Touching cosmic web DM with gravitational lensing?

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On the wall of my bedroom at Munger residence

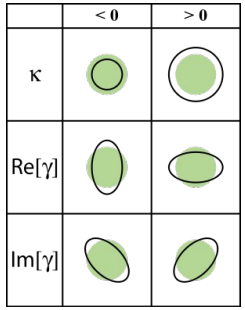
Galaxy/web cross-talk calls for a direct probe of DM scaffolding : Lensing

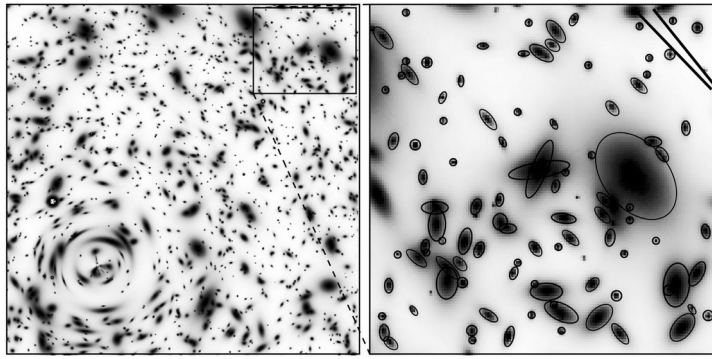
- **A direct view of the web, irrespective of galaxy bias is desirable**
  - Lensing could help lift growth rate / bias degeneracy in cosmic web studies just like it already does in 3x2pt statistics? [eg Judith's talk]
  - Lensing always brings information if bias model has enough degrees of freedom
  - Intrinsic alignments (IA) of galaxies is a web-dependent nuisance for 2-pt (and higher order) statistics that we ought to understand better
- **Small scale weak and strong lensing can probe shape of halos**
  - Differences with lights on smaller scales… (De)coupling between galaxy shape (spin/inertia) and halo shape with radius. Useful for IA.
- **More questions than results in this program!**

How easy is it with weak lensing?

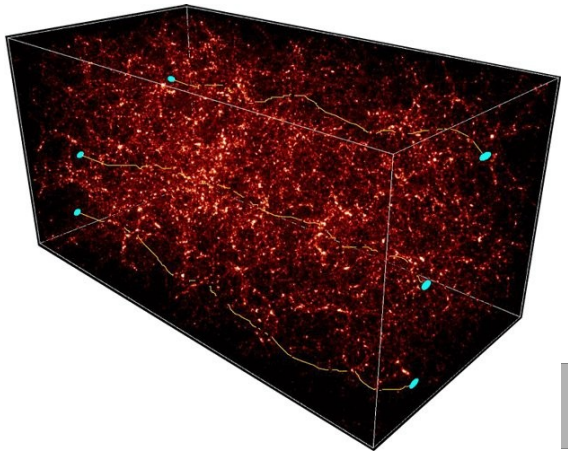
$$\psi(\boldsymbol{r}) = \frac{2}{c^2}\frac{D_\mathrm{l} D_\mathrm{ls}}{D_\mathrm{s}} \int \mathrm{d}z\, \Phi(\boldsymbol{r}, z),$$

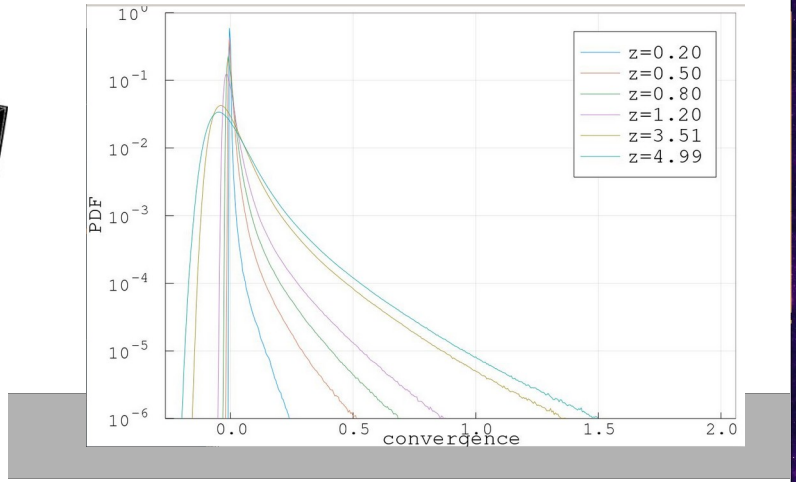
$$\begin{aligned} 2\kappa &= \psi_{,11} + \psi_{,22}, \\ 2\gamma_1 &= \psi_{,11} - \psi_{,22}, \\ \gamma_2 &= \psi_{,12}. \end{aligned}$$

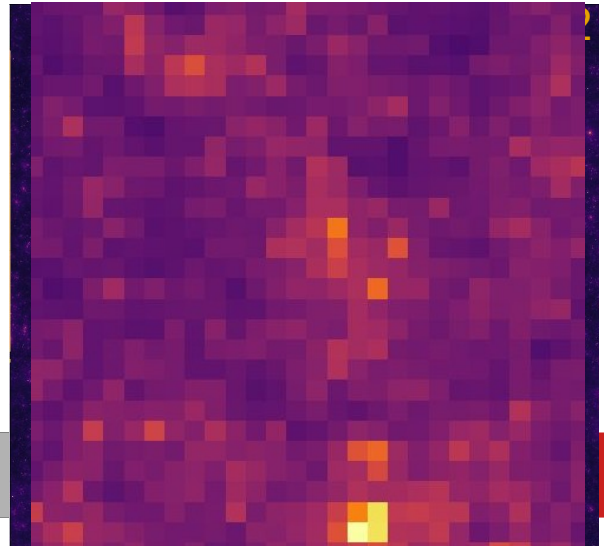




Broad projection: non-gaussianity is damped and anisotropy average out







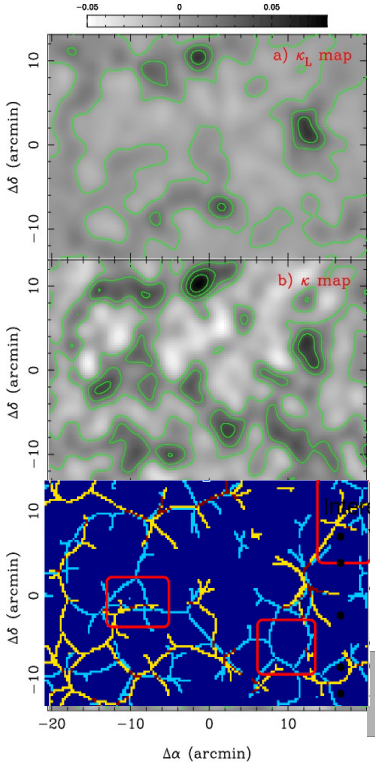
Different ways to go about signal extraction

Mapping “super clusters”

MS0302+17 (Gavazzi++04, Kaiser98)

(See also A901/A902, Gray++03)

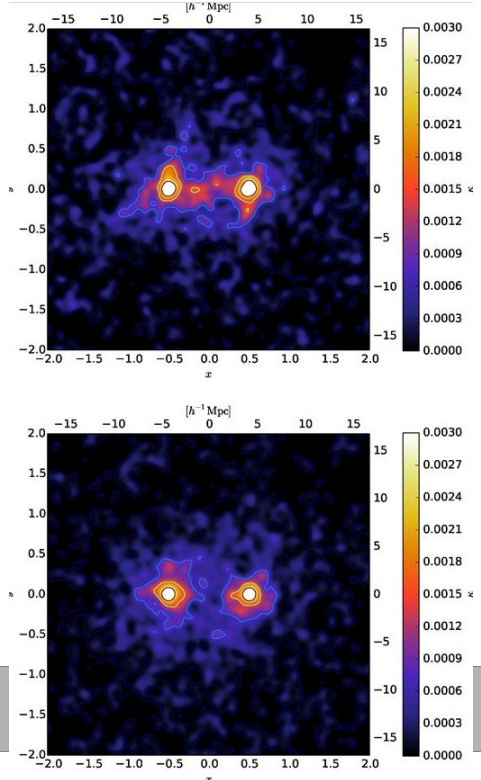
A222/A223, Dietrich++12



Stack lensing by galaxy pairs

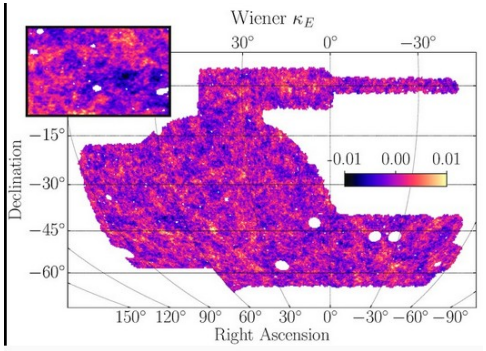
Epps&Hudson17, 23000 z~0.4 BOSS LRG pairs in CFHTLS footprint.

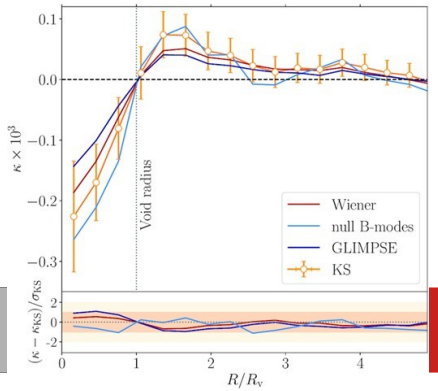
(Clampitt++14, Simon++12,19)



Large scale maps

DES Y3, Jeffrey++21 photo-z voids





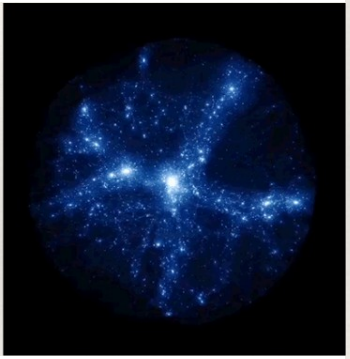
Multipolar moments of convergence around clusters

C. Gouin et la 2017

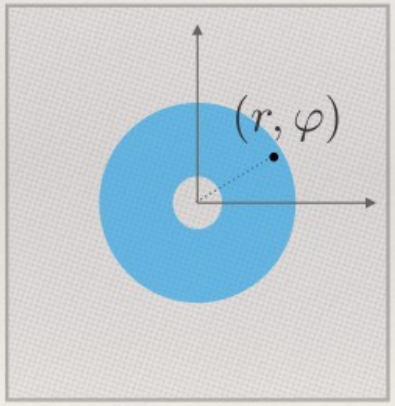
- **Connectivity of clusters**
  - Predictions exist in 3D (Codis++17,18)
  - where lensing signal should be stronger

- **Can lensing probe counterpart of filaments along azimuth near clusters?**
  - Lensing study of moments for WL in N-body sim
  - Rich follow-up work on hydro-sims and galaxy catalogs [not in this talk] (Gouin++20,21)

Multipolar moments of convergence around clusters



Aperture multipole moments of the projected density (Schneider & Bartelmann,1997)



Projected plane

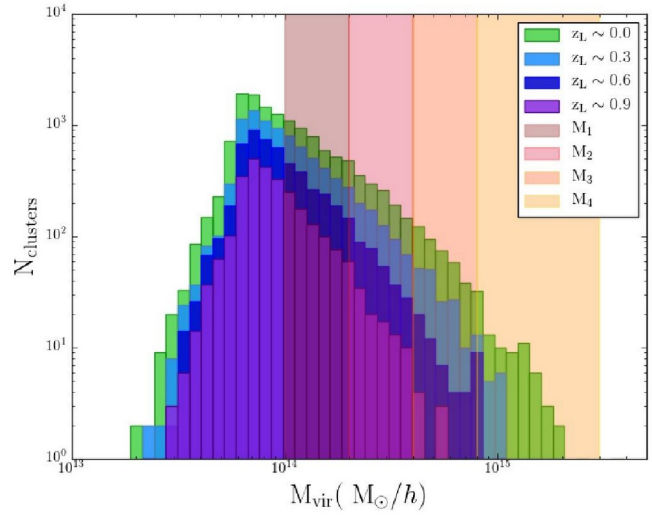
$$Q_m = \int_{r_{min}}^{r_{max}} dr\ r^{m+1}\ w_m(r) \int d\varphi\ e^{im\varphi}\ \Sigma(r, \varphi)$$

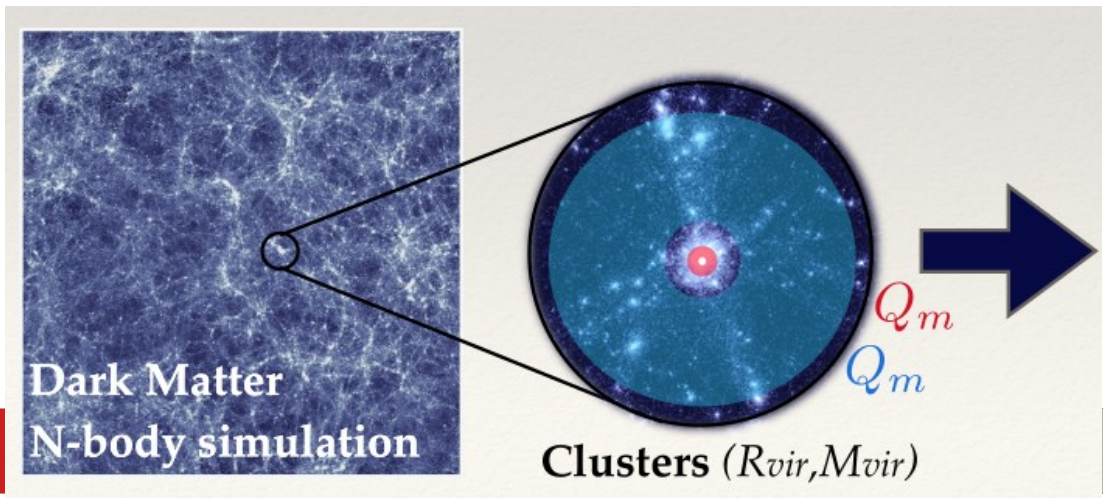
Aperture Radial weight function $w_m(r)$ **Projected density**

Multipole order m

Multipolar moments of convergence around clusters

- **Extract cluster halos in N-body sim**
  - PLUS simulation (Peirani++): 2048^3, 600 Mpc/h, 10 Mpc spheres
  - 10^4 clusters $M_{vir}>10^{14}$ M_{sun}, 4 epochs.
- **Project density onto sky along 3 directions**
- **Compute multipolar moments Q_m of surface density**
  - inside different annuli: R_1=[0.25-0.5] R_{vir} and R_4=[1.0-4.0] R_{vir}
- **Stack the modulus of $|Q_m|$**

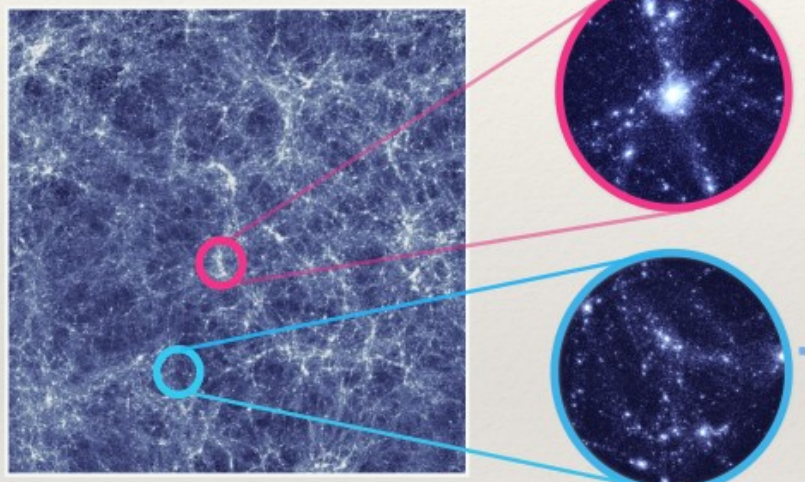


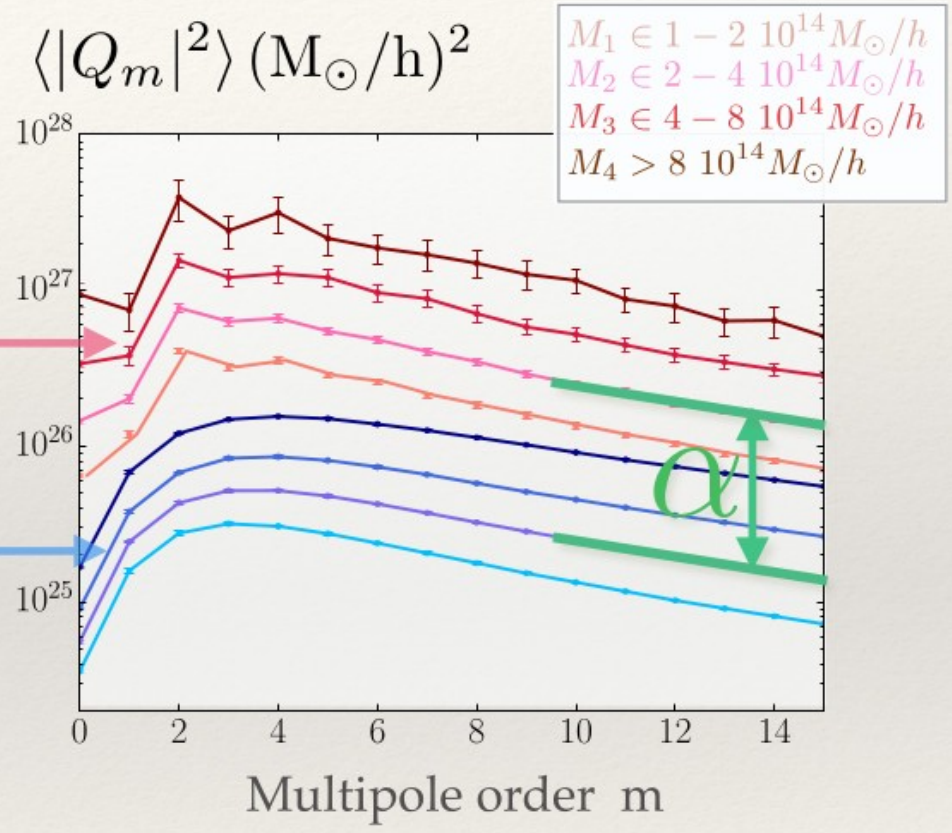


$$\langle |Q_m|^2 \rangle = \frac{1}{N_{clusters}} \sum_i |Q_m|_i^2$$

Multipolar moments of convergence around clusters

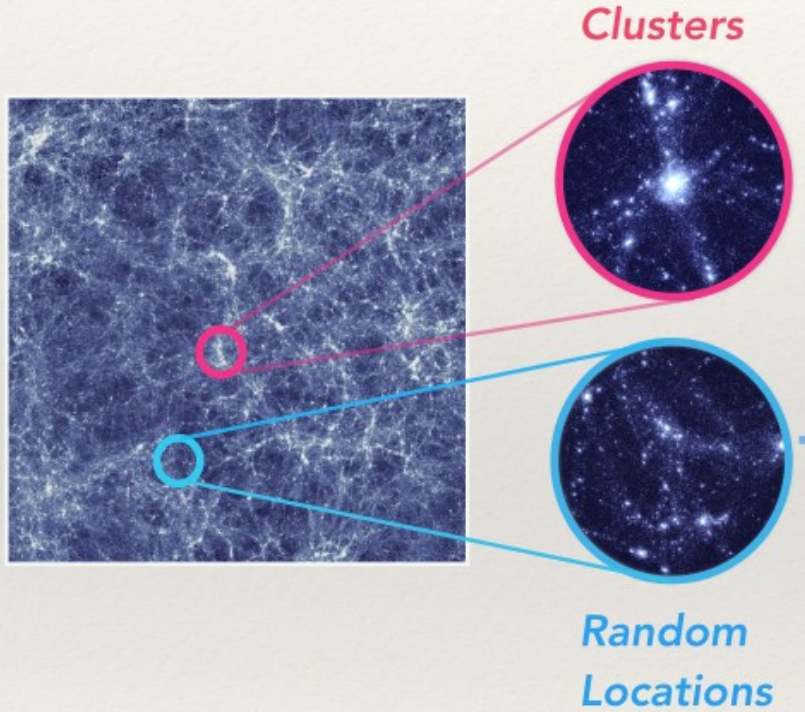
At z~0, for the annulus R_4=[1-4] Rvir

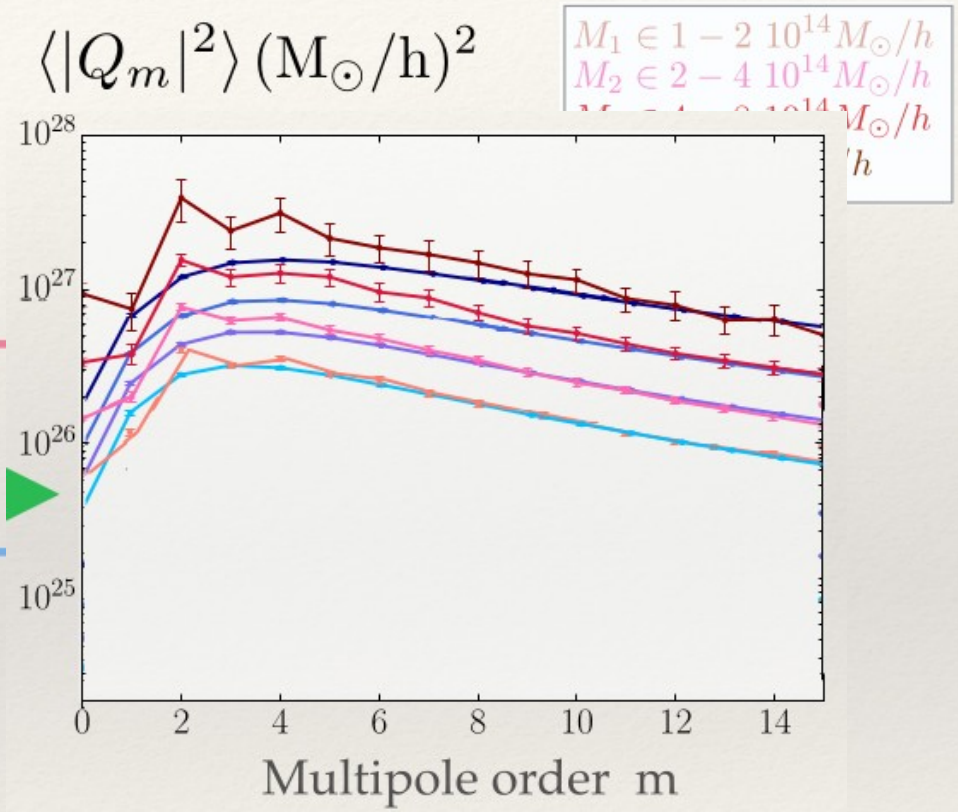




Multipolar moments of convergence around clusters

At z~0, for the annulus R_4=[1-4] Rvir





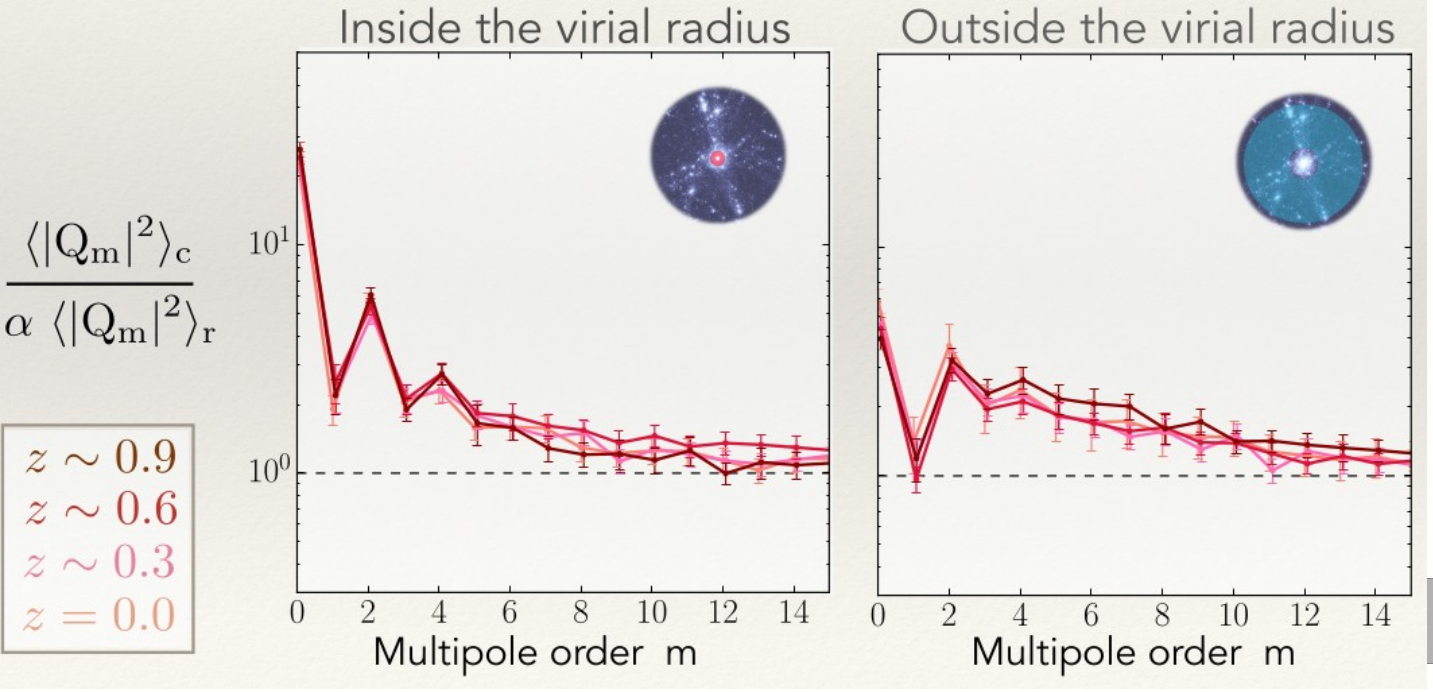
Time evolution of multipolar moments

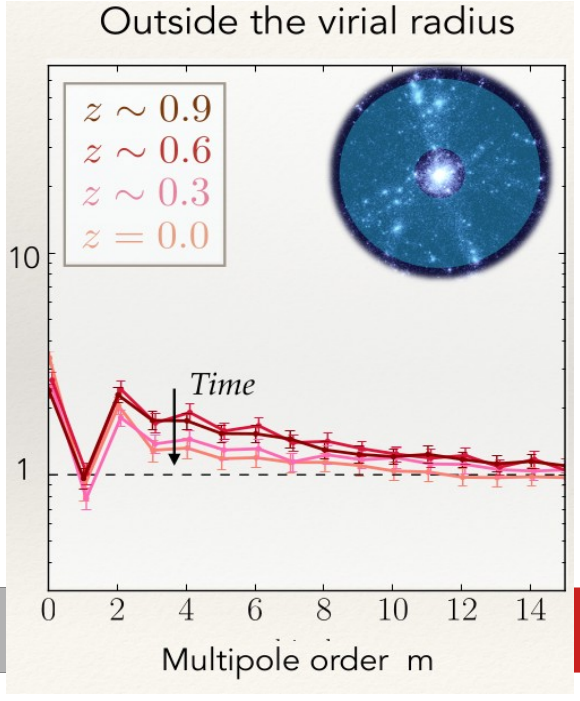
100 most massive (10^{15})

- Moments are frozen from initial conditions (growth absorbed by boost)
- Depletion of odd m (centered peak constraint)
- Inside, m=2 prevails, outside more power at m>2 due to bifurcations (Pogosyan++09, Pichon++10)

300 least massive (10^{14})

- Less power at m>2
- Disconnection with time





Can a

15 000 deg^2, 3

1 single M-

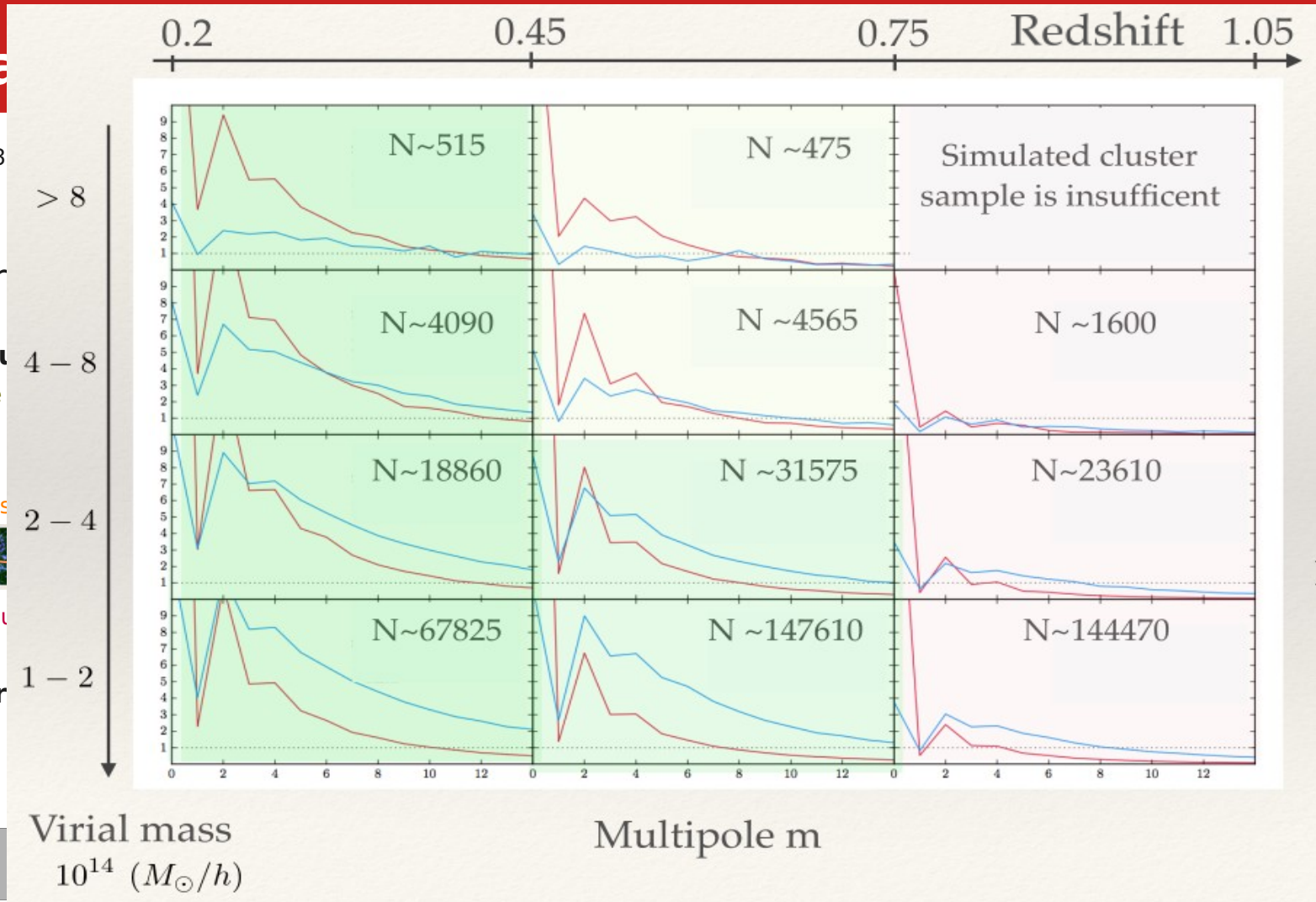
Various sou

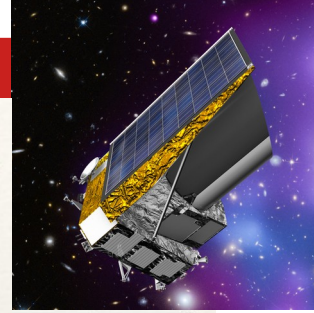
- Shape noise

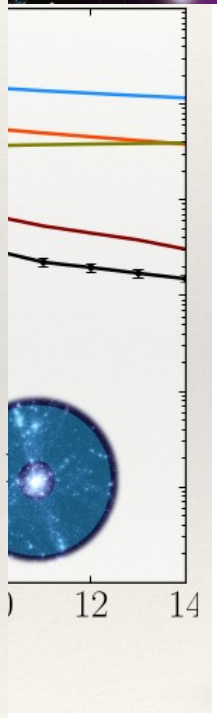
- Large scale s

- Cluster-to-clu

Stacking is r







Conclusion

- **Weak lensing can probe DM content of the cosmic!**
- **Multipolar moments of the shear/convergence understood and can be measured with upcoming Euclid**
- **TBD: Cross-correlation of moments of galaxy distribution** $\langle Q_m G_n \rangle$
  - Higher SNR than auto-spectrum of Q_m moments. Accessible with current data!
  - As a function of galaxy type: special biasing conditions!

- **Eager to talk about strong & weak lensing on smaller scales**
  - Orientation stellar component / DM and withing cosmic web
  - Ray-tracing Horizon-AGN: caustic patterns, external convergence/shear,

Questions?


THAT CONCLUDES MY TWO-HOUR PRESENTATION. ANY QUESTIONS?
DID YOU INTEND THE PRESENTATION TO BE INCOMPREHENSIBLE, OR DO YOU HAVE SOME SORT OF RARE "POWERPOINT" DISABILITY?
ARE THERE ANY QUESTIONS ABOUT THE CONTENT?
THERE WAS CONTENT?
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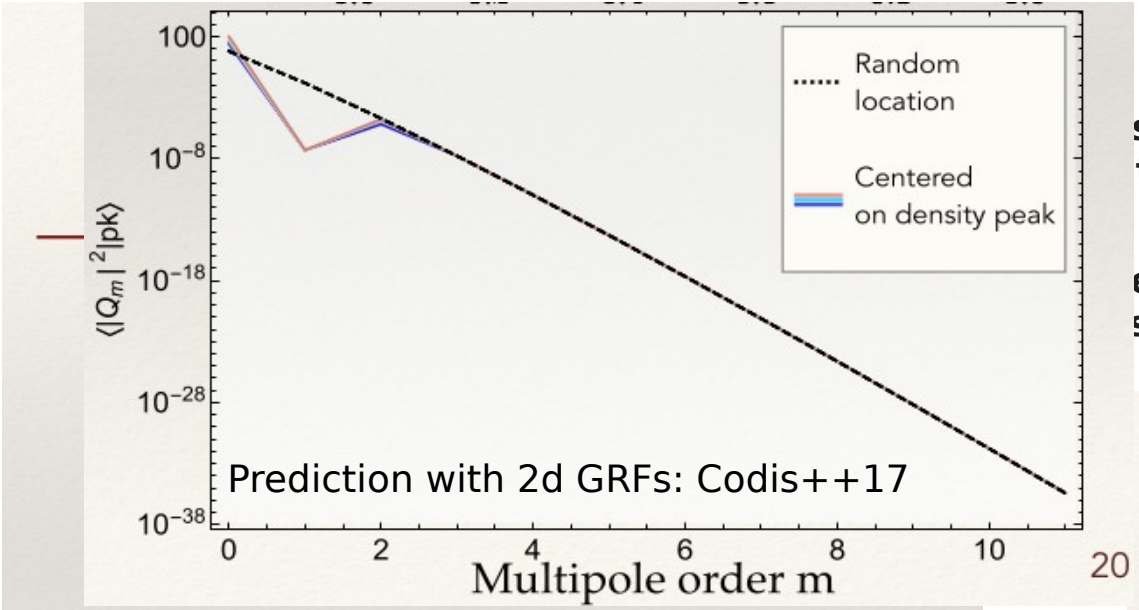
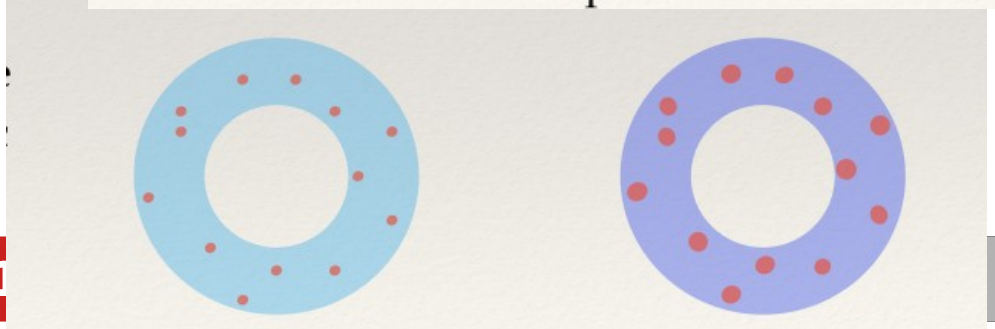
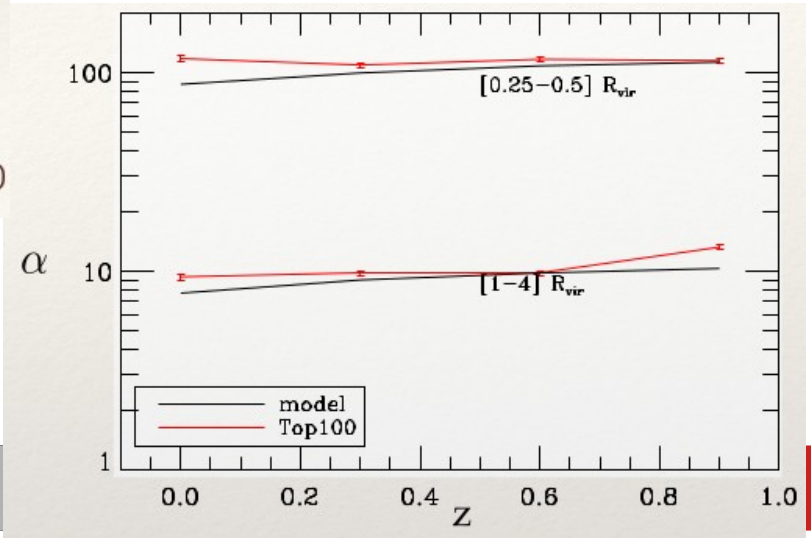
Explaining the overall constant high-order boost



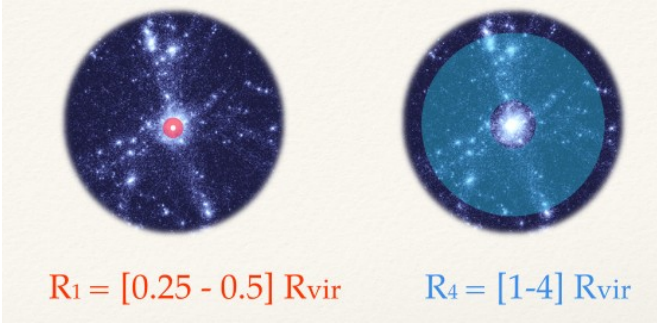


shells of same size at z=0, had different
s at early time near peak or at random
tion.

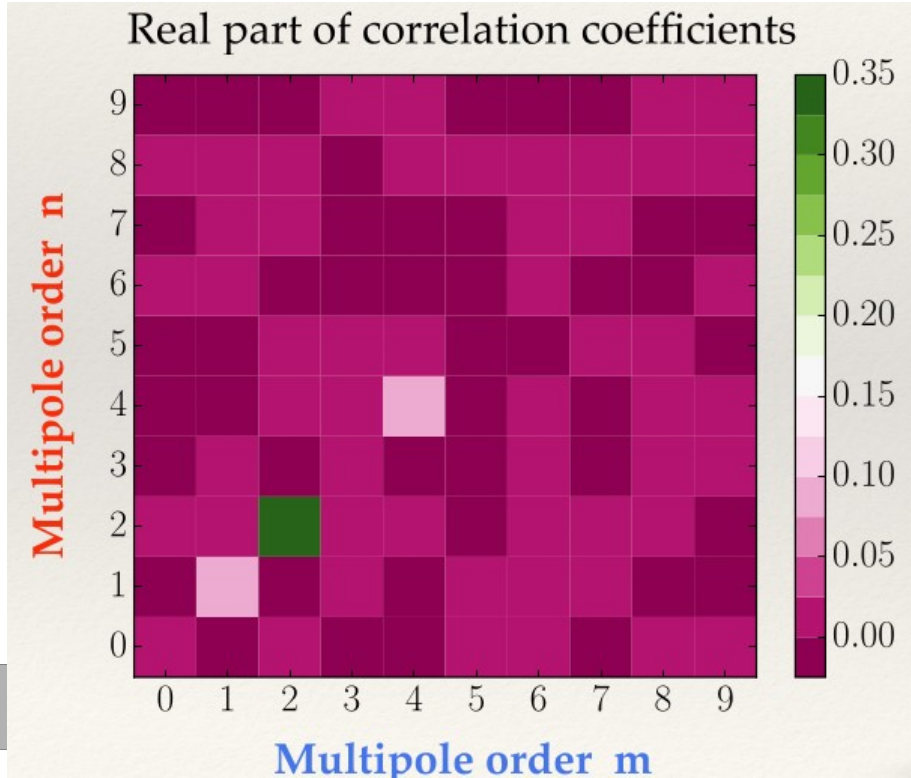
erical collapse (→ NFW profile) boosts
sity of sub-halos!



Radial correlation of multipolar moments

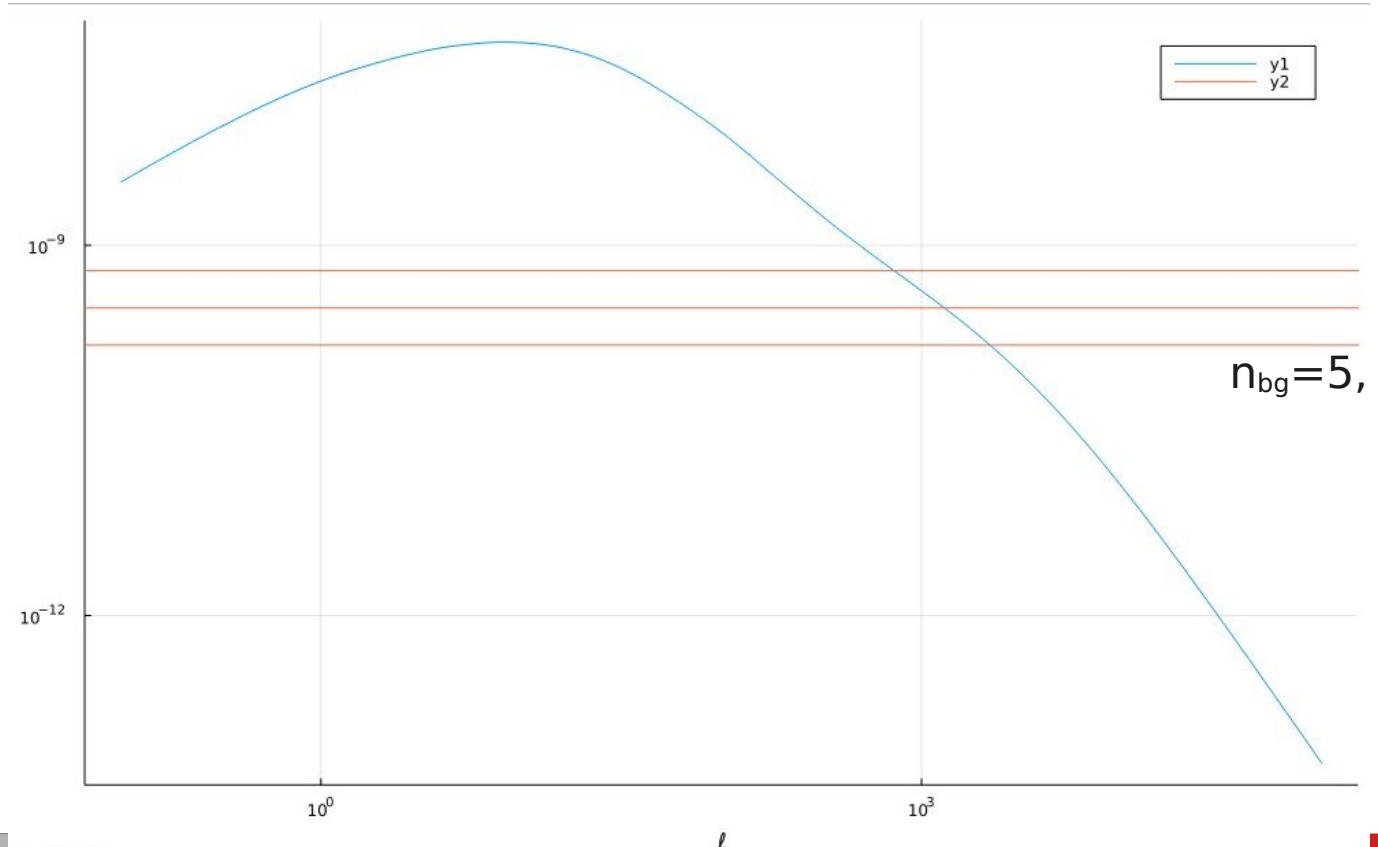


$$\rho_{1,4}(m,n) = \frac{\langle Qm(R1)\ Qn(R4)\rangle}{\sigma_{Qm}(R1)\ \sigma_{Qn}(R4)}$$



Two filaments are connected to the node on small scales. Away from the node, bifurcation points appear and increase filament numbers (Pogogsyan et al, 2009)

Convergence power-spectrum at zs=1.1



n_{bg}=5, 20, 80 arcmin^{-2}