

Intrinsic galaxy alignments and the cosmic web

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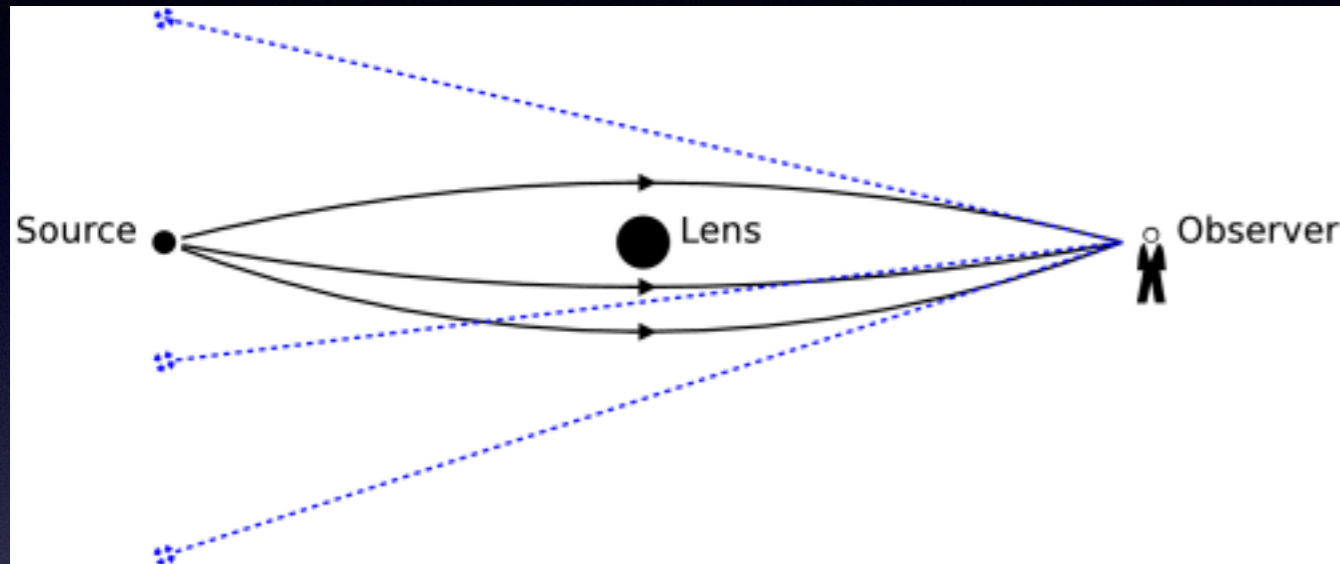
9/10/2015

Outline

(Or, *A Tale of Two Grad Students?*)

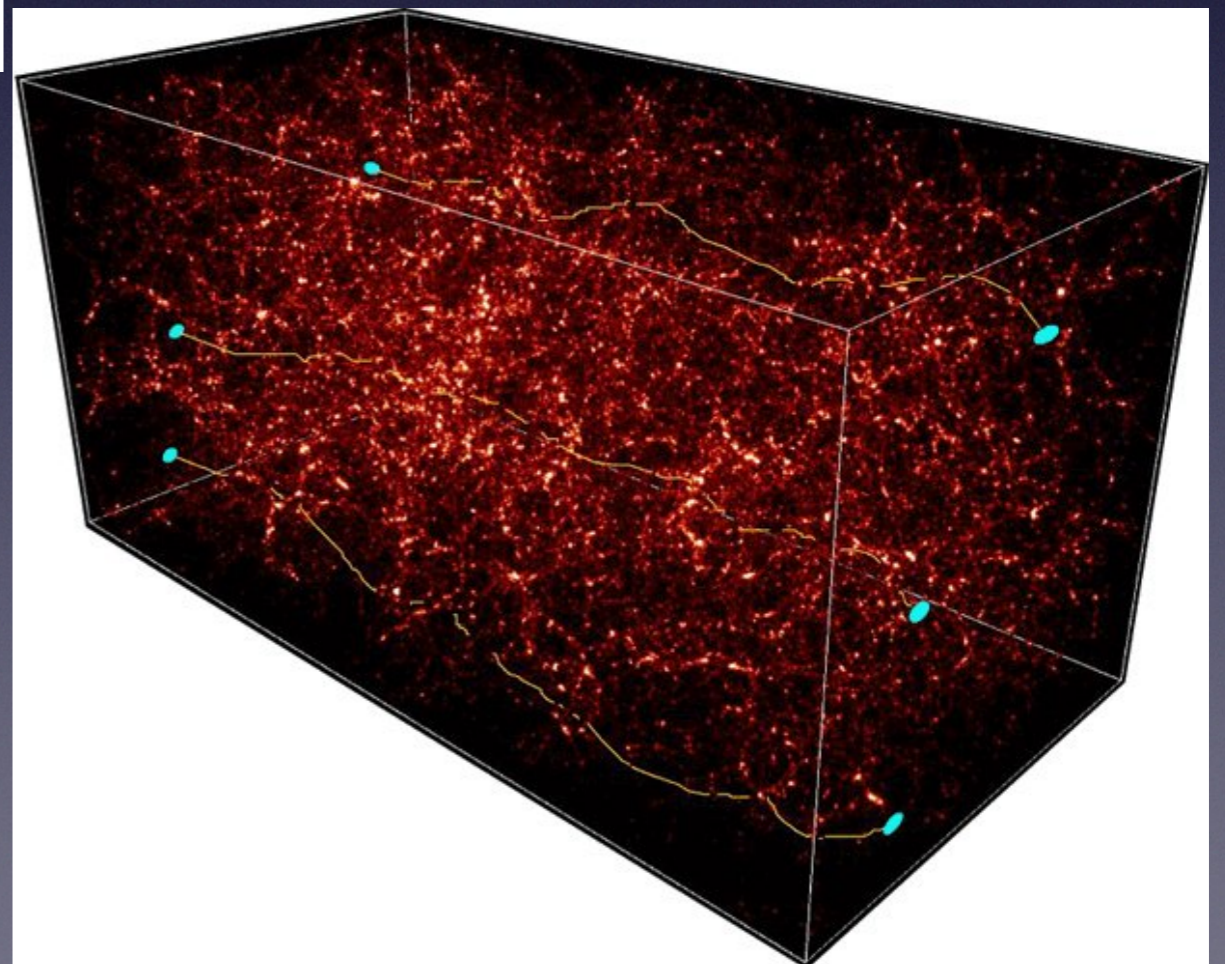
- Intro: what are intrinsic alignments and why we care about them
- Recent observational constraints
 - S. Singh, RM, S. More (2015), MNRAS 450, 2195
- Recent numerical predictions
 - A. Tenneti, RM et al., 2014, MNRAS, 441, 470
 - A. Tenneti, S. Singh, RM et al., 2015, MNRAS, 448, 3522

Gravitational lensing



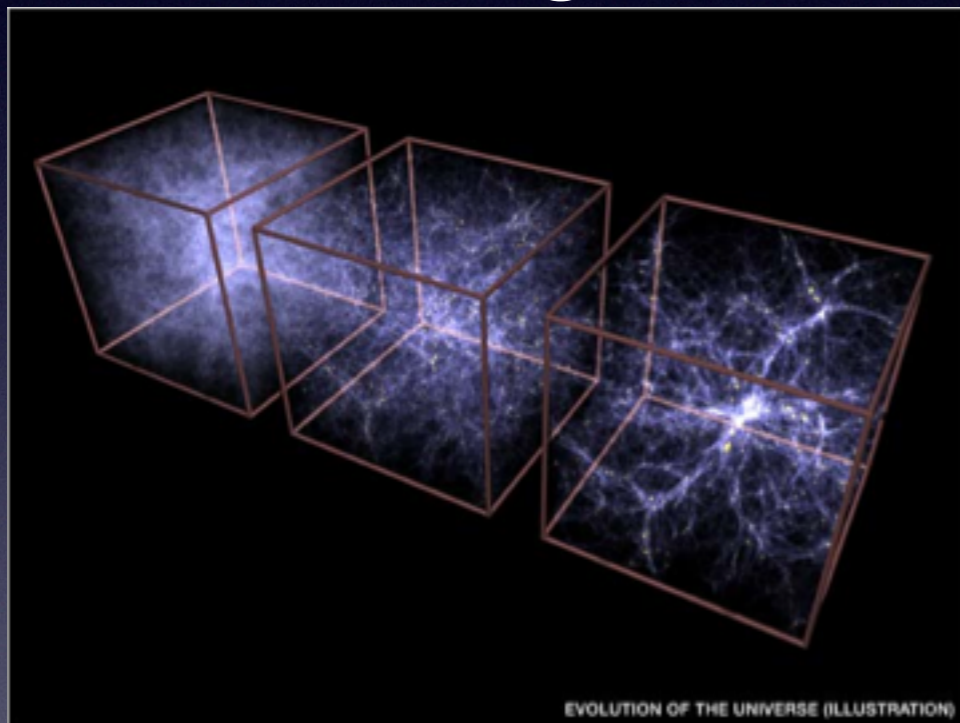
Strong:
multiple images

Weak: slight shape distortion
and magnification

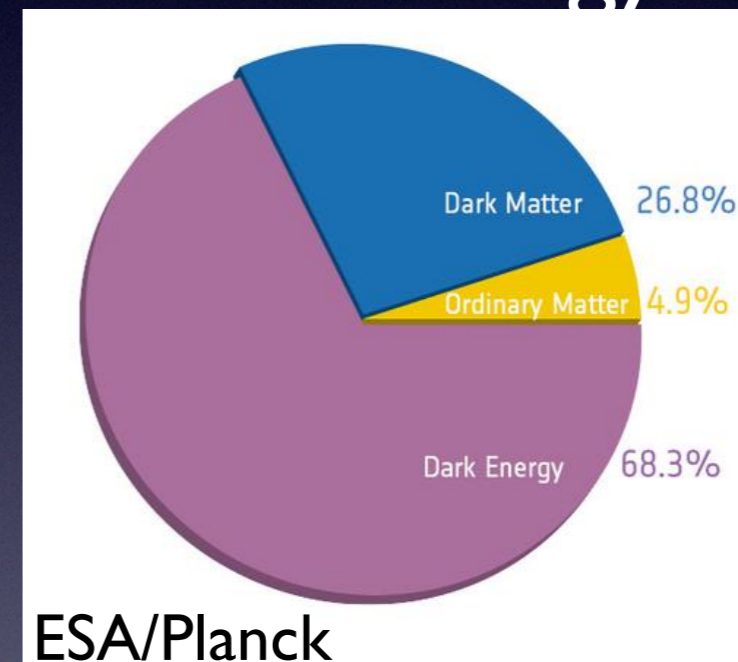


Why should you care about weak lensing?

Structure growth!



Dark matter and dark energy!



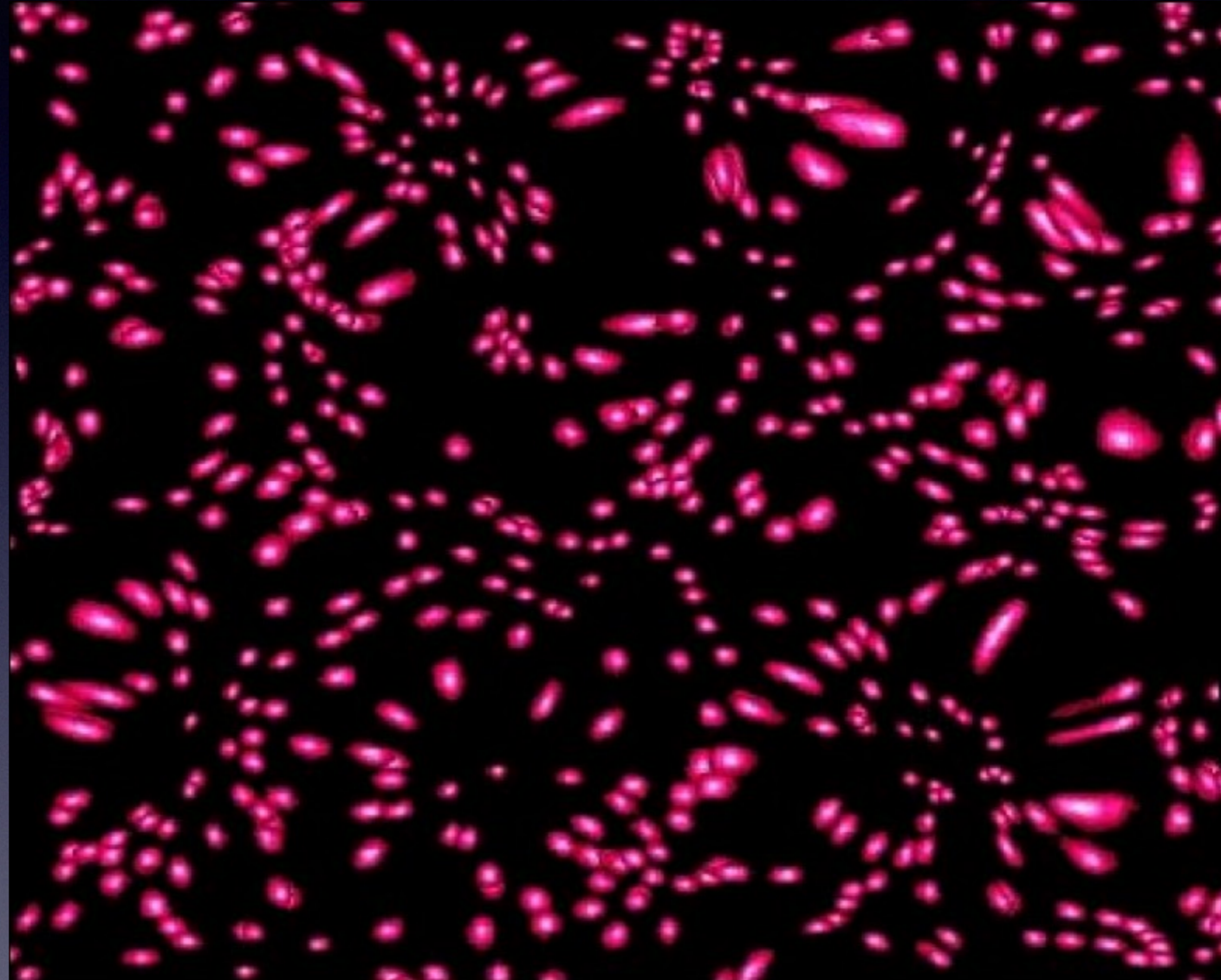
Theory of gravity!

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = 8\pi GT_{\mu\nu}$$



Galaxy-dark matter connection!

A lensing measurement (schematically)

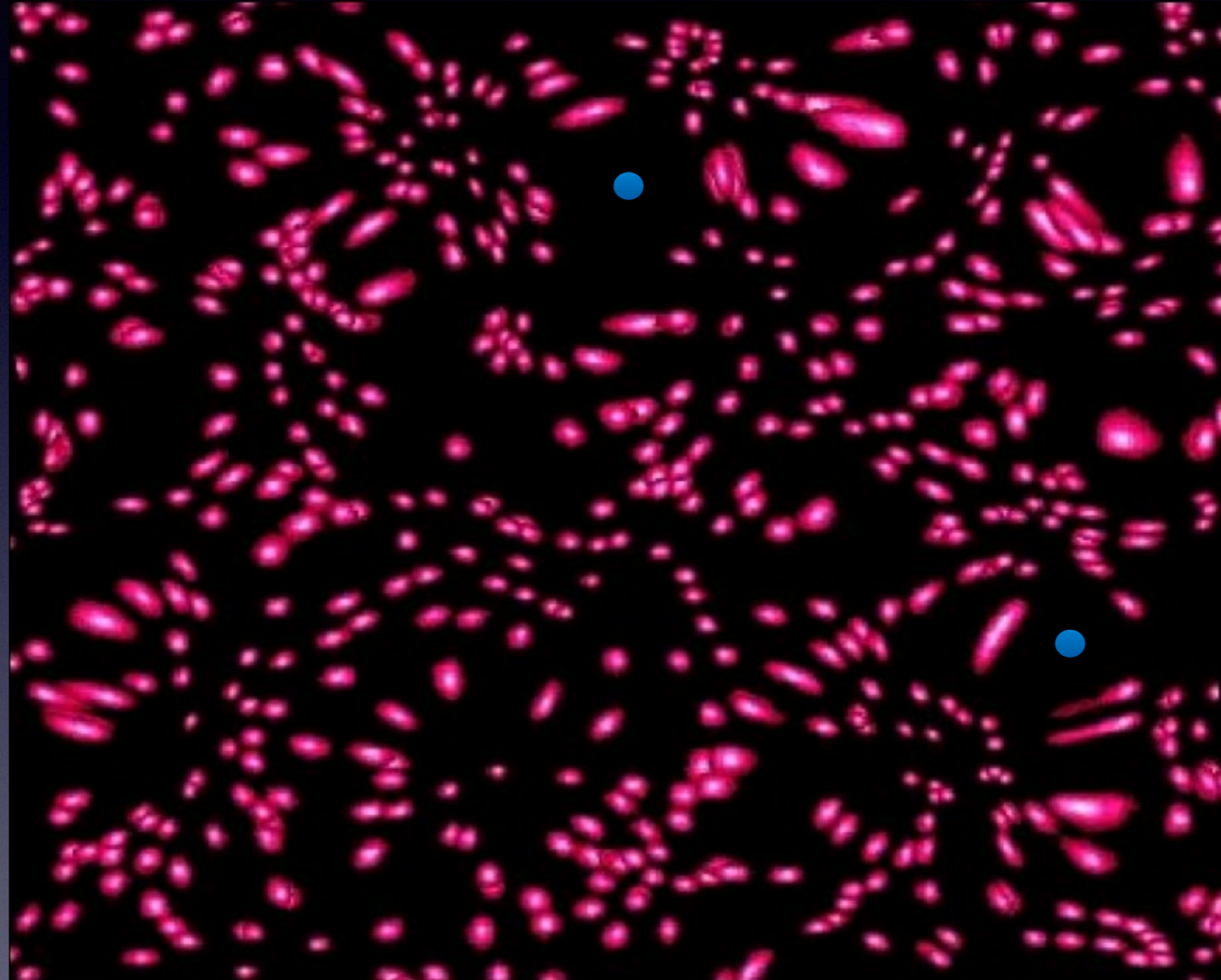


Coherent shape-shape alignments

OR

Coherent foreground position-background shape alignments

A lensing measurement (schematically)



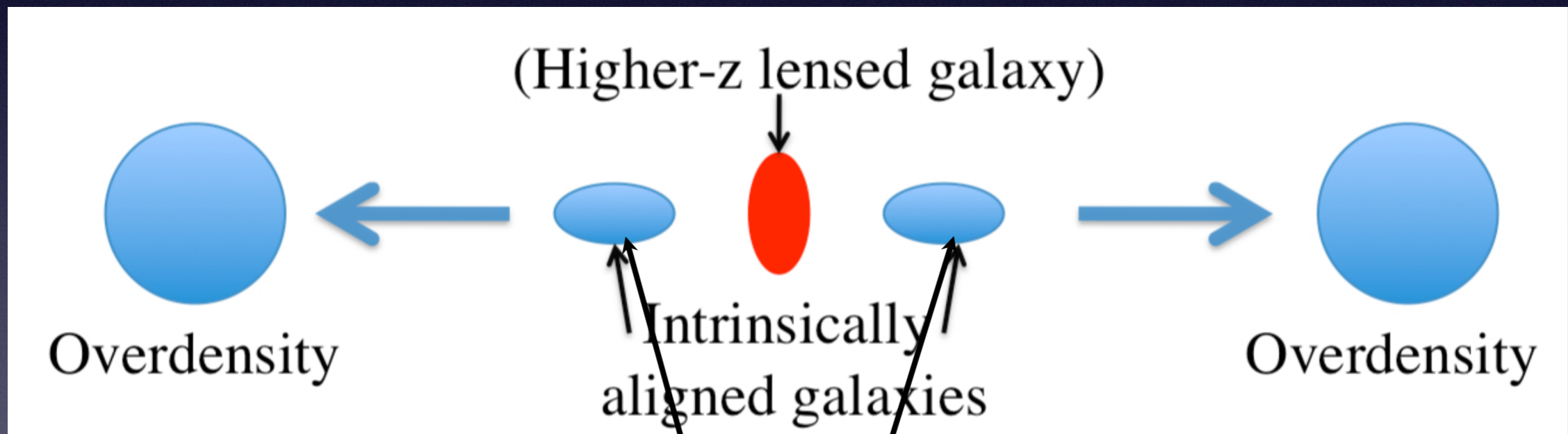
Coherent shape-shape alignments

OR

Coherent foreground position-background shape alignments

Intrinsic alignments

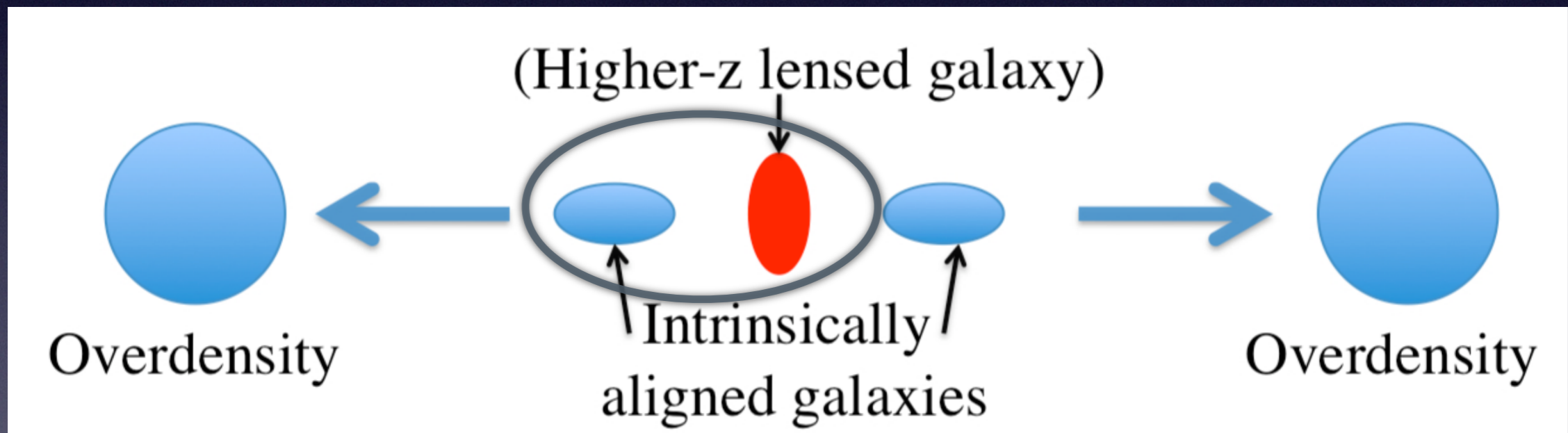
Coherent shape alignments due to localized effects (< 100 Mpc) rather than lensing



Correlate these: “I” term
(intrinsic shear - intrinsic shear)

Intrinsic alignments

Coherent shape alignments due to localized effects (< 100 Mpc) rather than lensing



Correlate these: "GI" term
(lensing shear vs. intrinsic shear)

Spoiler alert: they are real!

- Red galaxies: numerous strong detections of large-scale (tens of Mpc) alignments between galaxy shapes and local density field
- Blue galaxies: null detections on large scales, some detections of localized spin alignments
- Satellite alignments: controversial!

Effect on lensing measurements

- Can give tens of % error on cosmological parameter estimates if ignored!
- ➔ Need to marginalize over intrinsic alignments
- ➔ We need really good models for them
 - ➔ + priors on model parameters
 - ➔ + ways of making mock datasets with complex intrinsic alignments to make sure we are really removing them

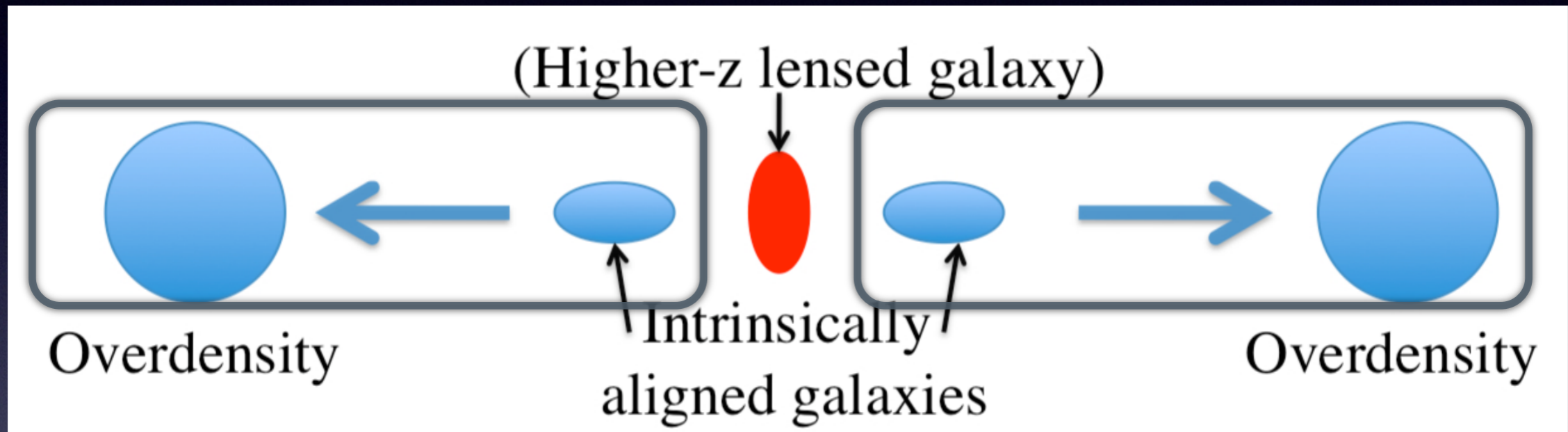
The physics: a window into galaxy formation?

- Disk galaxies
 - Connection between galaxy angular momentum and tidal quadrupole that spins up the galaxy?
- DM halo shapes and elliptical galaxy shapes
 - Tidal alignment model: triaxial halo collapse in a tidal field gives rise to alignment with the field

Recent observational constraints

S. Singh, RM, S. More (2015), MNRAS 450, 2195

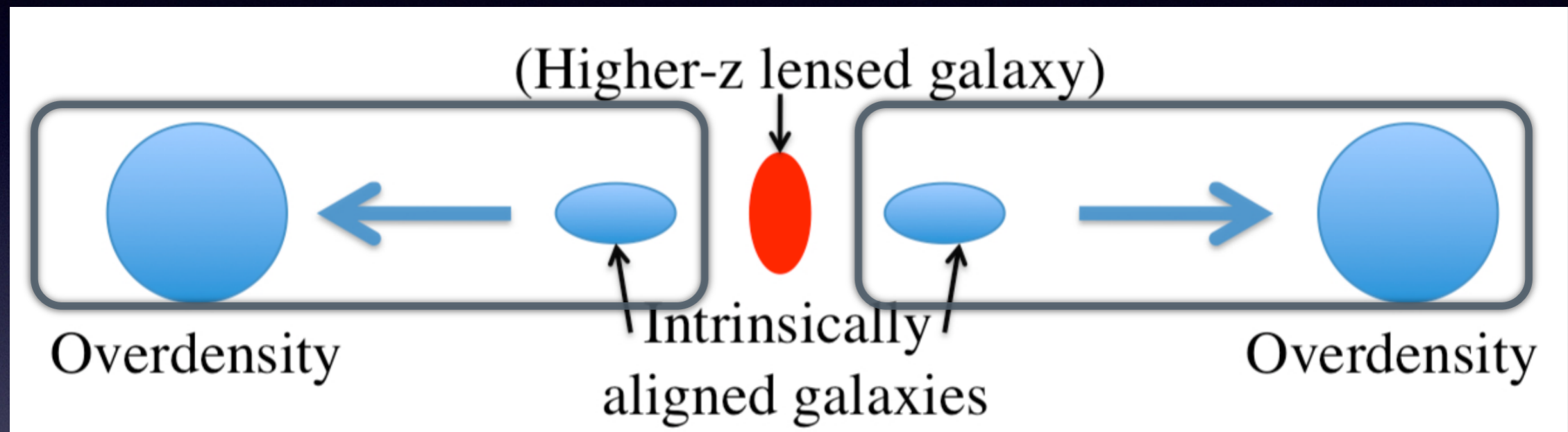
How to measure intrinsic alignments



We need:

- Galaxy shapes
- Galaxy redshifts
- A “density tracer sample” that serves as the overdensities

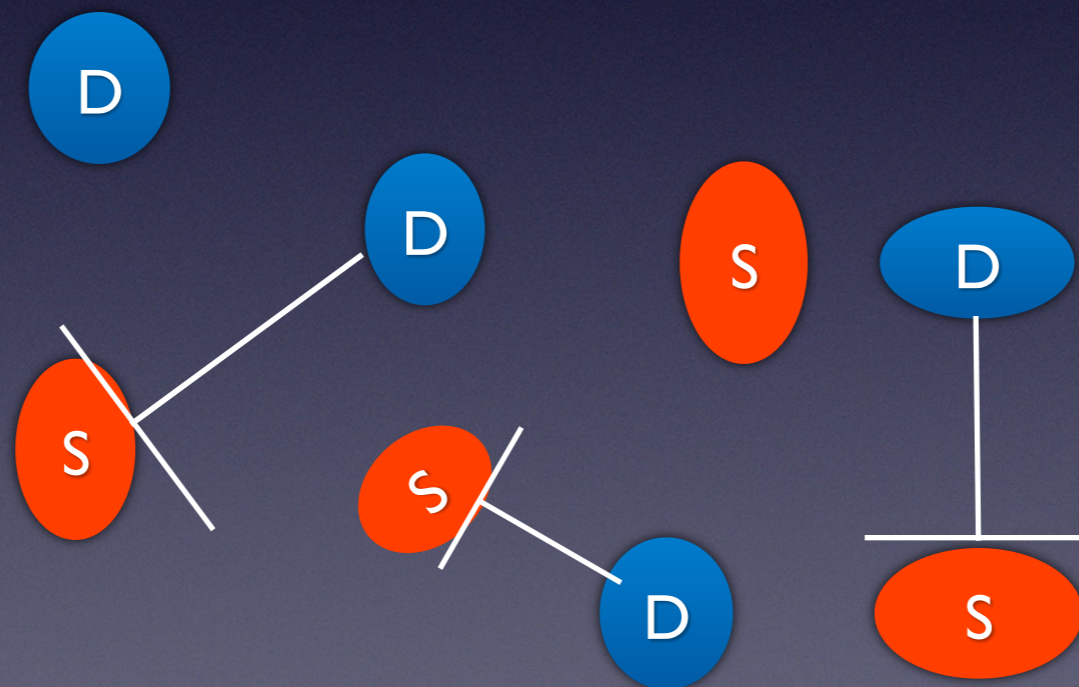
How to measure intrinsic alignments



...and enough data to beat down the noise due to mostly random component of galaxy shapes!

Density-shape correlation function

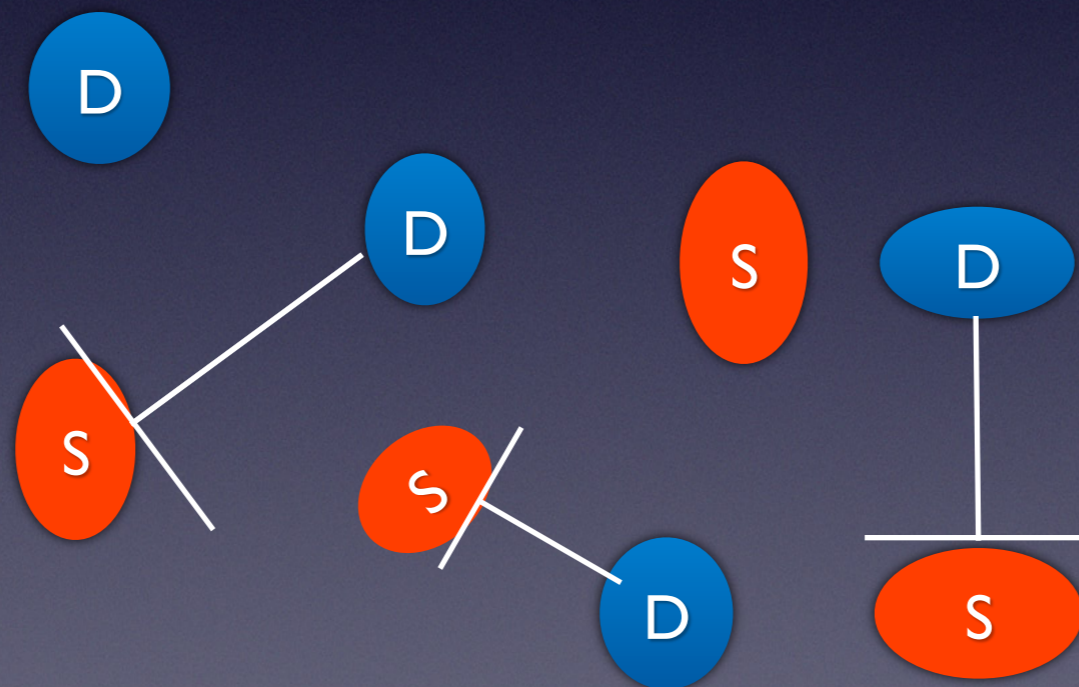
Do galaxies point towards other galaxies?



3D: Density-weighted mean intrinsic shape distortion

Density-shape correlation function

Do galaxies point towards other galaxies?



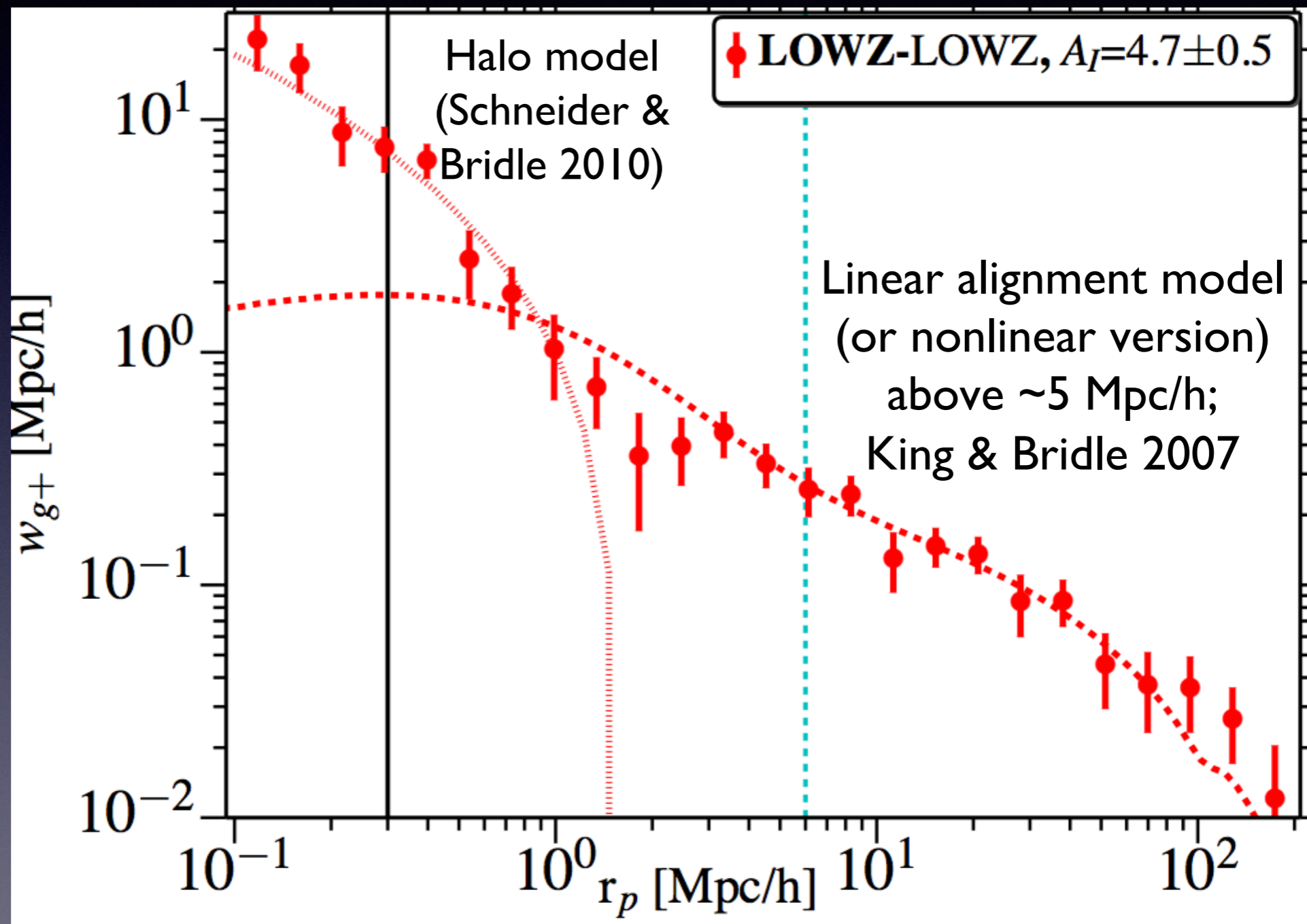
Then project to 2D along line-of-sight: w_{g+}

A few points to note...

- This is not a position angle statistic. It includes the shape of the galaxy because...
 - Errors are closer to Gaussian
 - No shape selection required
 - IA contamination to weak lensing also depends on the shape
- We are not looking at spin:
 - Early type galaxies have detectable IA and late type do not, so spin is unlikely to be the dominant factor

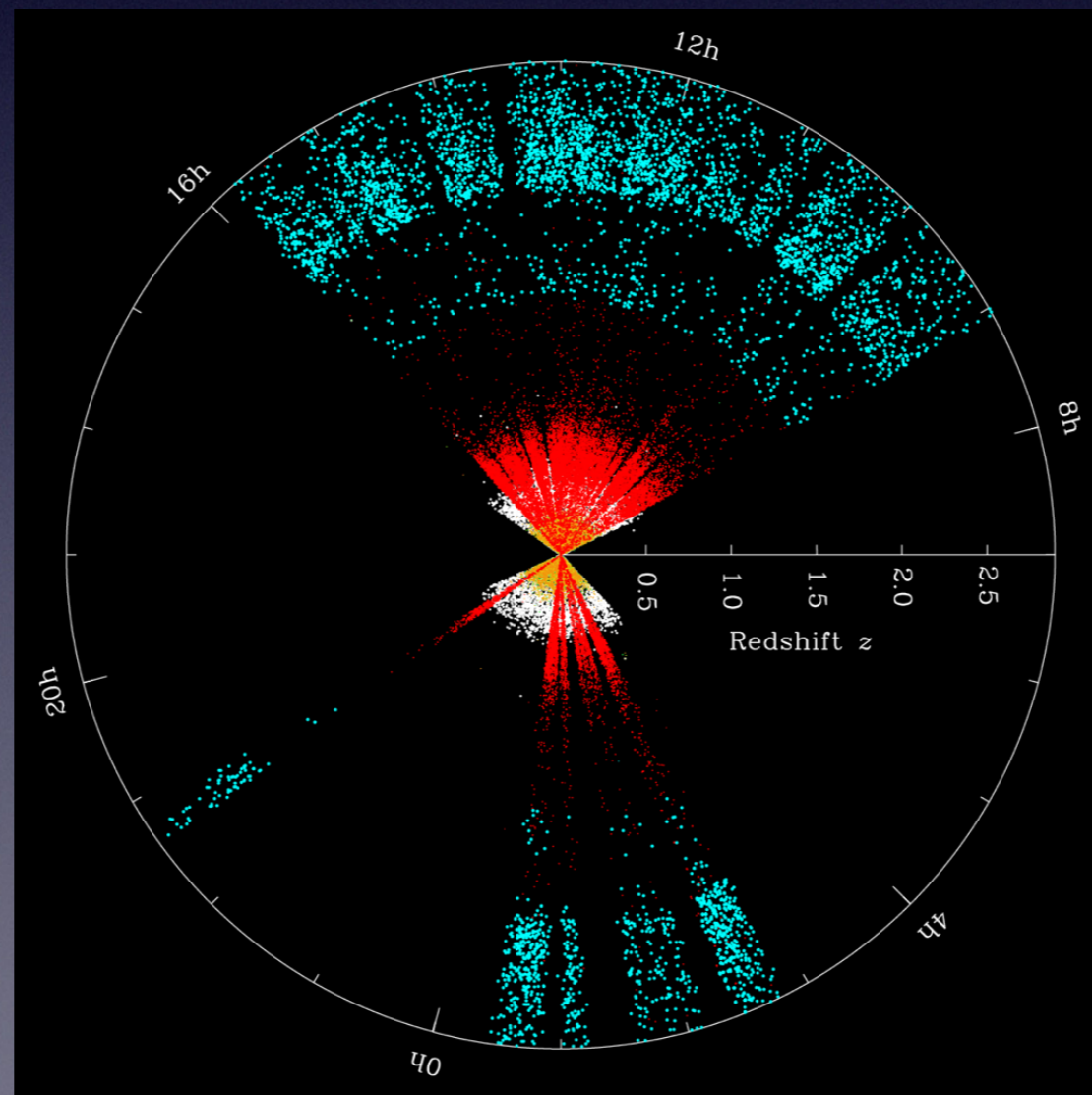
Interpretation

Density-
shape
correlation



Transverse separation

Dataset: SDSS-III BOSS LOWZ galaxies



Dataset: SDSS-III BOSS

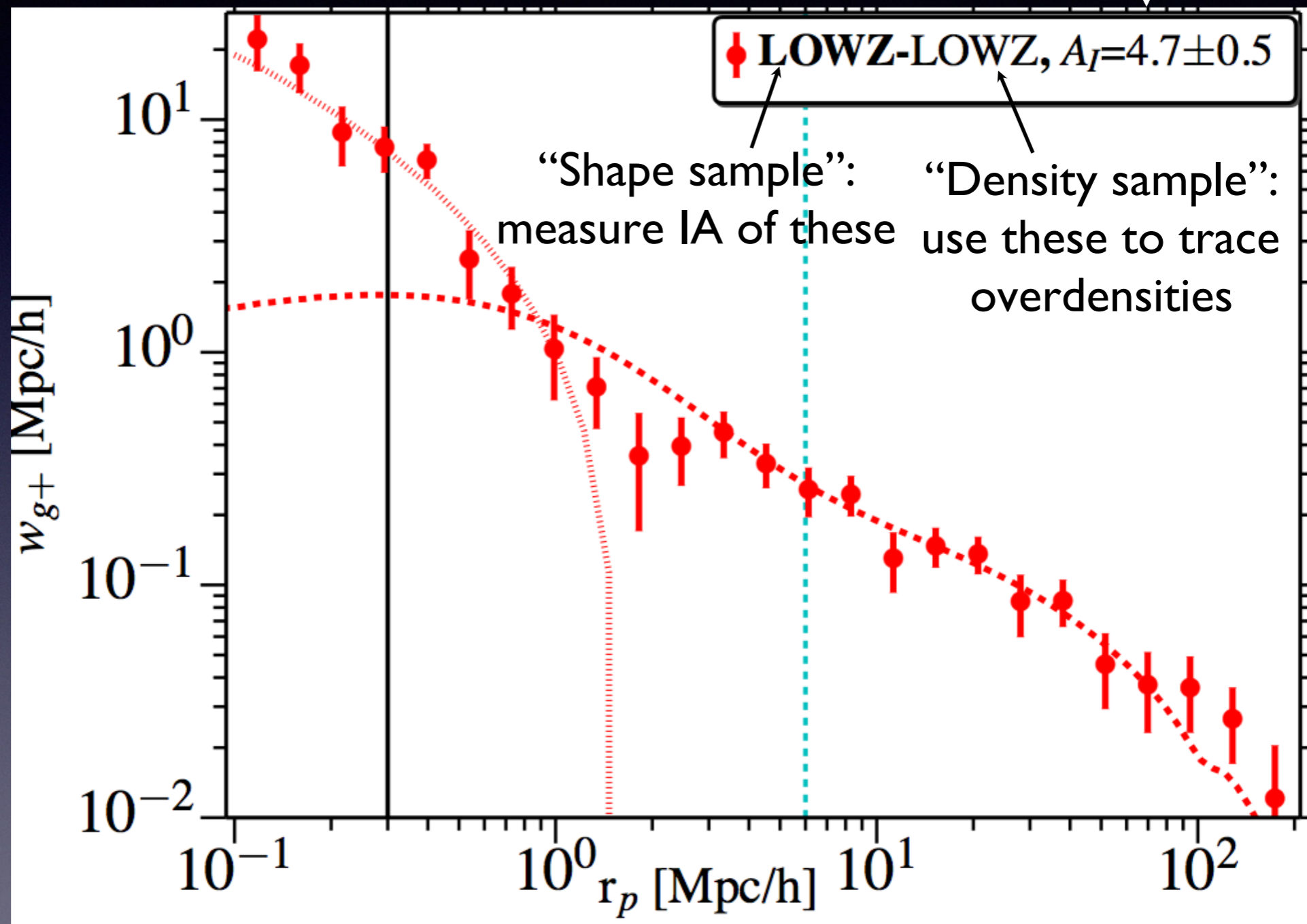
LOWZ galaxies

- Red galaxies, $0.16 < z < 0.36$
- $n = 3 \times 10^{-4} (h/\text{Mpc})^3$, $>200\text{k}$ galaxies
- Fills in a missing regime in previous measurements:
 - Lower luminosity than original SDSS LRG sample
 - Spans a range of environments

Basic measurement

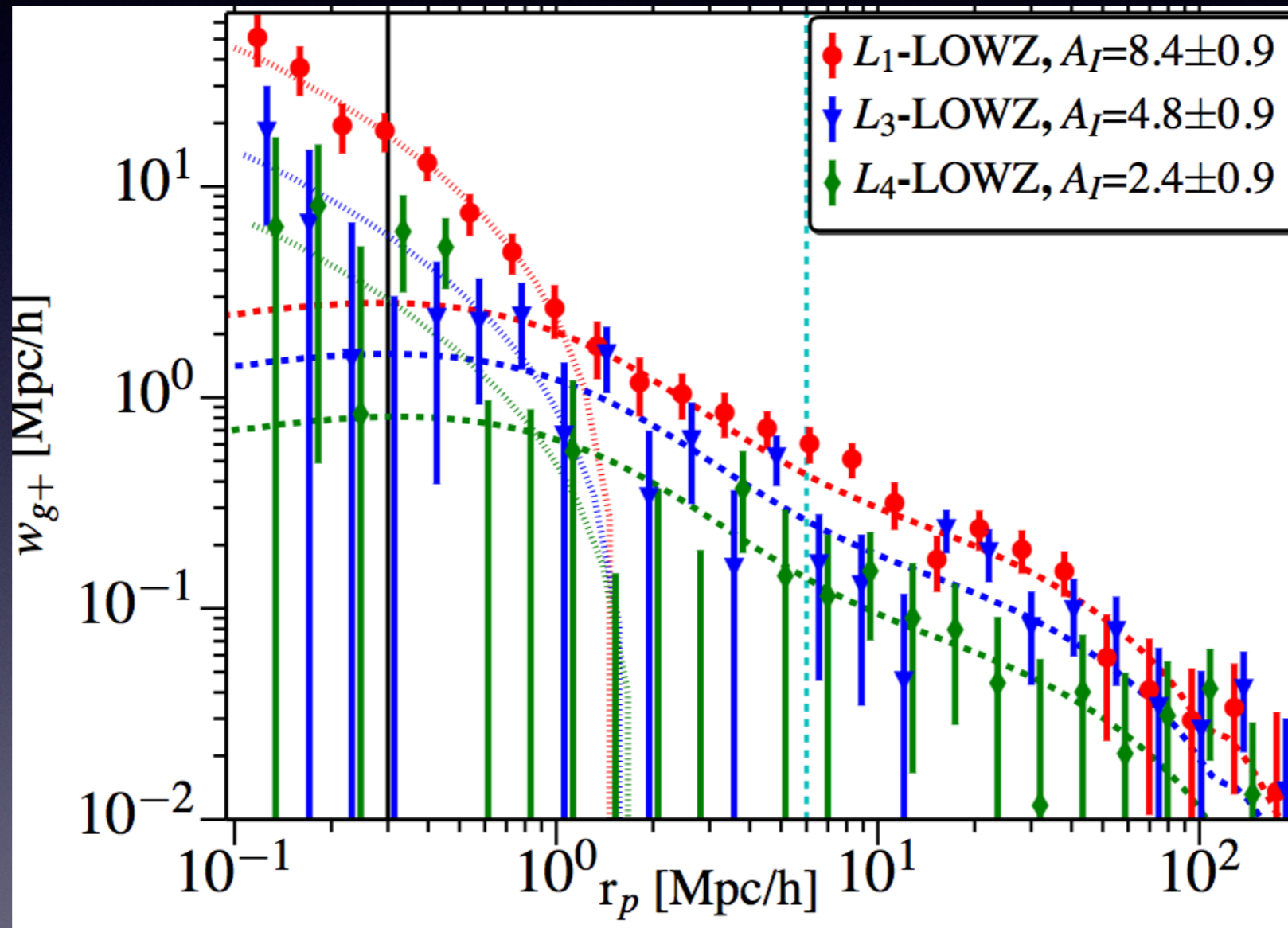
Amplitude associated with NLA model

Density-
shape
correlation



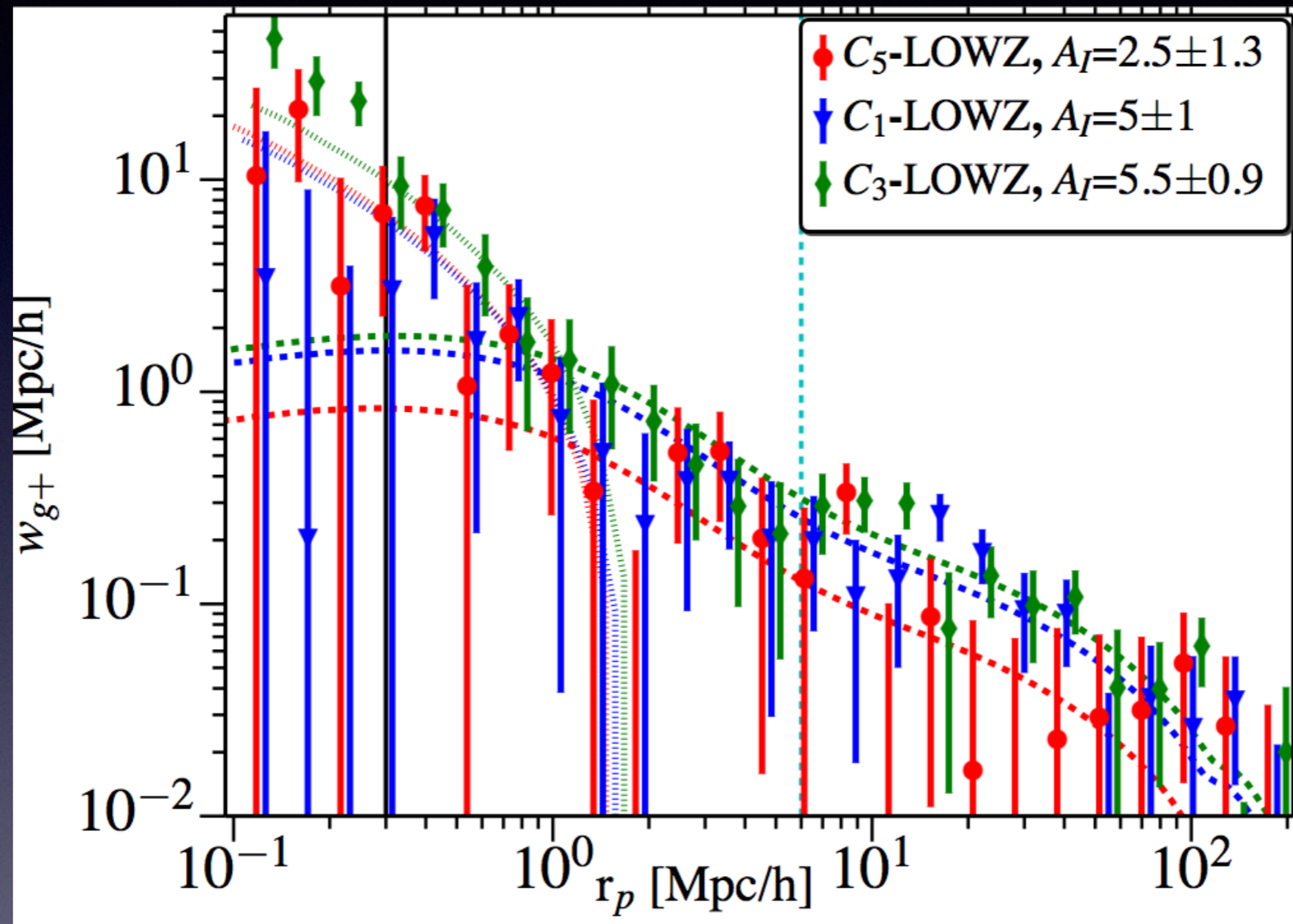
Transverse separation

Luminosity dependence



Brighter galaxies are more strongly aligned with LSS

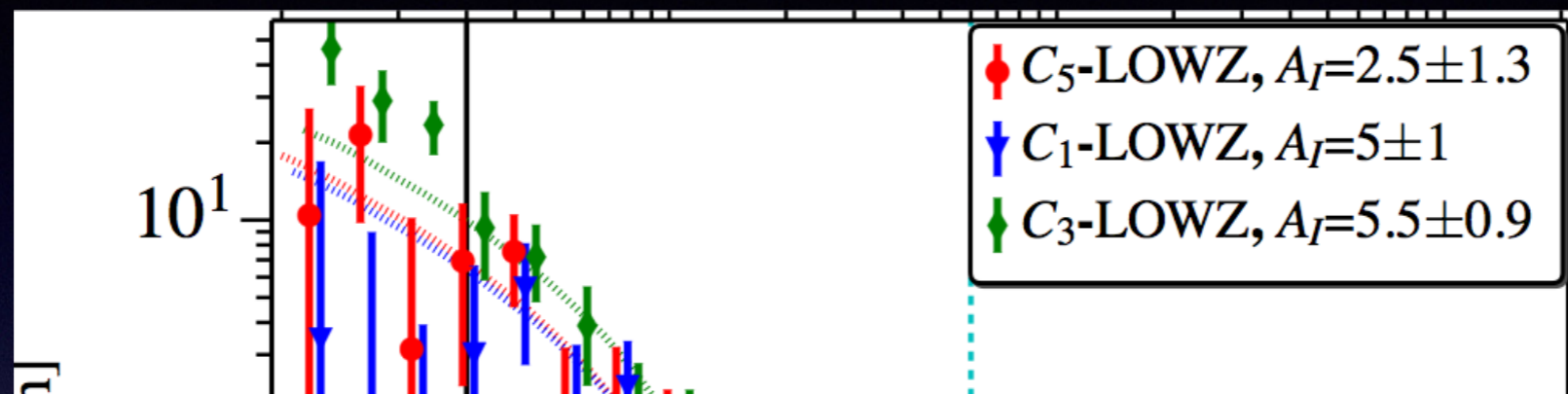
Color dependence



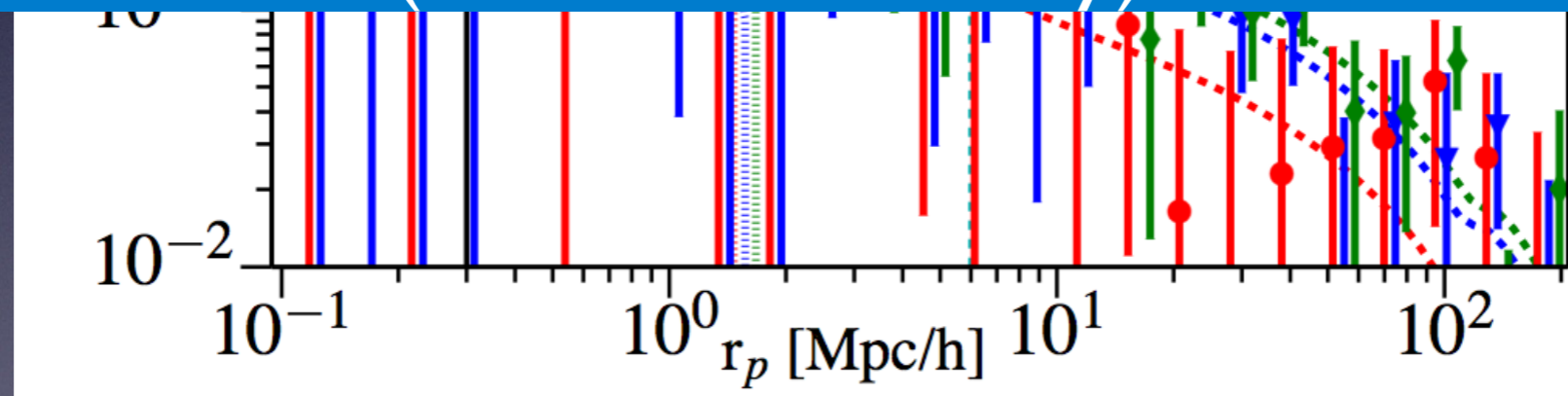
No significant evolution with color at fixed luminosity
(within the red sequence)

Small possible contamination from disks?

Color dependence



Validates the common assumption that we can split into blue vs. red, and treat all red galaxies similarly (at fixed luminosity)



No significant evolution with color at fixed luminosity (within the red sequence)

Small possible contamination from disks?

How do we quantify environments?

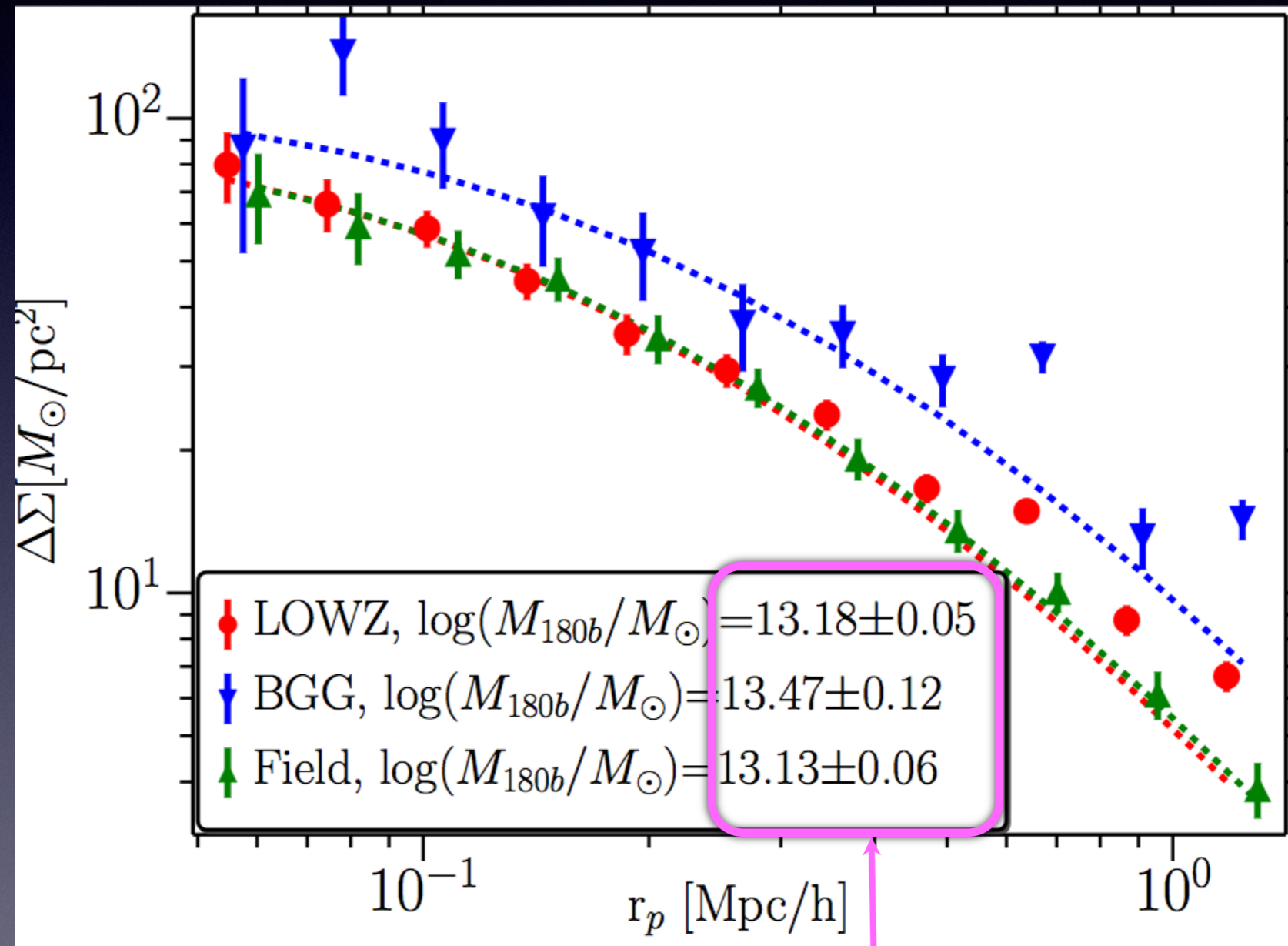


Use Counts-in-Cylinders
(CiC) technique
(Reid & Spergel 2009)

- ~14% are satellites
- ~11% are brightest group galaxies
- ~75% are in the field

Mass dependence?

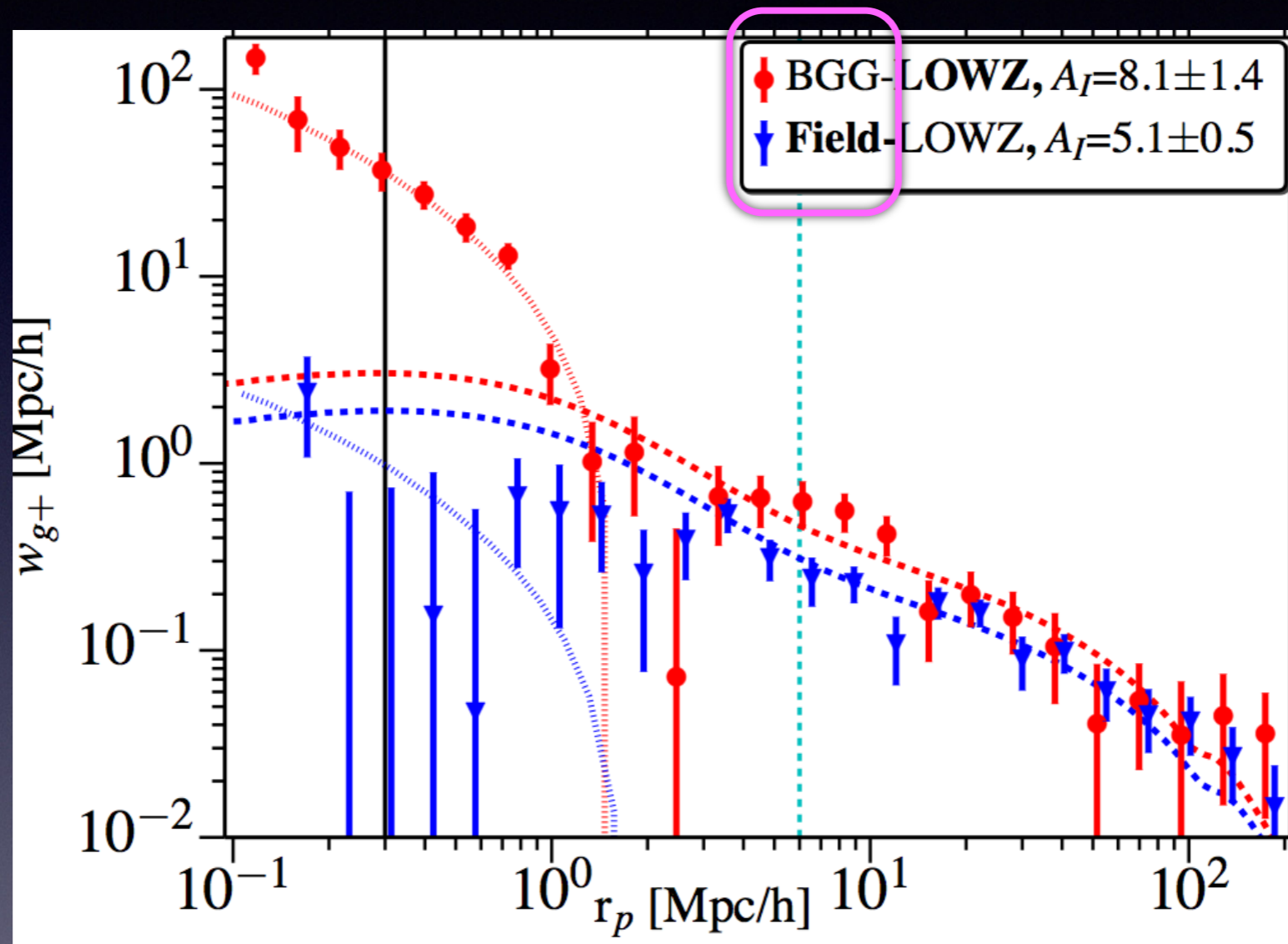
Surface mass density profile from WL



Mass range: $M > 10^{13} M_{\text{sun}}/h$

BGGs vs. field galaxies

HUGE
difference
(at small r)



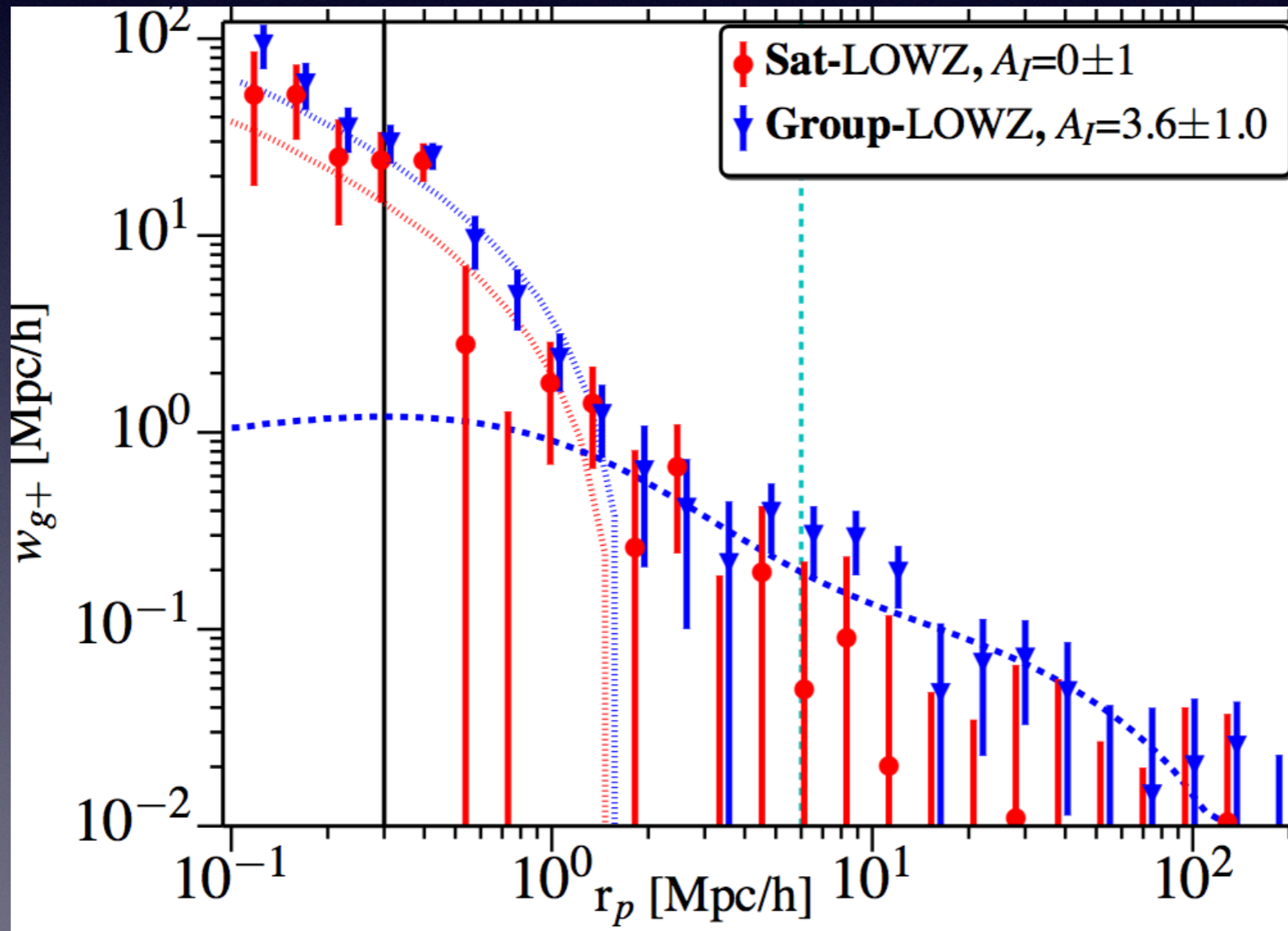
little
difference
(at large r)

BGGs have higher alignments than field galaxies.

... but they are brighter, so is this just a luminosity effect?

What about satellites?

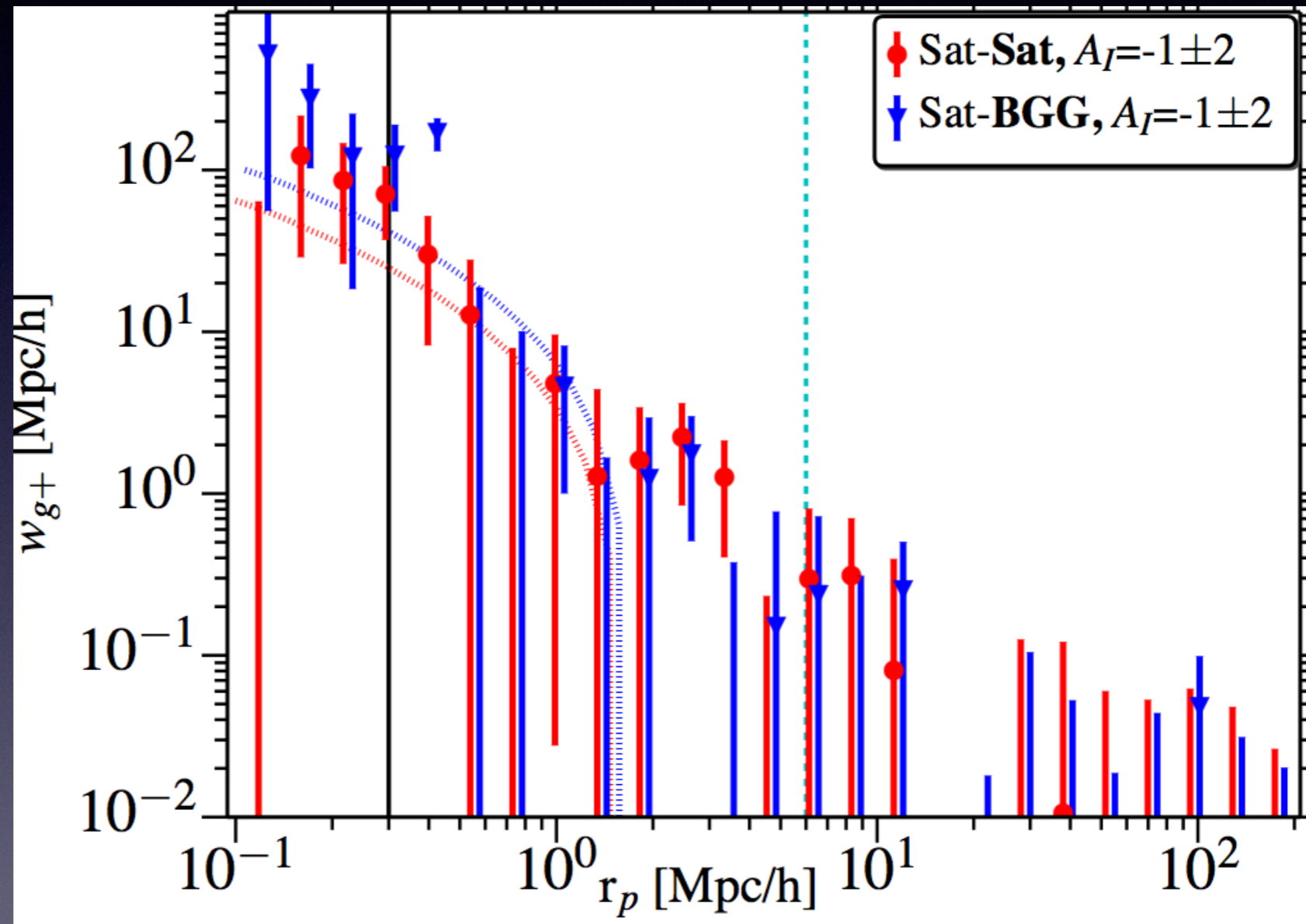
Small scales:
their alignments have
similar strength as BGGS



Large scales:
undetectable
alignments

Satellite-BGG relations

Satellites point towards BGGs
(1-halo term)

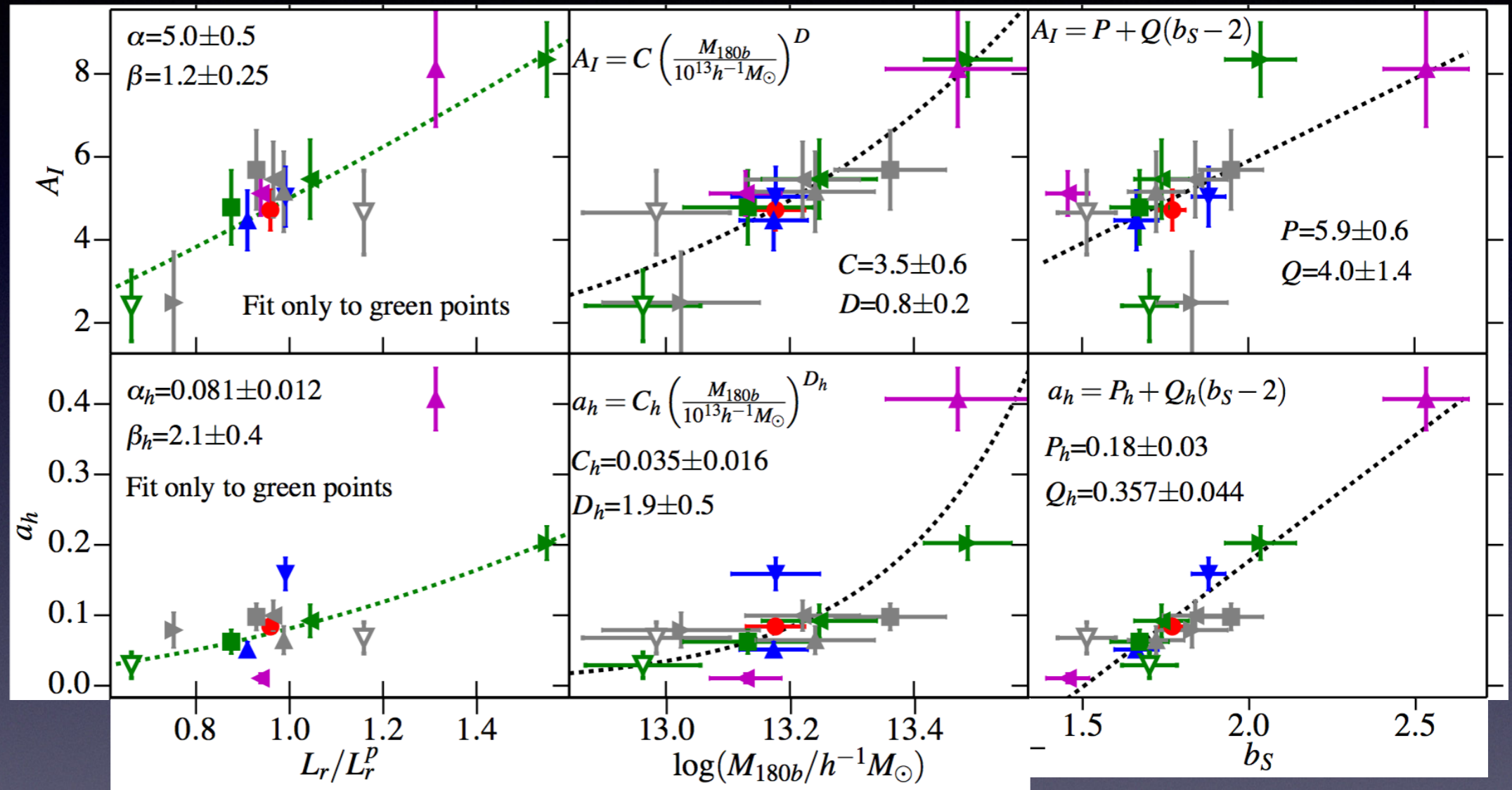


They don't point noticeably towards BGGs
in other halos (2-halo term)

Putting it all together

Large-scale amplitude

Small-scale amplitude

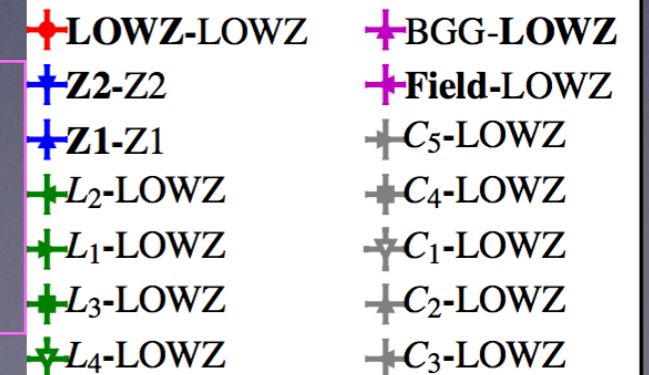


Luminosity

Host halo mass

Large-scale bias

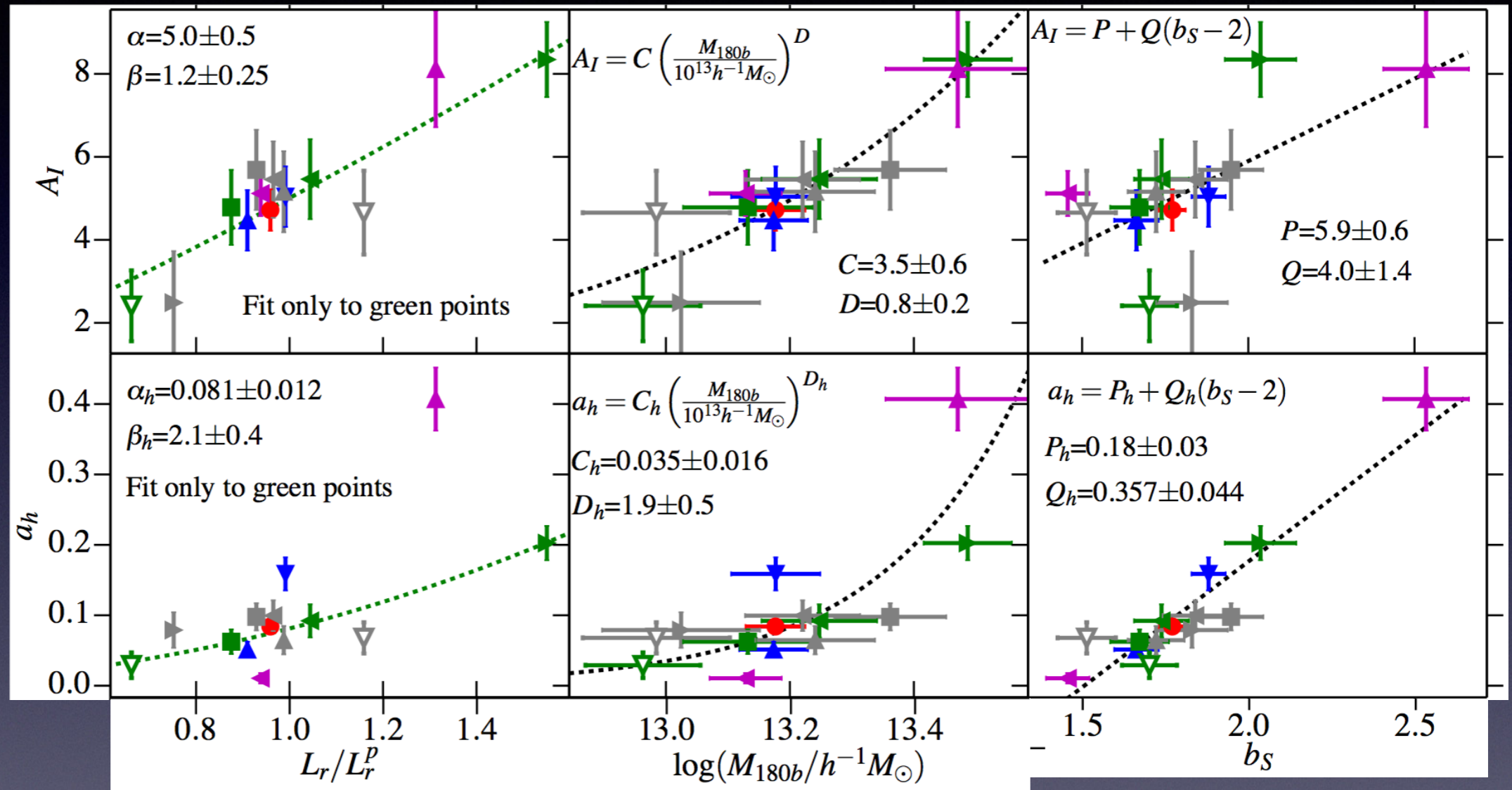
Luminosity or mass: explains all large-scale amplitudes, NOT small-scale amplitudes



Putting it all together

Large-scale amplitude

Small-scale amplitude



Luminosity

Host halo mass

Large-scale bias

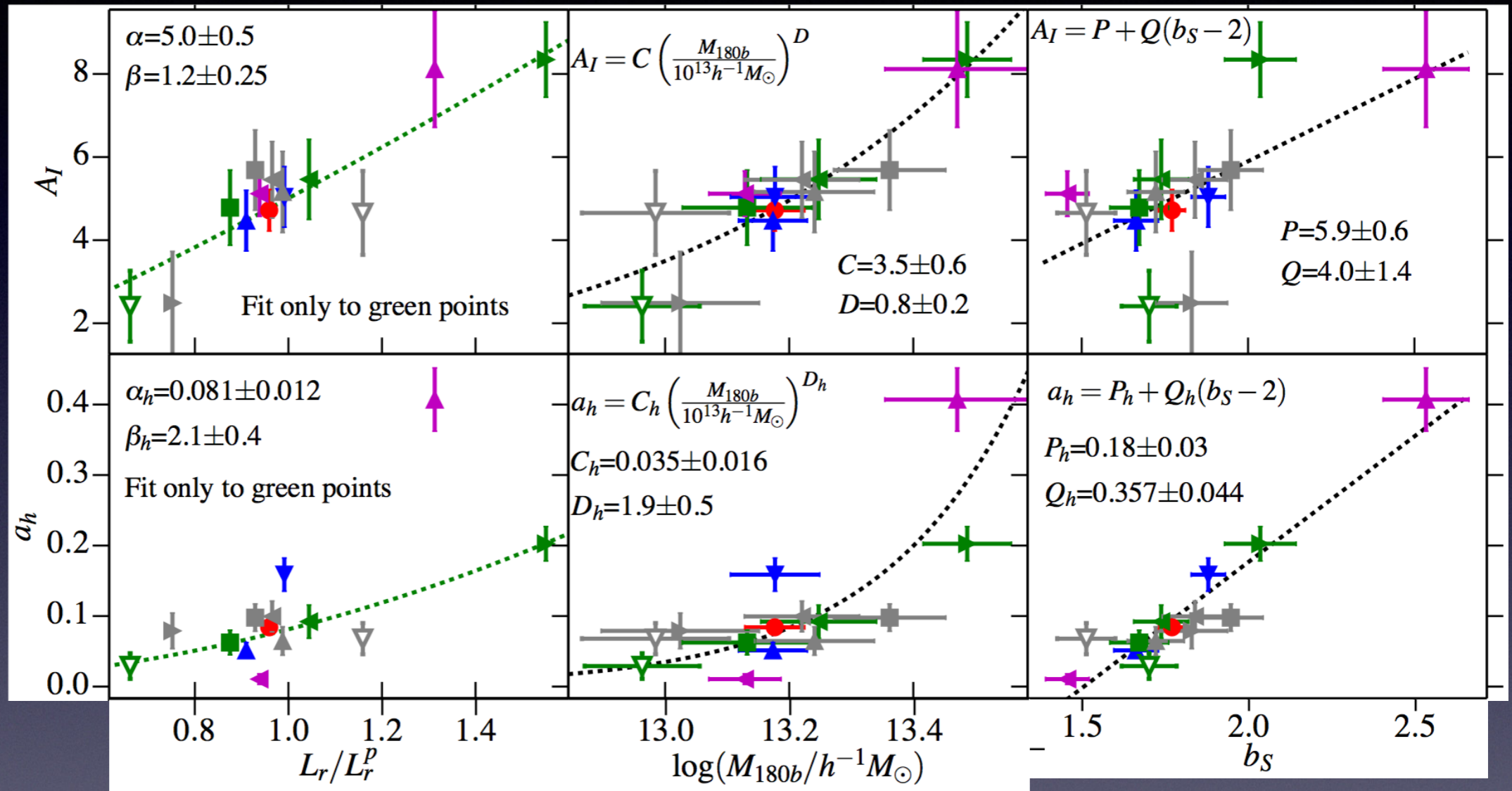
Luminosity scaling:
steeper for small scales than large scales

- ◆ LOWZ-LOWZ
- ◆ Z2-Z2
- ◆ Z1-Z1
- ◆ L2-LOWZ
- ◆ L1-LOWZ
- ◆ L3-LOWZ
- ◆ L4-LOWZ
- ◆ BGG-LOWZ
- ◆ Field-LOWZ
- ◆ C5-LOWZ
- ◆ C4-LOWZ
- ◆ C1-LOWZ
- ◆ C2-LOWZ
- ◆ C3-LOWZ

Putting it all together

Large-scale amplitude

Small-scale amplitude



Luminosity

Host halo mass

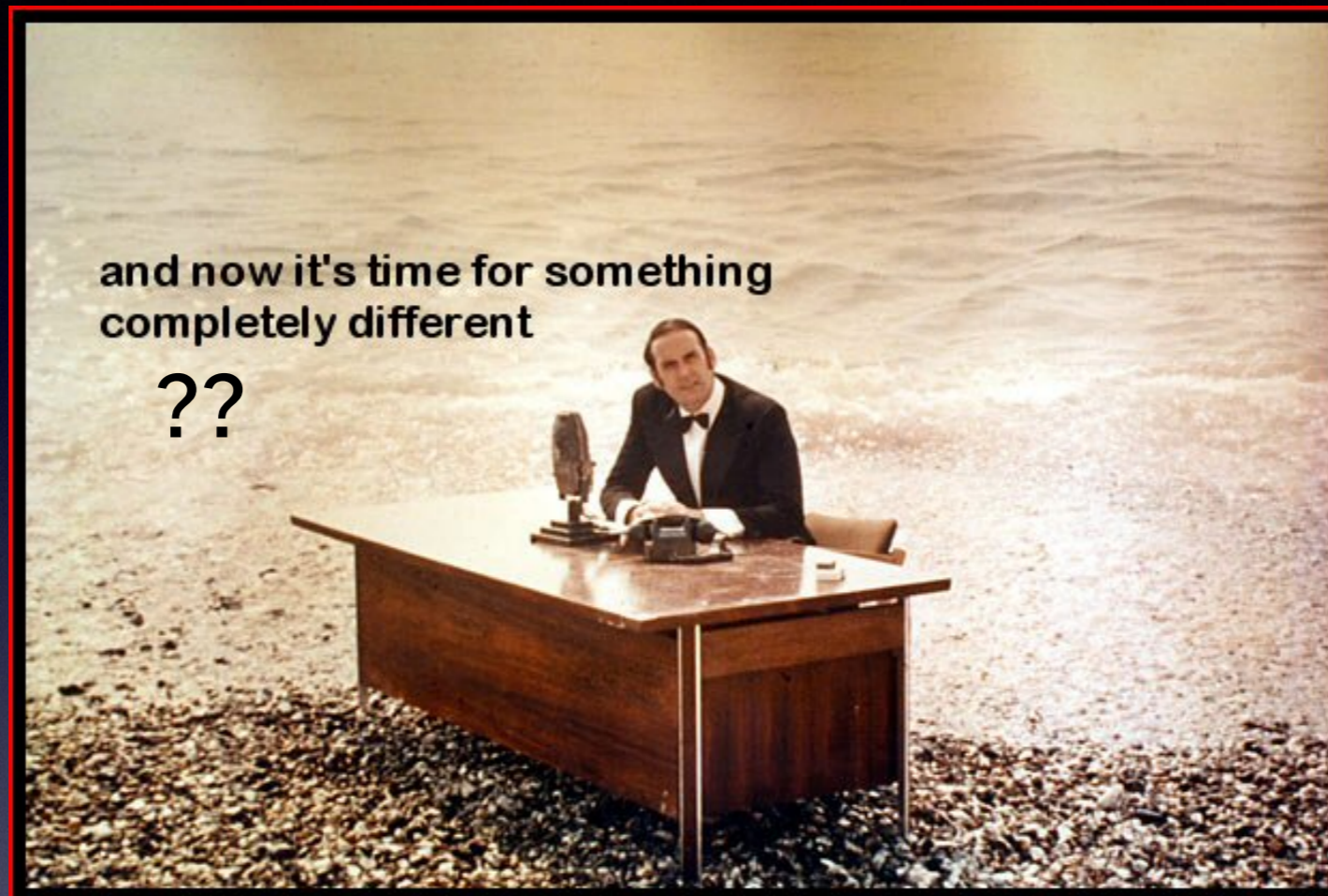
Large-scale bias

Large-scale bias is best predictor of small-scale intrinsic alignments (??!!)

- ◆ LOWZ-LOWZ
- ◆ Z2-Z2
- ◆ Z1-Z1
- ◆ L2-LOWZ
- ◆ L1-LOWZ
- ◆ L3-LOWZ
- ◆ L4-LOWZ
- ◆ BGG-LOWZ
- ◆ Field-LOWZ
- ◆ C5-LOWZ
- ◆ C4-LOWZ
- ◆ C1-LOWZ
- ◆ C2-LOWZ
- ◆ C3-LOWZ

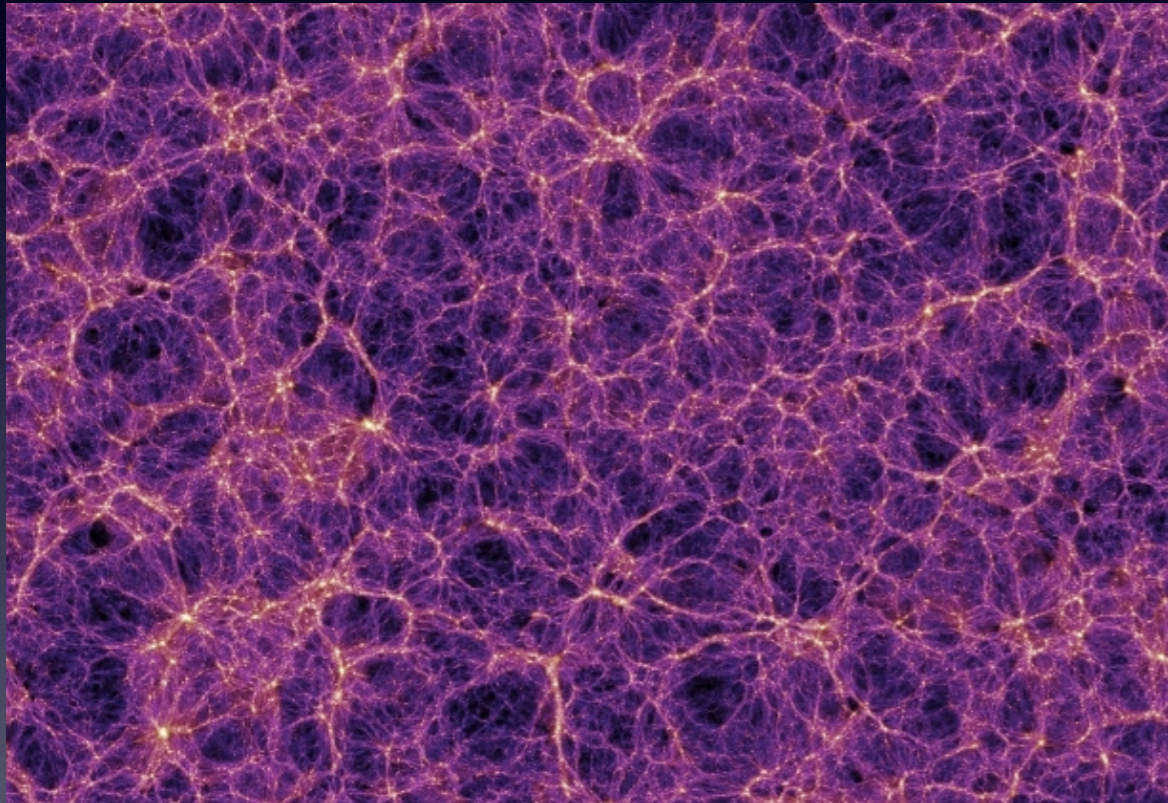
Conclusions (part I)

- Red galaxy intrinsic alignments measurements can constrain IA models
 - Dependence on separation, luminosity, color, z (Joachimi et al. 2011), ...
 - Can be used in mitigation schemes for lensing
- We are starting to understand environment dependence
- We have a basic picture for what determines IA strength on small and large scales



and now it's time to study the same physics
in a completely different way

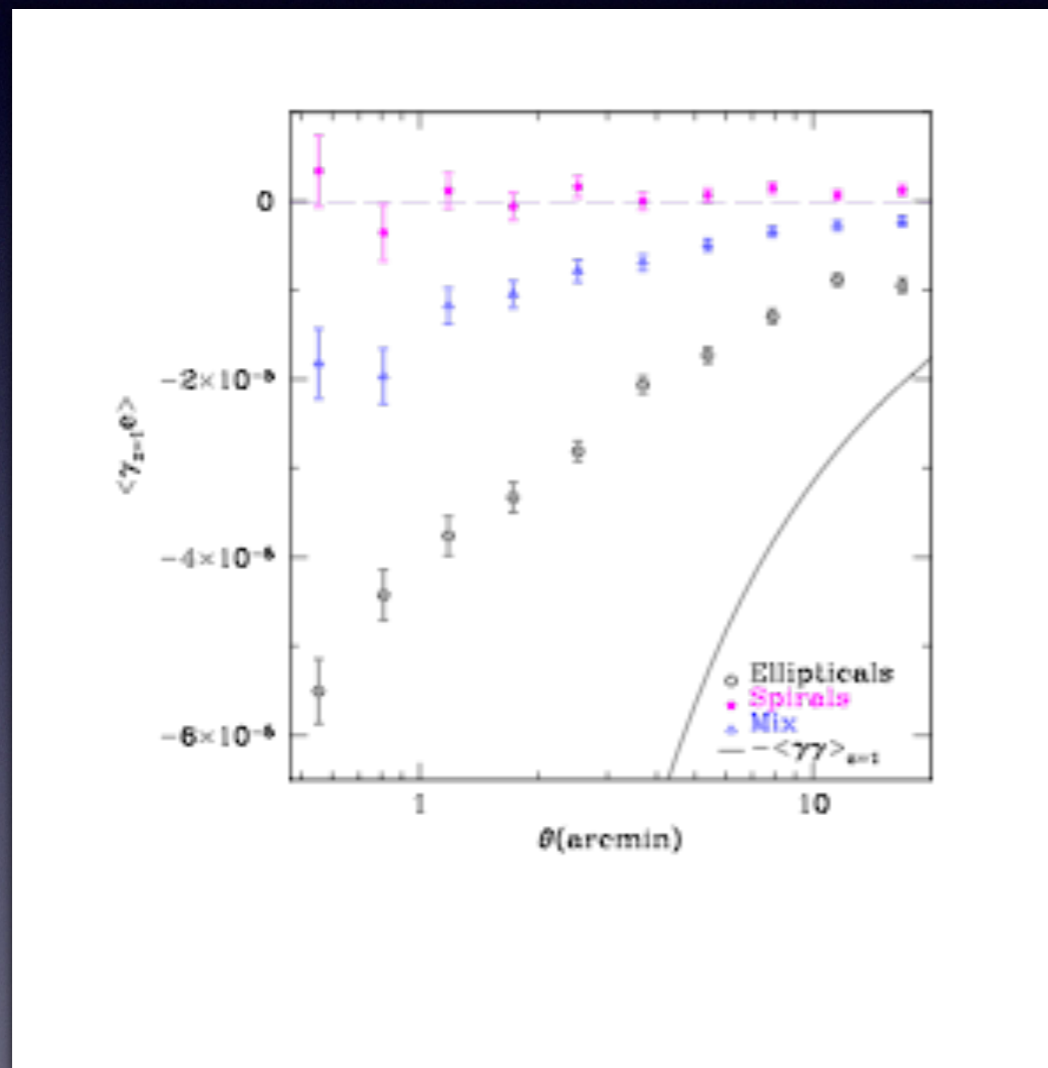
Intrinsic alignments in N-body simulations



e.g., Millenium simulation

DM halo alignments are
well-defined!

Intrinsic alignments in N-body simulations



Galaxy alignments depend
entirely on how you
assume
galaxies populate halos

Heymans et al. (2006)

Hydrodynamic simulations

- The good part: they have galaxies!
- The questionable part: is the physics right?
Are the galaxies realistic enough?

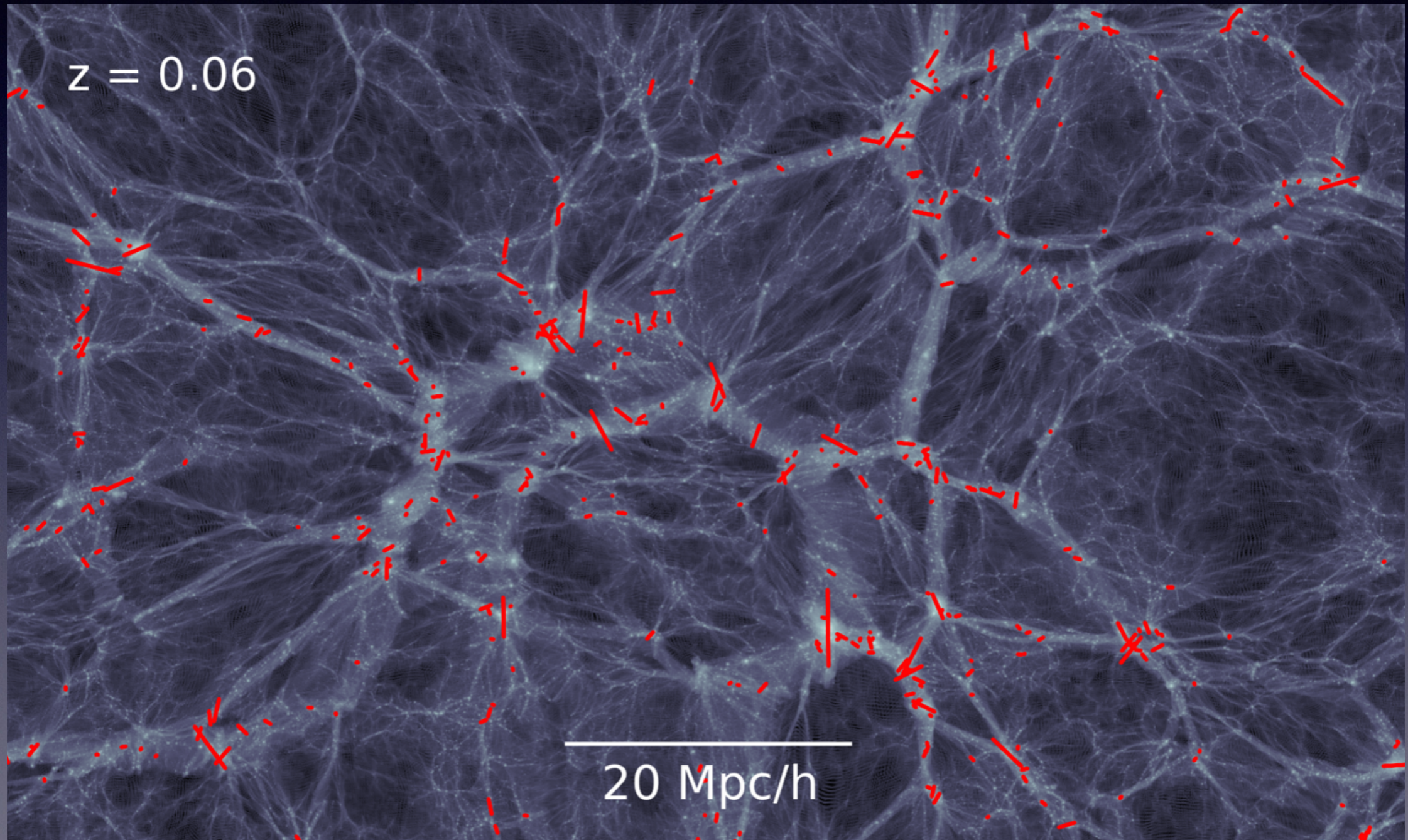
My approach: reserve judgment at first, and try to answer this question by comparing with real galaxy observations

The really tricky part

- To measure large-scale IA, you need large volumes (minimum 100 Mpc/h box length)
- To measure galaxy shapes well enough, you need $>\sim 300-1000$ particles in the galaxy (particle mass of order $10^6 M_{\text{sun}}/h$)
- This is ridiculously expensive and only recently became feasible at all. (Cen et al. 2014, Codis et al. 2014, and more...)

MassiveBlack-II

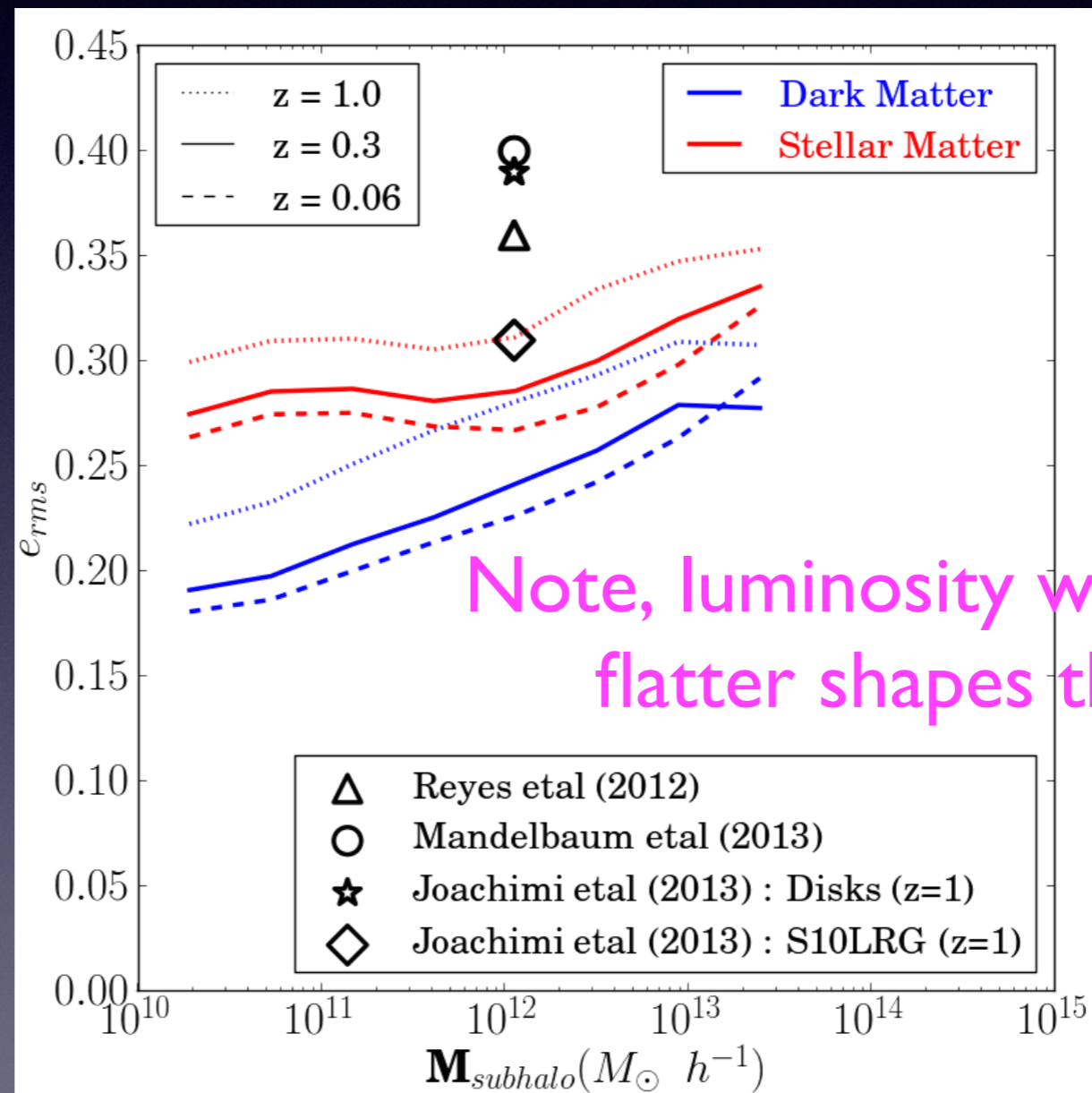
(Khandai et al. 2014)



Galaxy shape distributions?

(Tenneti, RM, et al. 2014)

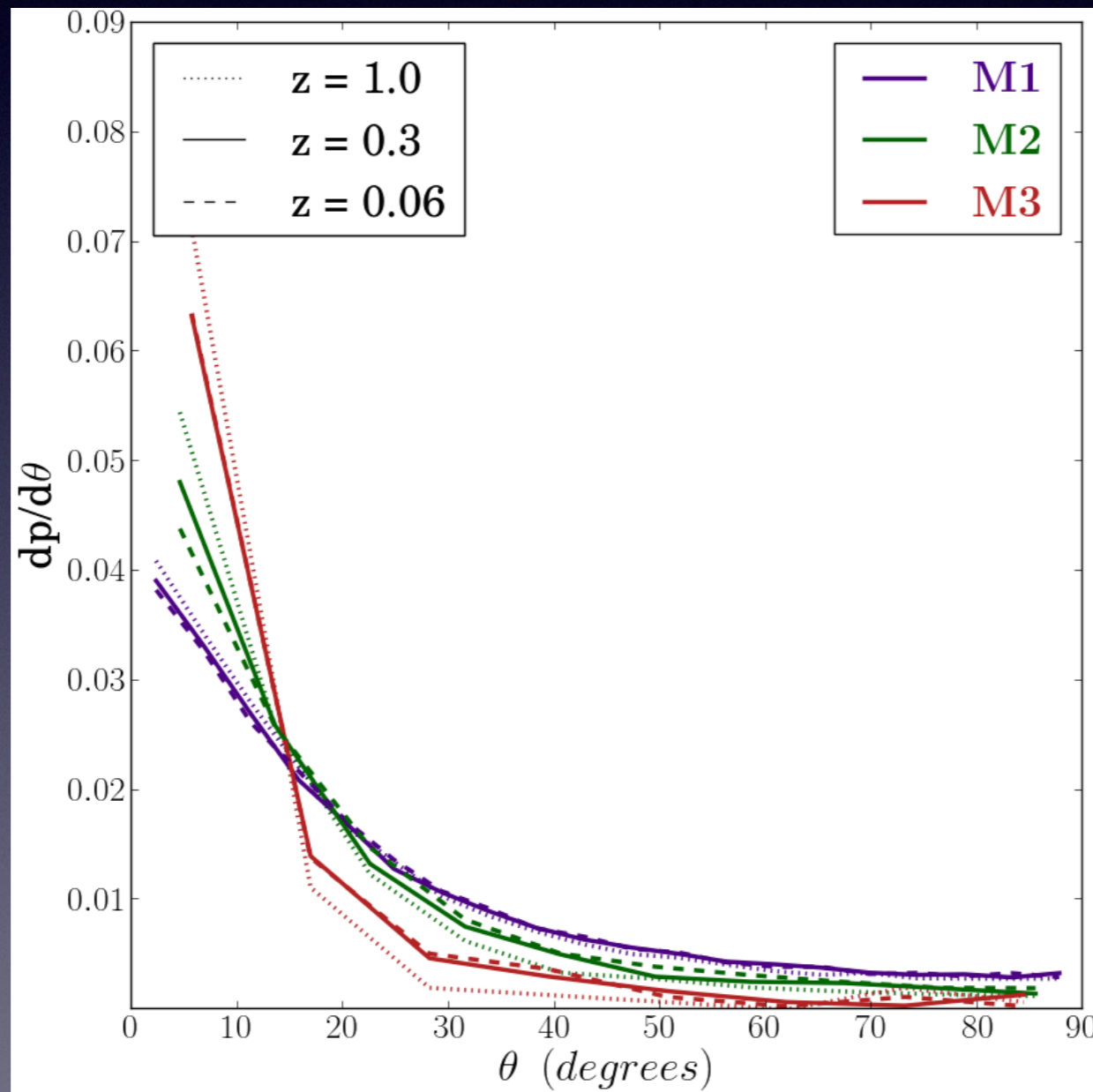
Projected RMS
ellipticity
(per component)



Note, luminosity weighting yields
flatter shapes than these!

Halo mass

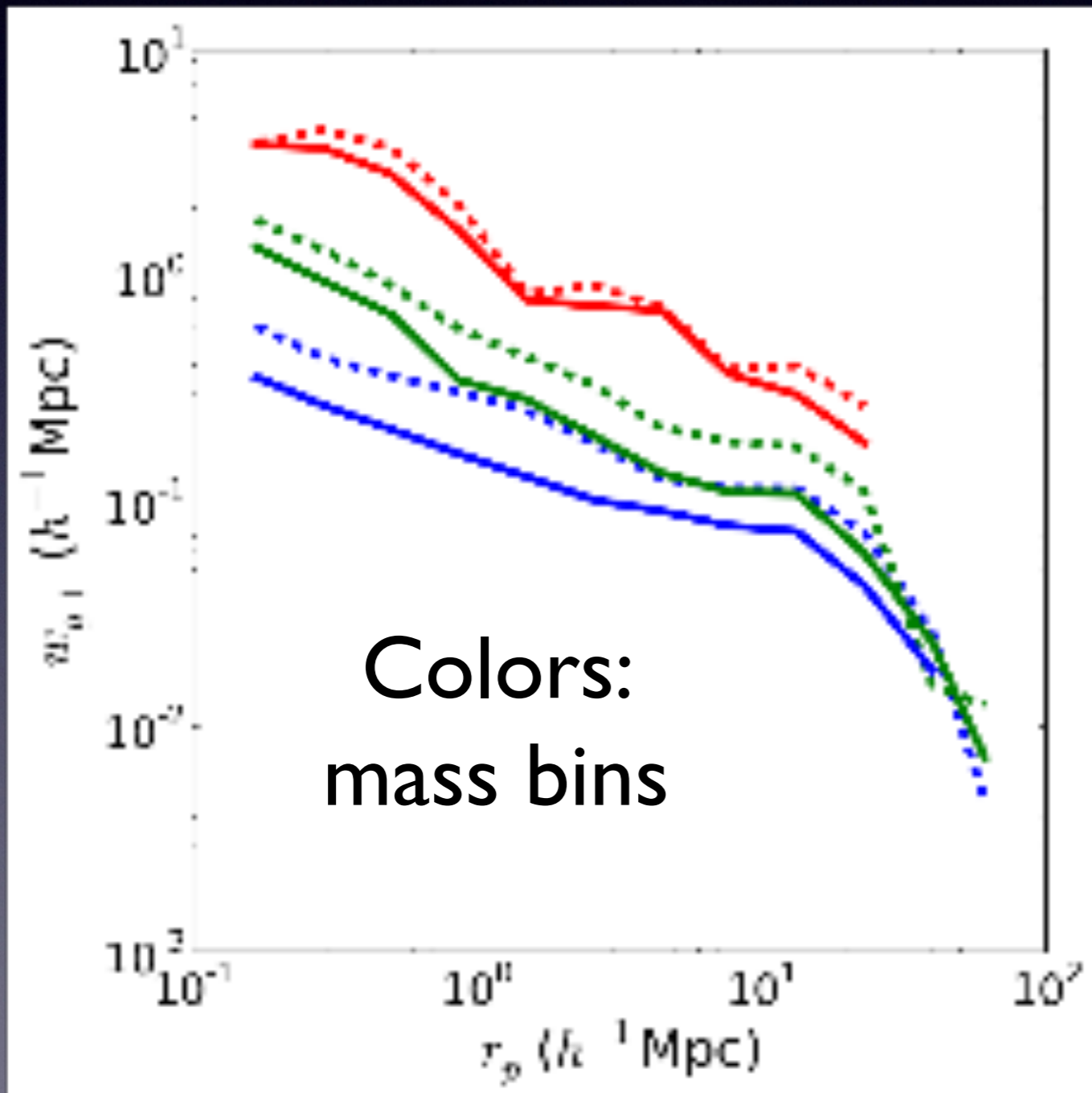
Misalignment angle between galaxy vs. halo



M1: lowest mass
(10^{10} - $10^{11.5} M_{\text{sun}}/h$)

M3: highest mass
($>10^{13} M_{\text{sun}}/h$)

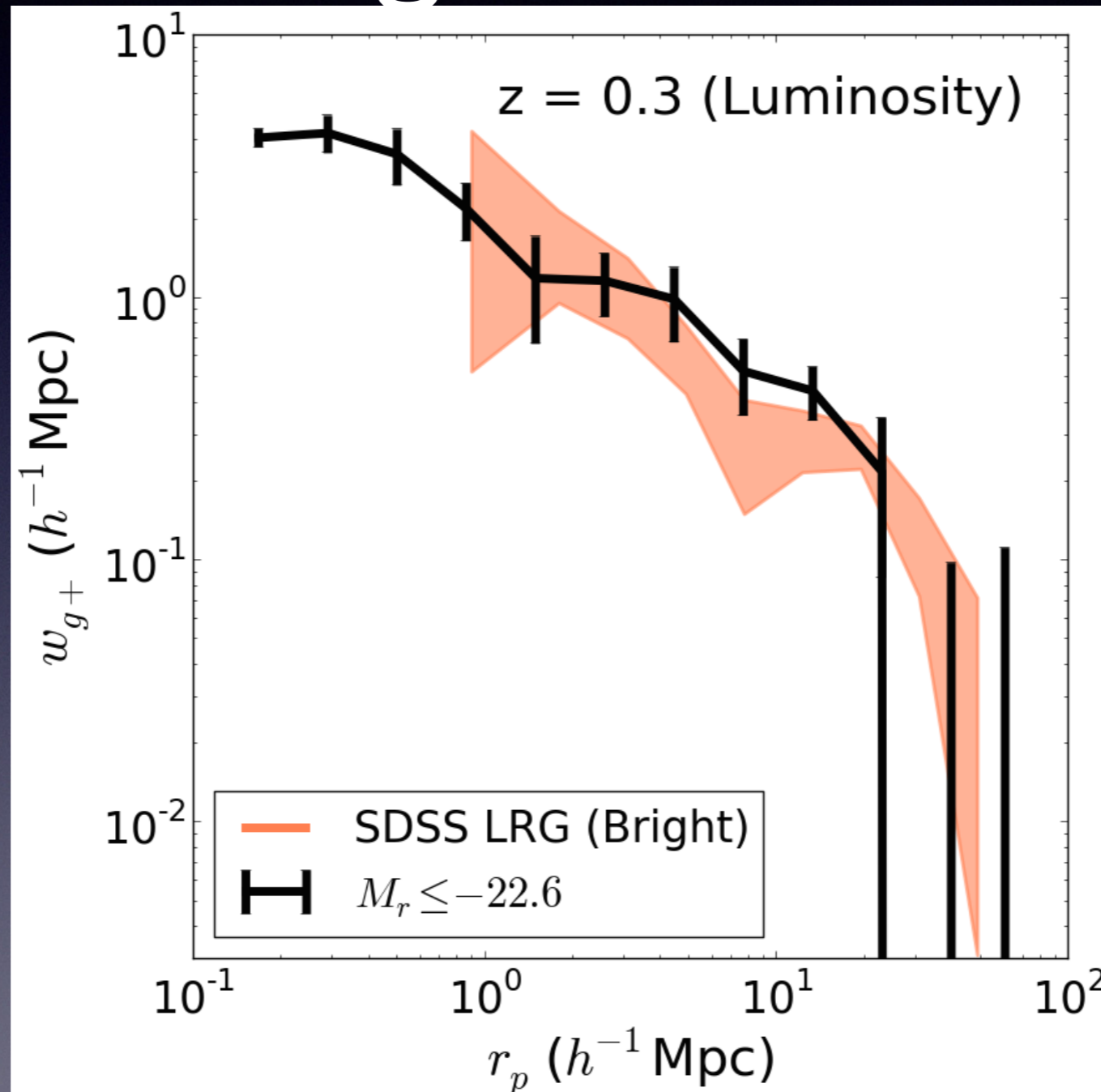
Intrinsic alignments (Tenneti, Singh, RM et al. 2014)



Solid: reduced inertia tensor
Dashed: unweighted inertia tensor

Using inner vs. outer parts
of galaxies matters!

Comparison: LRG alignments



Data vs. MB-II, no free parameters

And there's more...

- Trends with environment; Tenneti et al. (2014)
- Correlations with filaments; Chen et al. (2015)
- MB-II vs. dark matter-only simulation with same resolution, box size, initial conditions - baryonic effects? Tenneti et al. (2015)
- Nearly complete: study of bulge-like and disk-like galaxies separately
- Other feedback prescriptions?
- Ultimately: more informed models to populate N-body based mocks with IA!

Conclusions

- The physics of intrinsic alignments is non-trivially complex and requires study from multiple angles
- Observations are still yielding new insights
- Hydrodynamic simulations are just starting to be a powerful tool for predicting IA: expect more very soon!
- Lots to do, but there is progress...