Intrinsic alignments (and nonlinear modeling) in multi-probe analyses

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Swiss Euclid Days
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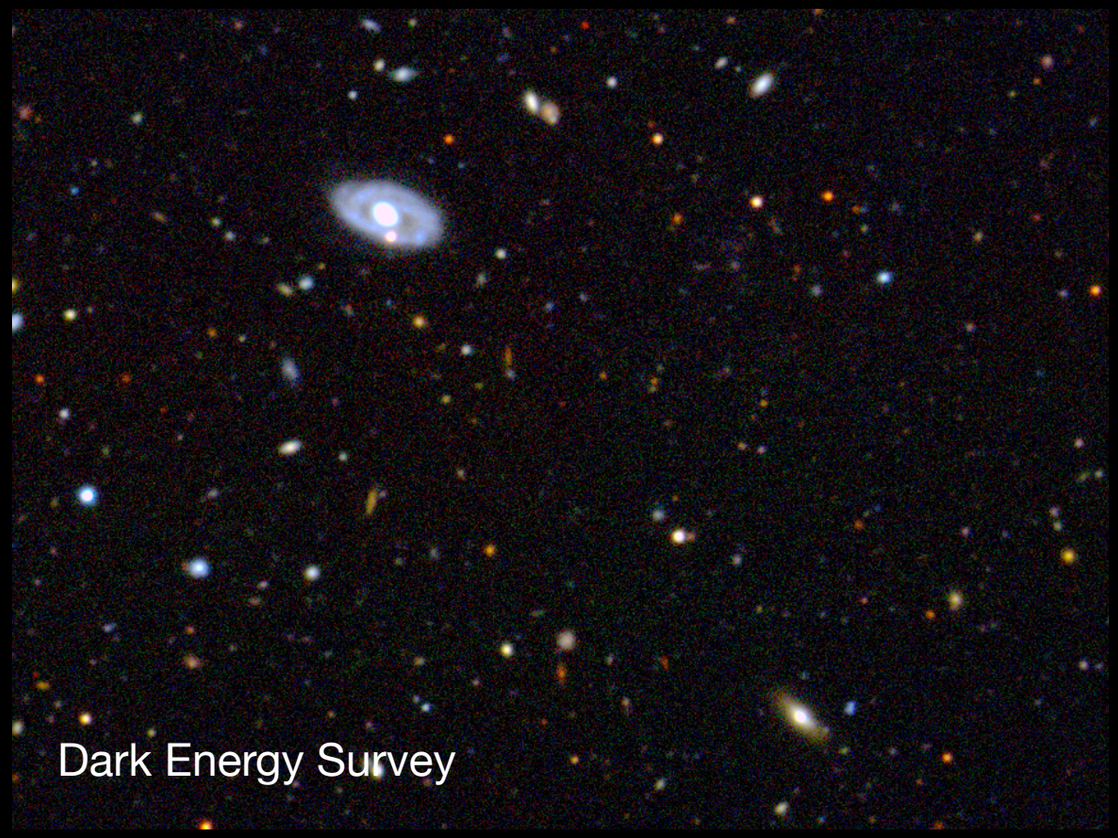
Outline

- Galaxy observables and intrinsic alignments
- Effective perturbative models
- Implementations for Euclid and other future surveys

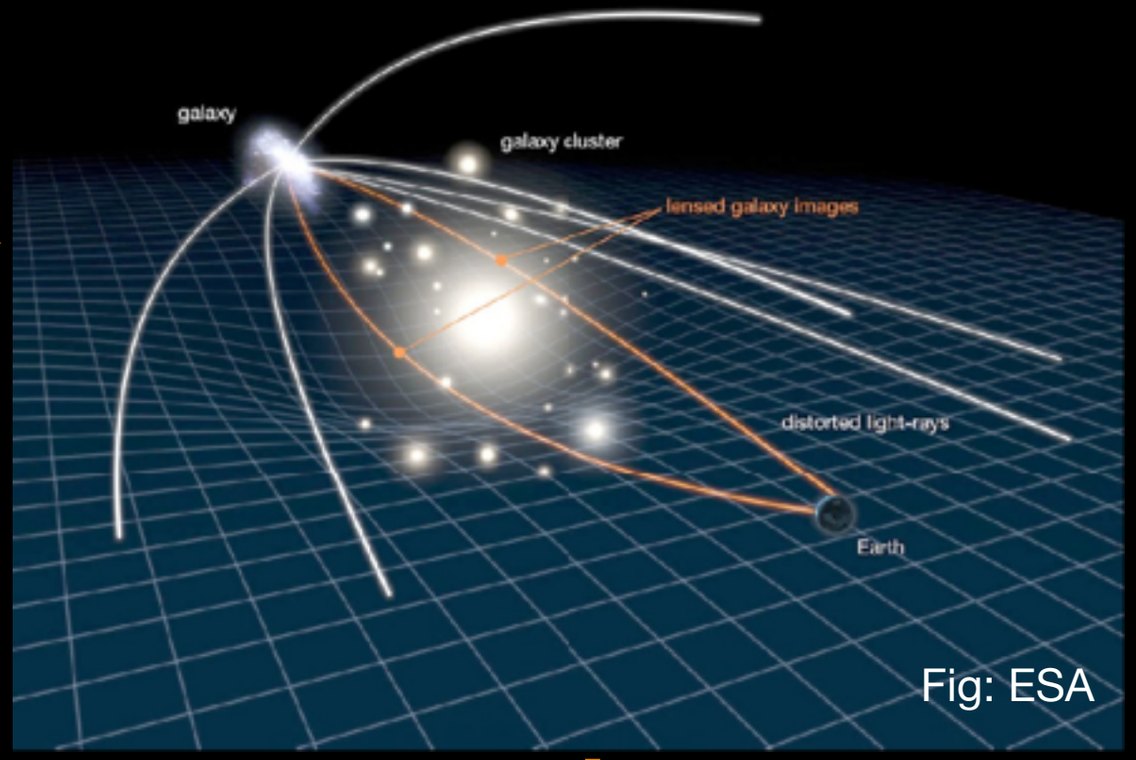
In collaboration with:

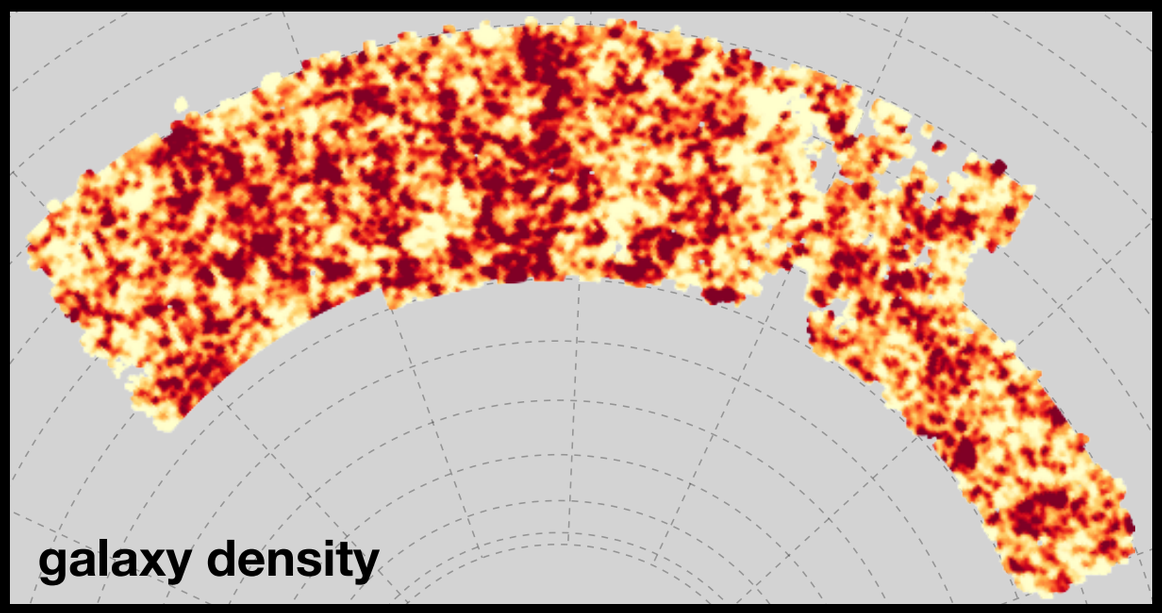
Euclid: Weak Lensing SWG (IA), IST:Nonlinear
DES, LSST-DESC

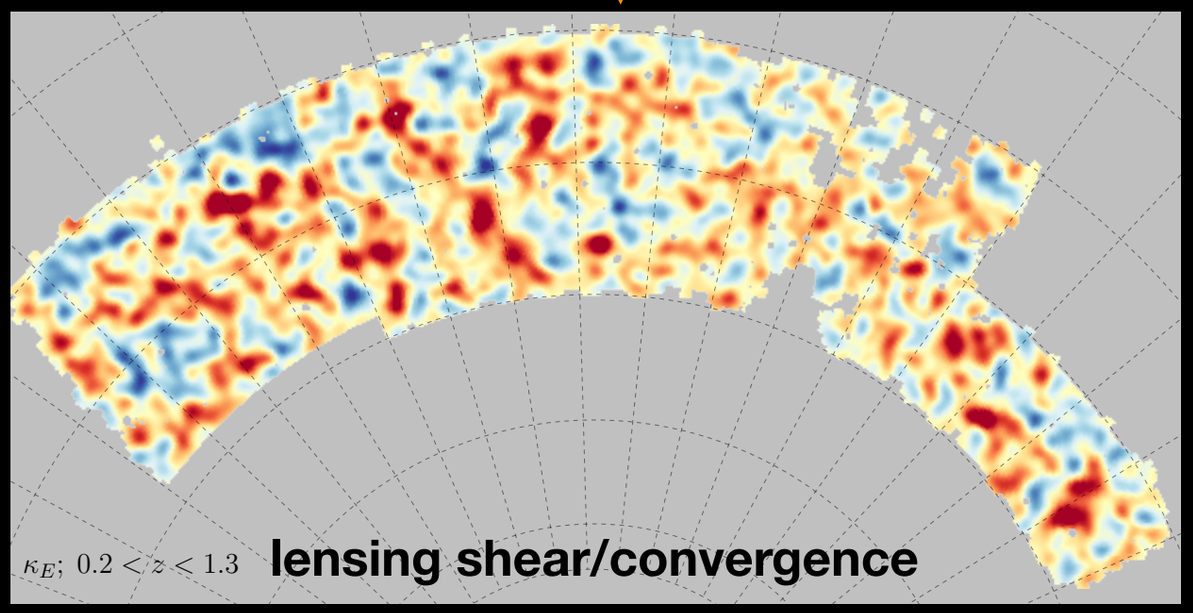
Galaxy observables



(Weak) Gravitational Lensing

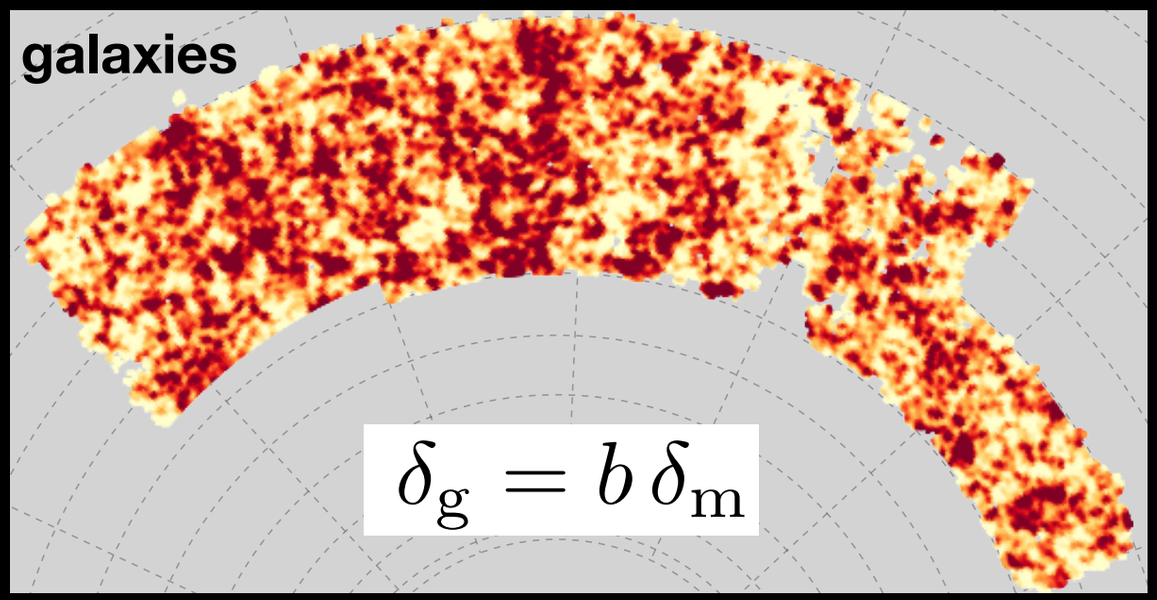


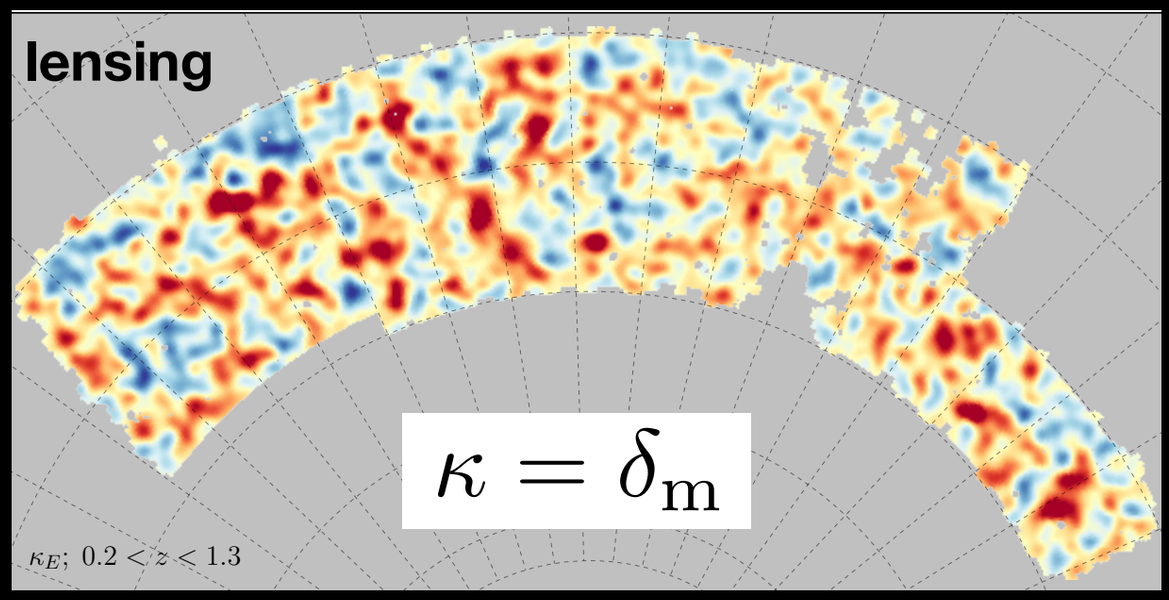




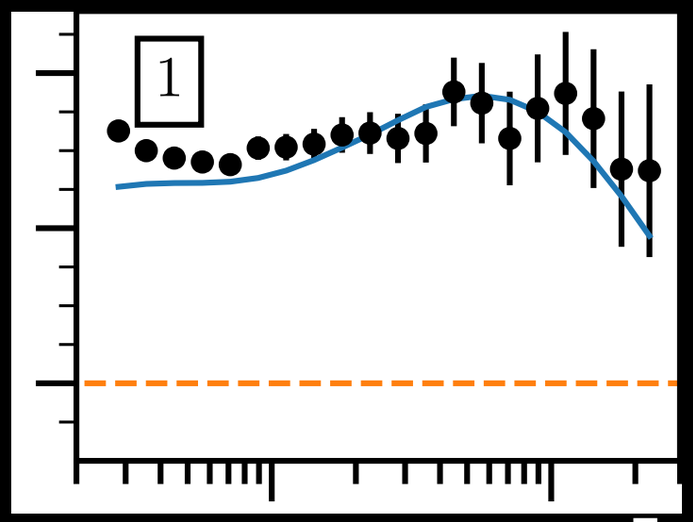
DES Year 1: Elvin-Poole+ 2018; Chang+ 2018

Combining probes



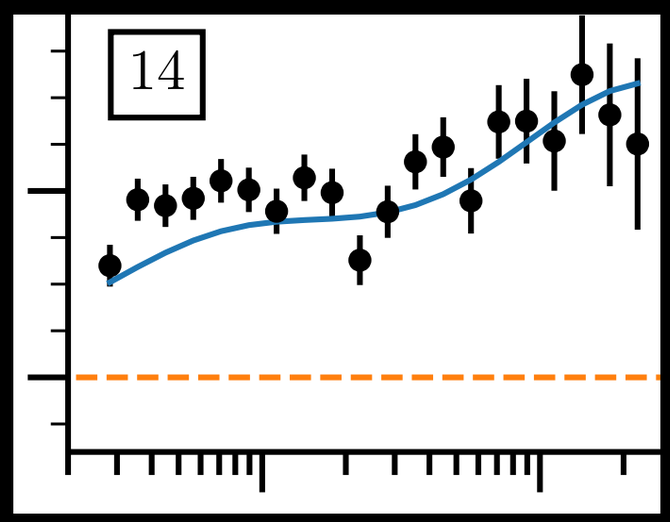


$\langle \delta_g | \delta_g \rangle = \xi_{\rm gg} \sim b^2 \sigma_8^2$



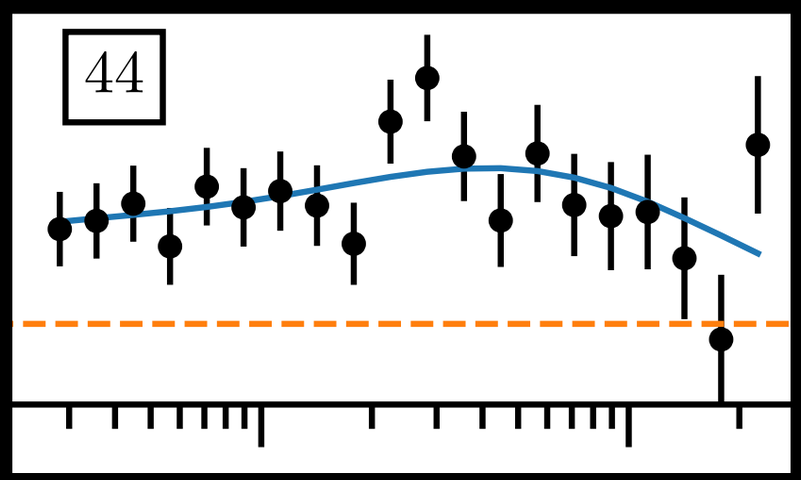
Elvin-Poole+ 2018

$\langle \delta_g | \kappa \rangle = \xi_{\rm gm} \sim b \sigma_8^2$



Prat, Sanchez+ 2018

$\langle \kappa | \kappa \rangle = \xi_{\rm mm} \sim \sigma_8^2$

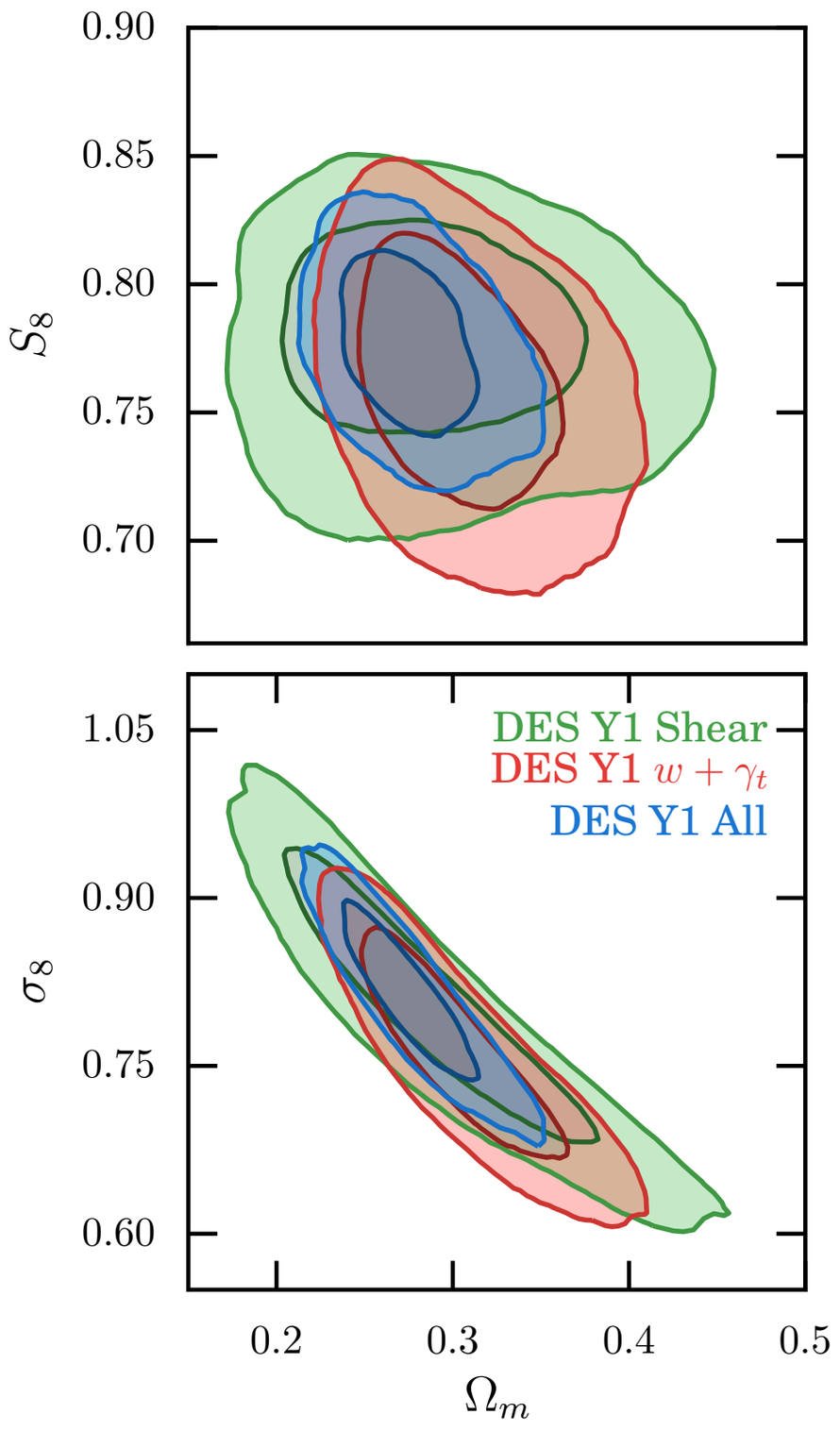


Troxel+ 2018

"3x2 analysis"

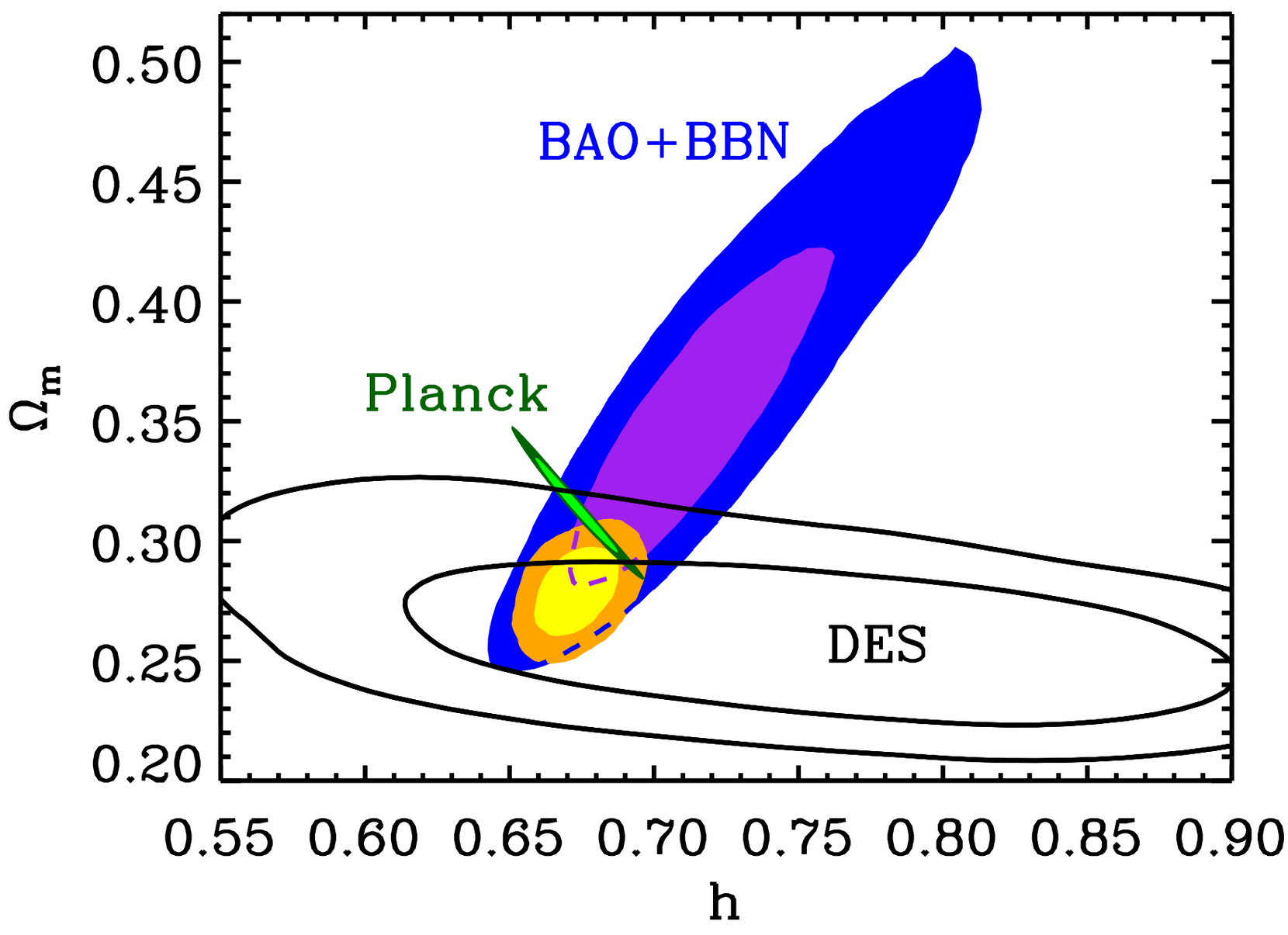
DES Y1 Combined Probes

DES Collaboration 2018 (Year 1)



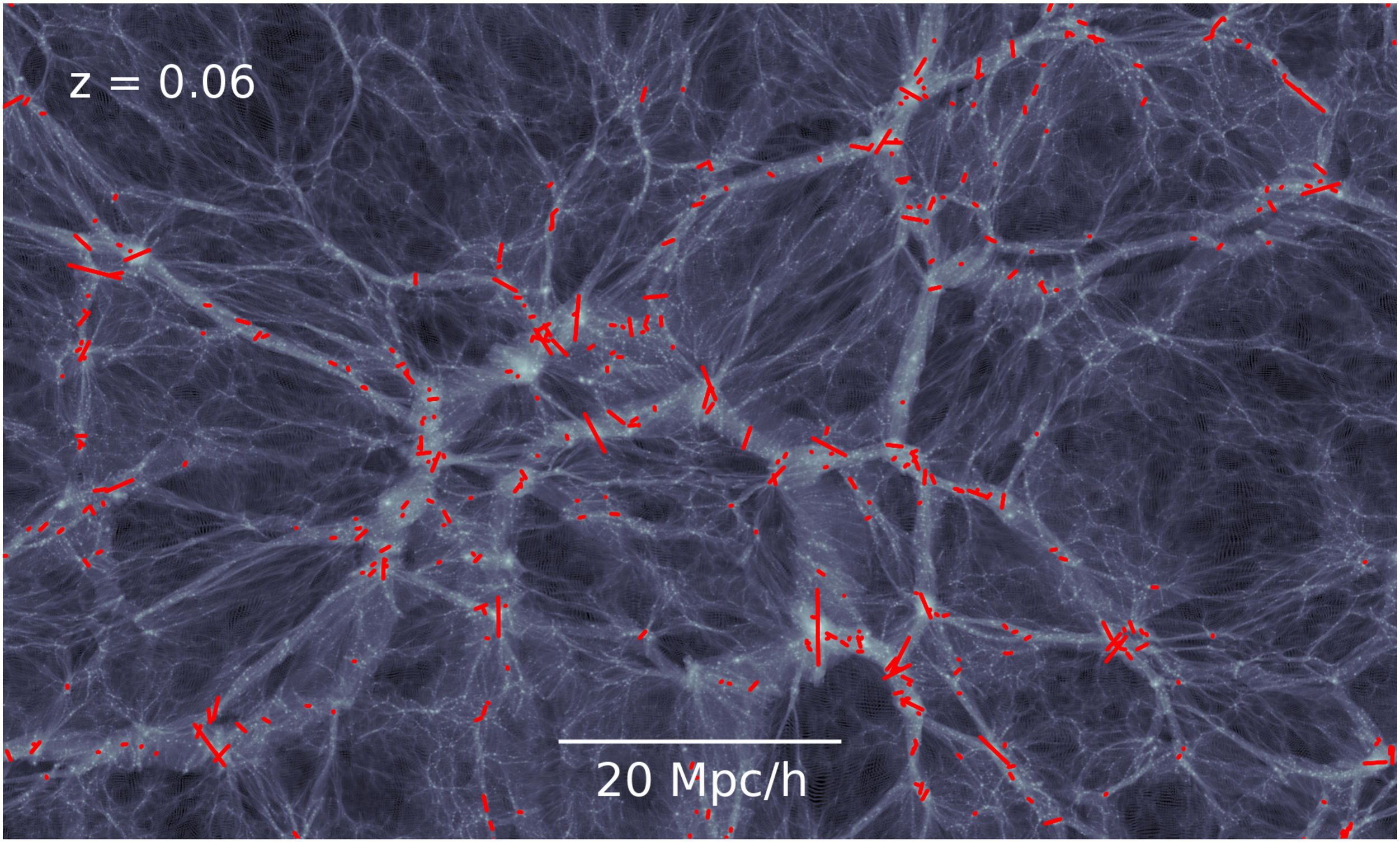
DES Y1 Combined Probes

DES Collaboration 2018 (Year 1)



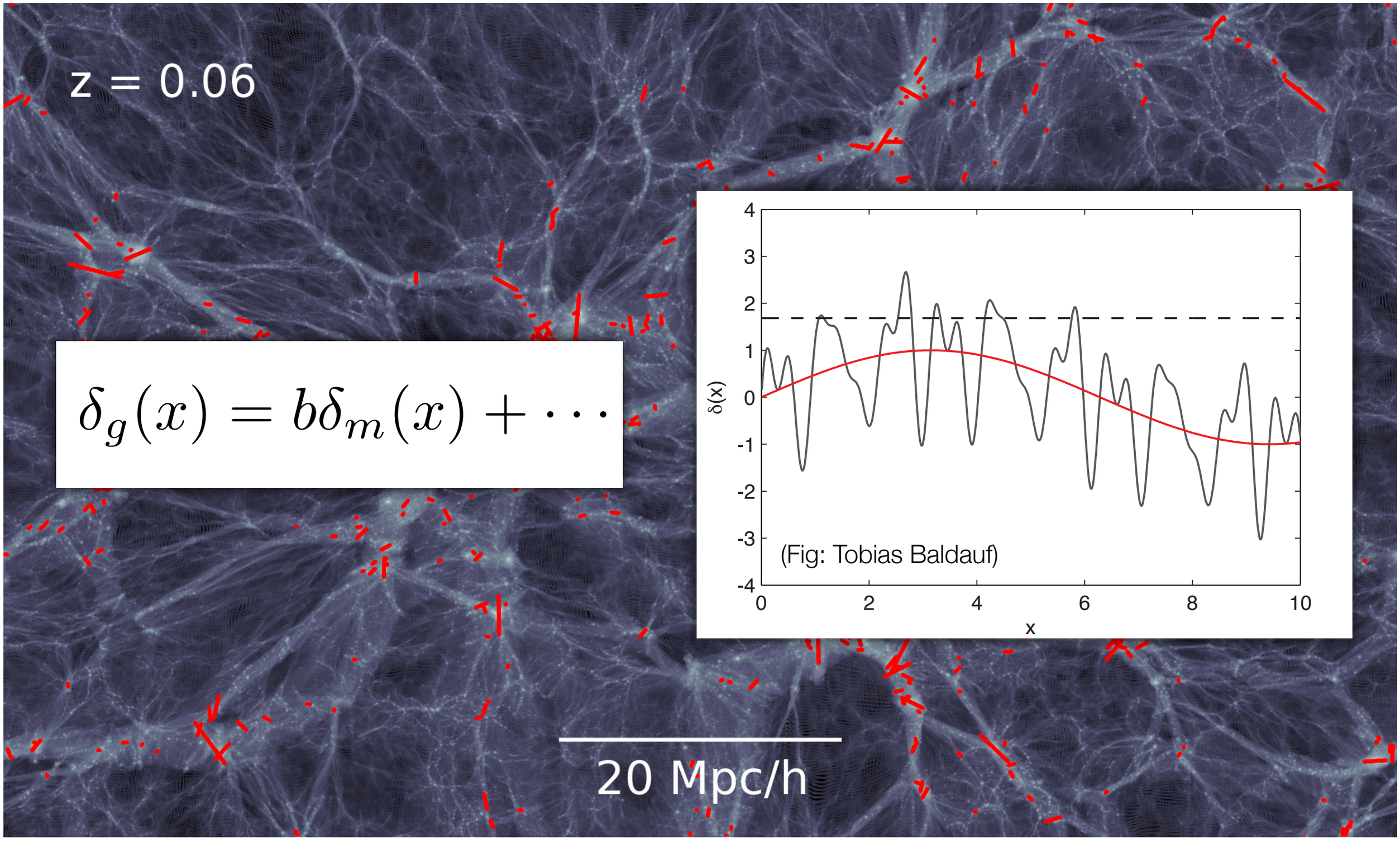
Galaxy observables:

positions and shapes (“3x2”)

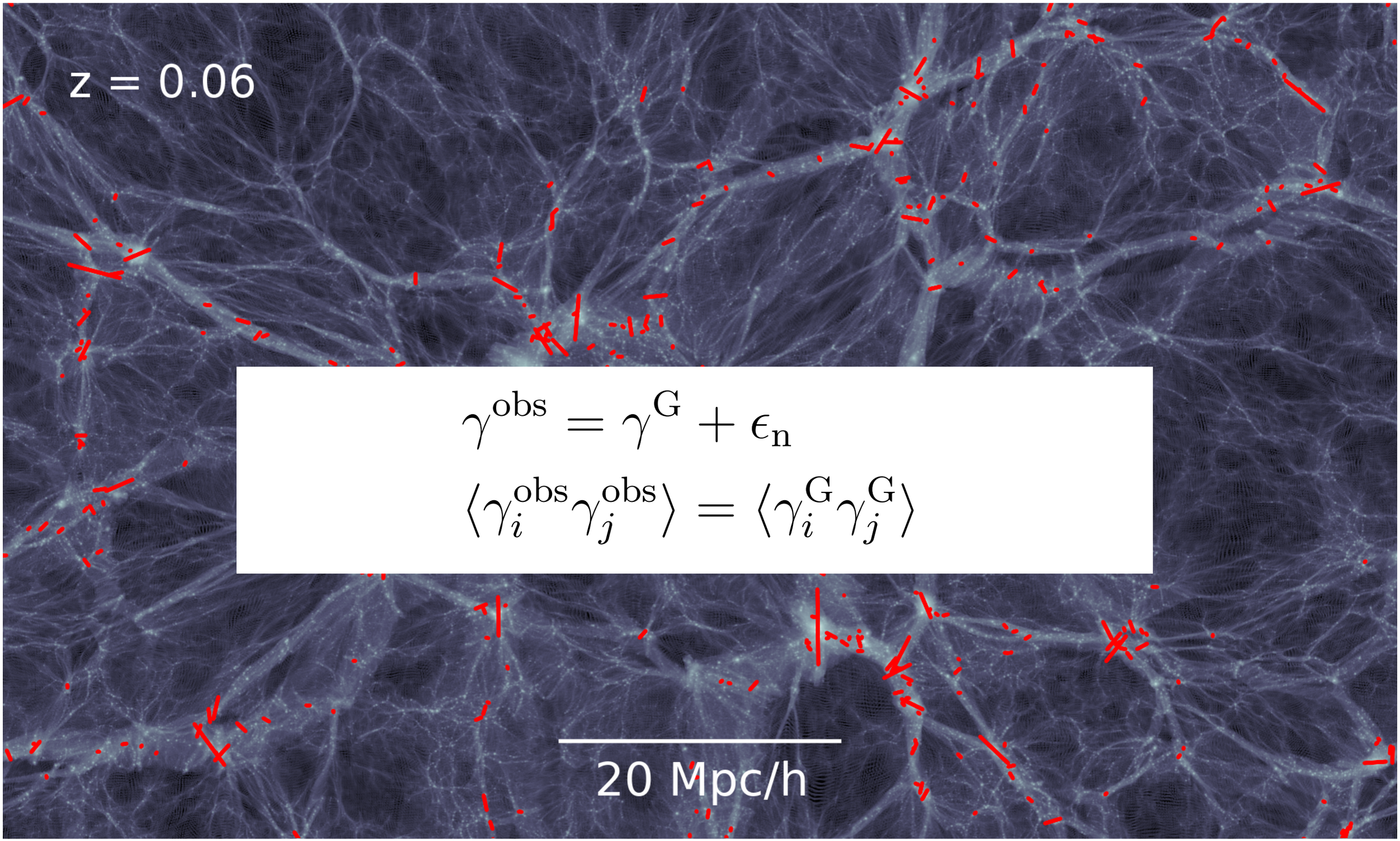


(MassiveBlack II: Khandai+ 2014; Tenneti+ 2014a,b)

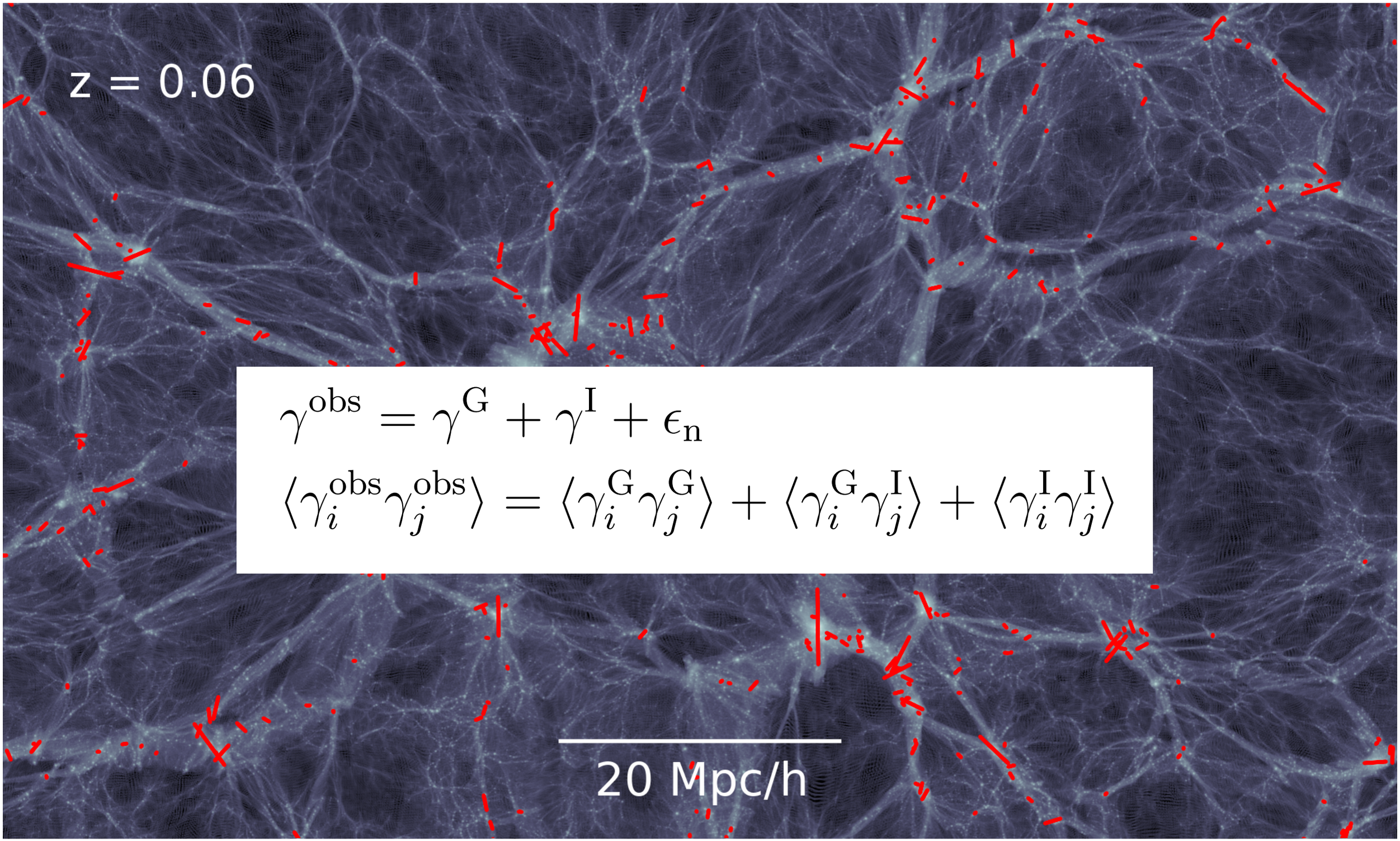
Galaxy positions (“bias”)



Galaxy shapes (“intrinsic alignments”)

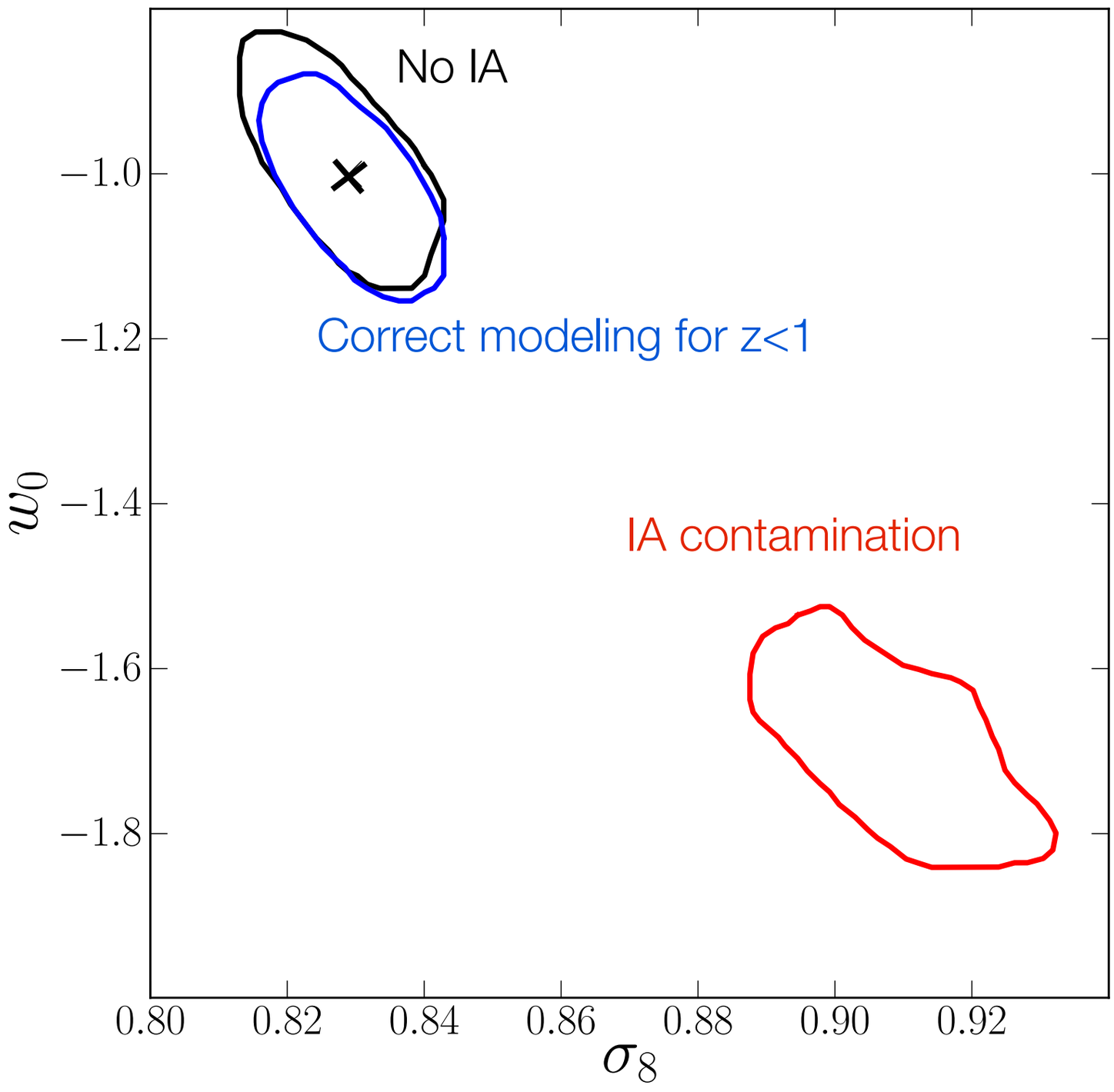


Galaxy shapes (“intrinsic alignments”)

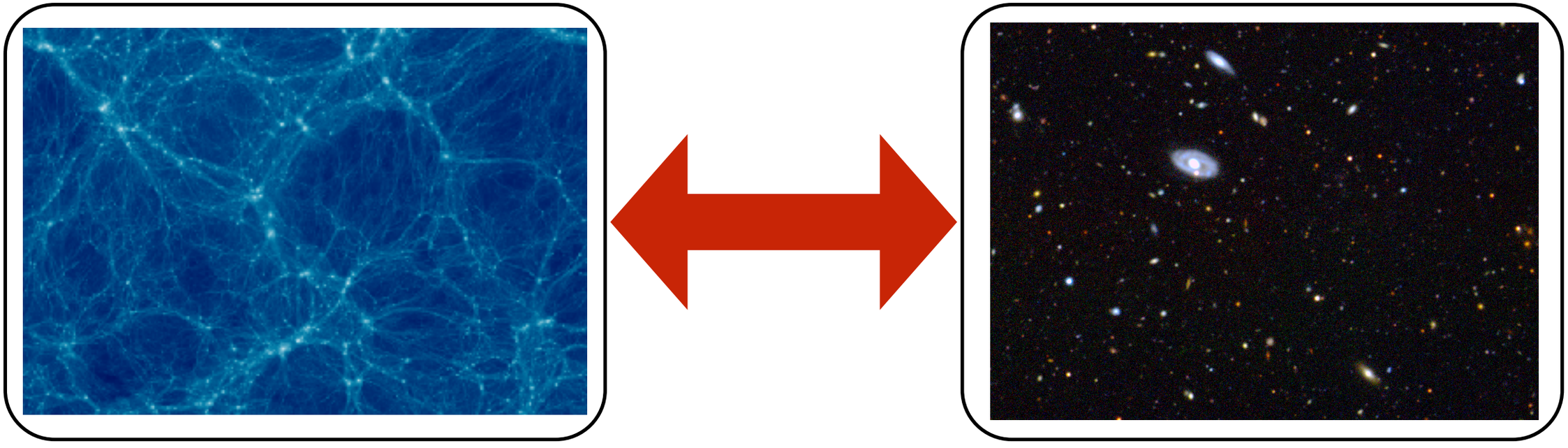


Galaxy shapes (“intrinsic alignments”)

Euclid-like cosmic shear (Krause, Eifler, JB 2016)



Linear modeling

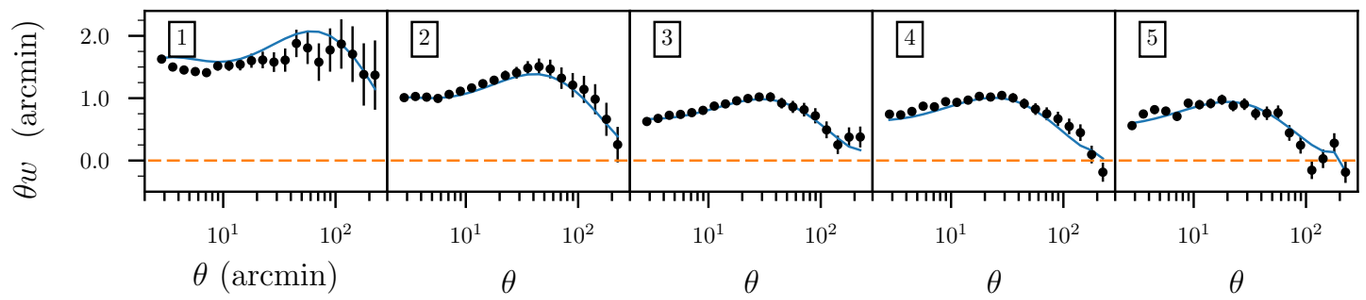


galaxy positions (biasing)

$$\delta_g(x) = b_1 \delta_m(x)$$

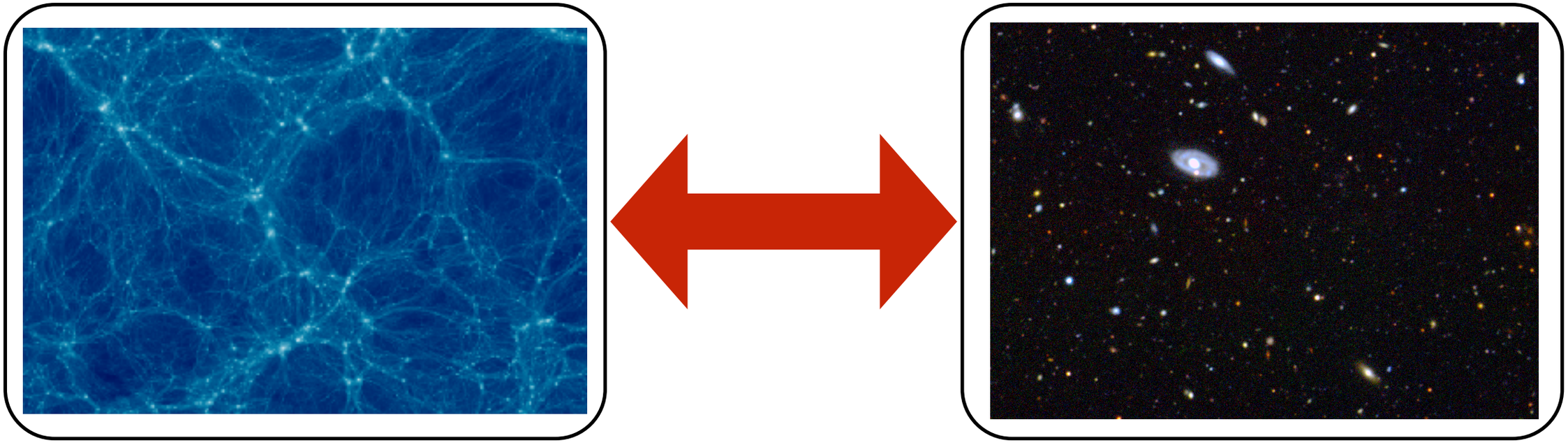
$$\gamma^I_{ij} = C_1 s_{ij}$$

galaxy shapes (intrinsic alignments)



conservative scale cuts

Nonlinear modeling



galaxy positions (biasing)

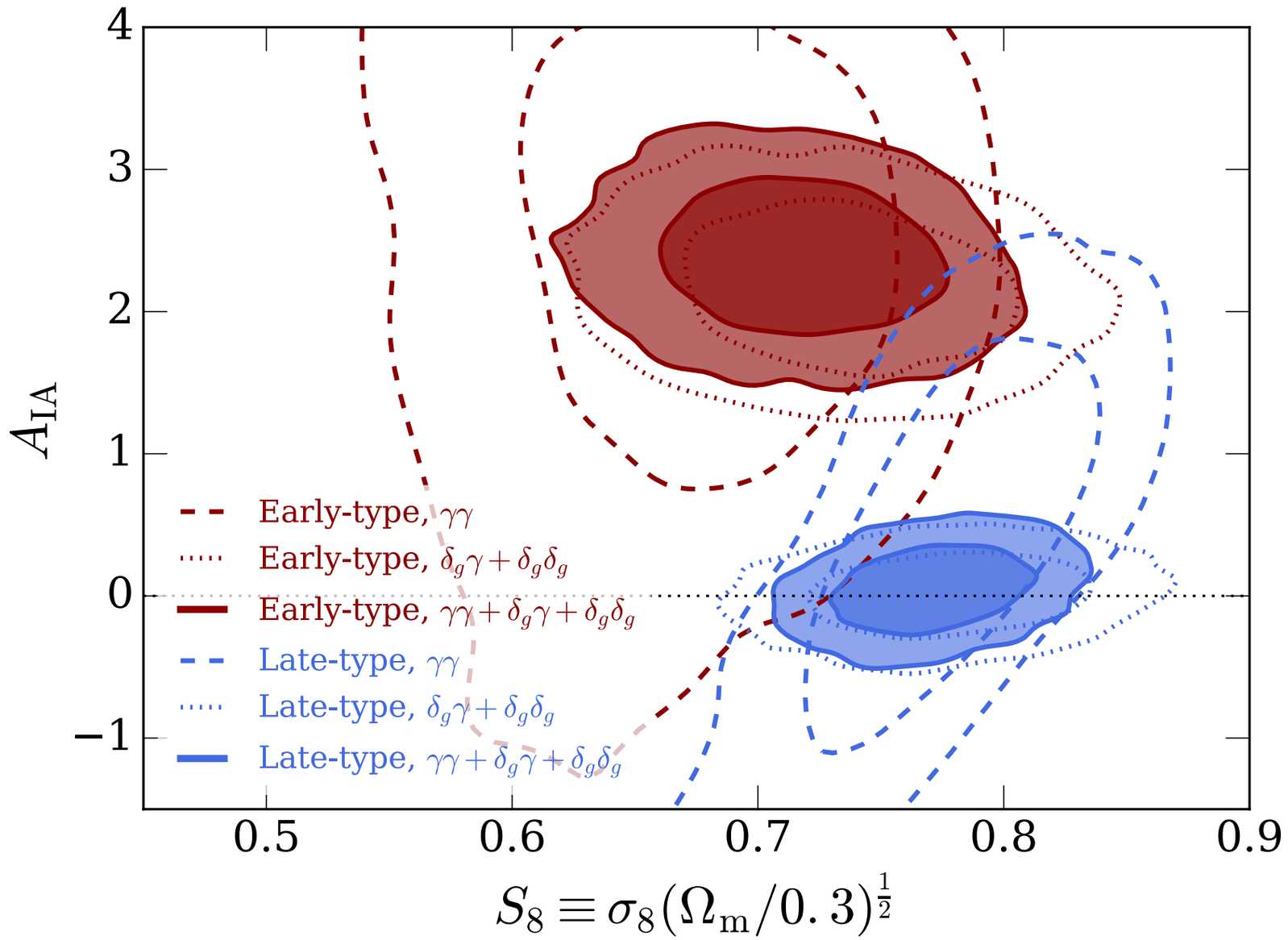
$$\delta_g(x) = \boxed{b_1}\delta_m(x) + \boxed{b_2}\delta_m^2(x) + \boxed{b_s}s^2(x) + \cdots$$

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

galaxy shapes (intrinsic alignments)

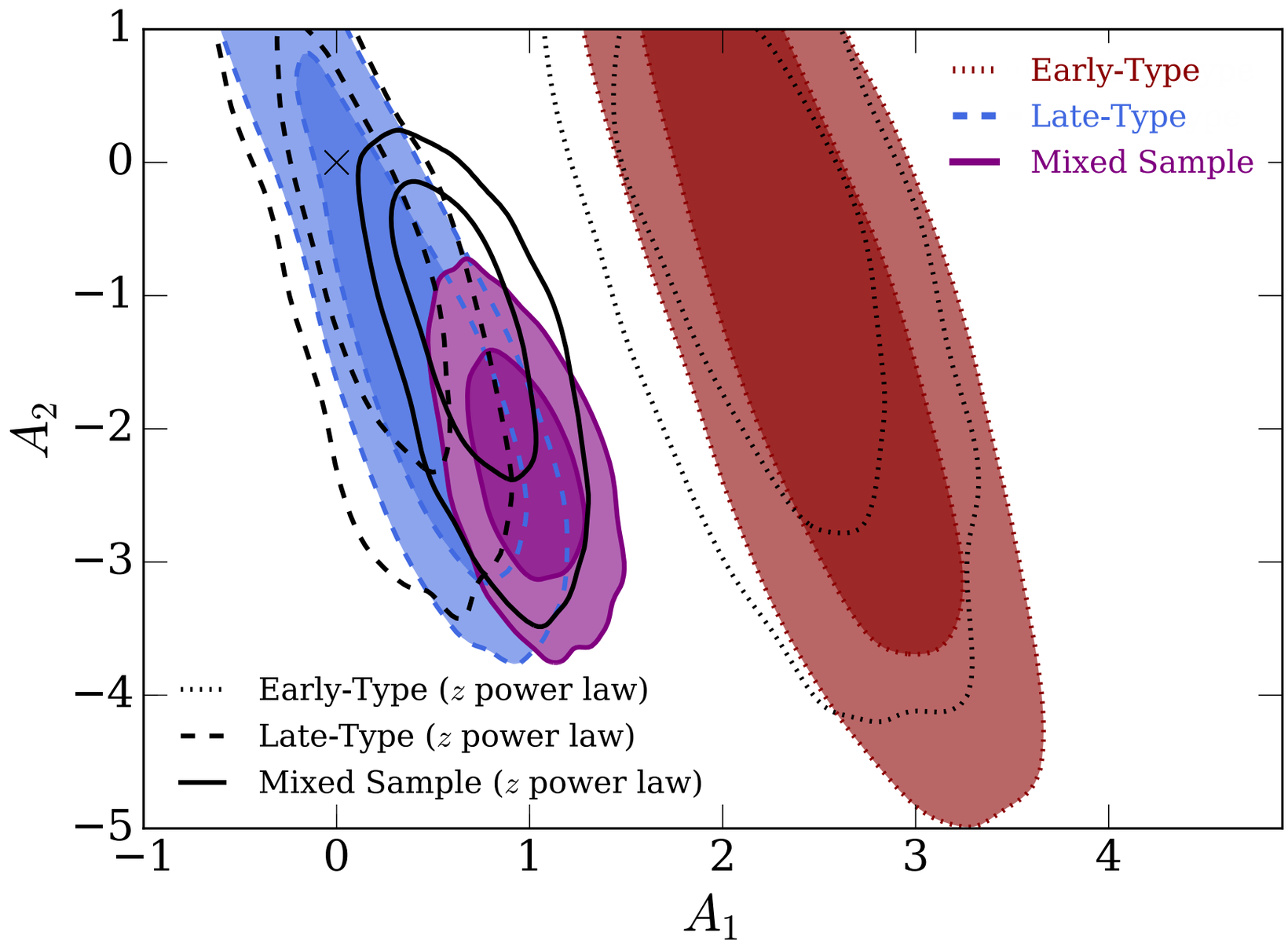
e.g. McDonald & Roy 2009, Angulo+ 2015;
Blazek+ 2015, 2019, Schmitz, Hirata, JB+ 2019, Vlah+ 2020

Galaxy alignments



JB+ 2019; Samuroff, JB+ 2019 (DES Collaboration)

Galaxy alignments



JB+ 2019; Samuroff, JB+ 2019 (DES Collaboration)

Implementation

- Accurate
- Fast
- Consistent between probes/effects
- Flexible and expandable
- Shared tools with other collaborations

FFT methods and **FAST-PT**

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

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

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

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

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

For 1-loop calculations: 1000 *k* values in ~0.1s

FAST-PT as a PT engine

- galaxy biasing (SPT, LPT), intrinsic alignments
- nonlinear structure growth, BAO evolution
- redshift-space distortions
- streaming baryon velocities
- ... your modeling needs? …

- python and C versions
- incorporated into CosmoSIS, CosmoLike, CCL
- Euclid tools through IST:Nonlinear

- FAST-PT - github: JoeMcEwen/FAST-PT
- $ pip install fast-pt
- Core Cosmology Library - github: LSSTDESC/CCL

Summary

- Astrophysical effects including **intrinsic alignments** and galaxy bias must be understood for future cosmology analyses.
- Effective perturbative expansions provide a valuable modeling tool. **Implementation for Euclid in progress - let's talk!**
- Simulation and measurement efforts also critical.
- We can use these "systematics" to probe underlying astrophysics and fundamental physics.