IA of Galaxy Clusters and the Impact of Projection Effects

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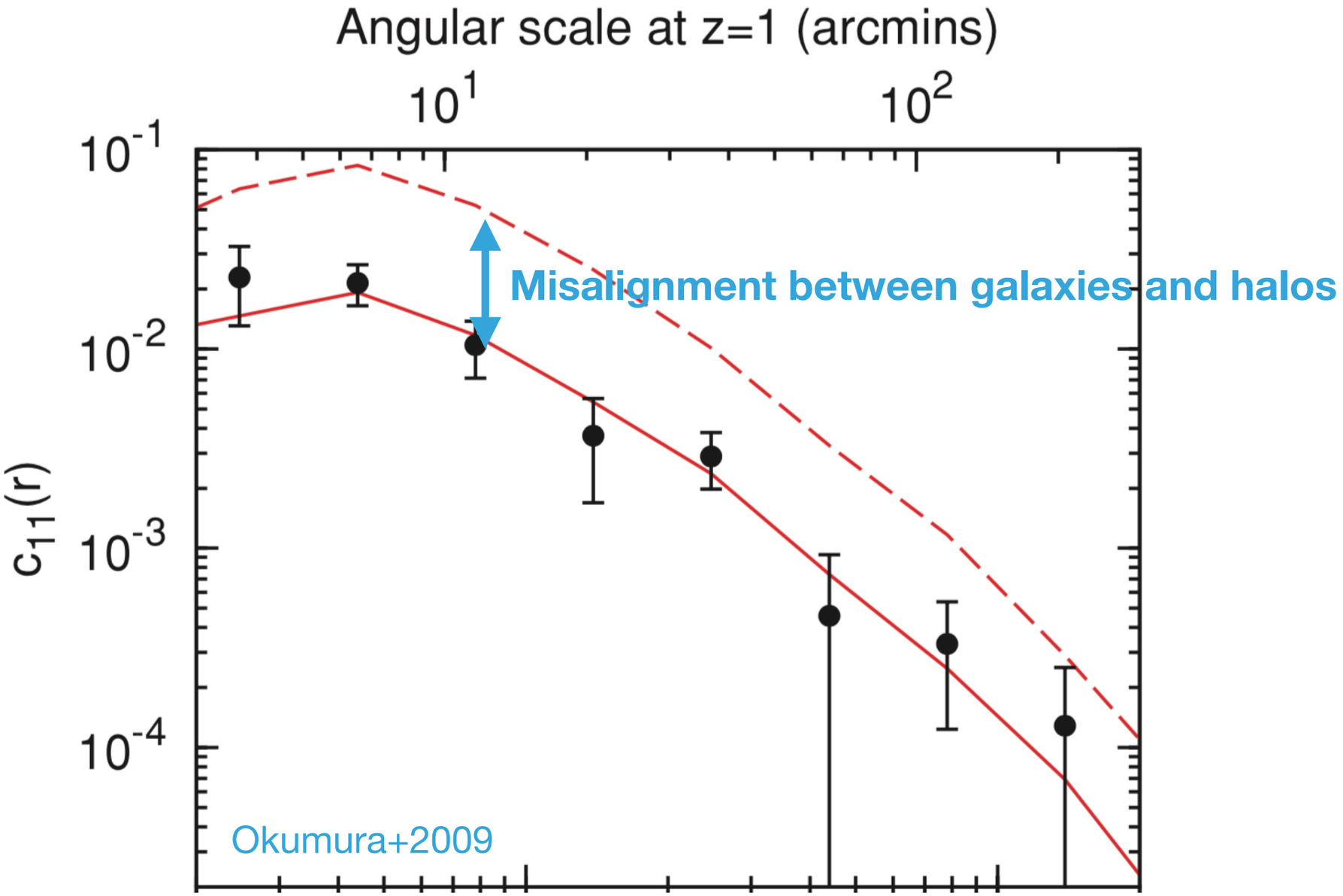


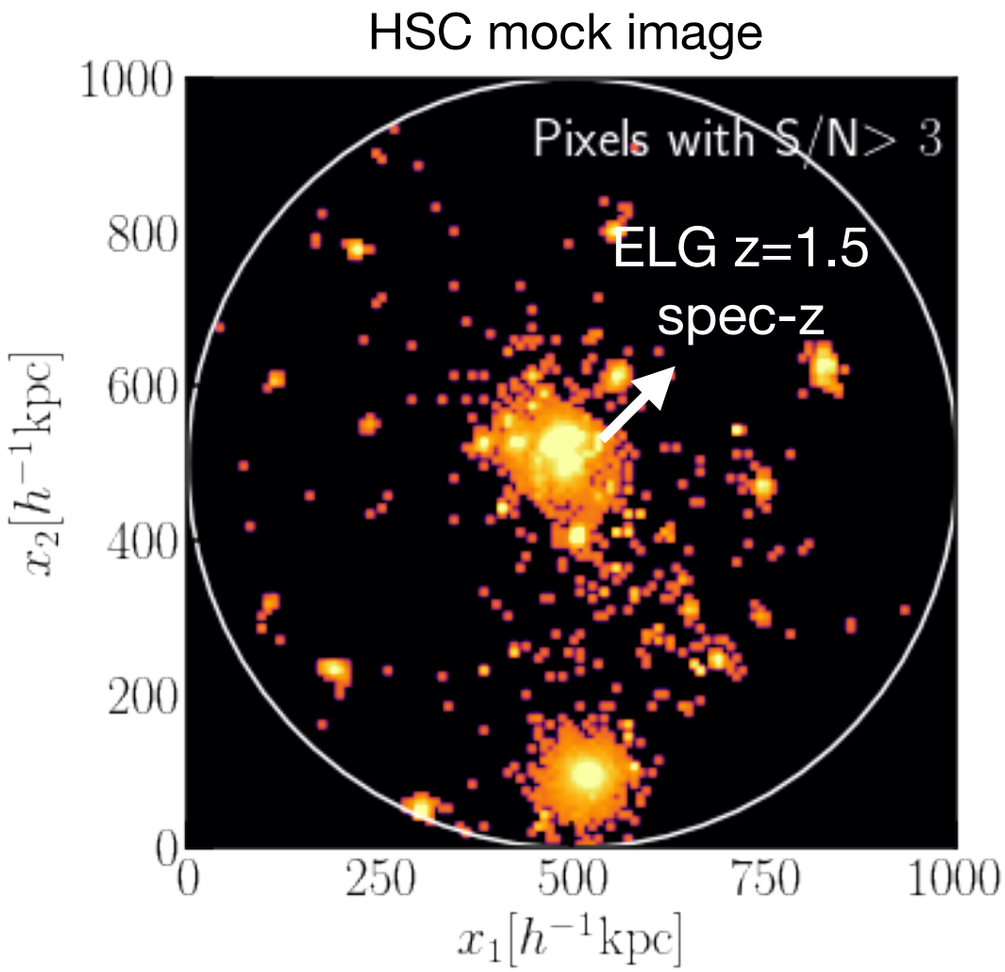
Dark matter halo shape/IA

- More sensitive to surrounding tidal field, compared to galaxies
- Probe of cosmology (Ho+09, Lee+22, Shen+22)
- Important for cluster cosmology constraint of DE (i.e. projection effects)

How to obtain the shape/IA of dark matter halos in observation?

Solution 1: Aperture Shape Estimator

Aperture shape estimator around ELG galaxies



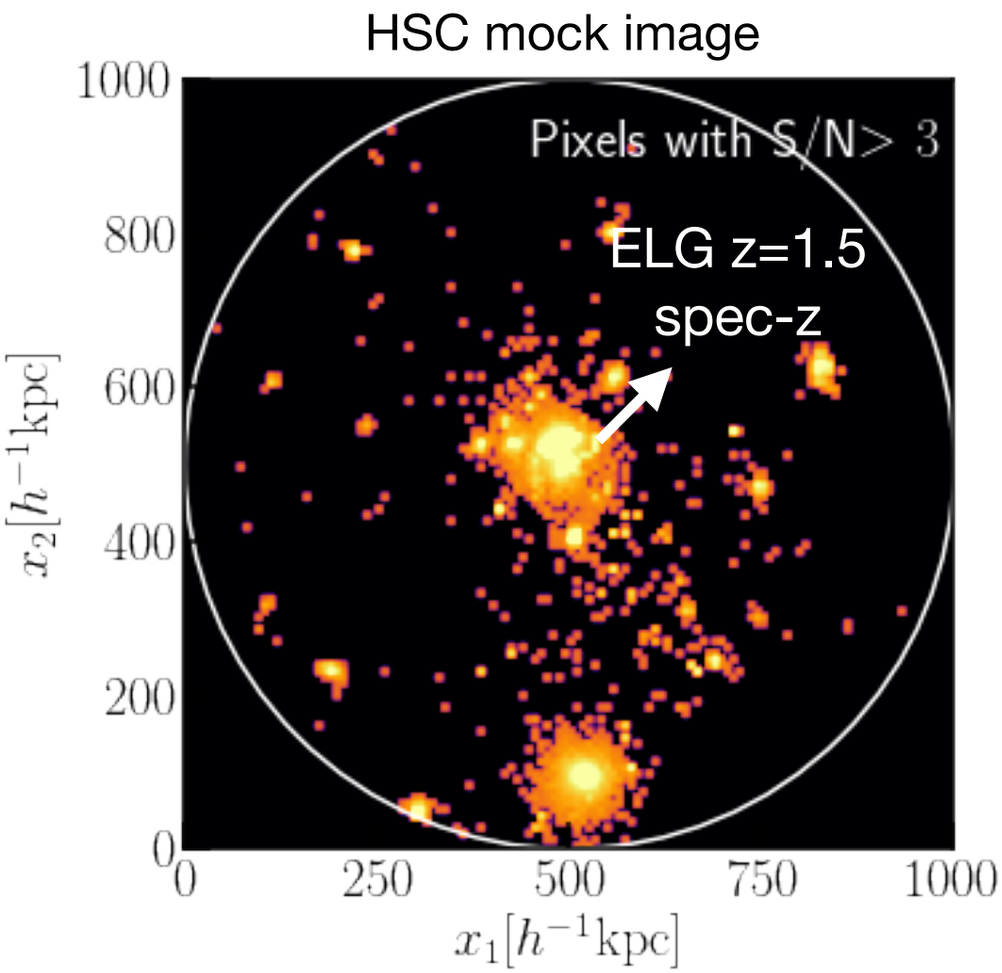
Aperture Inertia Tensor

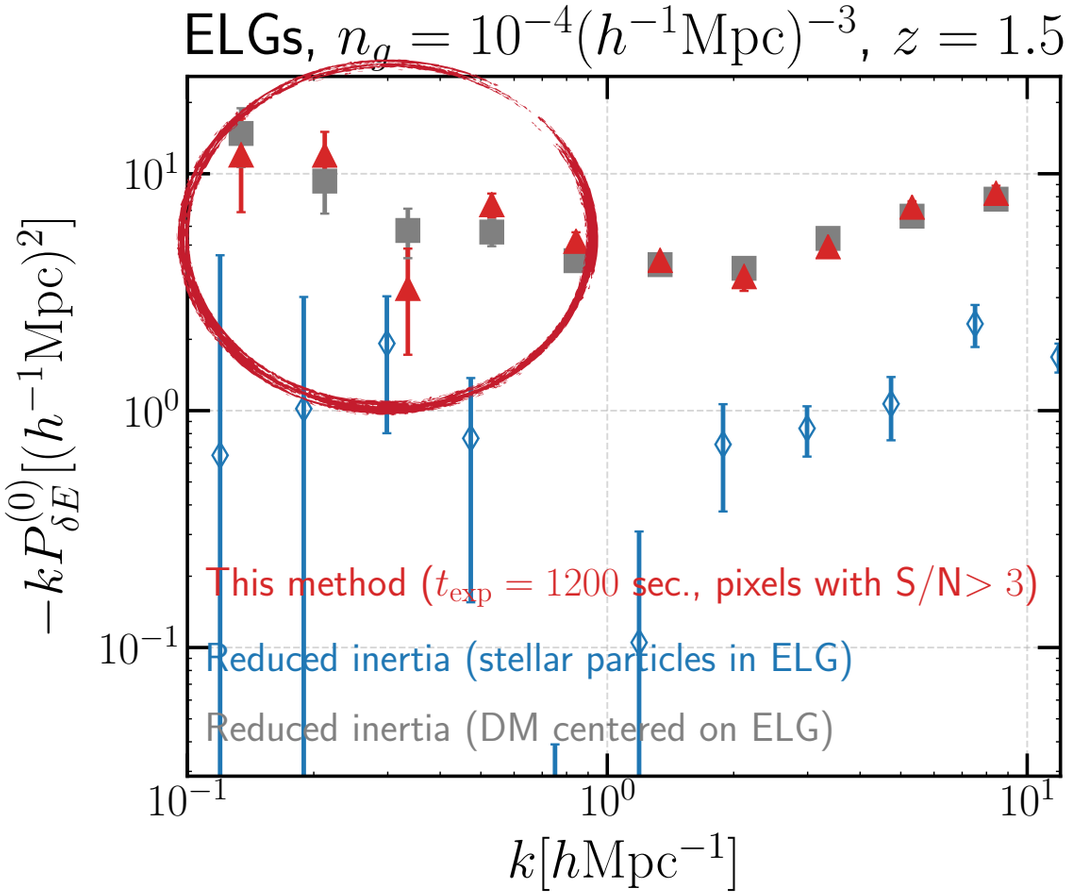
$$I_{ij}^{\mathrm{ap}} = \frac{\sum_{n;(S/N)_{\mathrm{pix}}>3;r_n^{\mathrm{2D}}\leq 500h^{-1}\mathrm{kpc}} f_n x_{ni} x_{nj}}{\sum_{n;(S/N)_{\mathrm{pix}}>3;r_n^{\mathrm{2D}}\leq 500h^{-1}\mathrm{kpc}} f_n}$$

f_n – flux of pixels

x_{ni}, x_{nj} – distance of pixels to the ELG

Aperture shape estimator around ELG galaxies





Shi, Kurita, Osato, Takada 2021b

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f_n – flux of pixels

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$$\langle \gamma_E(\boldsymbol{k})\delta_m(\boldsymbol{k'})\rangle \equiv (2\pi)^3\delta_D(\boldsymbol{k}+\boldsymbol{k'})P_{\delta E}(\boldsymbol{k})$$

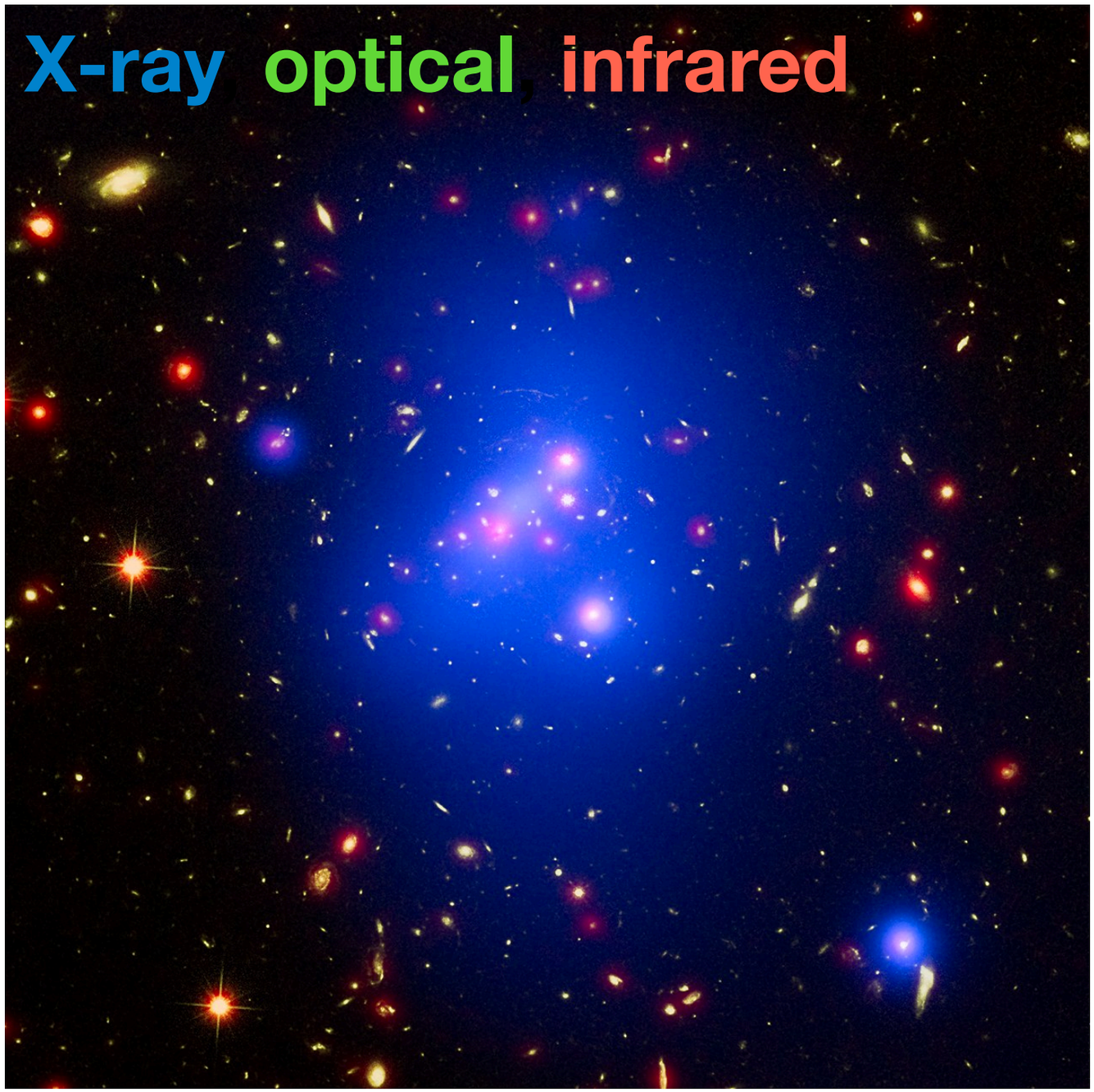
IA power spectrum

(Kurita+2020, Shi+2021a)

Solution 2: Galaxy Clusters

Measure Galaxy Cluster Shape

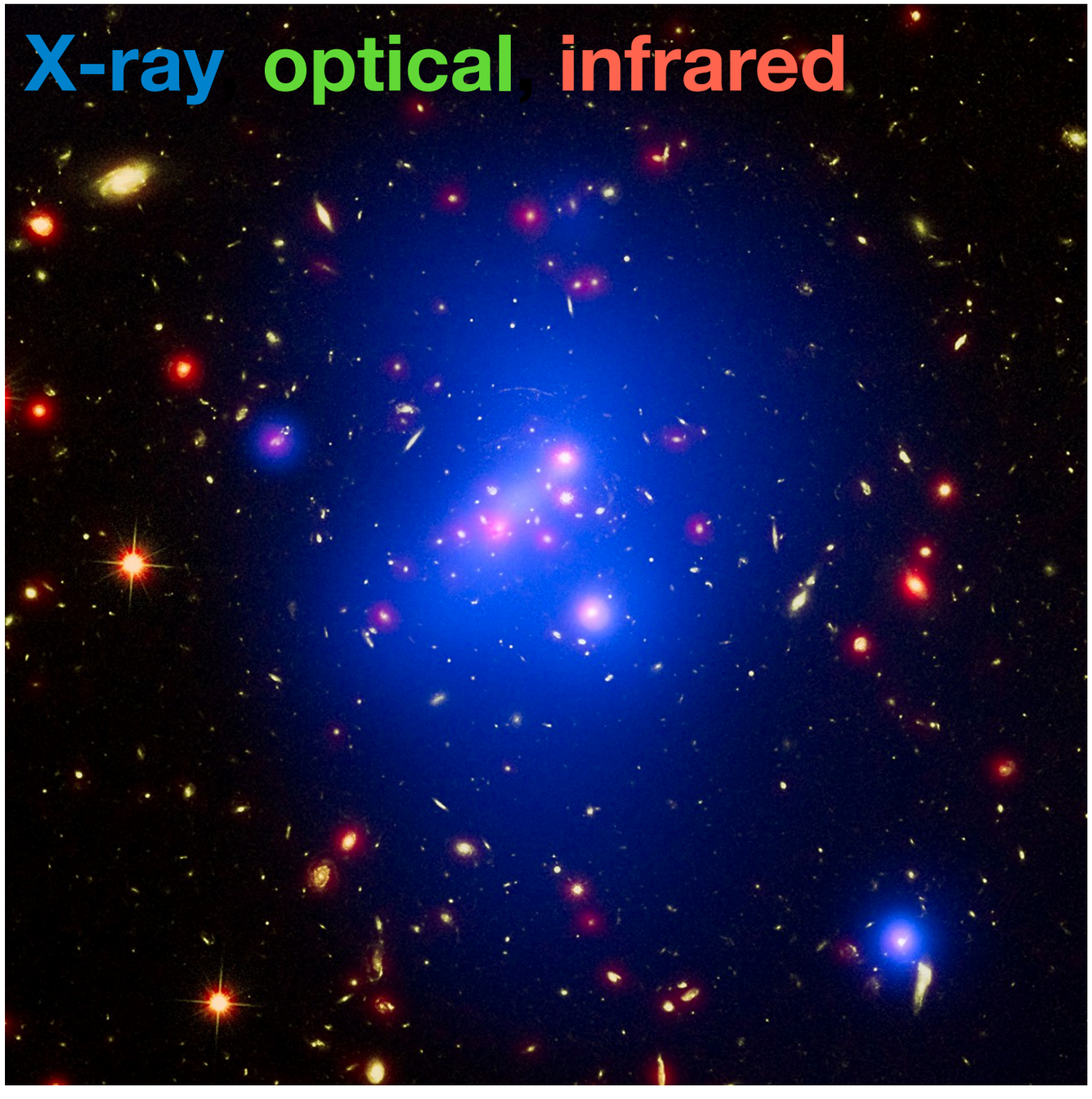
Cluster IDCS J1426



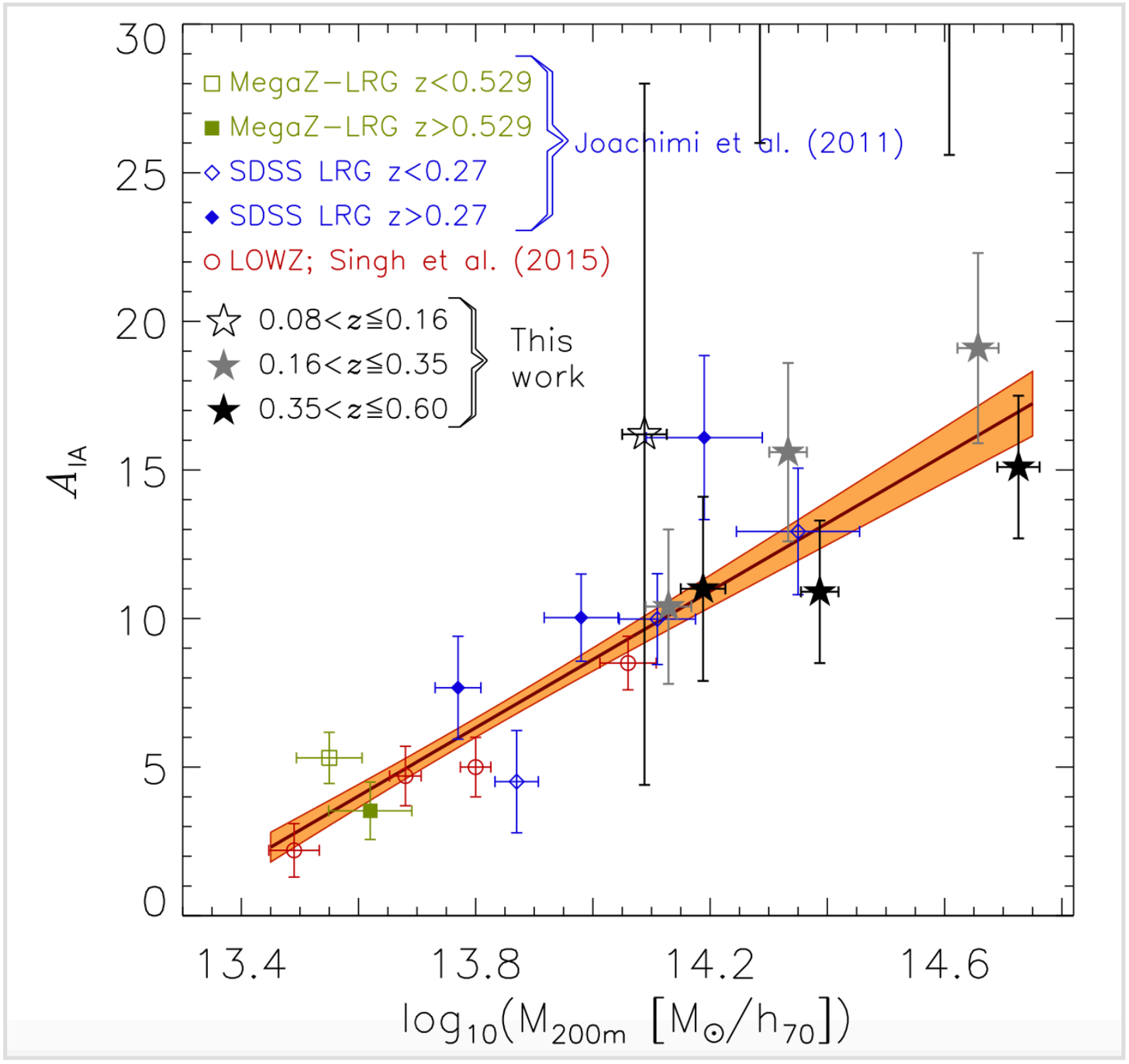
Measure Galaxy Cluster Shape

- Bright Central Galaxy (BCG)
- Satellite (member) galaxy distribution, w.r.t the center
- X-ray (e.g. Shen+22, SIDM Sim.)
- Lensing 2D shear fitting (Oguri, Takada+10; Evan & Bridle+09)
- 3D shape? (Limousin+13, X-ray + SZ + lensing data)

Cluster IDCS J1426



Clusters show the strongest alignment w.r.t large scale structure



Cluster Positions $\delta_{cluster}$

×

Cluster Shape

(member distribution)

Van Uitert, + Joachimi 17

See also Joachimi+15

Measure Cluster Shape Alignment

Landy–Szalay correlation function estimator

$$\xi_{g+} = \frac{S_+ D - S_+ R_D}{R_S R_D}$$

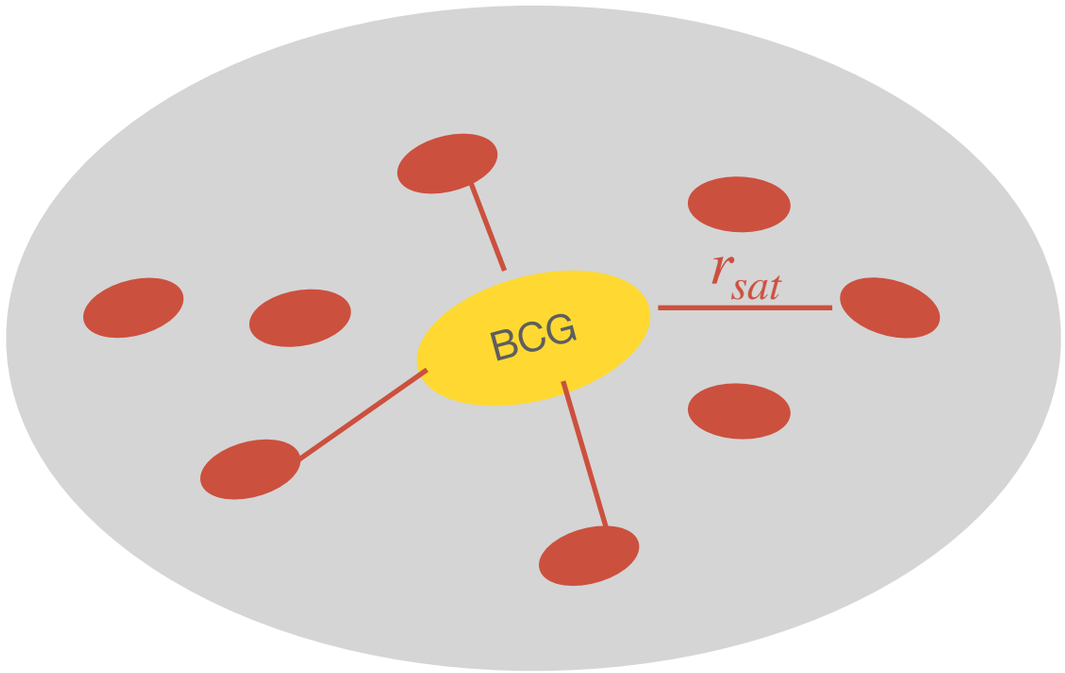
$$w_{g+}(r_p) = \int_{-\Pi_{max}}^{\Pi_{max}} \xi_{g+}(r_p, \Pi)\, d\Pi\,.$$

Density sample (D, δ_g): BOSS DR12 LOWZ

Shape sample (S, γ_+): public Redmapper Clusters, with SDSS DR8 image data, Richness $20 \leq \lambda \leq 200$ (Rykoff+16)

$$0.1 < z < 0.33$$

Measure Cluster Shape Alignment



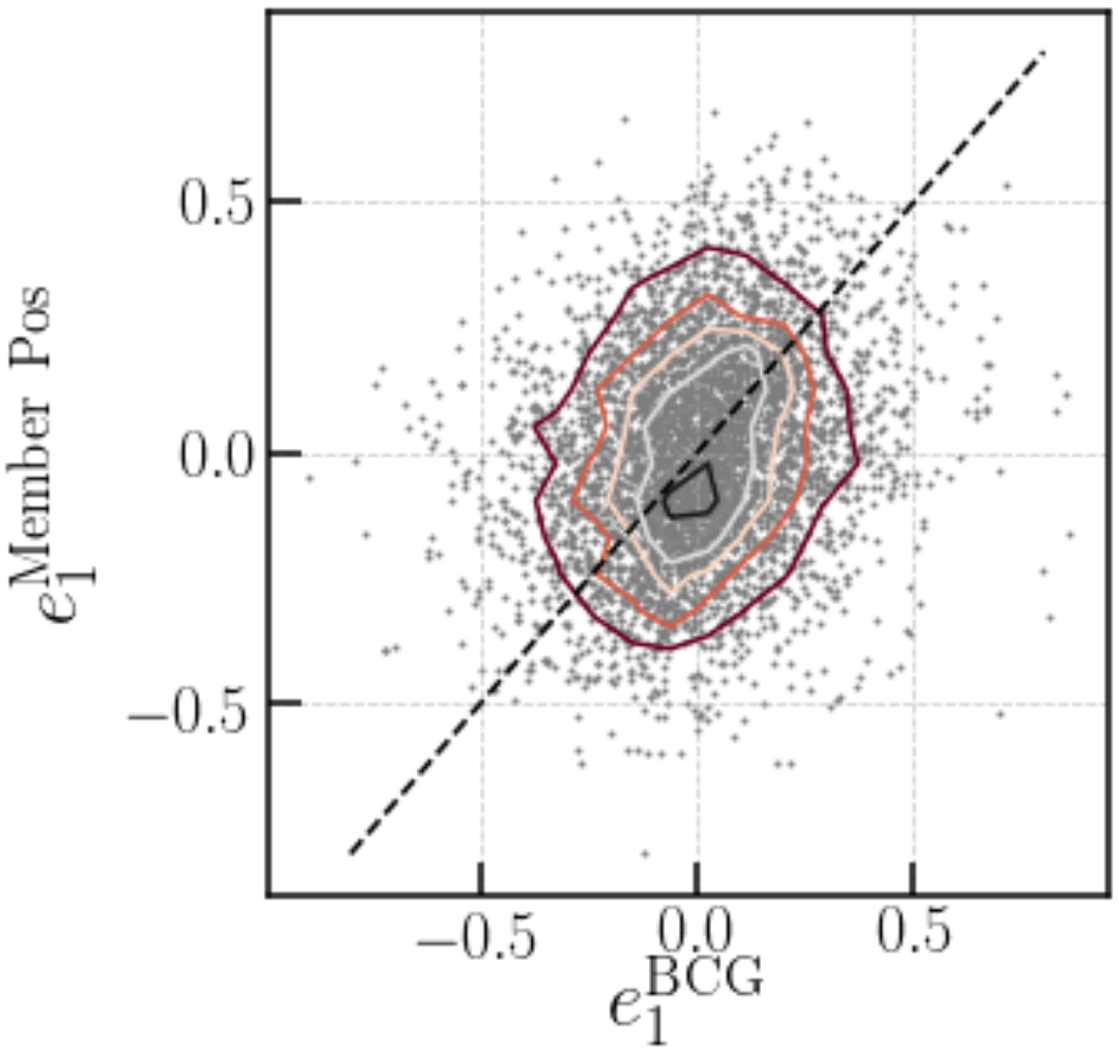
- Bright Central Galaxy (BCG) shape, cross matched with shear catalog of Reyes+12
- Member galaxy ($p_{\rm mem} > 0.2$)

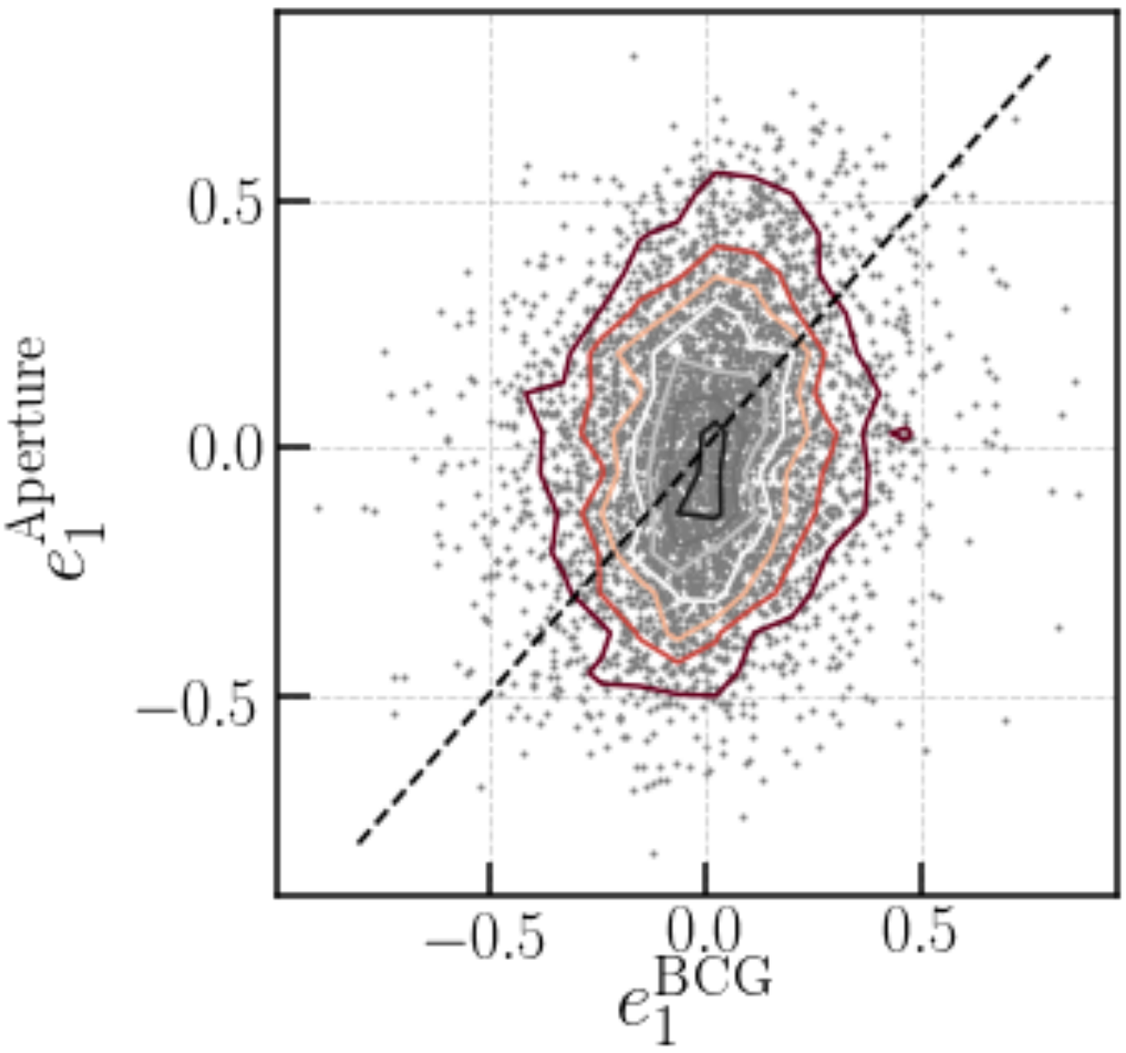
$$I_{ij} = \frac{\sum_k (\theta_{i,k} - \theta_i^{\rm BCG})(\theta_{j,k} - \theta_j^{\rm BCG}) p_{mem,k}}{\sum_k p_{mem,k}}, i, j \in 1,2.$$

- “Aperture” Shape: BCG shape + member galaxy distribution, weighted by the galaxy luminosity

Galaxy Cluster Shape

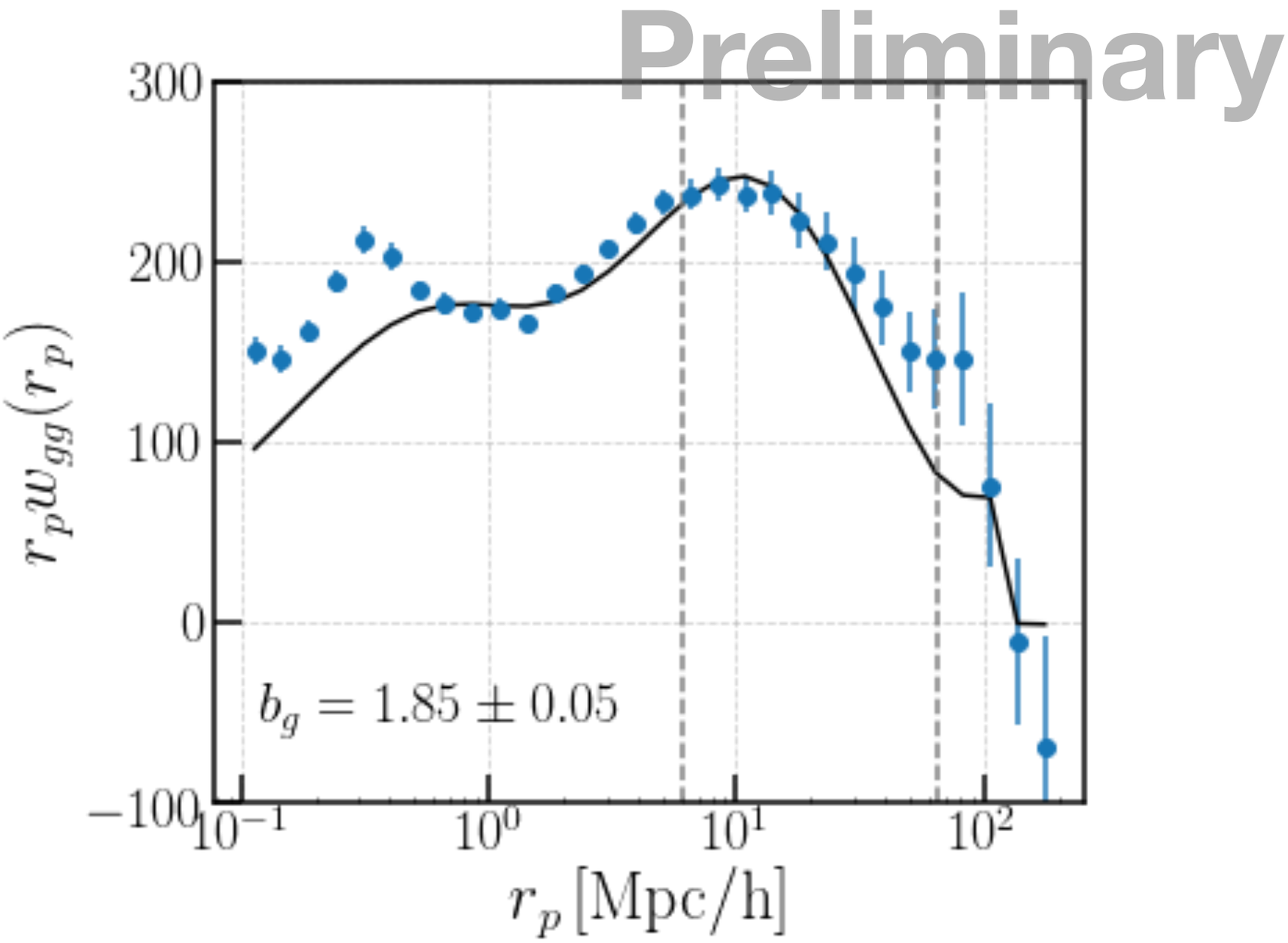
$$e_1 = \frac{I_{11} - I_{22}}{I_{11} + I_{22}}, e_2 = \frac{2I_{12}}{I_{11} + I_{22}}$$

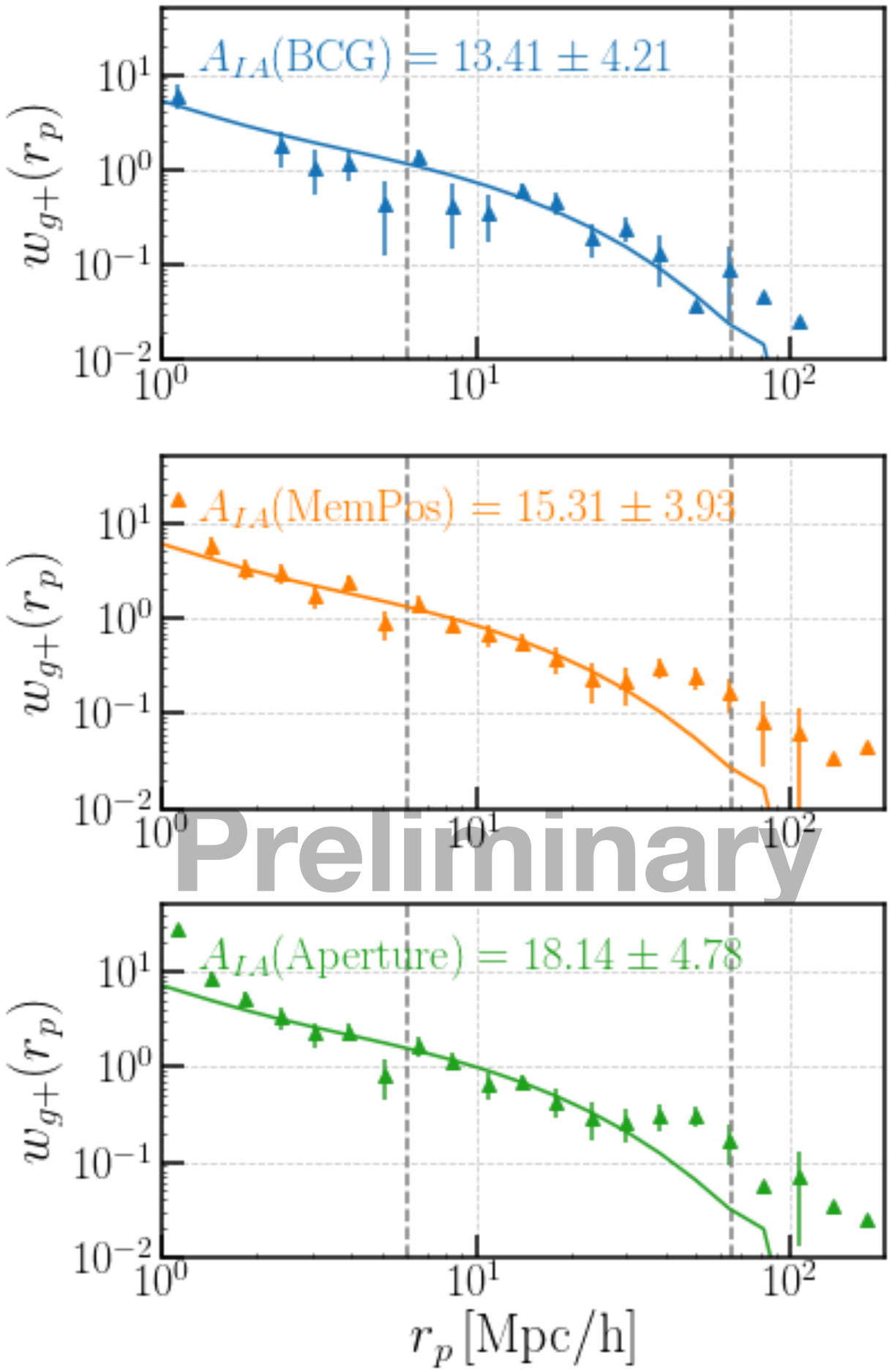




Correlated but with significant scatter, i.e. misalignment exists

LOWZ Galaxy Clustering





Preliminary

Non-linear Alignment (NLA) Model

$$P_{\delta I}(k, z) = -A_{\mathrm{IA}} C_1 \rho_{\mathrm{crit}} \frac{\Omega_{\mathrm{M}}}{D(z)} P_{\delta}(k, z),$$

Dark Emulator (Nishimichi+19)

$$w_{\mathrm{g+}}(R_{\mathrm{p}}) = -b_{\mathrm{g}} \int \mathrm{d}z\; W(z) \int_0^{\infty} \frac{\mathrm{d}k_{\perp}\, k_{\perp}}{2\pi} J_2(k_{\perp} R_{\mathrm{p}}) P_{\delta I}(k_{\perp}, z),$$

Bias of LOWZ sample

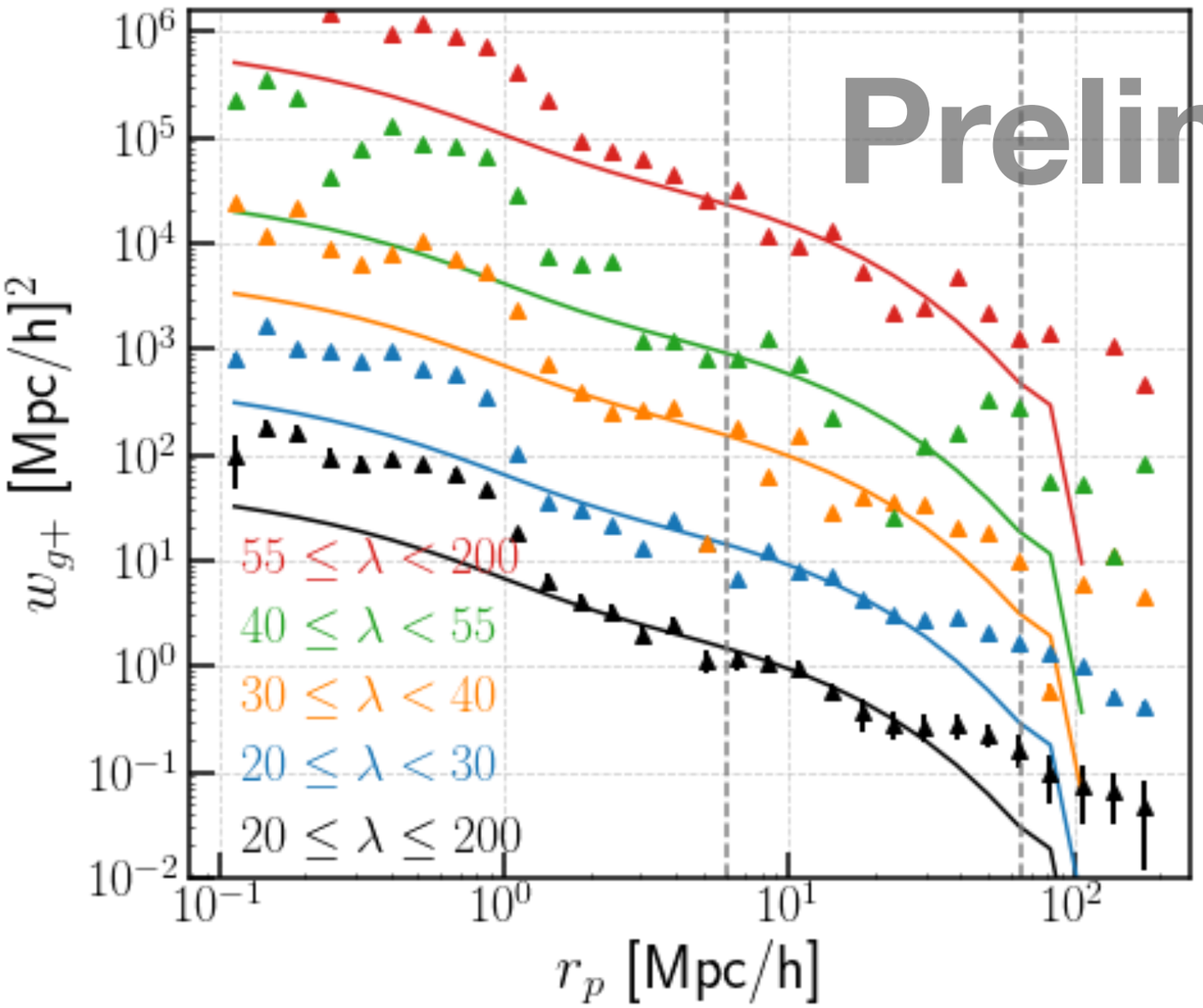
Redshift cut	Richness cut	$N_{\rm clus}$	$\langle z \rangle$	$\langle \lambda \rangle$	$\langle \epsilon_{\rm clus} \rangle$	$b_{\rm g}$	$A_{\rm IA}$
$0.08 < z \leq 0.16$	$19.8 < \lambda \leq 28$	490	0.127	23.7	0.160		16.2 ± 11.8
$0.08 < z \leq 0.16$	$28 < \lambda \leq 40.5$	301	0.127	33.2	0.164	4.22 ± 0.35	48.0 ± 22.0
$0.08 < z \leq 0.16$	$\lambda > 40.5$	206	0.127	58.2	0.134		36.9 ± 11.2
$0.16 < z \leq 0.35$	$19.8 < \lambda \leq 28$	4634	0.275	23.4	0.129		10.4 ± 2.6
$0.16 < z \leq 0.35$	$28 < \lambda \leq 40.5$	2628	0.273	33.2	0.122	$4.25^{+0.15}_{-0.16}$	15.6 ± 3.0
$0.16 < z \leq 0.35$	$\lambda > 40.5$	1609	0.272	57.9	0.112		19.1 ± 3.2
$0.35 < z \leq 0.60$	$19.8 < \lambda \leq 28$	3077	0.383	24.5	0.122		11.0 ± 3.1
$0.35 < z \leq 0.60$	$28 < \lambda \leq 40.5$	5371	0.420	33.8	0.116	4.61 ± 0.27	10.9 ± 2.4
$0.35 < z \leq 0.60$	$\lambda > 40.5$	6460	0.465	59.1	0.112		15.1 ± 2.4

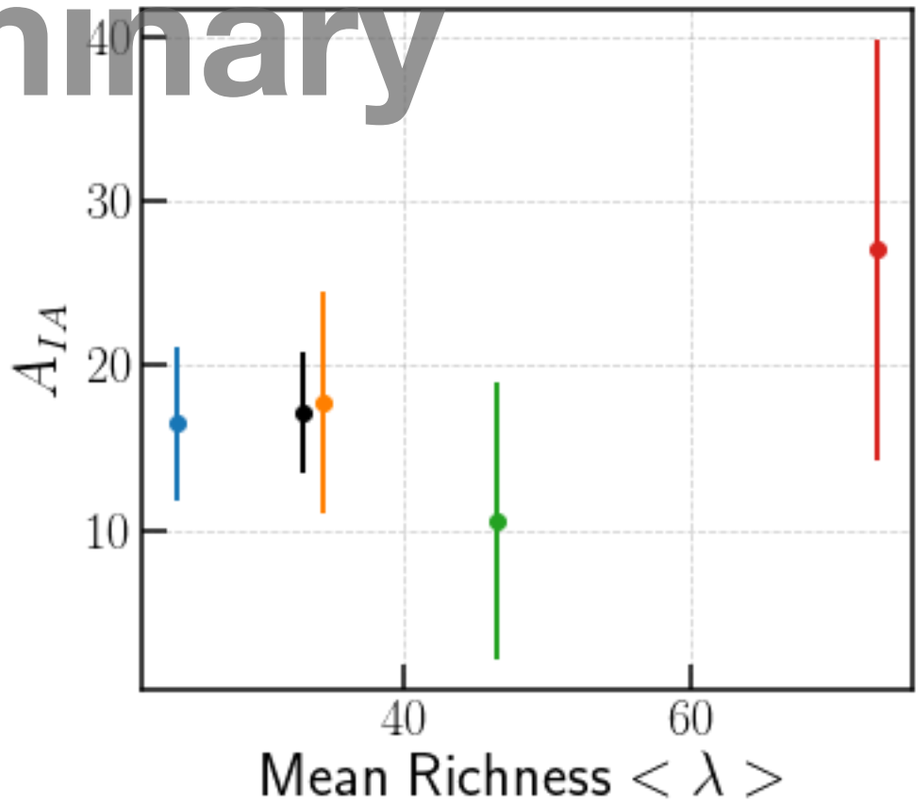
Van Uitert, + Joachimi 17

Comparison between the above results with previous results

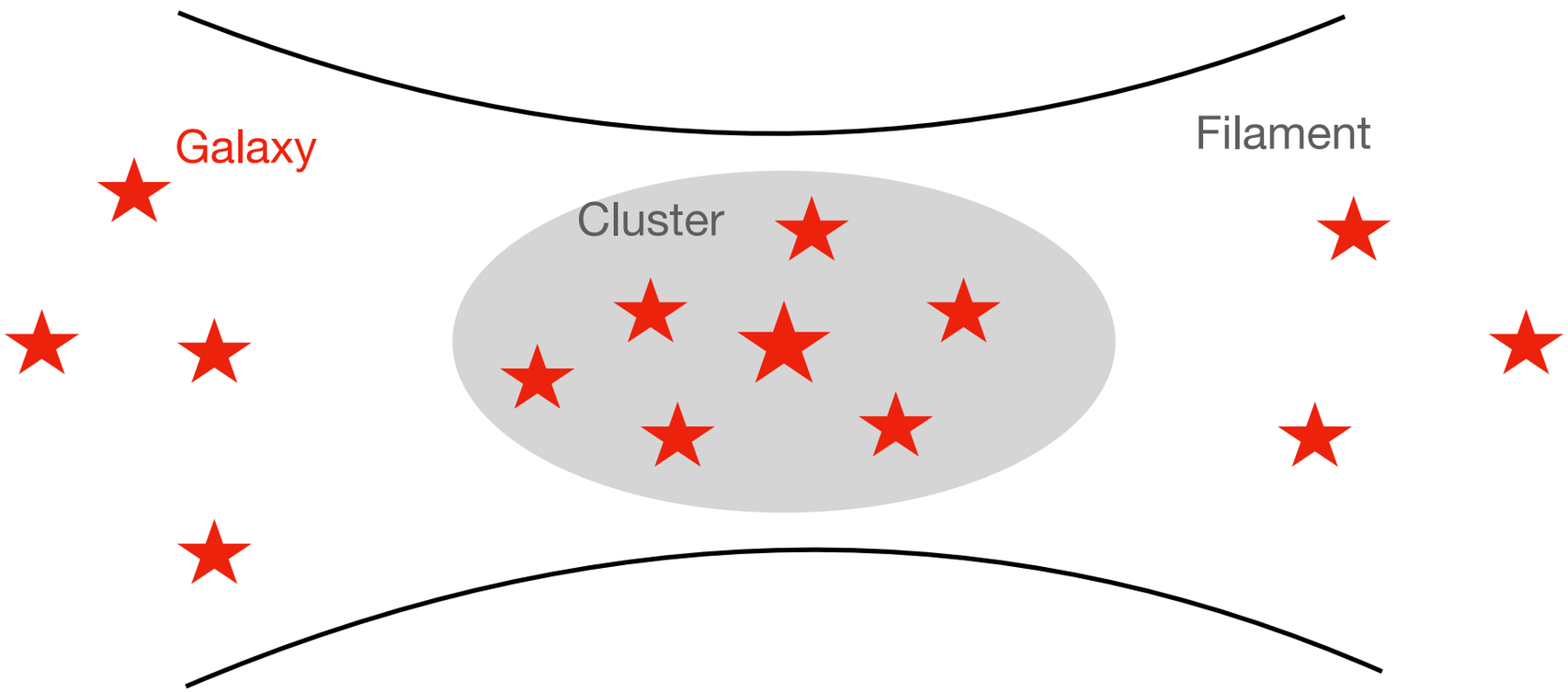
- Density sample differs (LOWZ LRGs versus Clusters)
- Different z and richness selection

Galaxy Cluster IA — dependence on richness





Projection Effects of Galaxy Clusters



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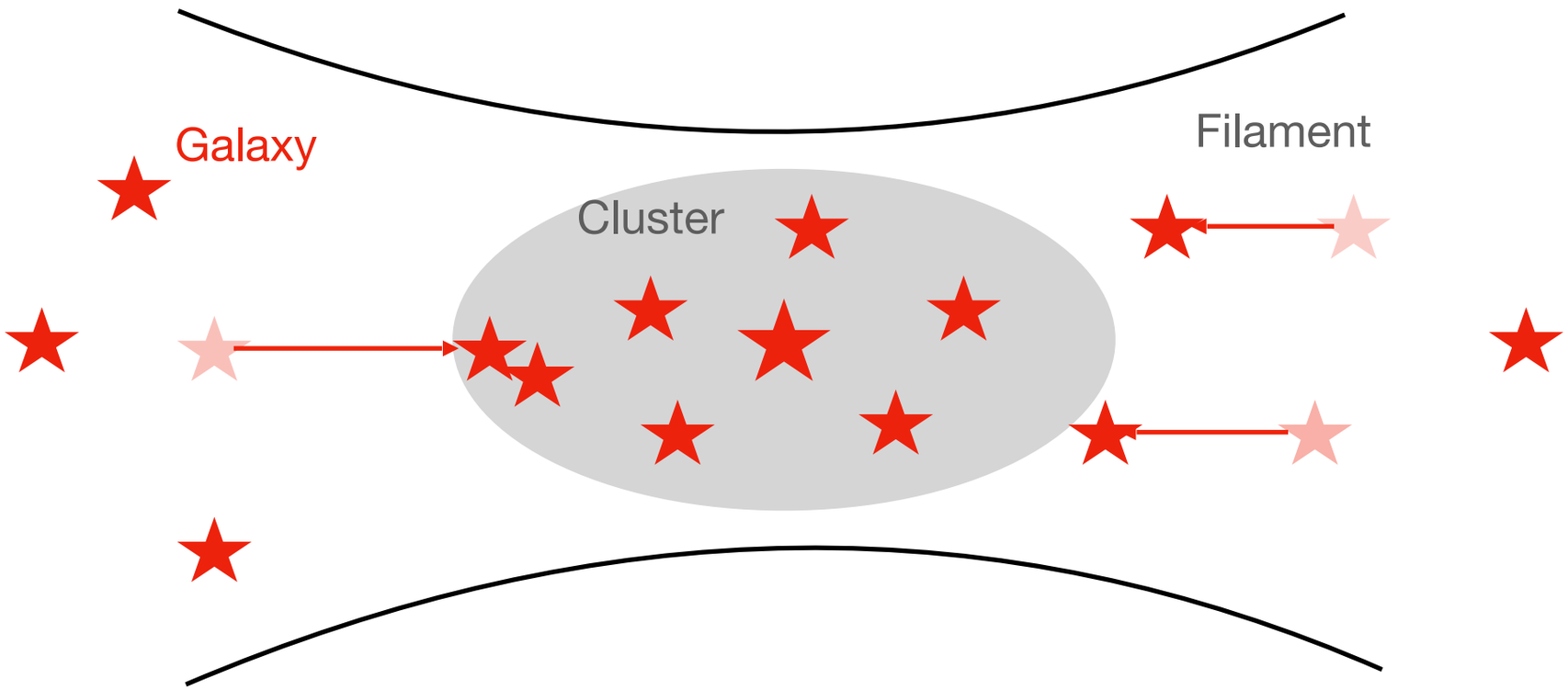
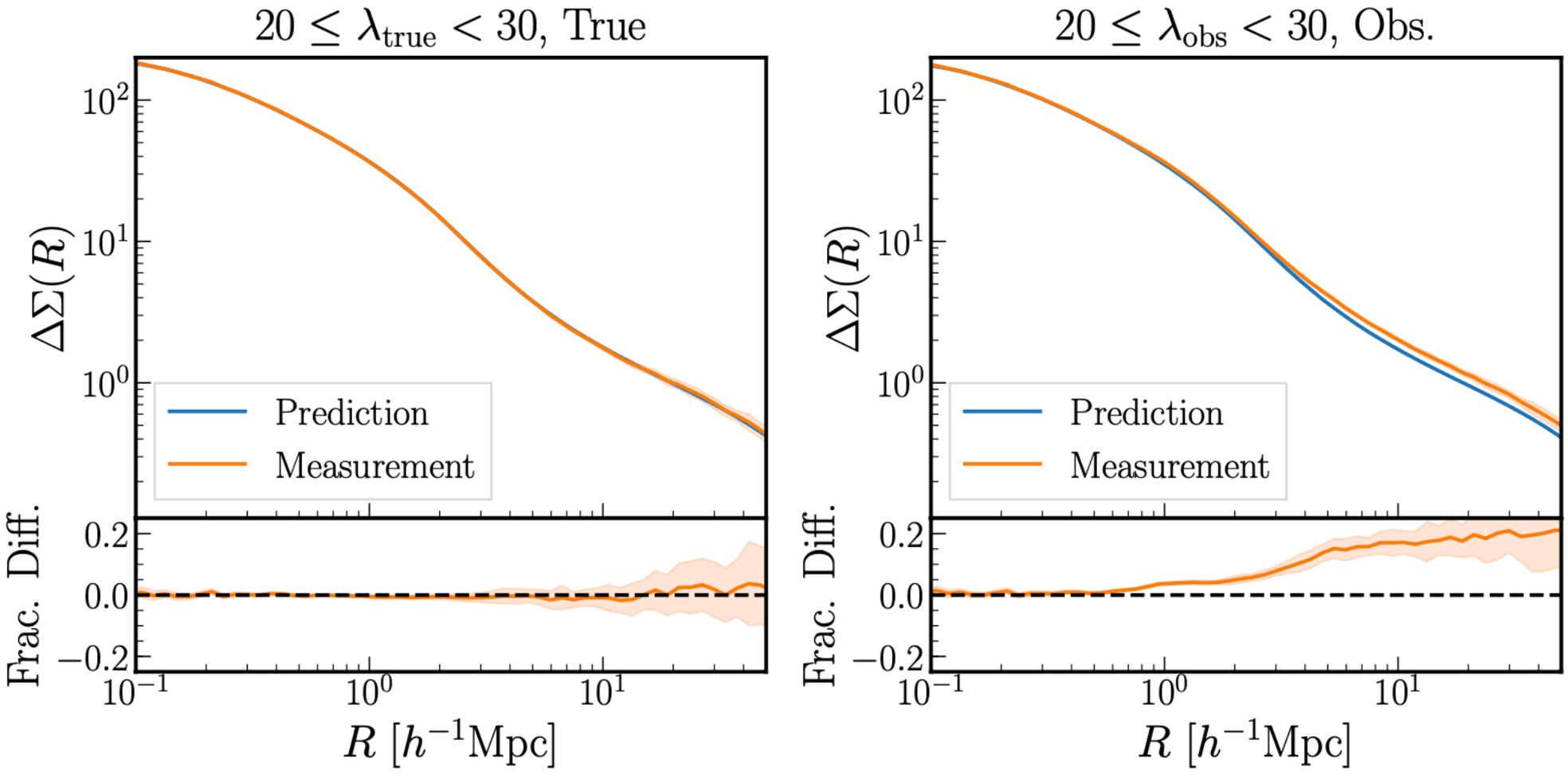


<u>Observed LOS galaxy position is offset from its true position due to photo-z uncertainty mostly</u>

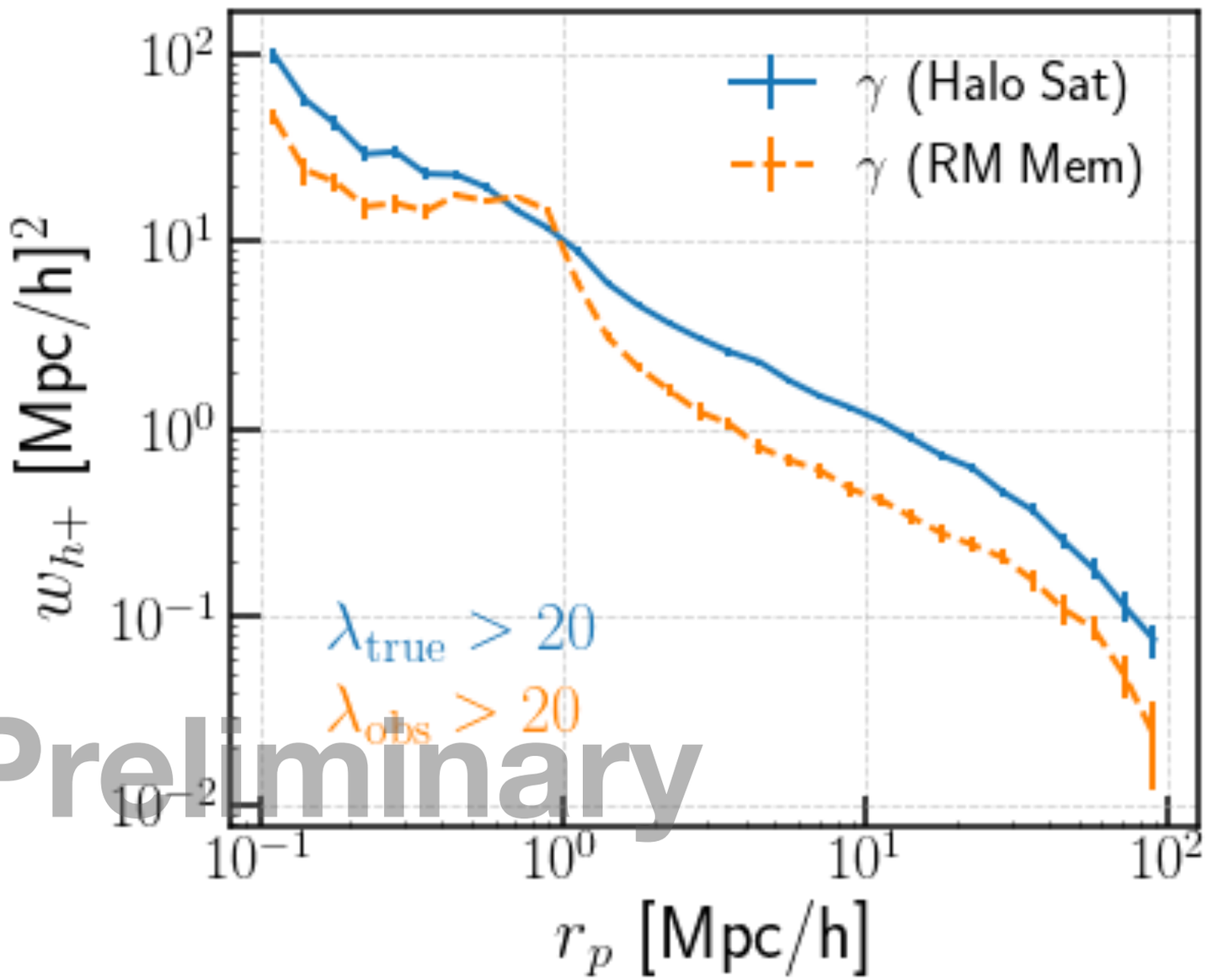
- Galaxy cluster membership messed up
- Selection bias of clusters
- One major systematic for galaxy cluster cosmology: mass-richness relation, cluster lensing and clustering (Sunayama+20, 22, Park+22, Osato+18)

Anisotropic boost of cluster lensing/clustering



Sunayama+20, see also Sunayama+22, Park+22, Osato+18

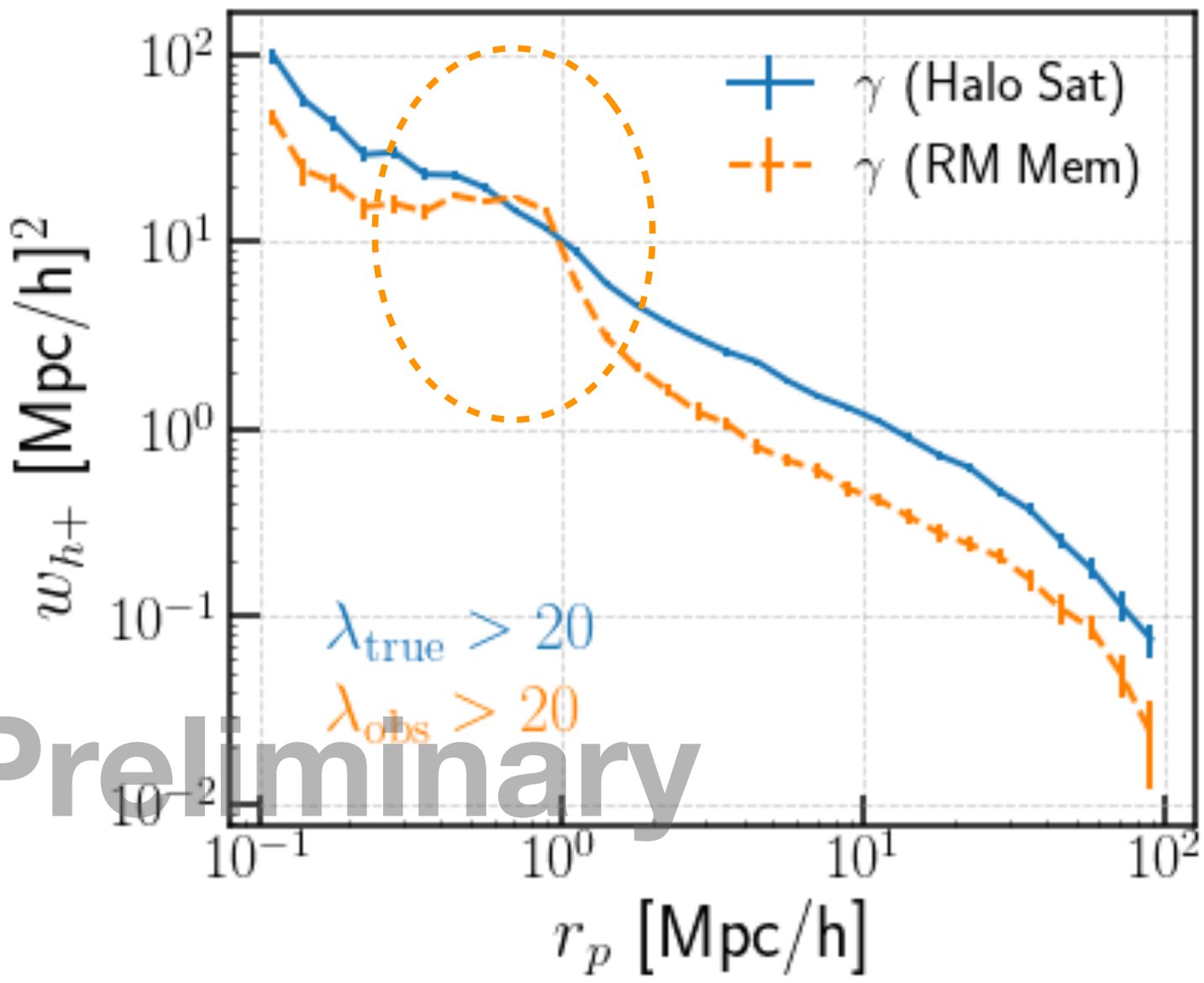
Impact of Projection Effects on Cluster IA



Redmapper Cluster Mock (Sunayama+20)

- Boxsize ~ 1 Gpc/h N-body simulation, z=0.2
- HOD populated galaxies
- LOS projection length = 60Mpc/h
- Redmapper (RM) finder run on the mock galaxy catalog, giving member galaxies and observed richness ($p_{\rm mem}$ and λ_{obs})
- Density sample (δ_h): halos with $M_h > 10^{12} M_\odot/h$

Impact of Projection Effects on Cluster IA

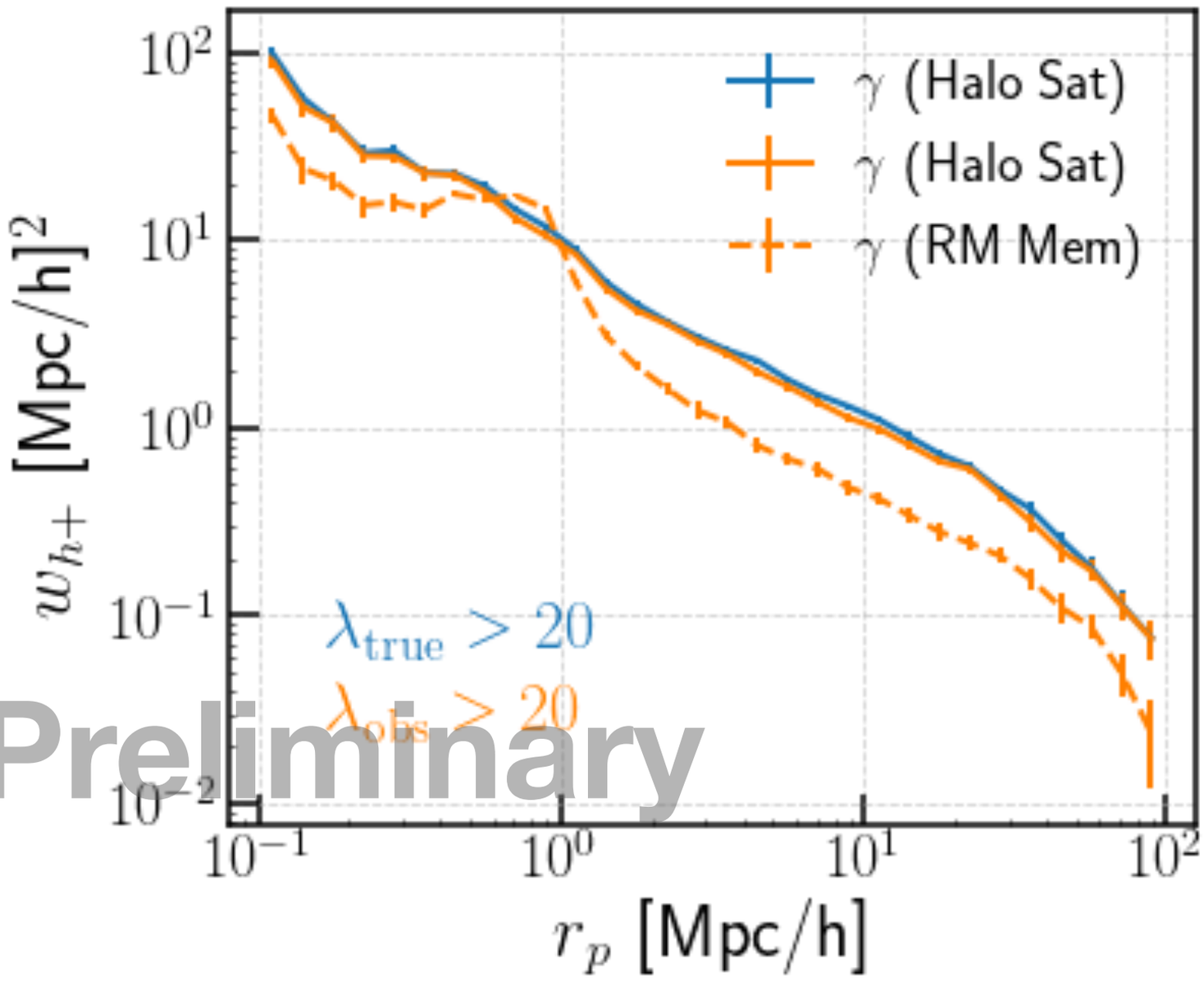


Observed cluster IA is much lower

- λ_{obs} selected versus λ_{true} selected clusters
- Cluster shape traced by satellite galaxies (true members) within cluster versus RM identified members

One halo - two halo transition bump caused by projection effects?

Impact of Projection Effects on Cluster IA



Preliminary

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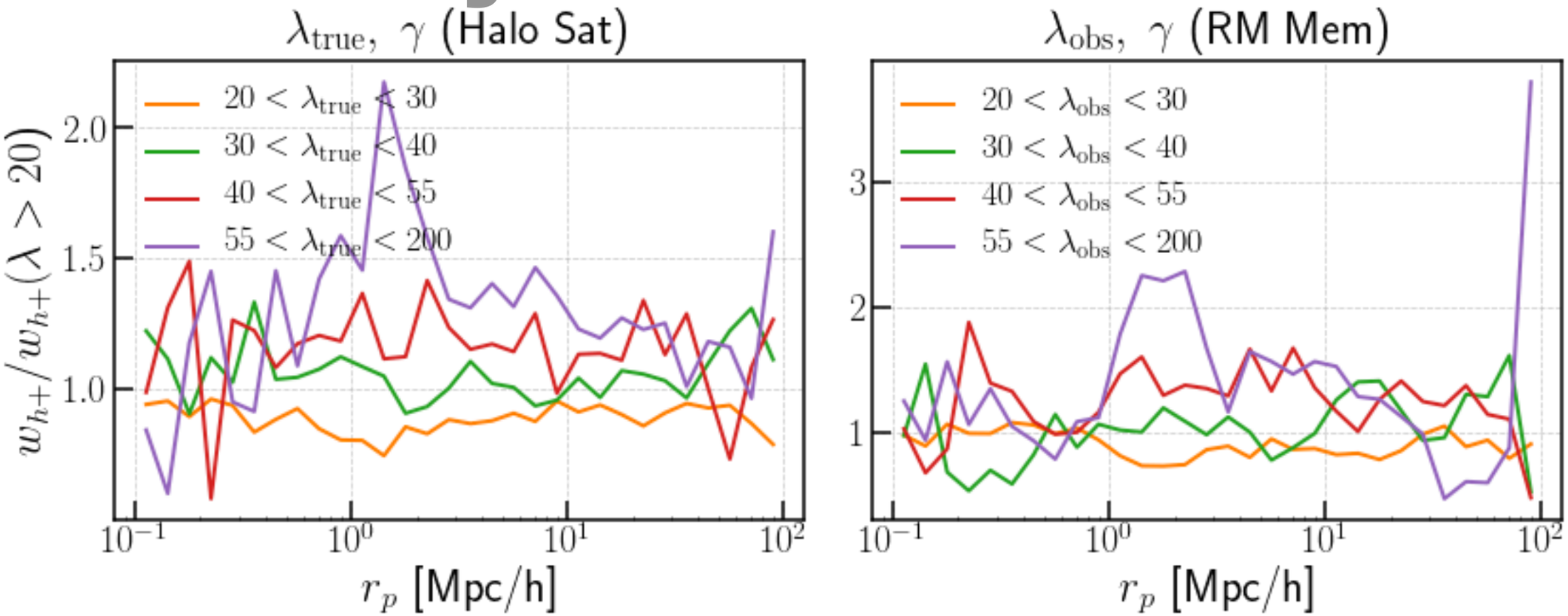
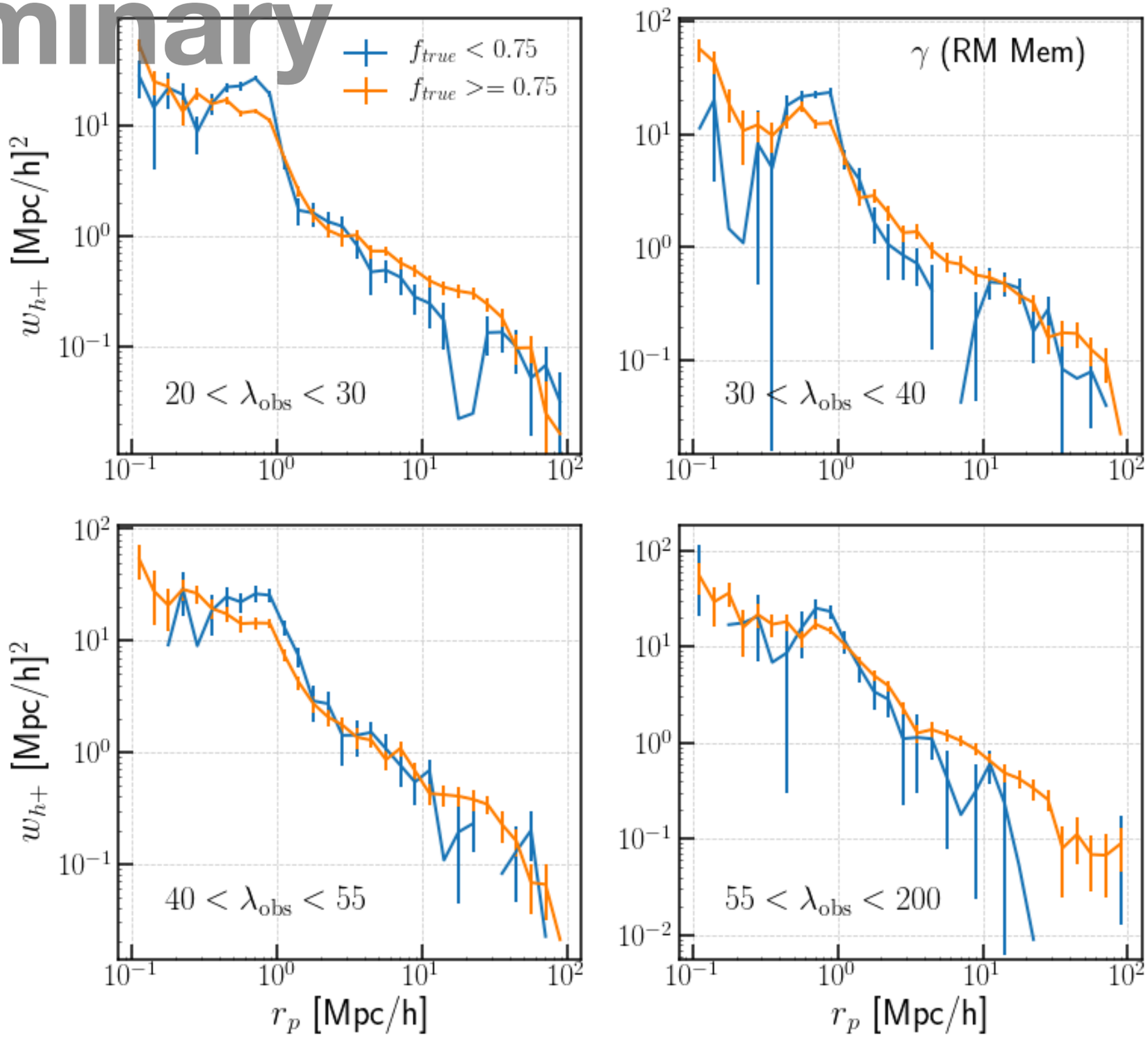
Impact of Projection Effects on Cluster IA

Preliminary



Projection effects messed the richness dependence of Cluster IA

Preliminary



$f_{true} = N_{\rm true,mem}/N_{\rm mem}$

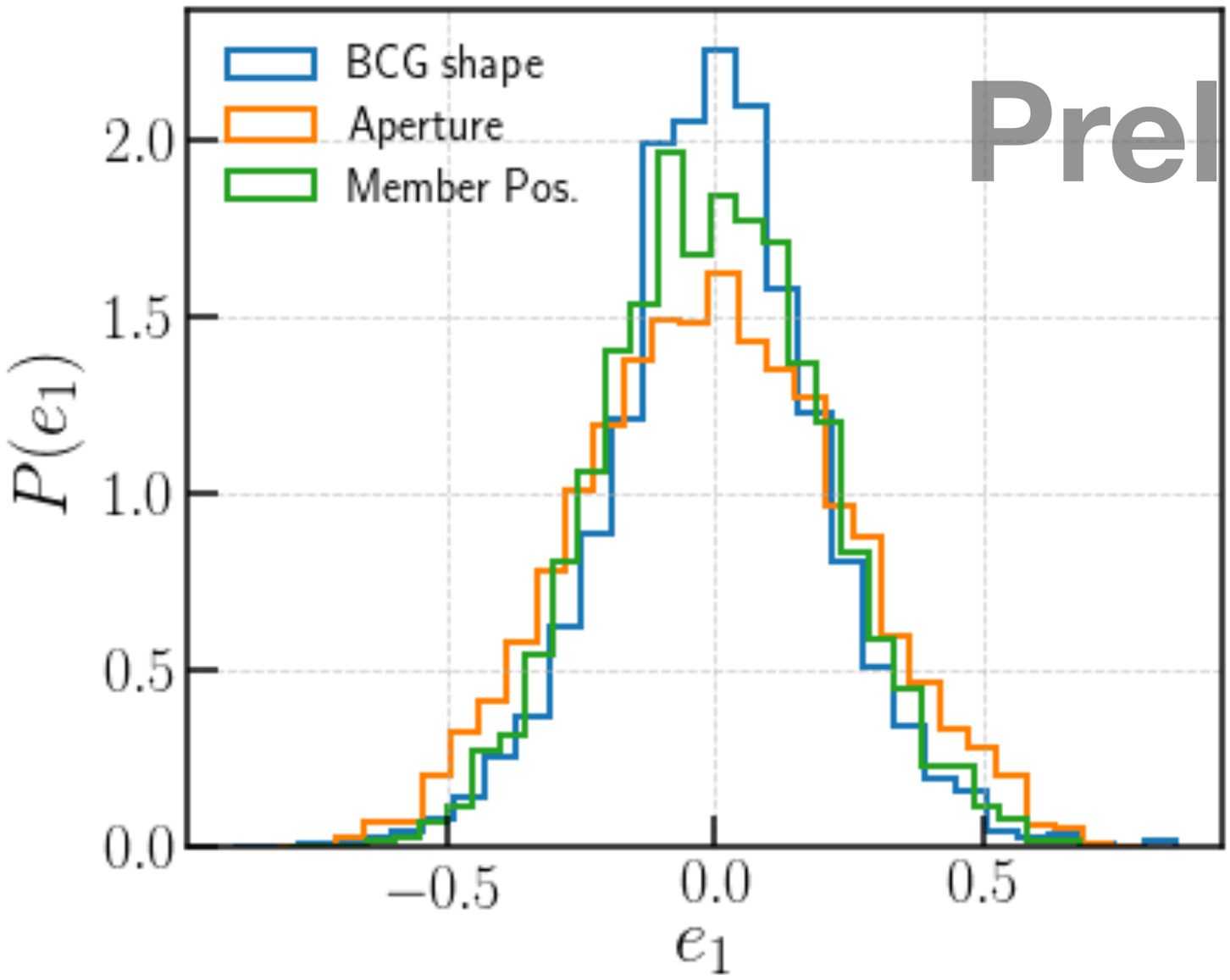
IA signal is decreased for clusters with more contaminated members (i.e. lower f_{true}, more severe projection effects)

Summary

- Obtaining dark matter halo shape/IA in observation is challenging
- Novel estimator — aperture inertia tensor can promisingly be applied to ELG surveys
- Galaxy clusters show strongest IA signal
- Projection effects decrease the observed cluster IA signal

Back-up slides

Galaxy Cluster Shape - ellipticity PDF



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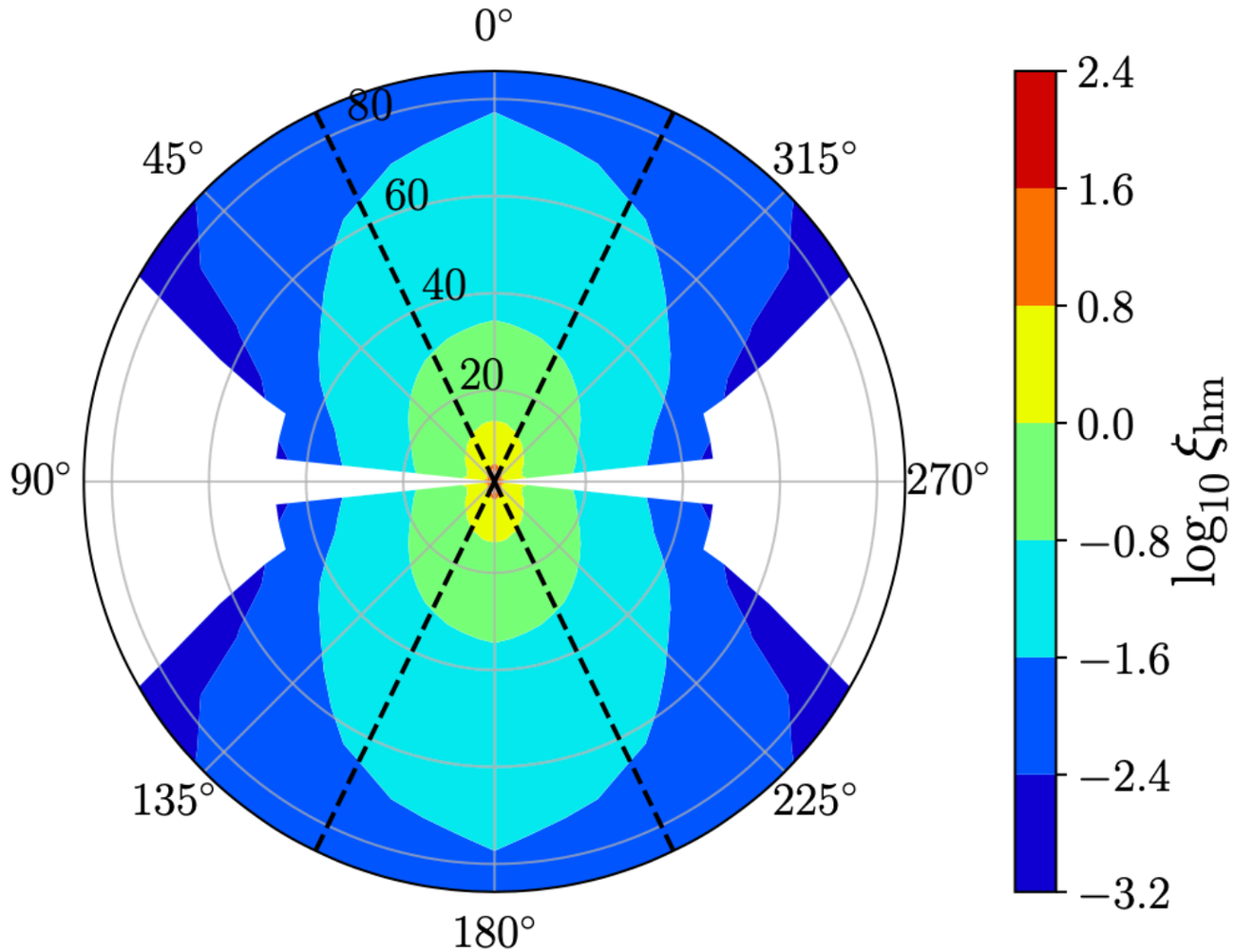

Osato, Nishimichi, Oguri, Takada and Okumura 18