Perturbative models for imaging surveys

(Intrinsic alignments in the Dark Energy Survey)

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Outline

- "3x2" cosmology and intrinsic alignments
- Analytic modeling of IA
- Observational results and future directions
- Galaxy-galaxy lensing at smaller scales

In collaboration with:

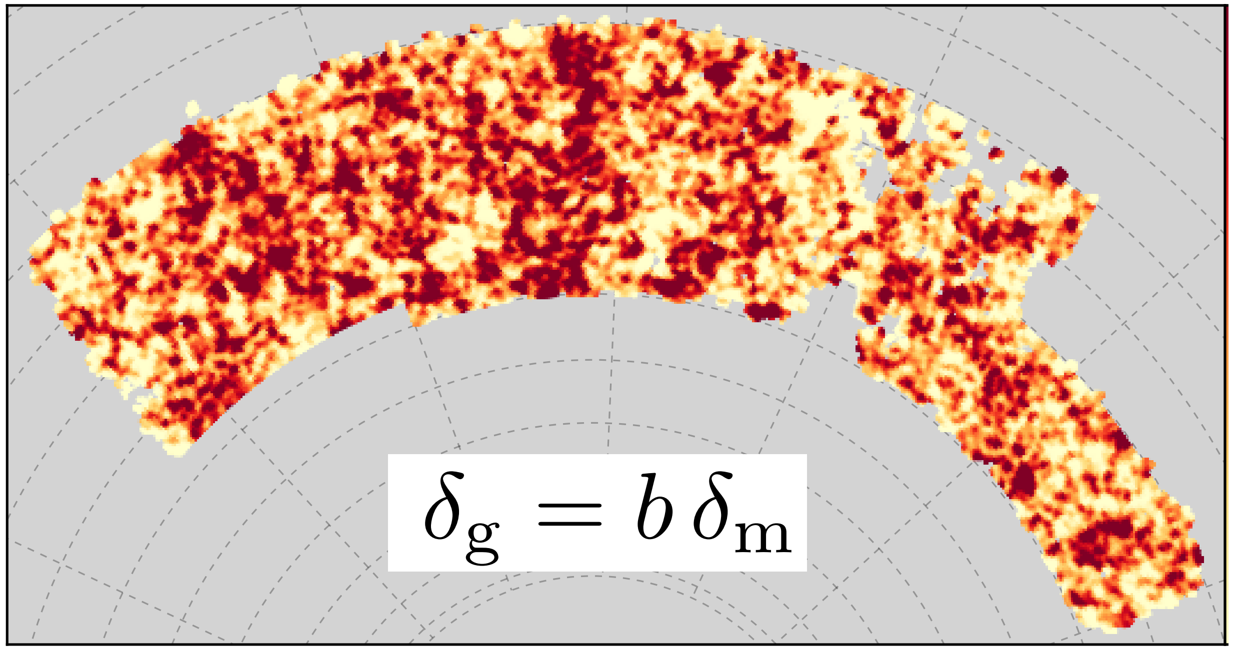
DES Collaboration,
T. Eifler, X. Fang, C. Hirata, B. Jain, E. Krause, N. MacCrann, J. McEwen, S. Samuroff, D. Schmitz, U. Seljak, M. Troxel, Z. Vlah

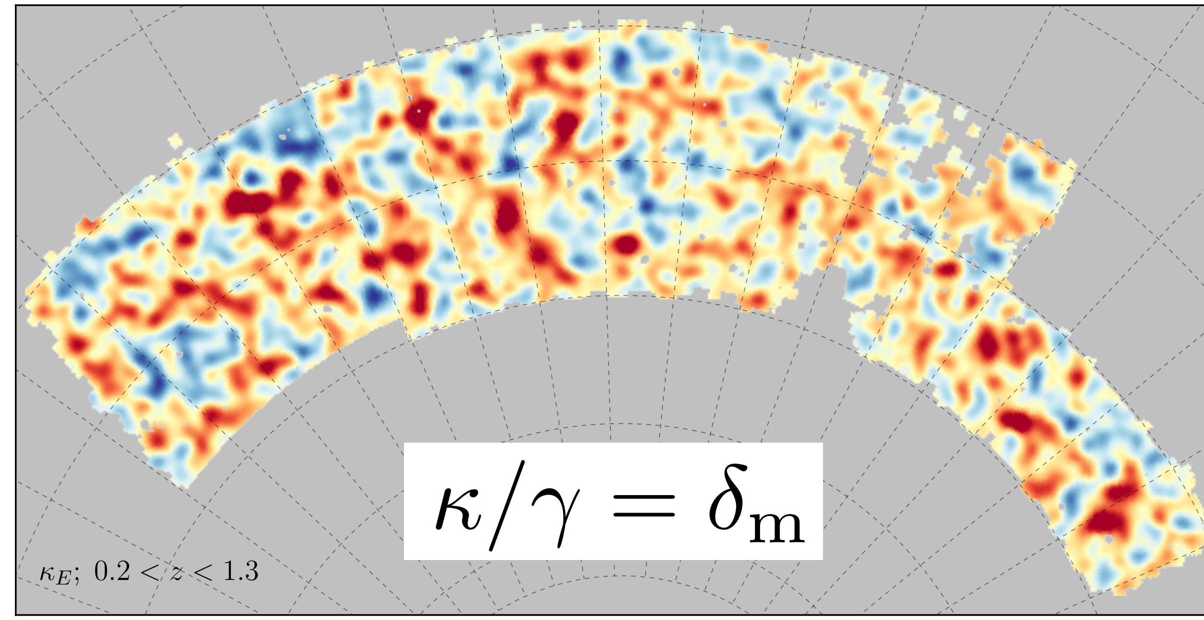
Summary

- “3x2” cosmology and intrinsic alignments
  - **Intrinsic shape correlations are important**
    arXiv: 1506.08730
- Analytic modeling of IA
  - **PT model analogous to bias expansion**
    arXiv: 1504.02510, 1708.09247, 1805.02649
- Observational results and future directions
  - **Hints of quadratic alignments in DES Y1**
    arXiv: 1708.01538, 1811.06989
- Galaxy-galaxy lensing at smaller scales
  - **Simple “point-mass” parameter**
    arXiv: 1903.07101

Combining probes

DES Year 1: Elvin-Poole+ 2017; Chang+ 2018





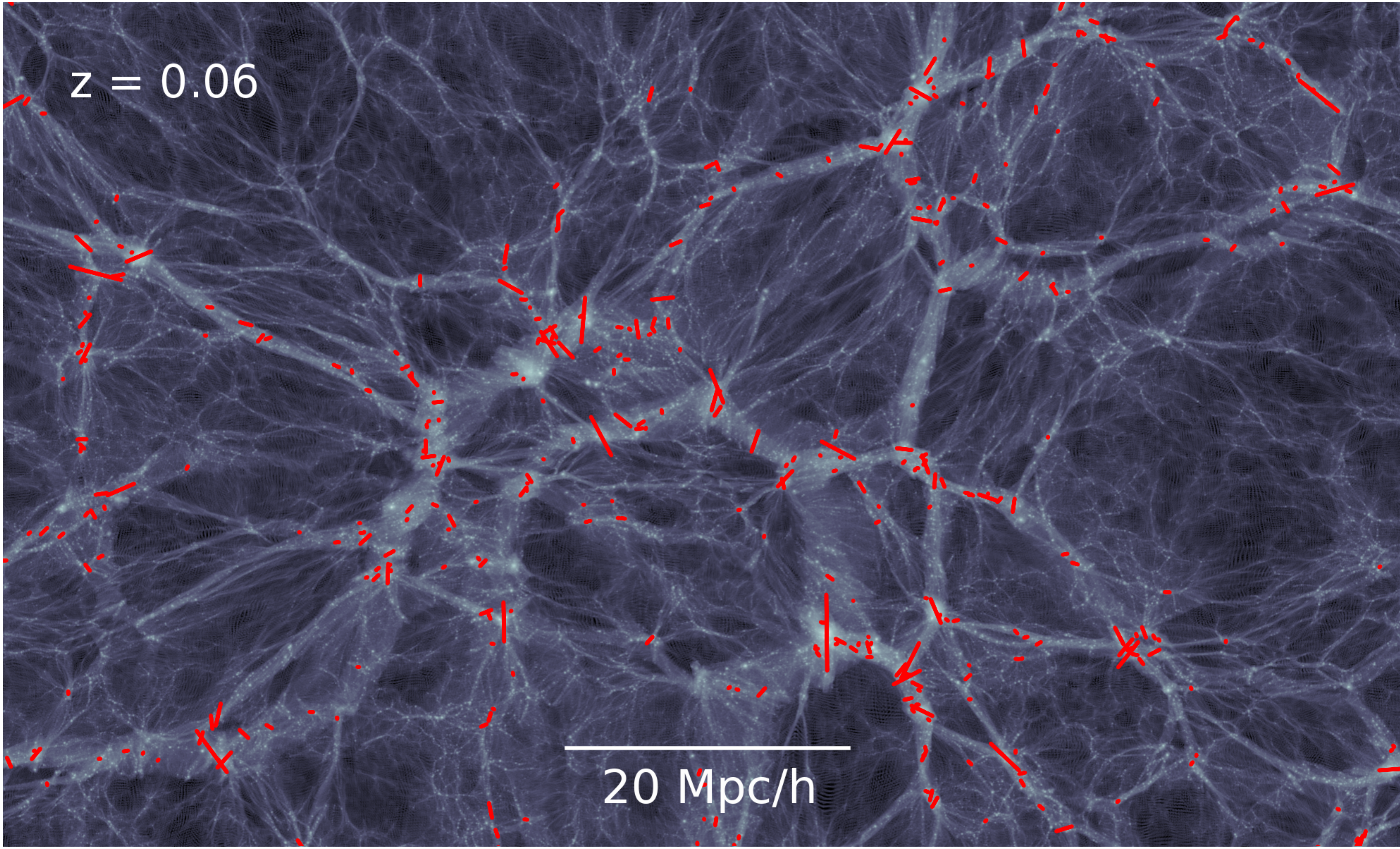
$$\langle \delta_g | \delta_g \rangle = \xi_{\rm gg} \sim b^2\sigma_8^2 \qquad \langle \delta_g | \gamma \rangle = \xi_{\rm mg} \sim b\sigma_8^2 \qquad \langle \gamma | \gamma \rangle = \xi_{\rm mm} \sim \sigma_8^2$$

“3x2” analysis

- More statistical power, different systematics, “self-calibration”
- Also: CMB, clusters, SNe, strong lensing, RSD, 21cm…

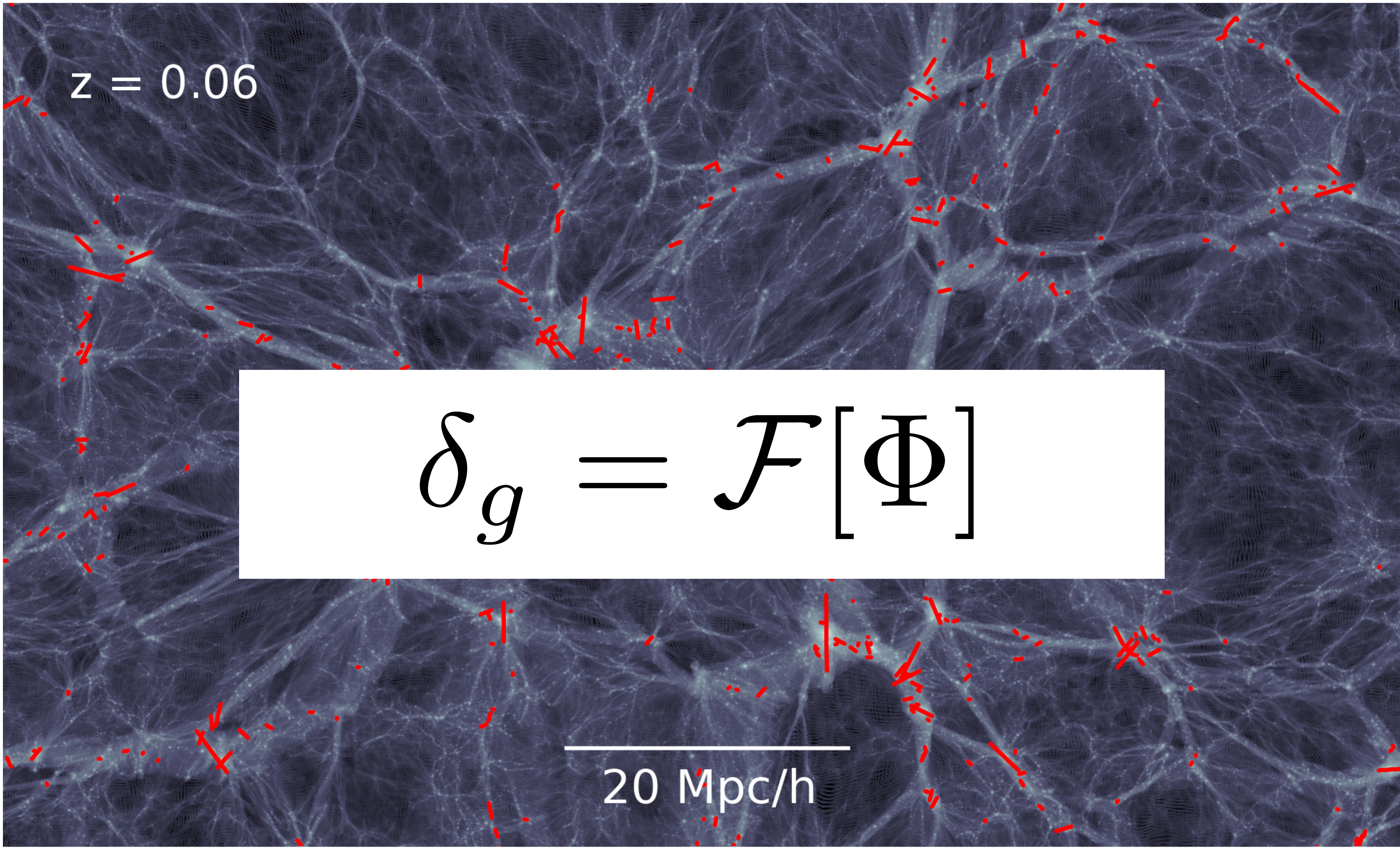
e.g. Mandelbaum+ 2013; Krause & Eifler 2017; DES Y1; Joudaki+ KiDS 2017

Galaxy observables:
positions and shapes



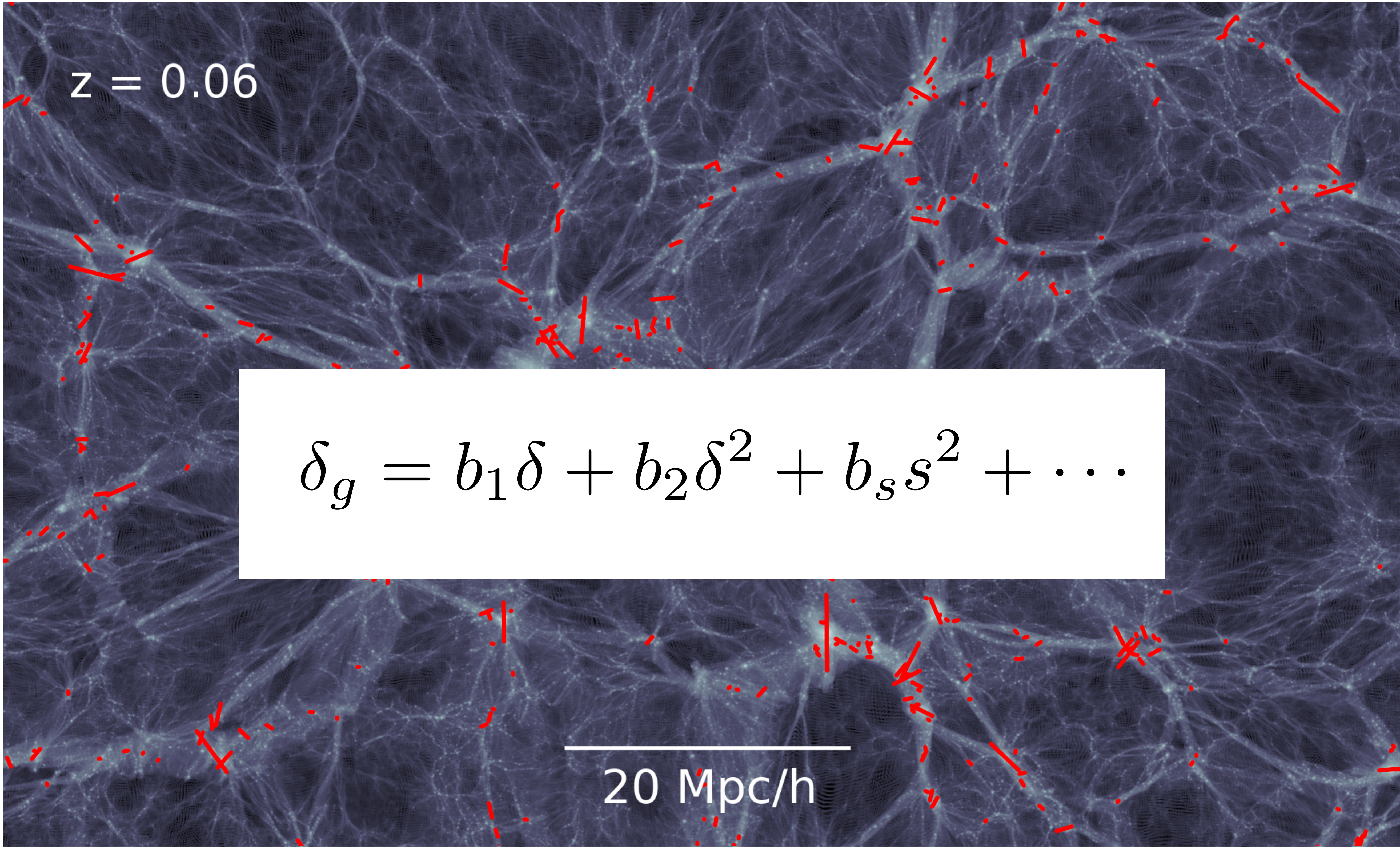
(MassiveBlack II: Khandai+ 2014; Tenneti+ 2014a,b)

Galaxy positions ("bias")



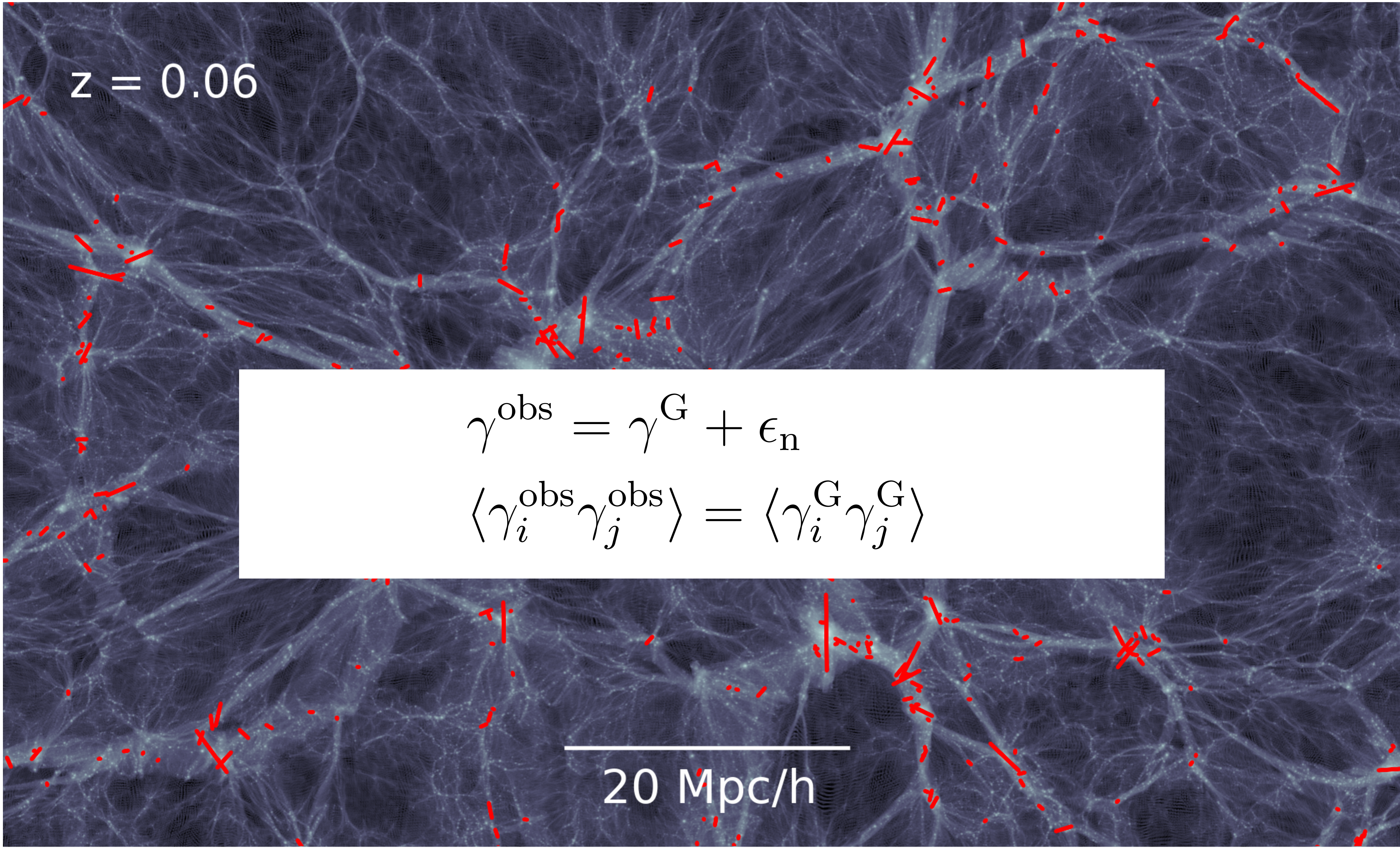
$$\delta_g = \mathcal{F}[\Phi]$$

Galaxy positions (“bias”)



$$\delta_g = b_1\delta + b_2\delta^2 + b_s s^2 + \cdots$$

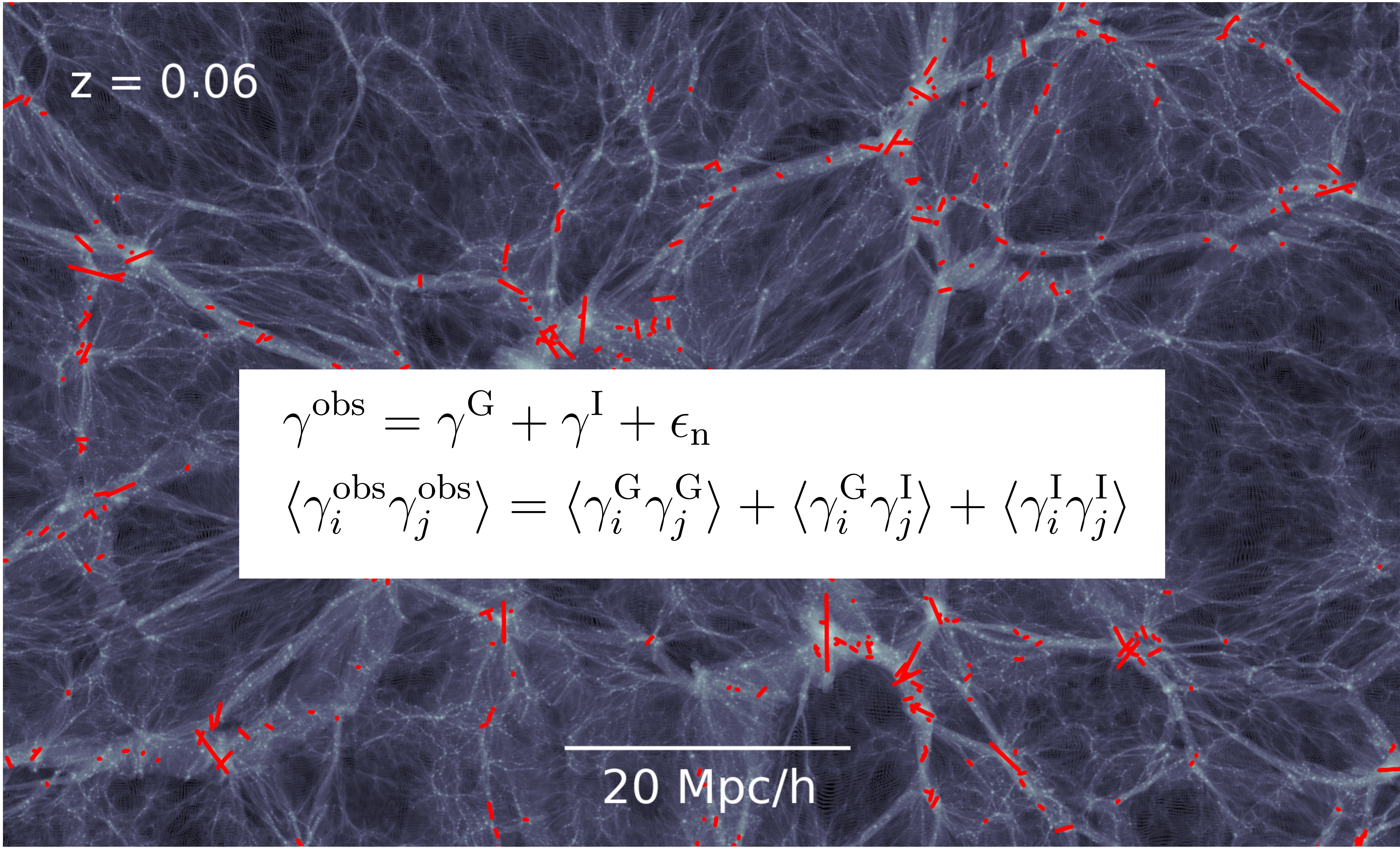
Galaxy shapes ("intrinsic alignments")



$$\gamma^{\rm obs} = \gamma^{\rm G} + \epsilon_{\rm n}$$

$$\langle \gamma_i^{\rm obs} \gamma_j^{\rm obs} \rangle = \langle \gamma_i^{\rm G} \gamma_j^{\rm G} \rangle$$

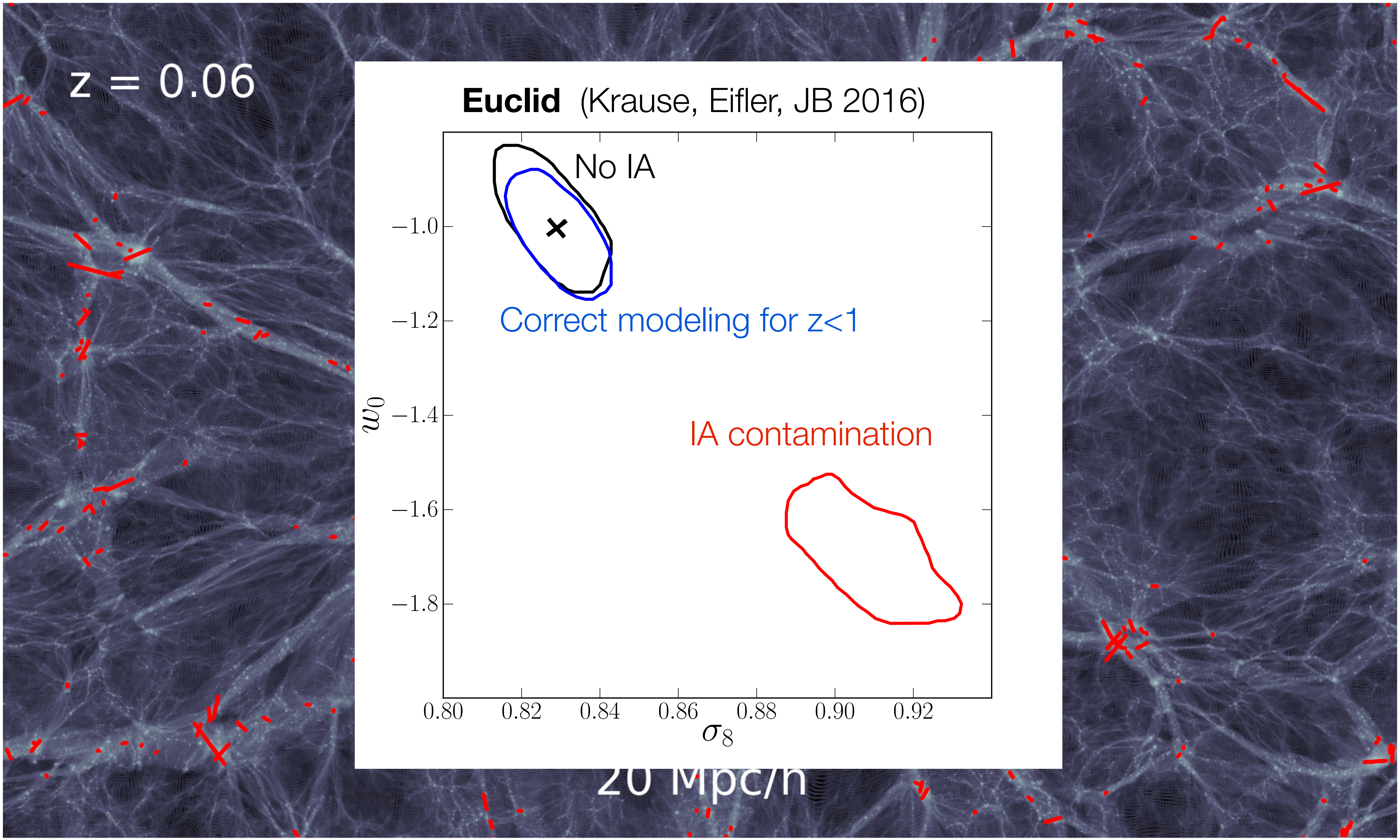
Galaxy shapes ("intrinsic alignments")



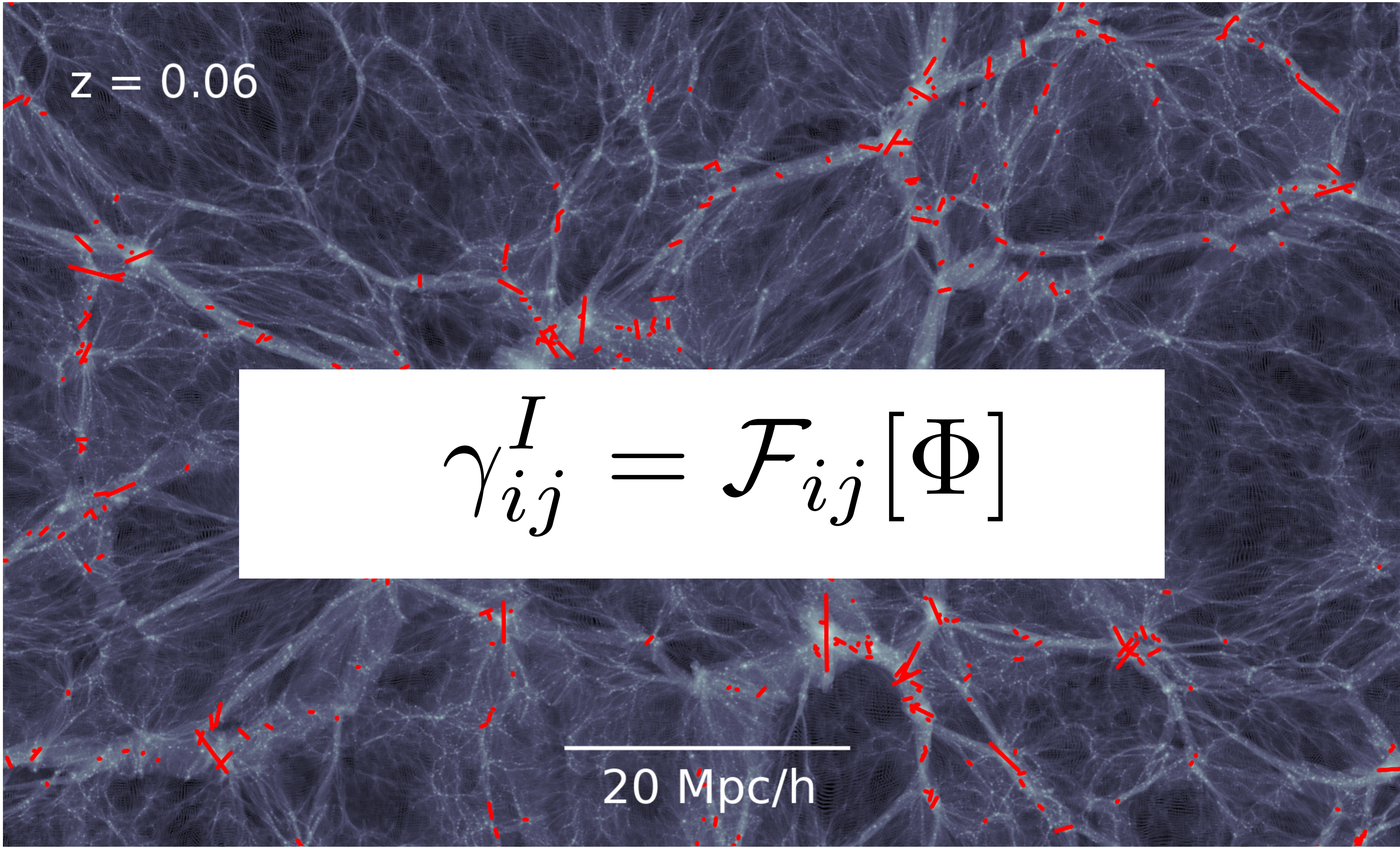
$$\gamma^{\mathrm{obs}} = \gamma^{\mathrm{G}} + \gamma^{\mathrm{I}} + \epsilon_{\mathrm{n}}$$

$$\langle \gamma_i^{\mathrm{obs}} \gamma_j^{\mathrm{obs}} \rangle = \langle \gamma_i^{\mathrm{G}} \gamma_j^{\mathrm{G}} \rangle + \langle \gamma_i^{\mathrm{G}} \gamma_j^{\mathrm{I}} \rangle + \langle \gamma_i^{\mathrm{I}} \gamma_j^{\mathrm{I}} \rangle$$

Galaxy shapes ("intrinsic alignments")

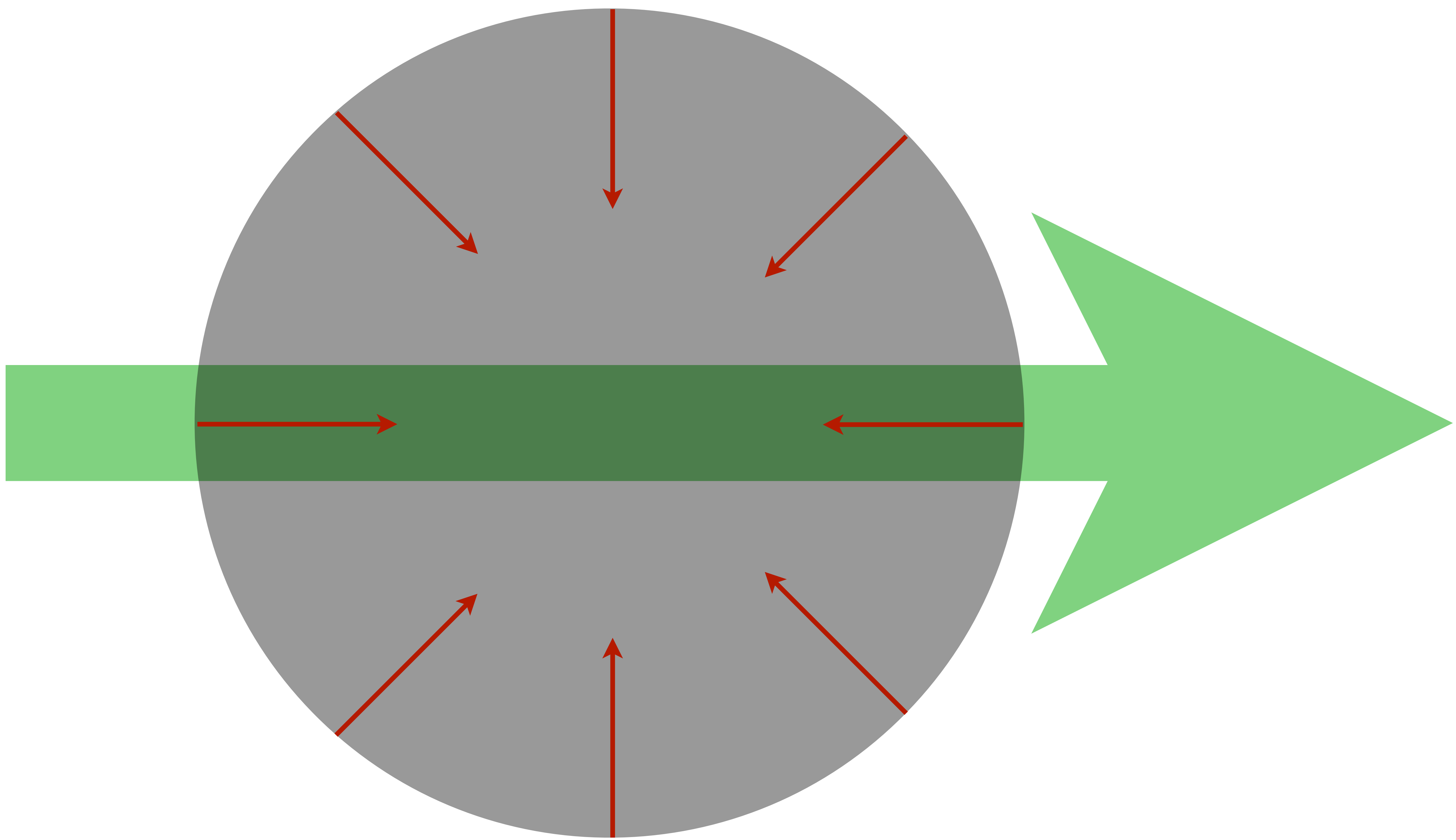


Galaxy shapes (“intrinsic alignments”)

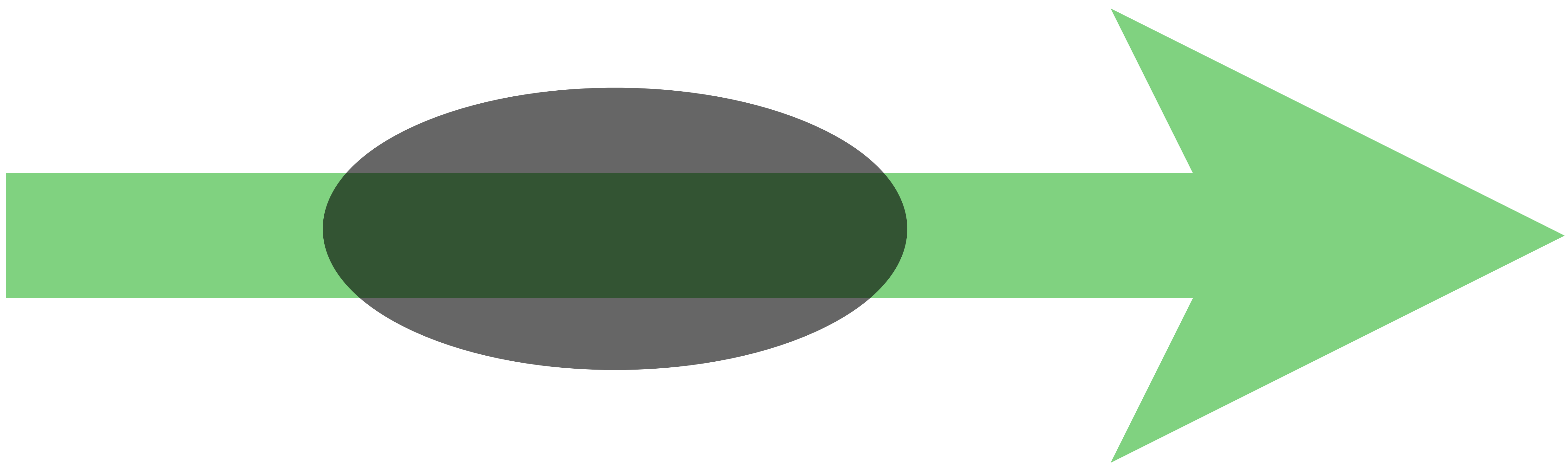


$$\gamma_{ij}^{I} = \mathcal{F}_{ij}[\Phi]$$

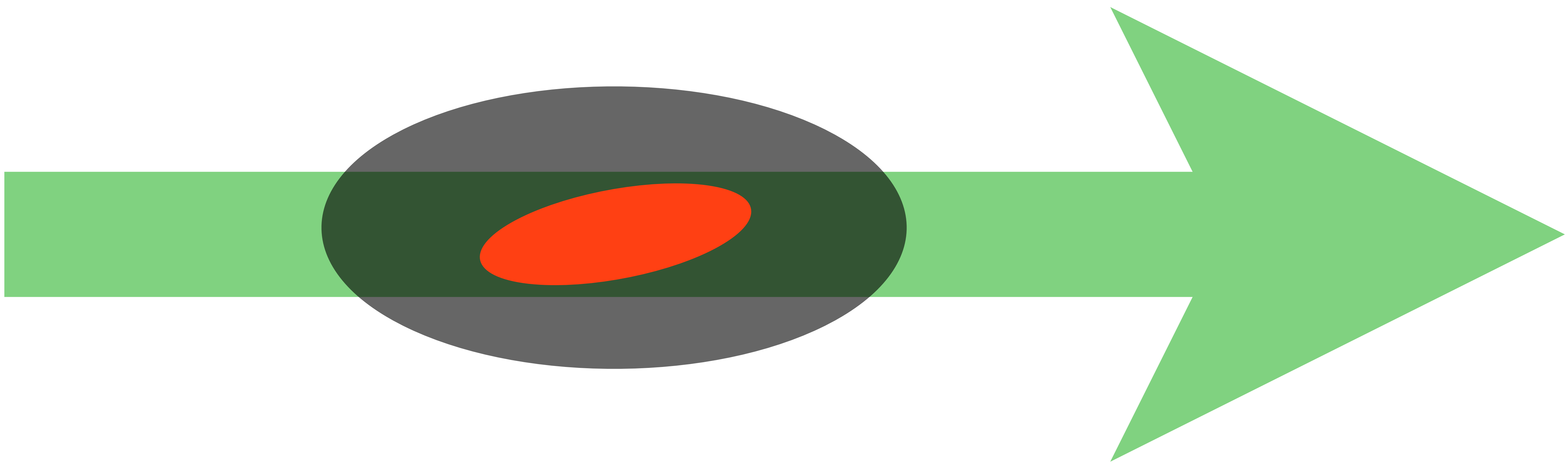
Tidal alignment: collapse in a tidal field



Tidal alignment



Tidal alignment:
collapse in a tidal field

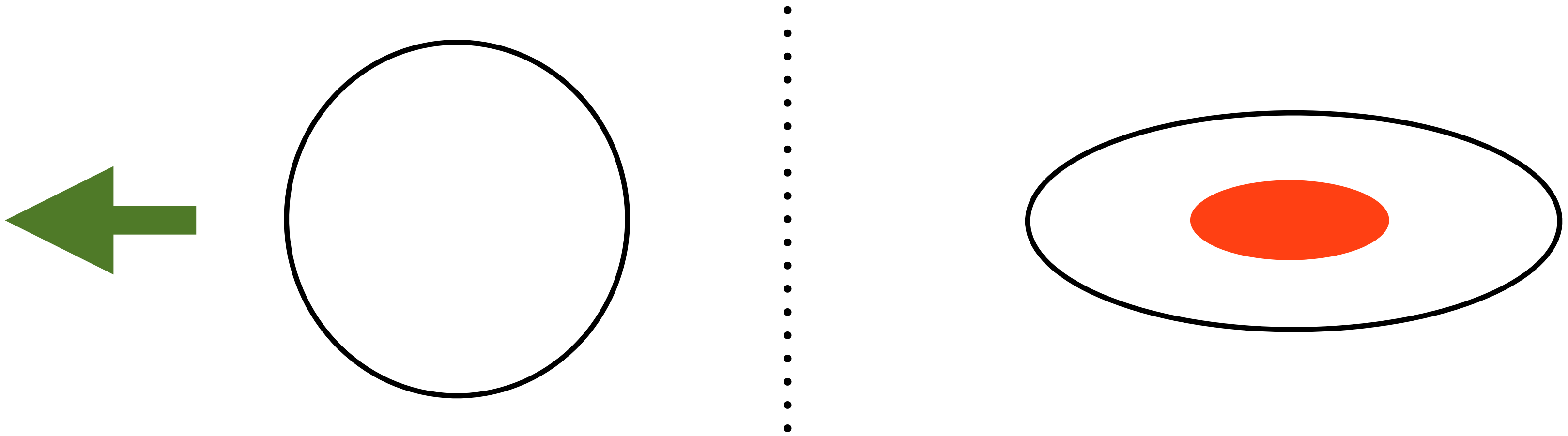


$$\gamma^I_{ij} = \frac{C_1}{4\pi G}\nabla_i\nabla_j\Phi \sim C_1\nabla_i\nabla_j\nabla^{-2}\delta = C_1 s_{ij}$$

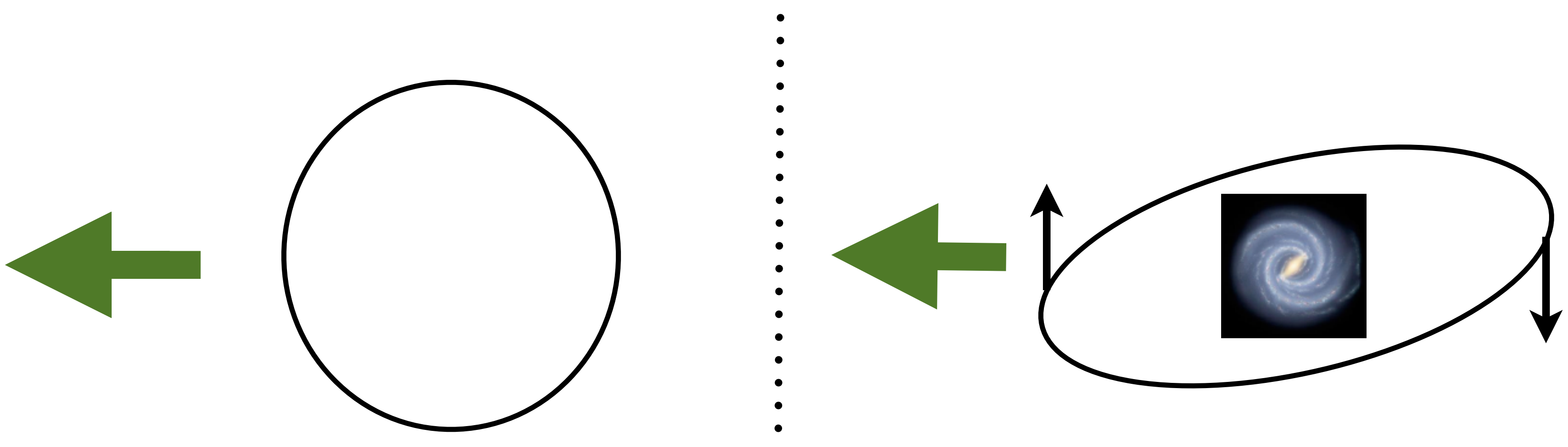
“NLA” model (see T. Okumura talk, T. Kurita poster)

Analytic IA models

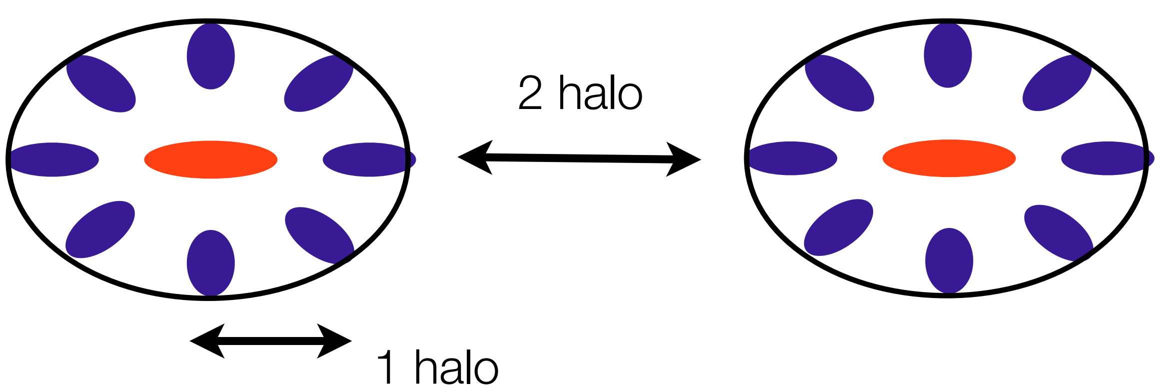
tidal field: s



tidal alignment:
linear in s
(Catelan+ 2001;
Hirata & Seljak 2004;
JB+ 2011, 2015)



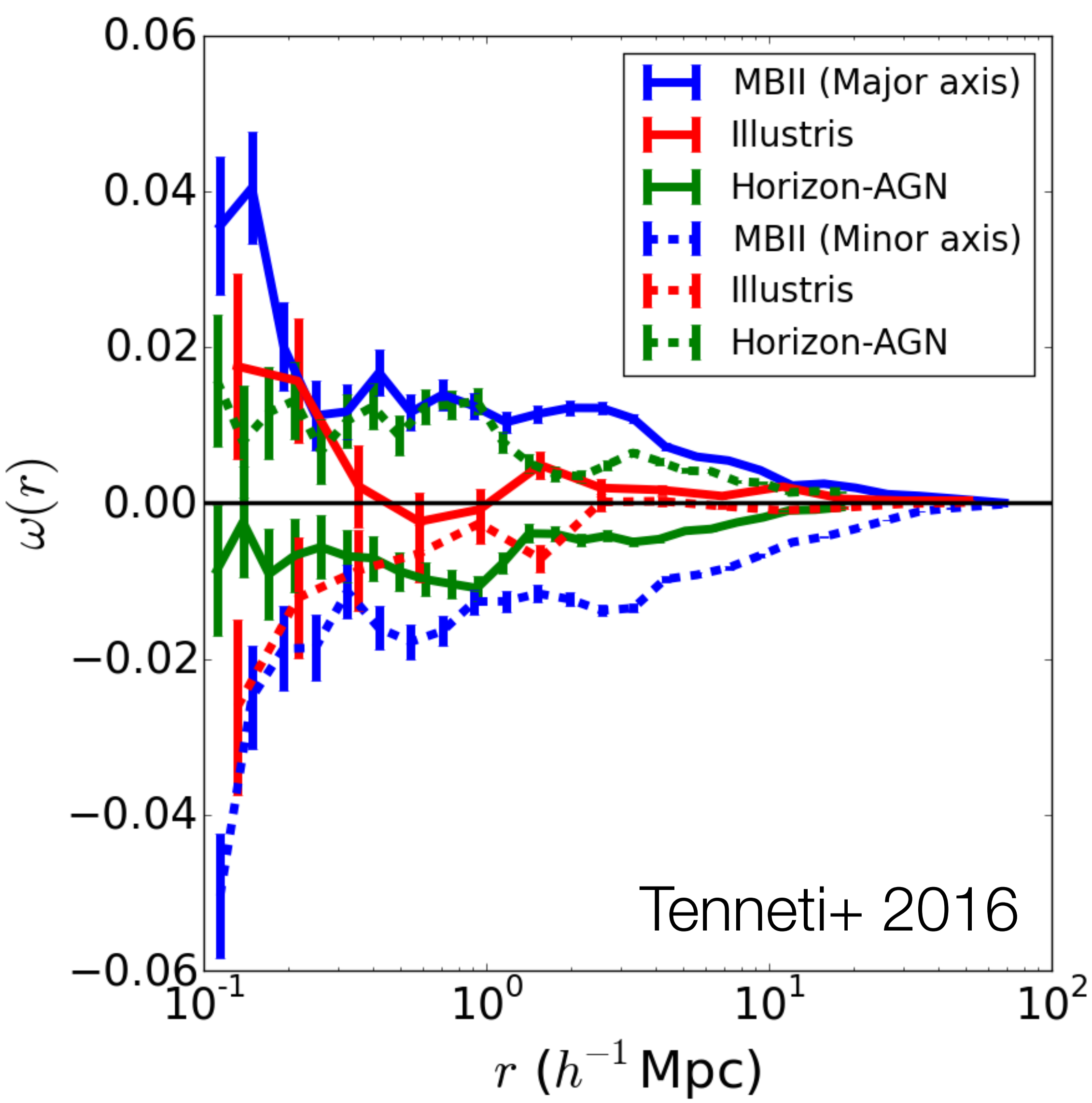
tidal torquing:
quadratic in s
(e.g. Lee & Pen 2000;
HIrata & Seljak 2004)

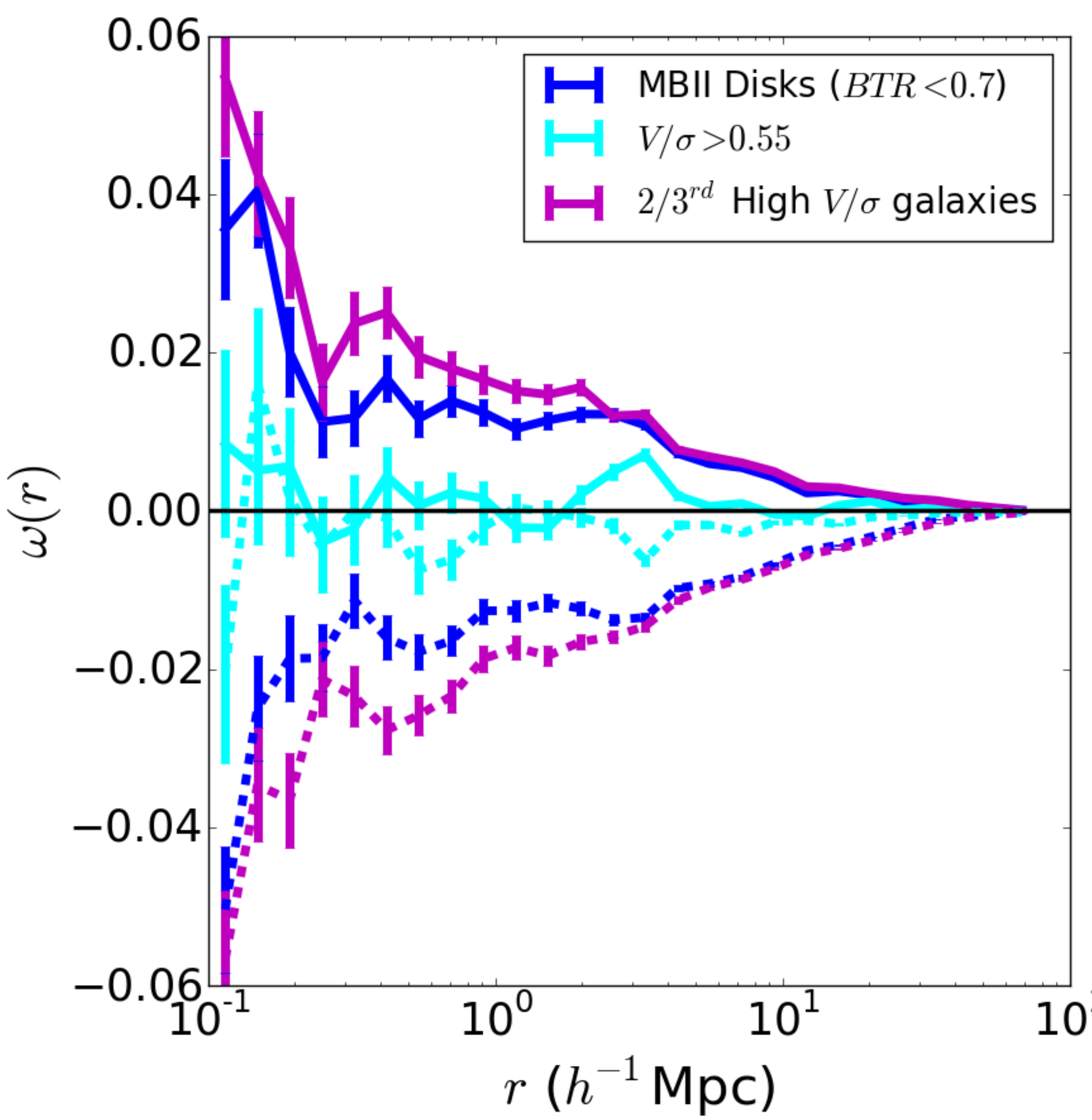


hybrid/halo
model
(e.g. Schneider & Bridle 2009)

Analytic vs simulation modeling

IA in hydro sims: MassiveBlack, Illustris, Horizon-AGN, EAGLE/Cosmo-OWLS
(e.g. Chisari+2016, Tenneti+ 2016, Codis+ 2018)





This is a hard problem!

Perturbative expansions for galaxy observables

galaxy bias (e.g. McDonald & Roy 2009; Desjacques, Jeong, Schmidt 2018)

$$\delta_g(x) = \boxed{b_1}\delta_m(x) + \boxed{b_2}\delta_m^2(x) + \boxed{b_s}s^2(x) + \cdots$$

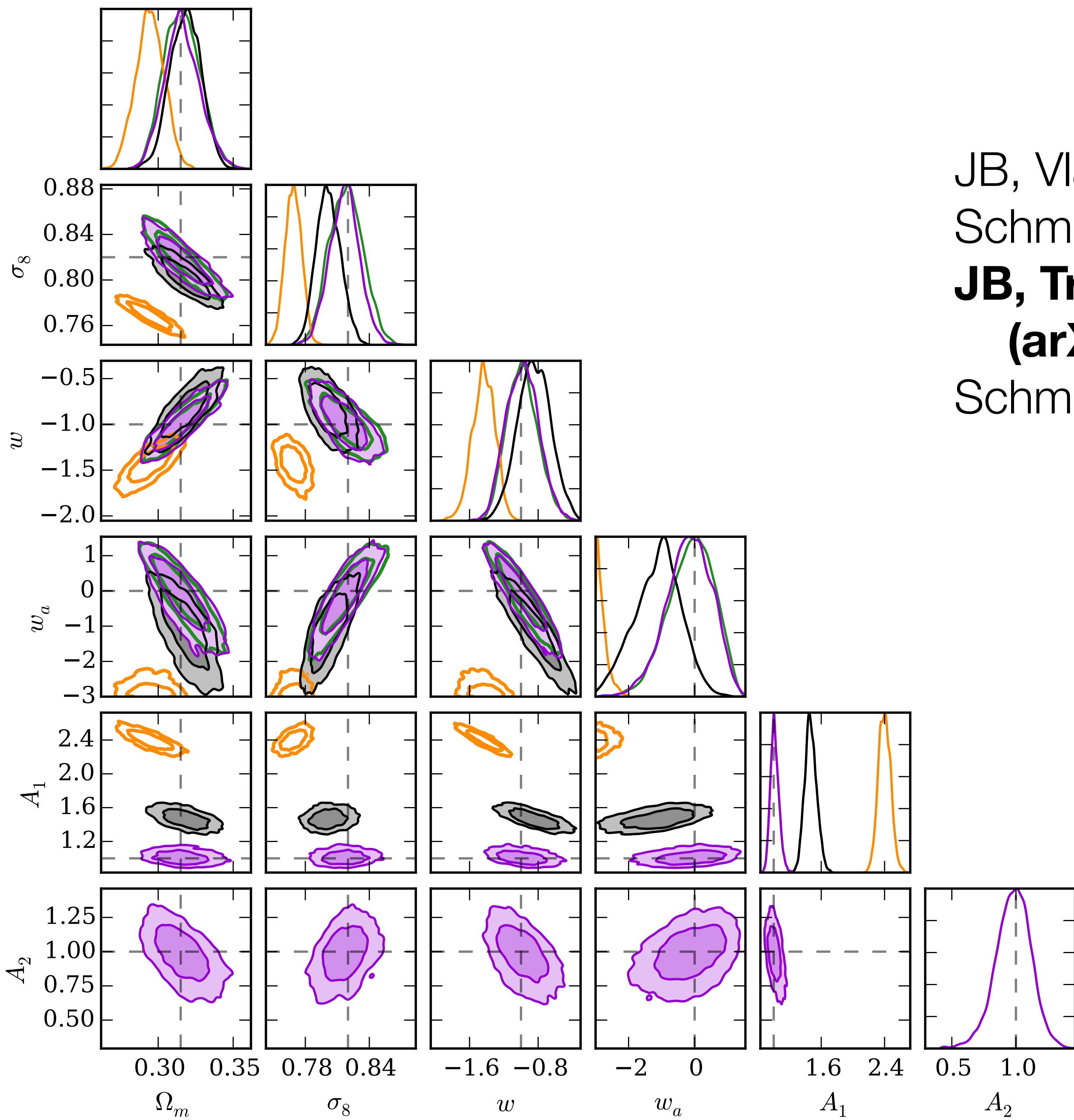
$$\gamma_{ij}^I = \boxed{C_1}s_{ij} + \boxed{C_2}(s_{ik}s_{kj}) + \boxed{C_\delta}(\delta s_{ij}) + \boxed{C_t}t_{ij} + \cdots$$

galaxy intrinsic alignments

(JB+ 2015; Schmidt+ 2015; JB+ 2017; Schmitz, Hirata, JB, Krause 2018; **Z. Vlah talk**)

Perturbative IA expansion

$$\gamma^I_{ij} = \boxed{C_1} s_{ij} + \boxed{C_2}(s_{ik}s_{kj}) + \boxed{C_\delta}(\delta s_{ij}) + \boxed{C_t} t_{ij} + \cdots$$



JB, Vlah, Seljak 2015
Schmidt, Chisari, Dvorkin 2015
JB, Troxel, MacCrann, Fang 2017
(arXiv:1708.09247)
Schmitz, Hirata, JB, Krause 2008

LSST-like cosmic shear
Green: no IA
Orange: NLA
Black: NLA + power-law z
Purple: Full model

FFT evaluation of PT integrals

McEwen, Fang, Hirata, JB 2016; Fang, JB, McEwen, Hirata 2017
see also: Schmittfull, Vlah, McDonald 2016; Schmittfull & Vlah 2016; Simonovic+ 2017
FAST-PT on github: JoeMcEwen/FAST-PT

$$I(k) = \int \frac{d^3\boldsymbol{q}_1}{(2\pi)^3} K(\hat{\boldsymbol{q}}_1 \cdot \hat{\boldsymbol{q}}_2, \hat{\boldsymbol{q}}_1 \cdot \hat{\boldsymbol{k}}, \hat{\boldsymbol{q}}_2 \cdot \hat{\boldsymbol{k}}, q_1, q_2) P(q_1) P(q_2)$$

$$\downarrow$$

$$f(k) = \int \frac{d^3\boldsymbol{q}_1}{(2\pi)^3} \mathcal{P}_\ell(\hat{\boldsymbol{q}}_1 \cdot \hat{\boldsymbol{q}}_2) \mathcal{P}_{\ell_1}(\hat{\boldsymbol{k}} \cdot \hat{\boldsymbol{q}}_2) \mathcal{P}_{\ell_2}(\hat{\boldsymbol{k}} \cdot \hat{\boldsymbol{q}}_1) q_1^\alpha q_2^\beta P(q_1) P(q_2)$$

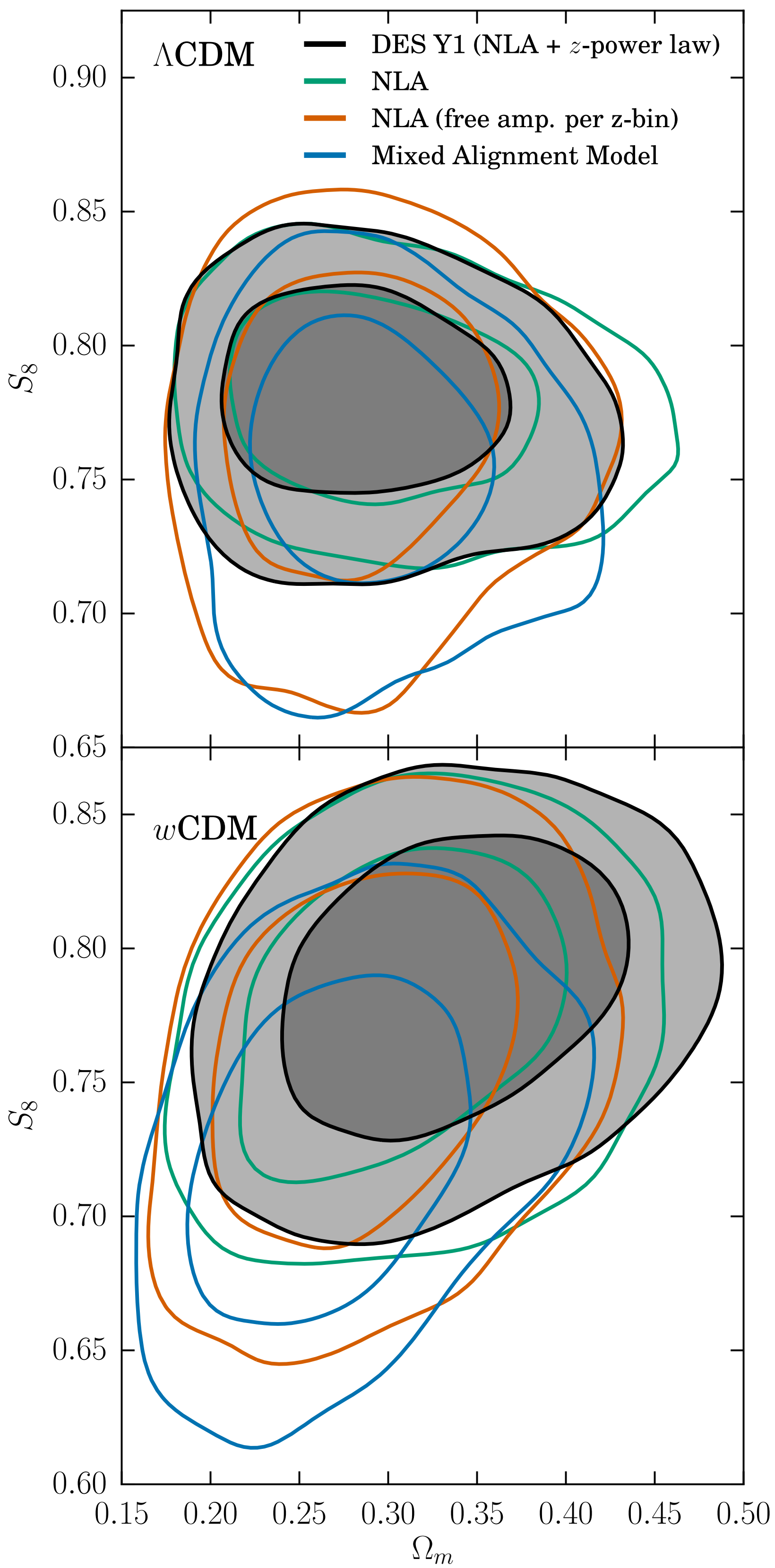
$$\downarrow$$

$$J^{\alpha\beta}_{J_1 J_2}(r) \equiv \left[\int_0^\infty dq_1 \; q_1^{2+\alpha} P(q_1) j_{J_1}(q_1 r)\right] \left[\int_0^\infty dq_2 \; q_2^{2+\beta} P(q_2) j_{J_2}(q_2 r)\right]$$

(e.g. `FFTLog`: Talman 1978, Hamilton 2000)

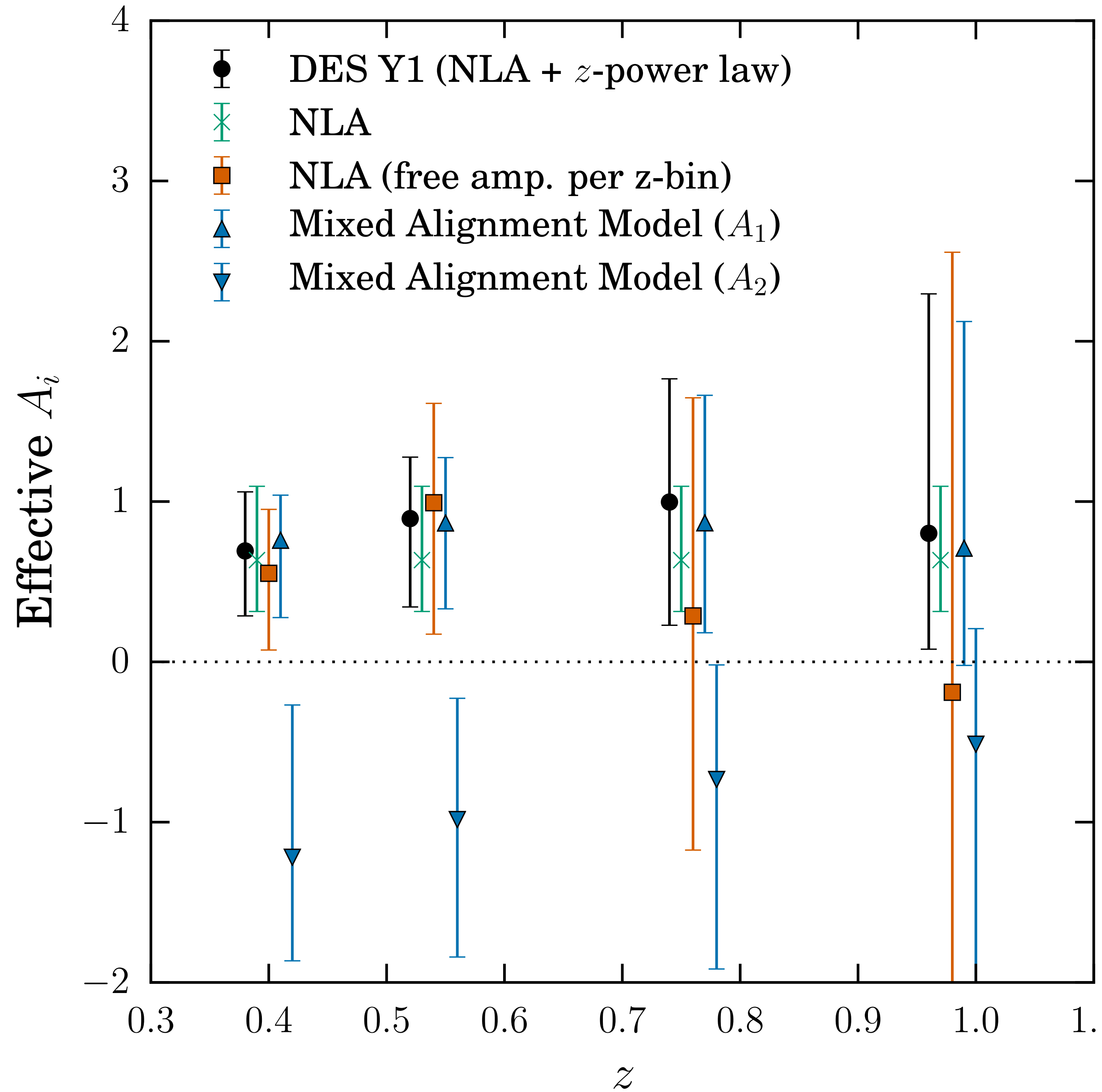
- Python; easy to use and integrate into other code
- Contact us! Always adding new features

Probing IA in DES Y1



Cosmic Shear

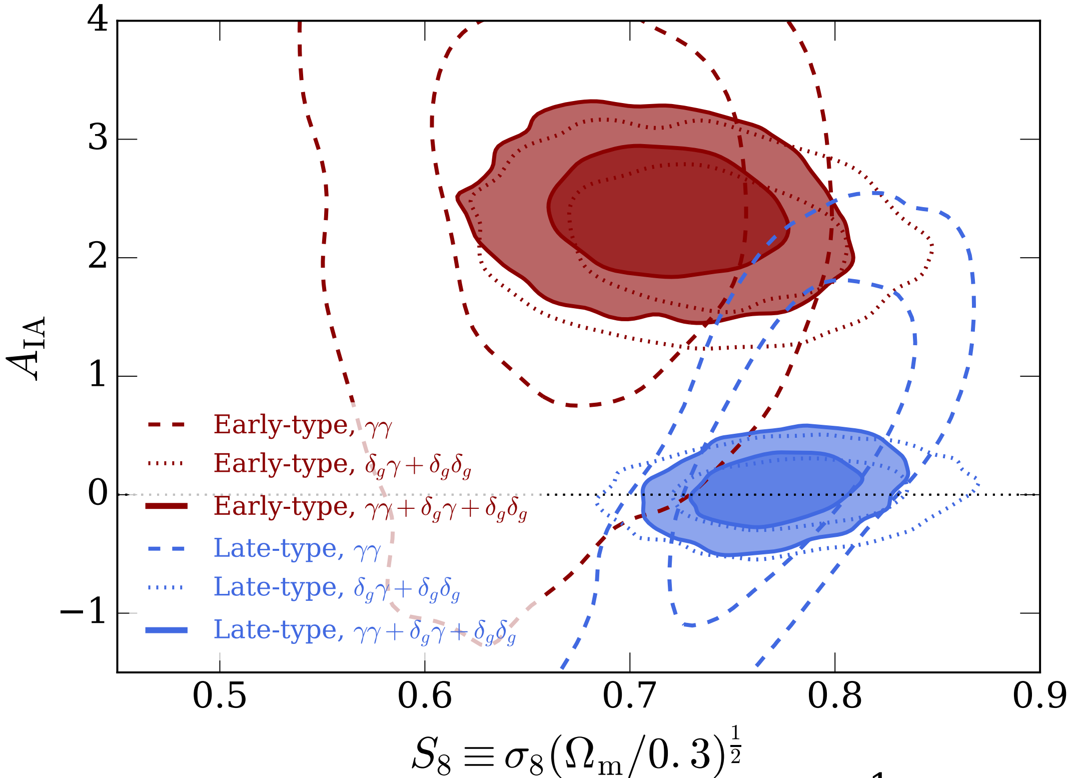
Troxel+ 2018, DES Y1

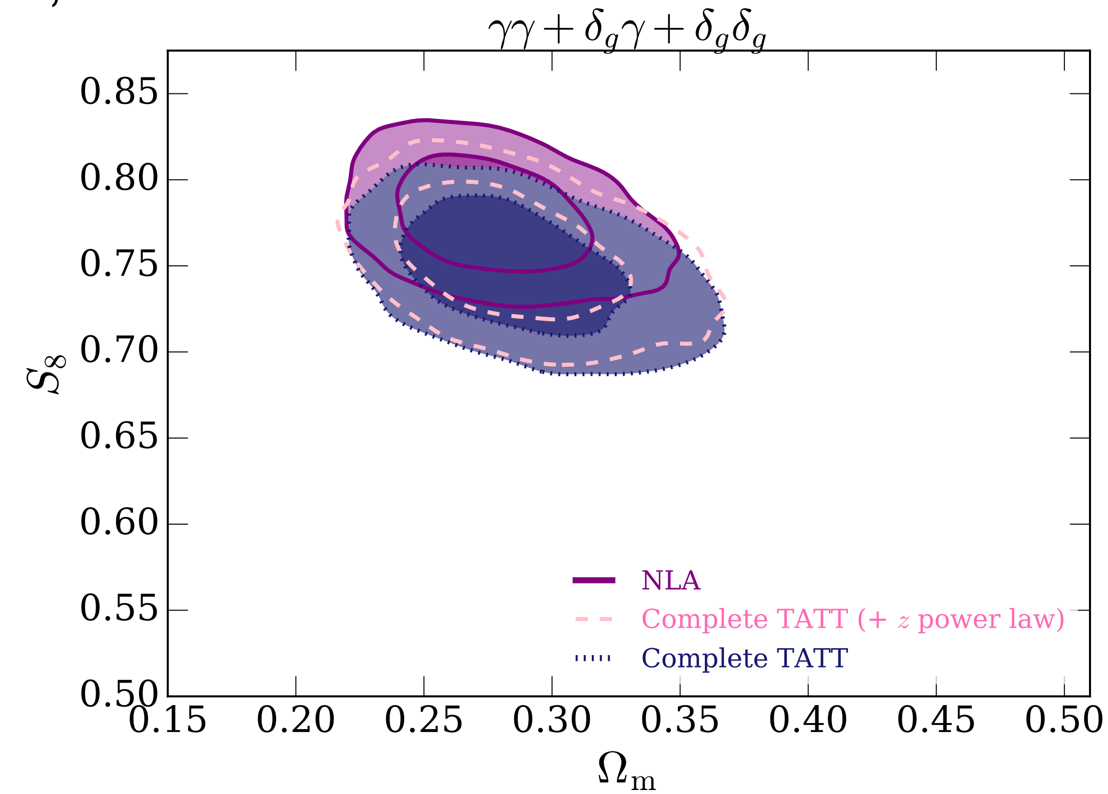


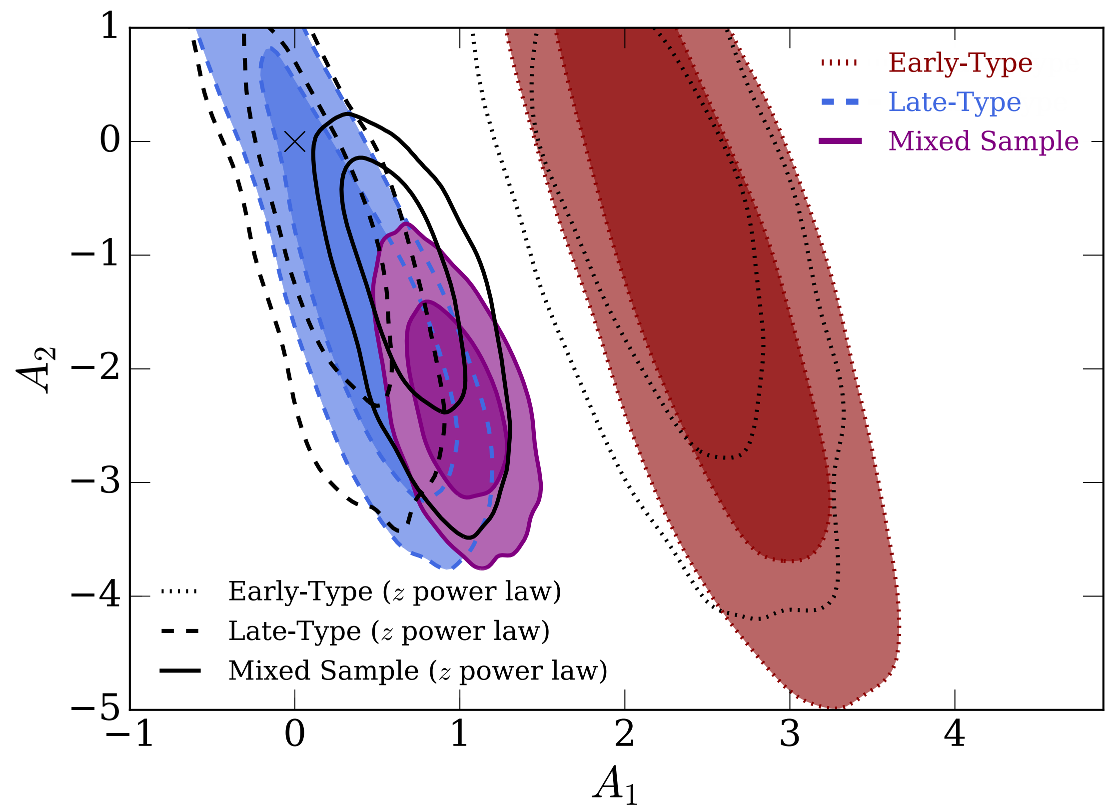
Probing IA in DES Y1

3x2 and morphology/color split

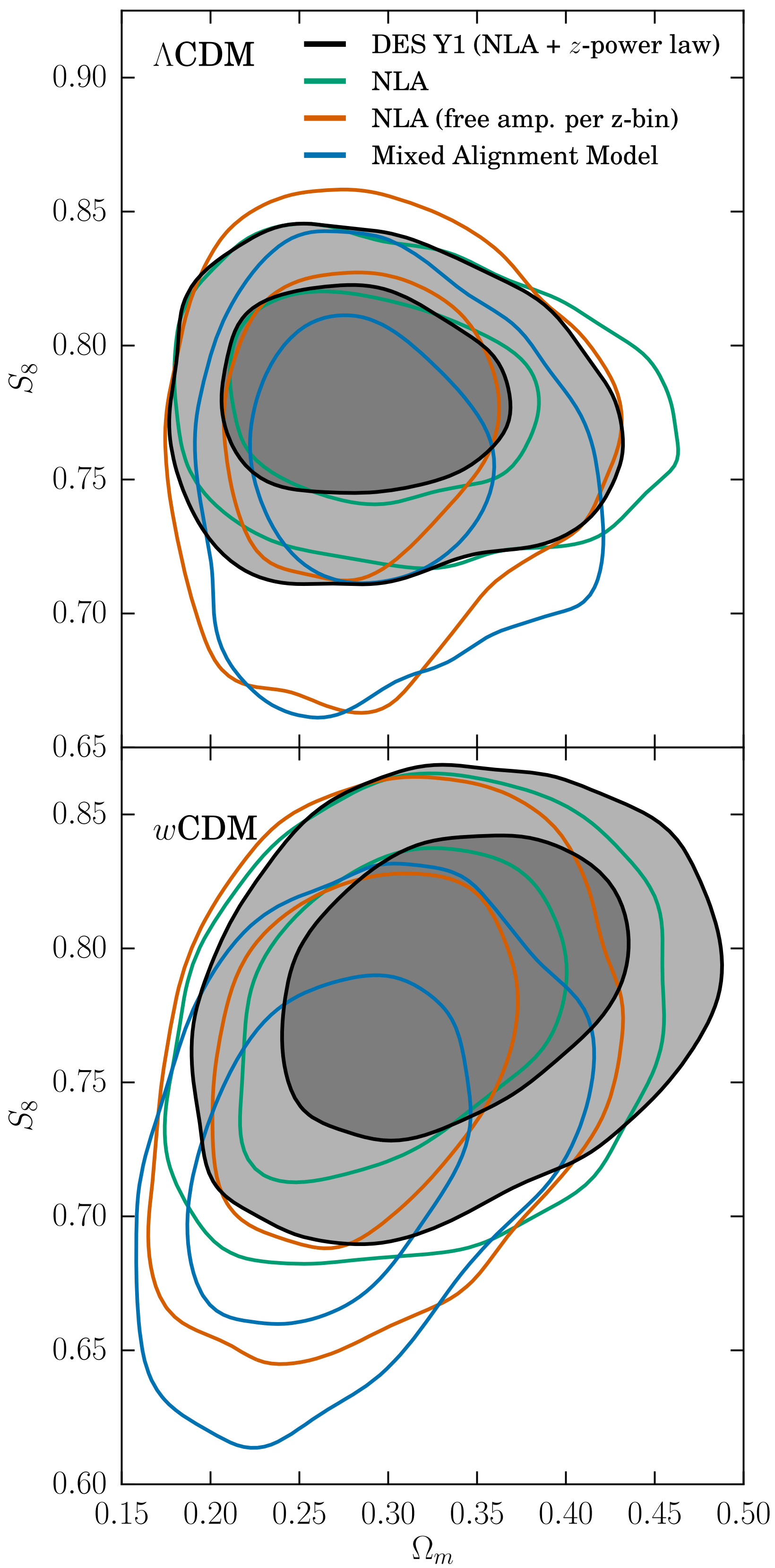
Samuroff, JB+ 2018, DES Y1







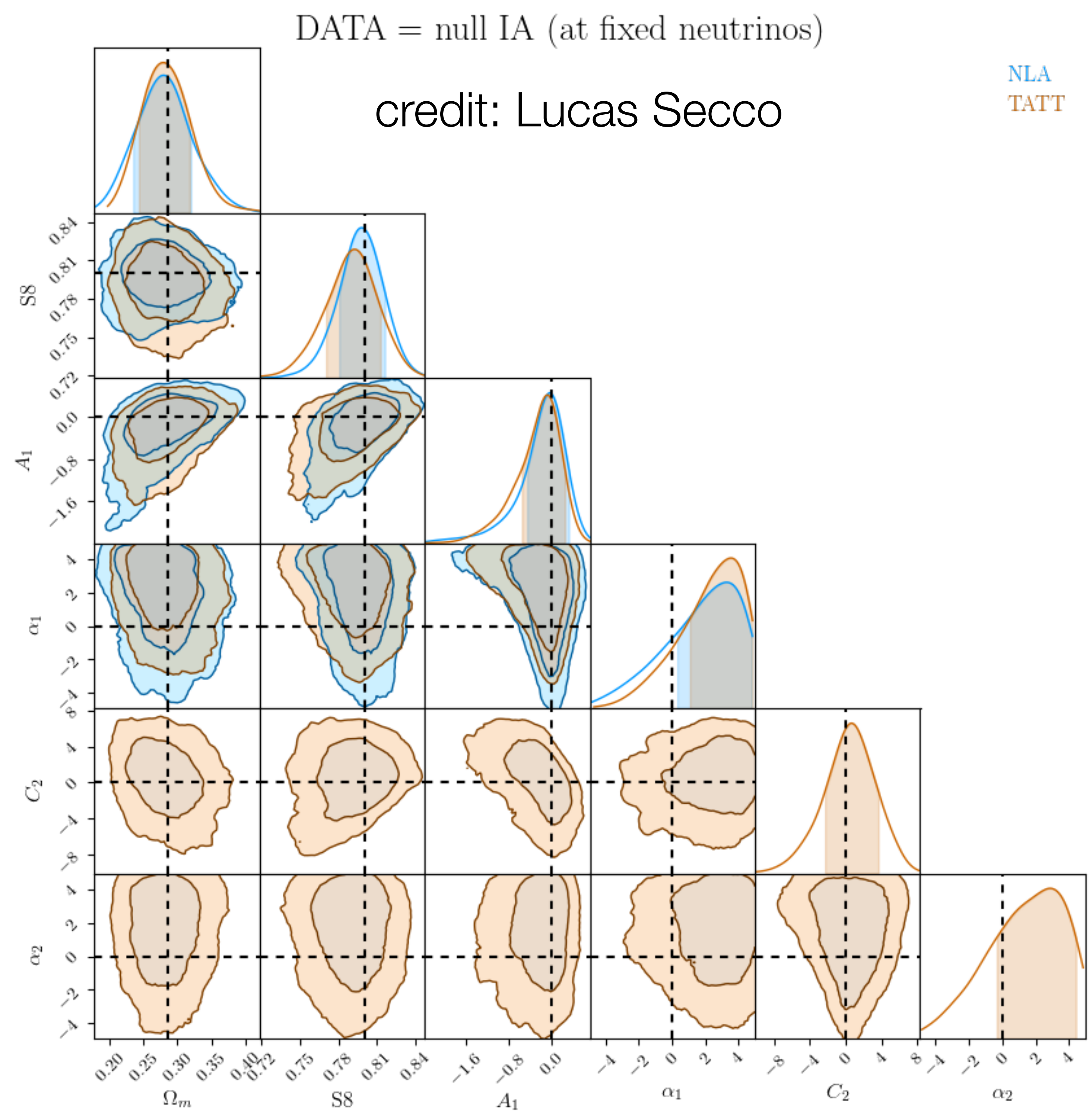
Are these results robust?



- Degeneracy with photo-z or other systematic?

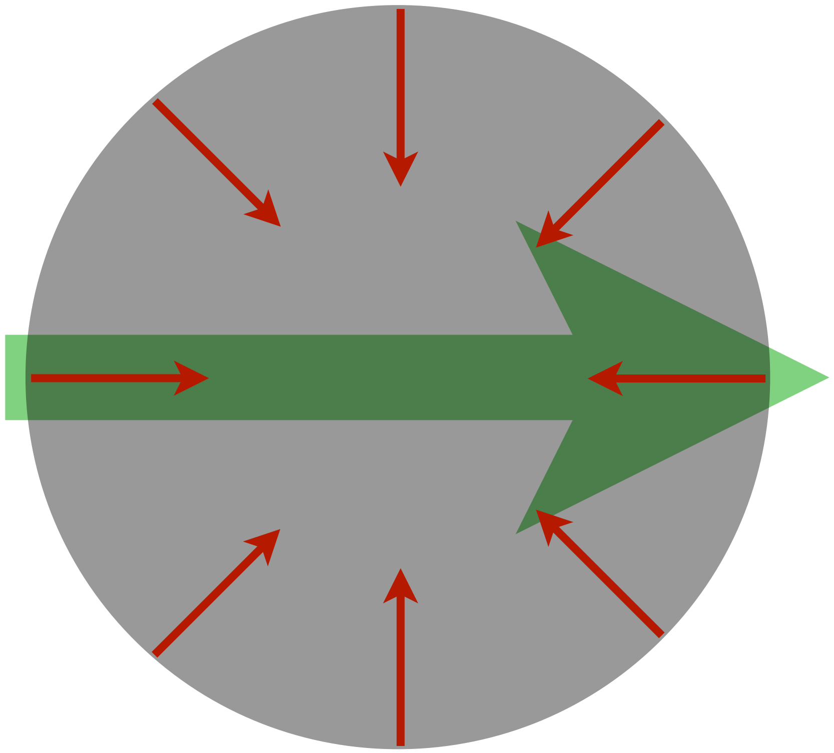
- Under-constrained parameters and degeneracies with cosmology causing shifts? (cf. E. Krause talk on nonlinear bias tests)

Are these results robust?

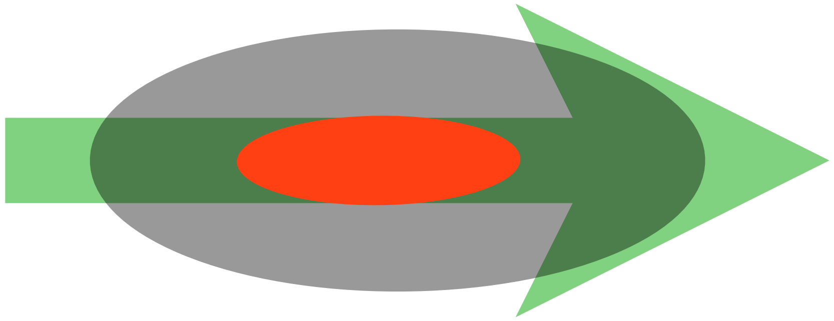


- Tests underway, DES Y3 appears to be sufficiently constraining

Non-locality in IA

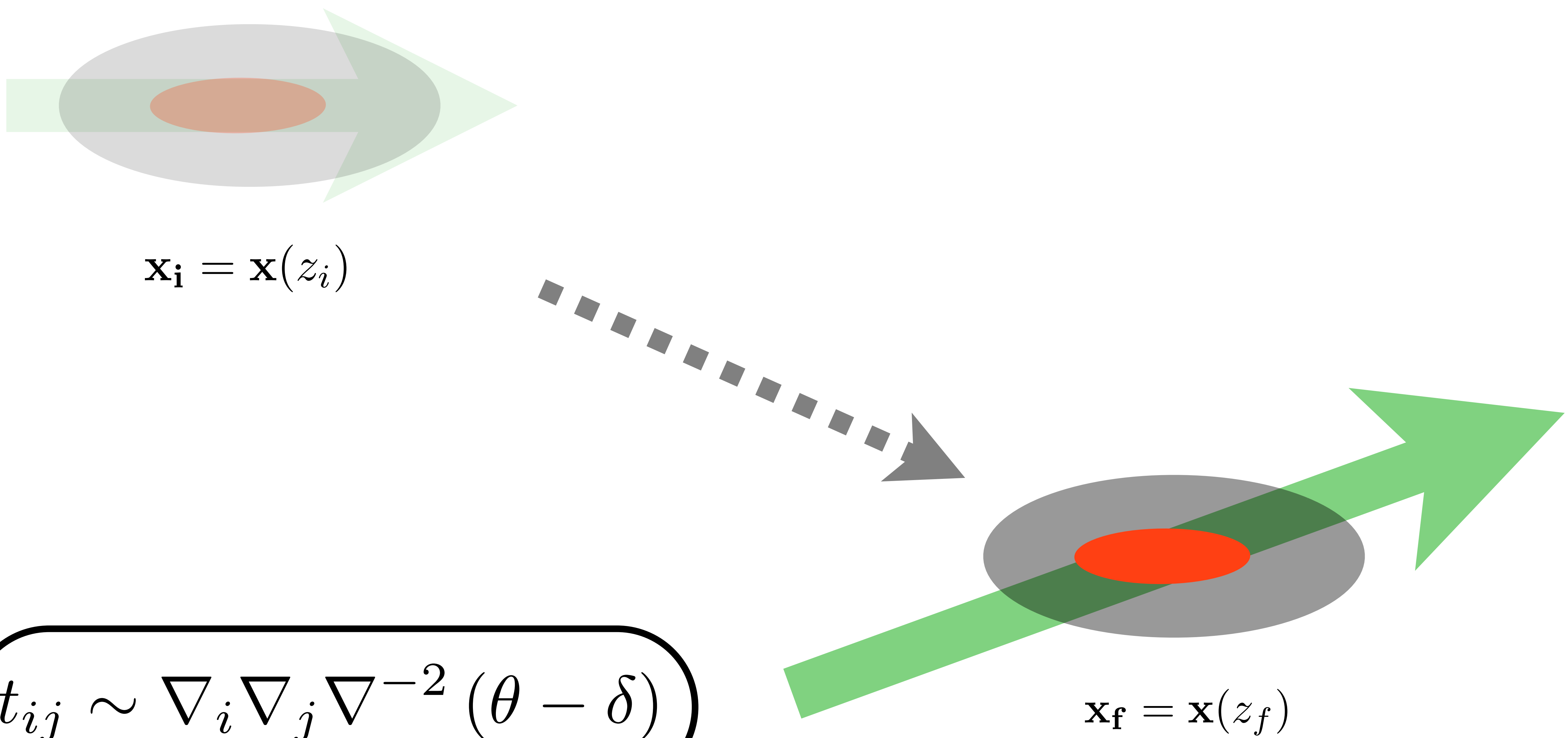


Non-locality in IA



$$\mathbf{x_i} = \mathbf{x}(z_i)$$

Non-locality in IA



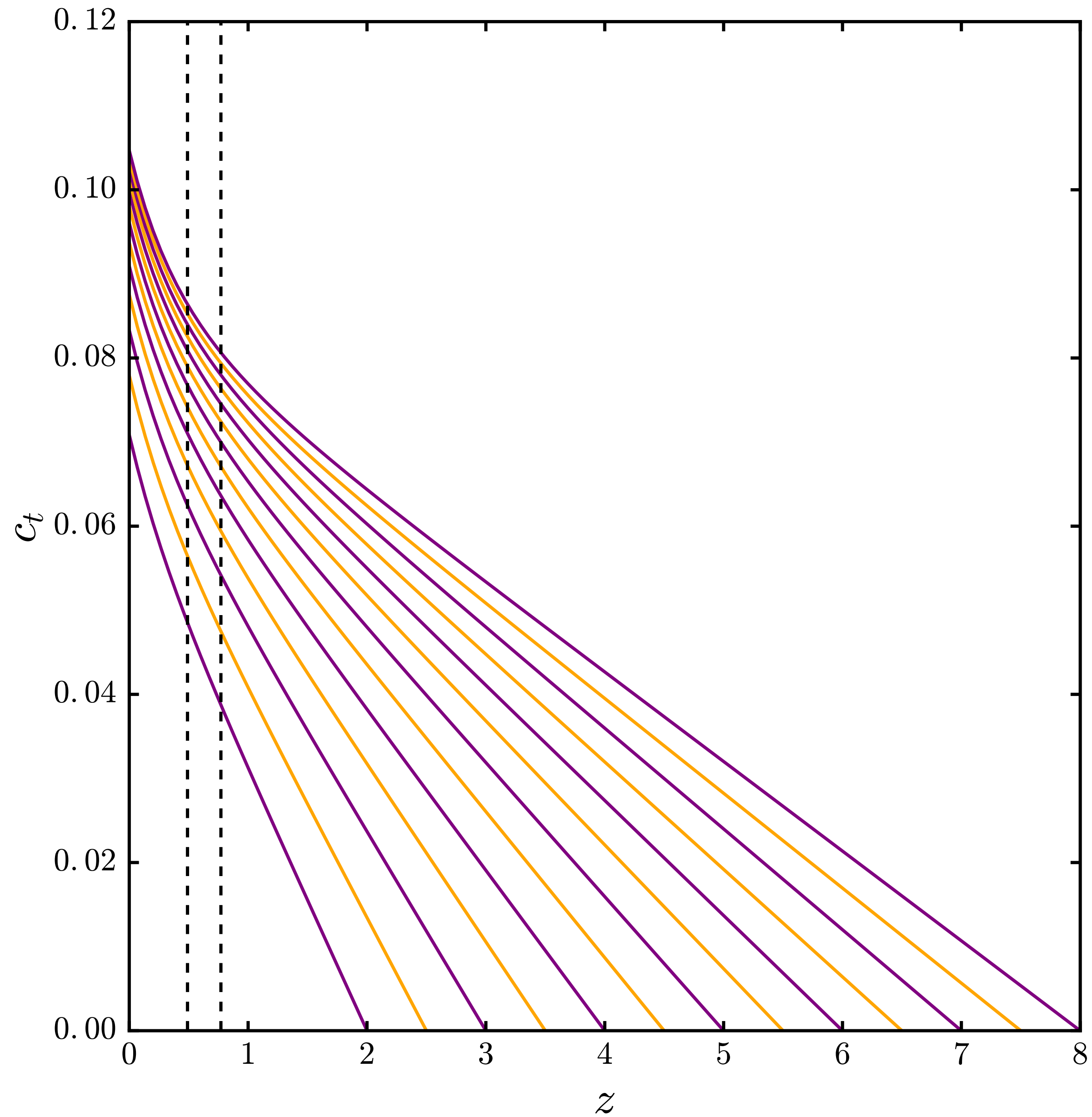
$$\boxed{t_{ij} \sim \nabla_i \nabla_j \nabla^{-2} (\theta - \delta)}$$

Measuring non-locality

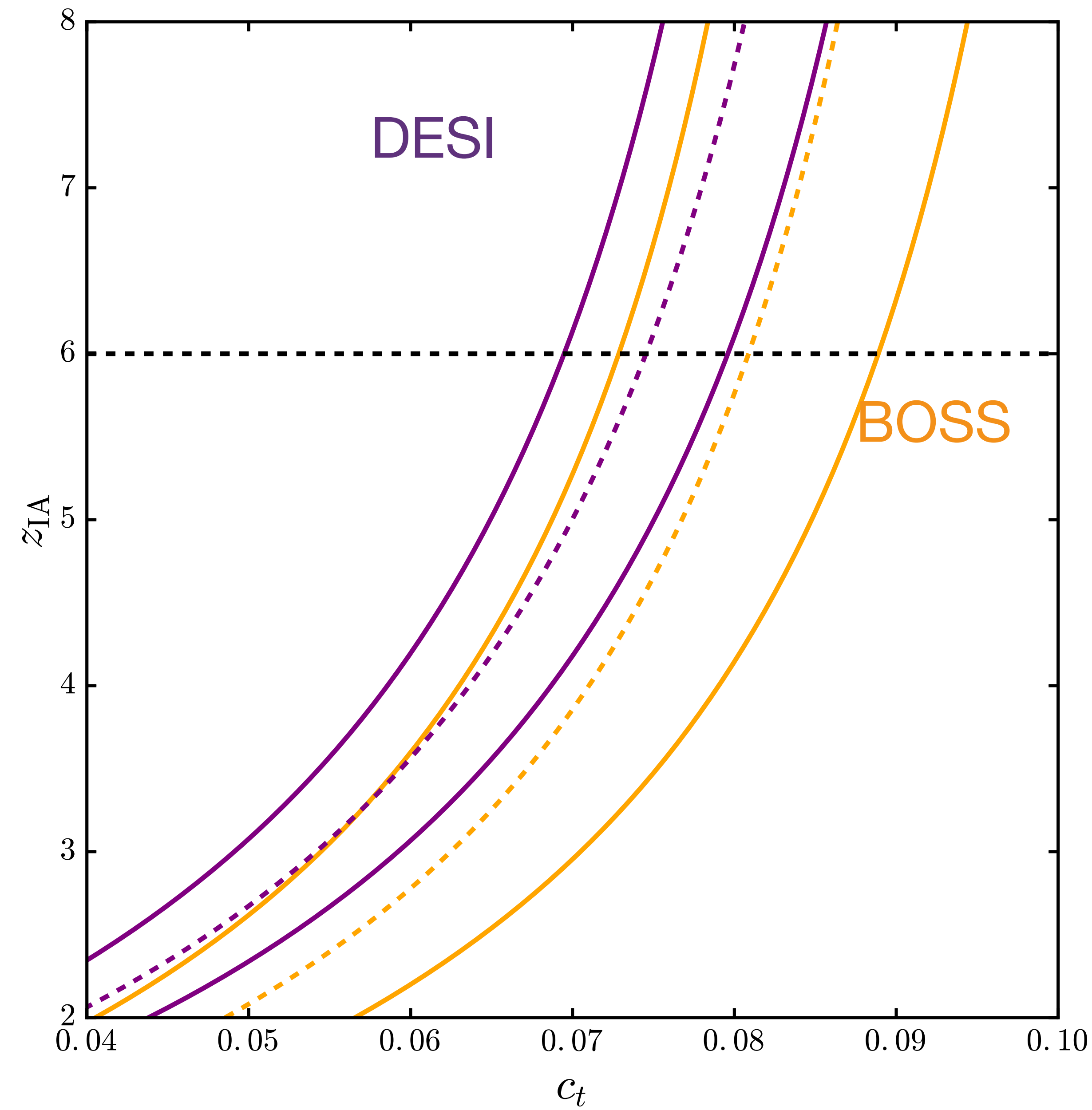
Schmitz, Hirata, JB, Krause 2018

$$B_{ggI} \sim \langle \delta_g(k_1)\delta_g(k_2)\gamma^I(k_3)\rangle$$

Signature of advection



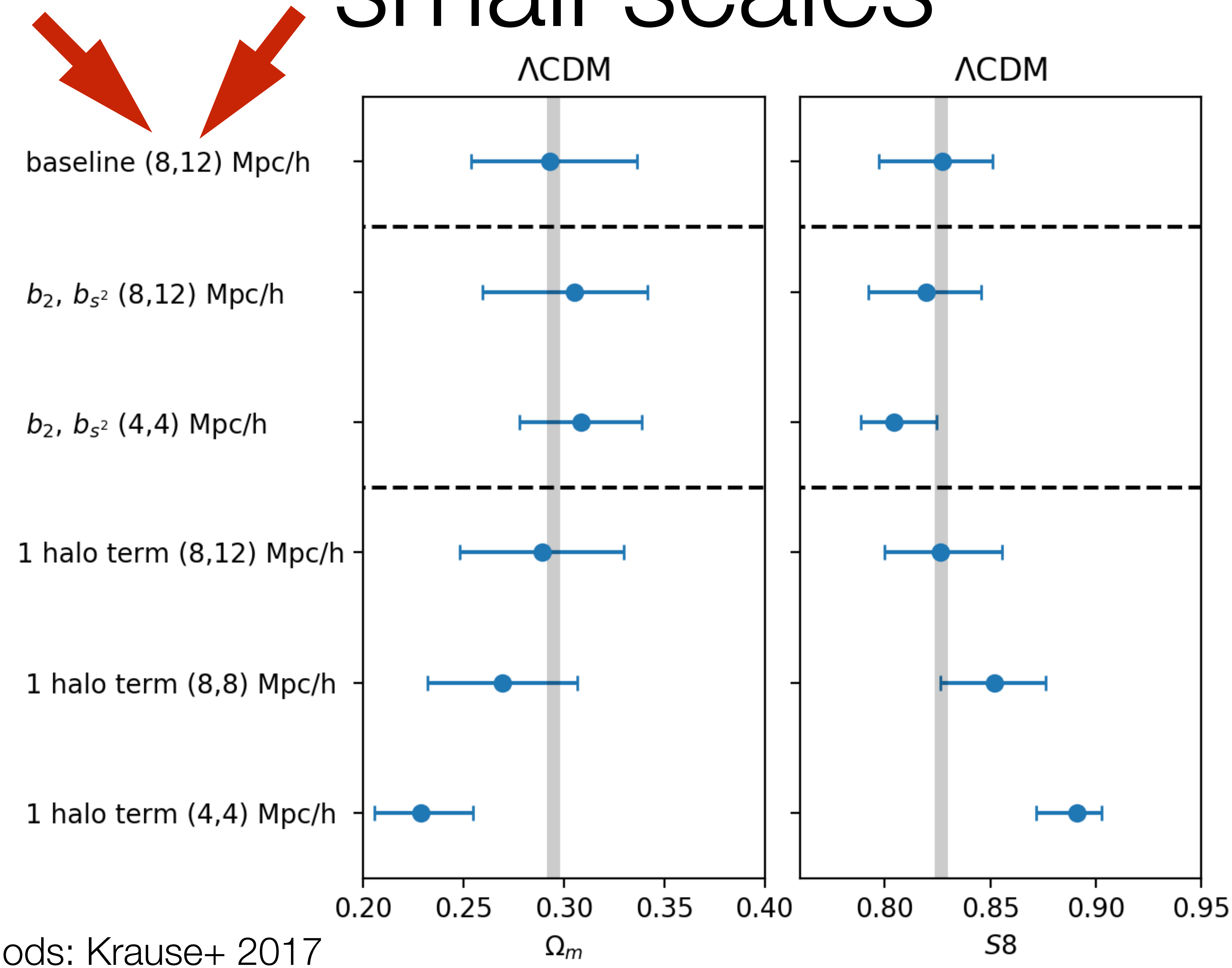
Constrain formation time



Looking ahead in IA

- DES Y3 analysis (~4200 deg 3x area of Y1)
- Implement and analyze complete 1loop model (cf Z. Vlah talk); pipelines for LSST and Euclid
- New hydro simulations and observational constraints (IllustrisTNG, PAU, eBOSS, DES, …)
- IA as a probe of LSS and fundamental physics

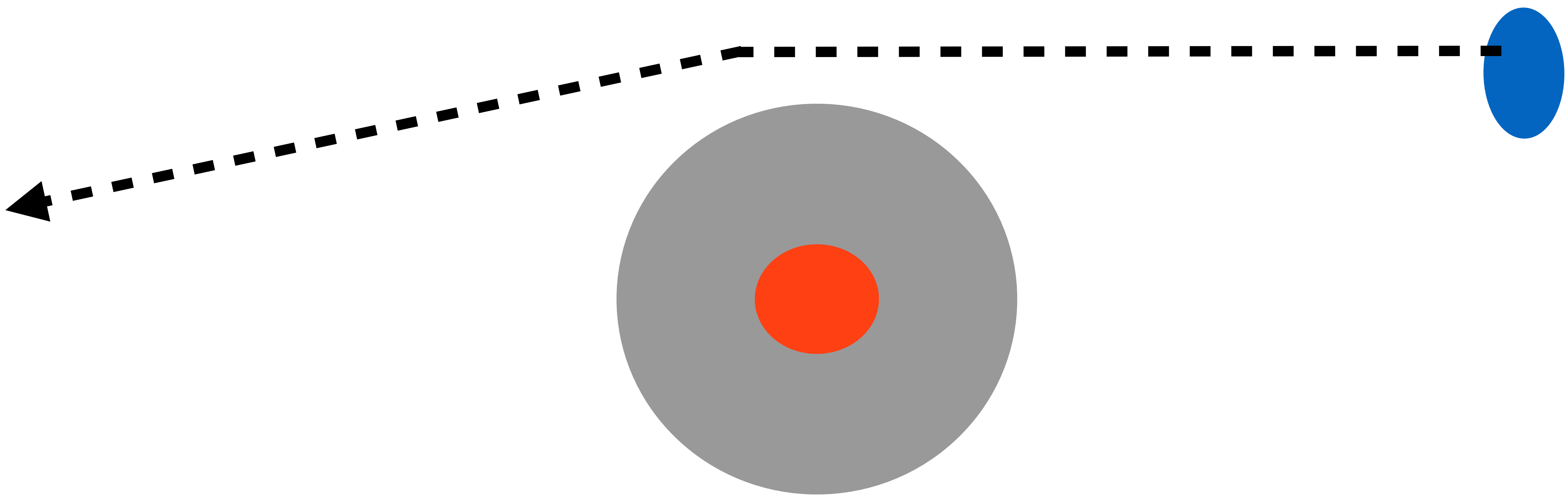
Galaxy-galaxy lensing and small scales



Y1 Methods: Krause+ 2017

Galaxy-galaxy lensing and small scales

MacCrann, JB, Jain, Krause 2018



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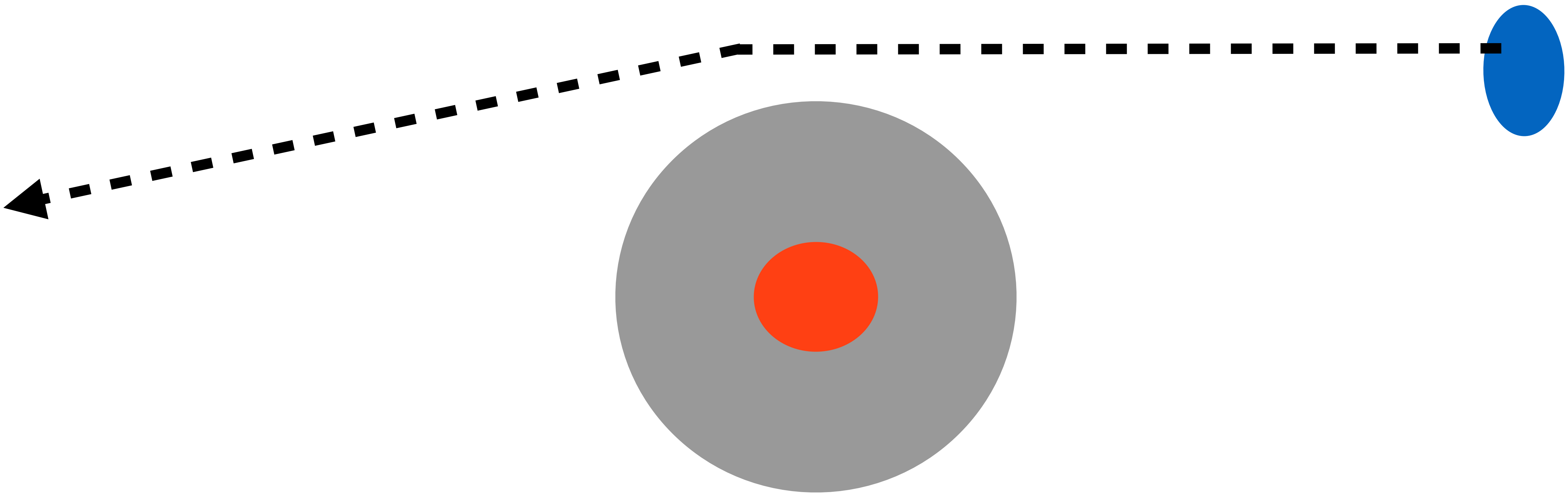
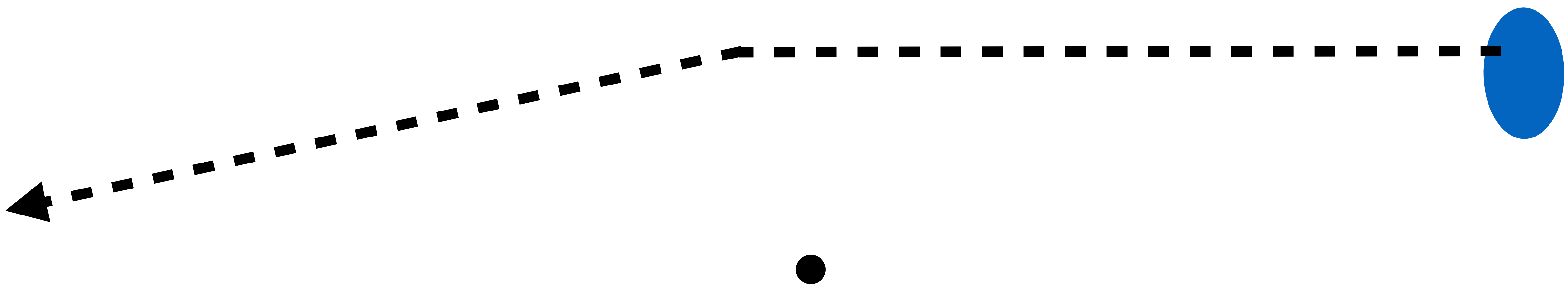


$$\Sigma(R) = \overline{\rho}_m \int_{-\infty}^{\infty} \mathrm{d}\Pi \left[1 + \xi_{gm}\left(\sqrt{R^2 + \Pi^2}\right)\right]$$

$$\Delta\Sigma(R) = \overline{\Sigma}(0, R) - \Sigma(R)$$

“Point mass” model

MacCrann, JB, Jain, Krause 2018



$$\Sigma(R) = \overline{\rho}_m \int_{-\infty}^{\infty} \mathrm{d}\Pi \left[1 + \xi_{gm}\left(\sqrt{R^2 + \Pi^2}\right)\right]$$

$$\overline{\Sigma}(0, R) = \frac{r_{\mathrm{min}}^2 \overline{\Sigma}(0, r_{\mathrm{min}})}{R^2} + \frac{(R^2 - r_{\mathrm{min}}^2)\overline{\Sigma}(r_{\mathrm{min}}, R)}{R^2}$$

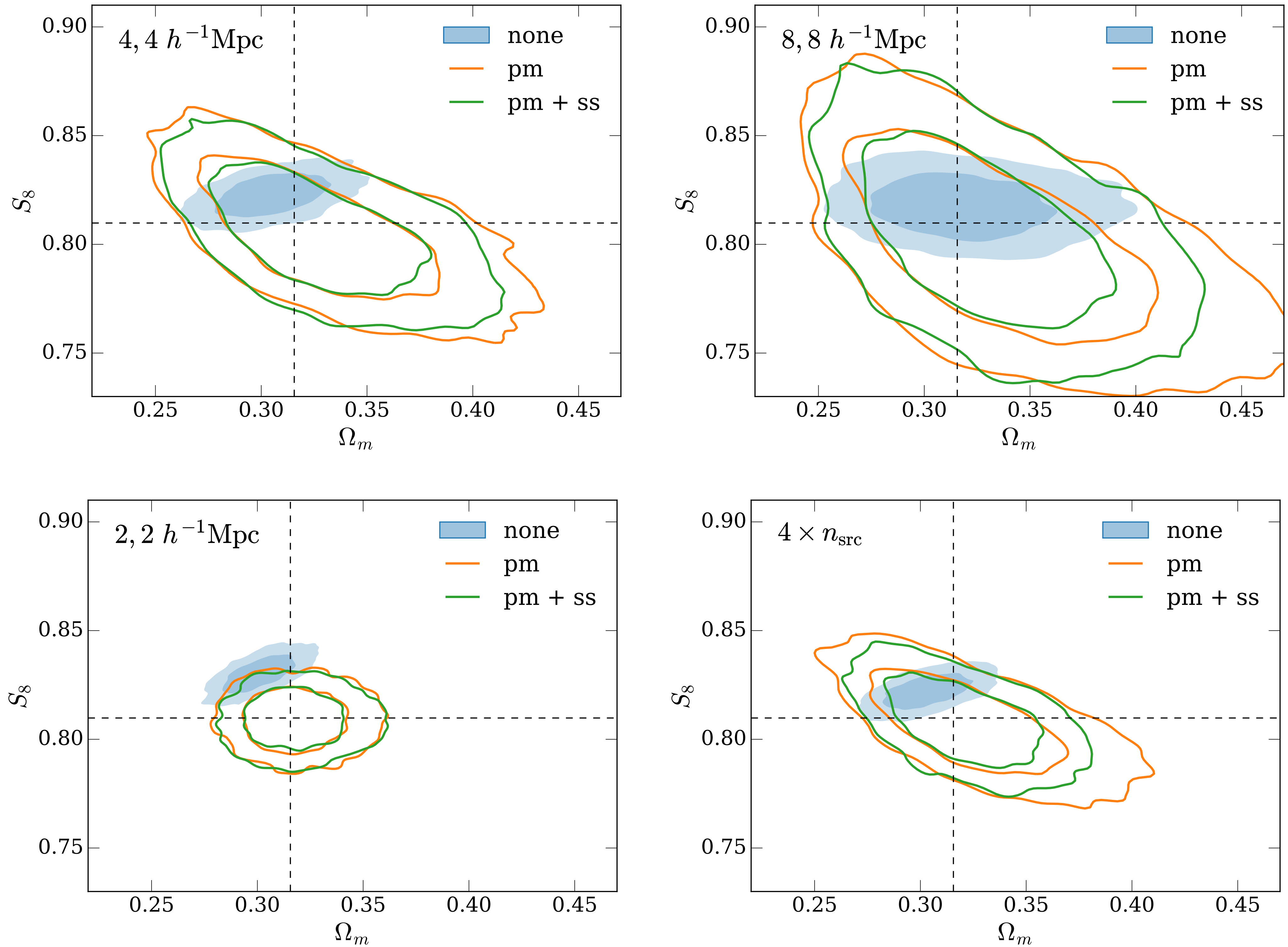
$$\Delta\Sigma(R) = \overline{\Sigma}(0, R) - \Sigma(R)$$

$$\Delta\Sigma(R) = \Delta\Sigma^{\mathrm{model}}(R) + B/R^2$$

cf. Annular statistics, Baldauf+ 2010;
Singh+ 2018; S. Sugiyama poster

“Point mass” model

MacCrann, JB, Jain, Krause 2018



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