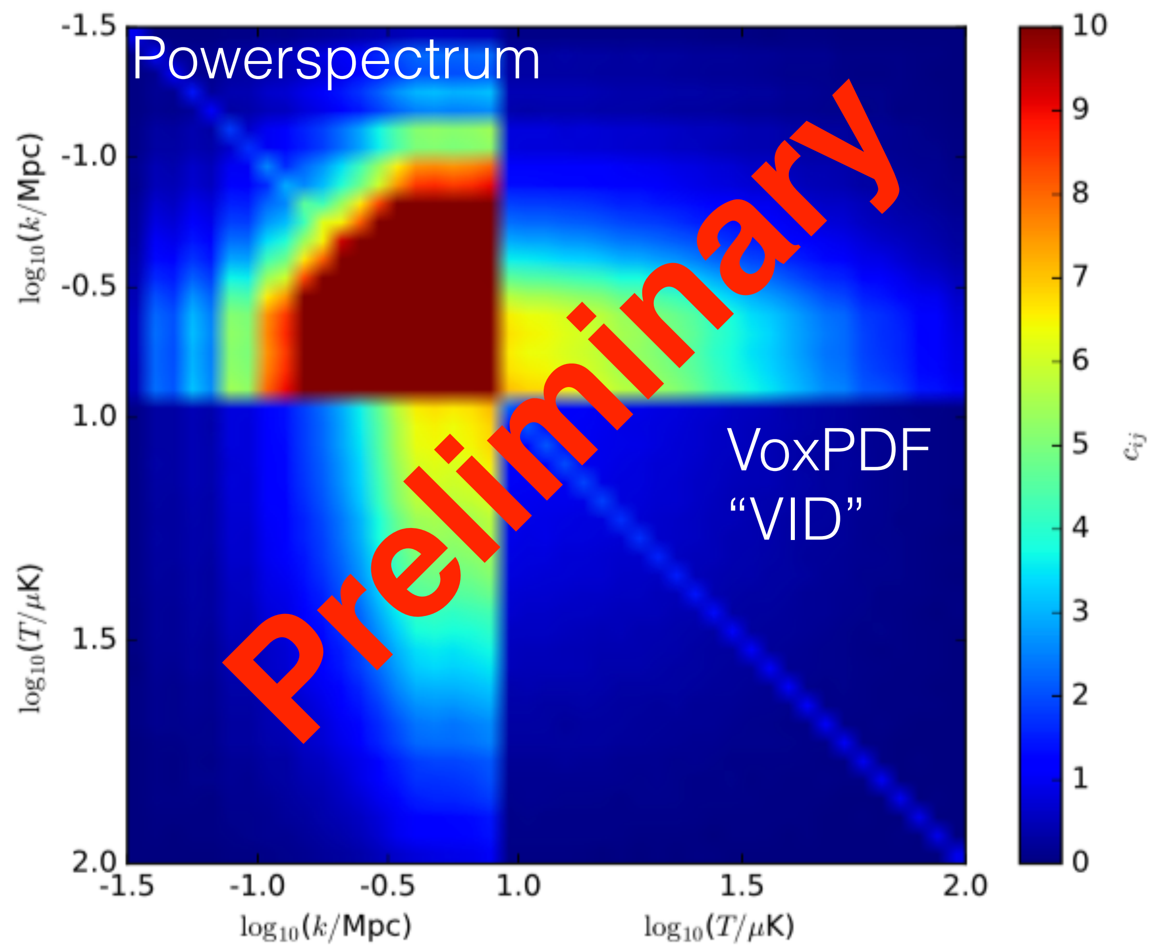
"VID Analysis for COMAP"
- in prep. w/ **Håvard Tveit Ihle,** Dongwoo Chung

$$M, z \rightarrow SFR \rightarrow L_{IR} \rightarrow L_{CO}$$

Li et al. 2016 Model

Normalized Covariance Matrix using 6000 Peak Patch Mocks of the full COMAP volume

- $(1140\mathrm{Mpc})^3$, 4096^3 resolution
- ~ 1000 core hours
- 200 runs



More Peak Patch CO at:
Line-Intensity Mapping: 2017 Status Report, arxiv:1709.09066

Euclid, CMB-s4, COMAP, CHIME, CCAT-p, …
All Require Mocks

Sims being used for AdvACT, SO, CMB-S4, Euclid, CHIME, COMAP

“Forward Modelling” from ICs works well

*for certain problems

LPT + Ellipsoidal Collapse = Peak Patch Approach

Matches well with N-body at HMF, 2point, x, visual, ++

- Covariance Matrix Estimation
- CMB weak lensing
- High res lensing?
- Intensity mapping mocks
- Primordial NG
- Mod-G?

Further Work

- Covariance matrix for different cosmological models + BSM? Or is standard LCDM enough?
- Add in BSM Physics
- We measure susceptibilities in gas/DM, is it good enough?
- halo catalogues => galaxy catalogues?