Optimal and accurate cosmology from the Dark Energy Survey (and beyond)

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DSU 2018

Annecy-le-Vieux

Outline

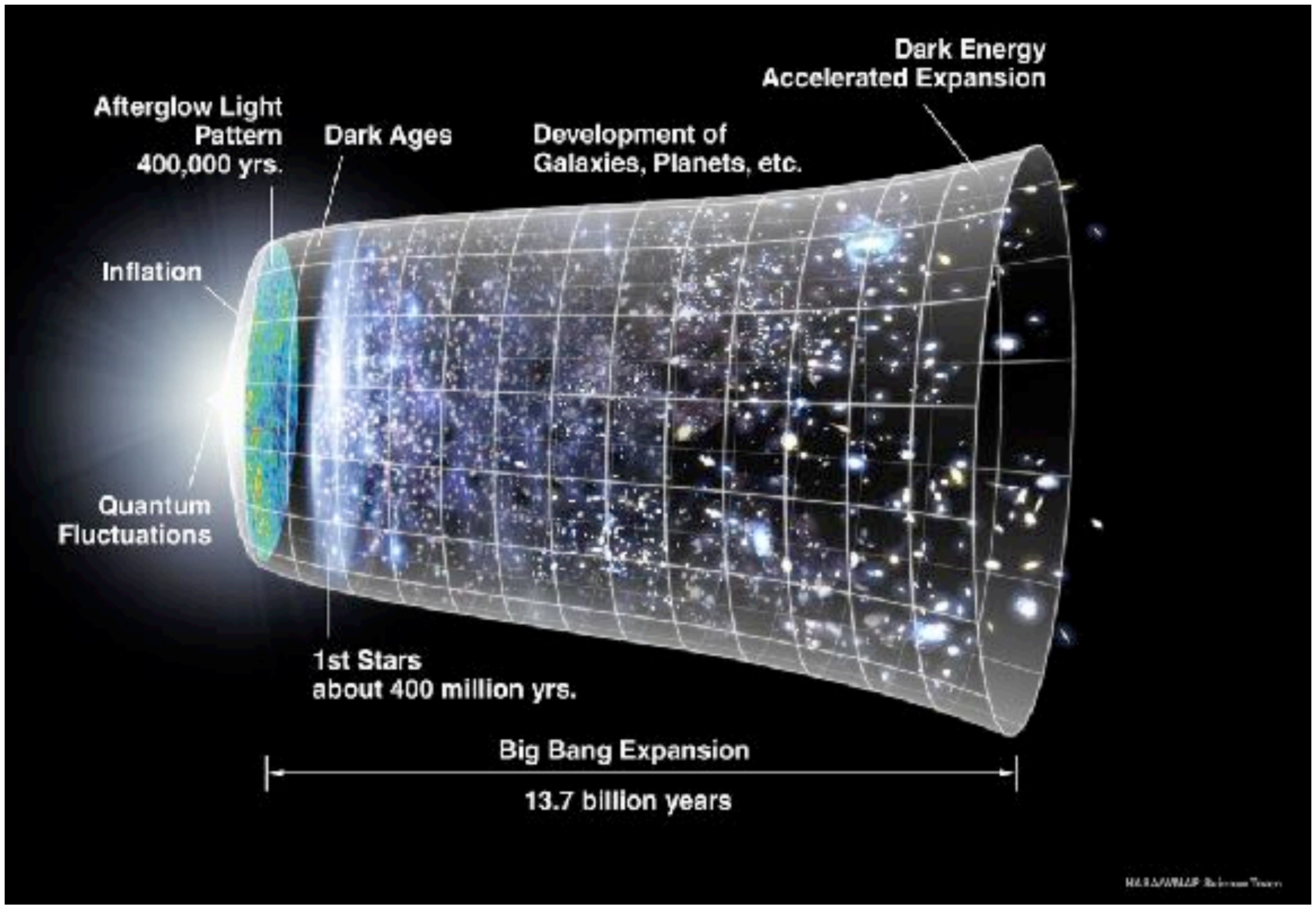
- Cosmology with large galaxy surveys
- Modeling challenges and effective perturbative expansions for shapes and bias
- Results from the Dark Energy Survey Year 1

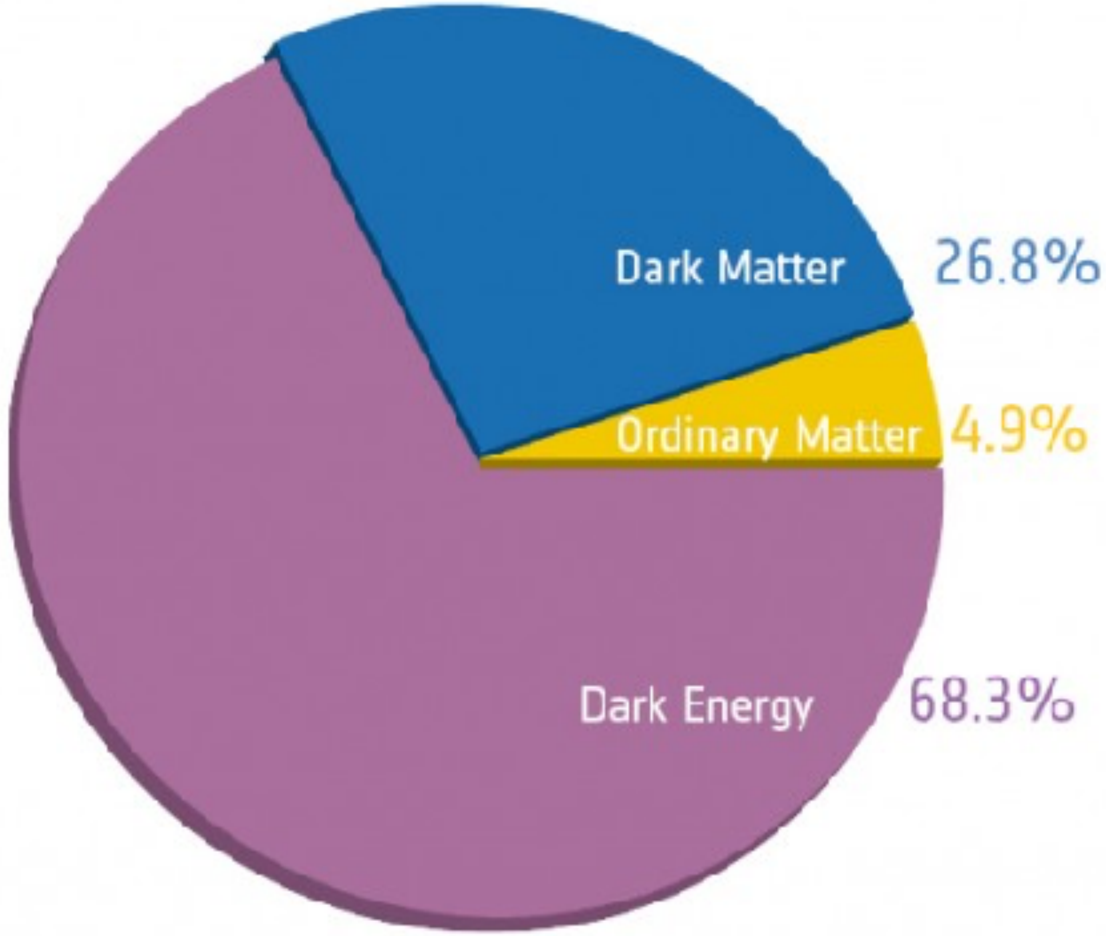
In collaboration with:

DES, LSST-DESC,

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

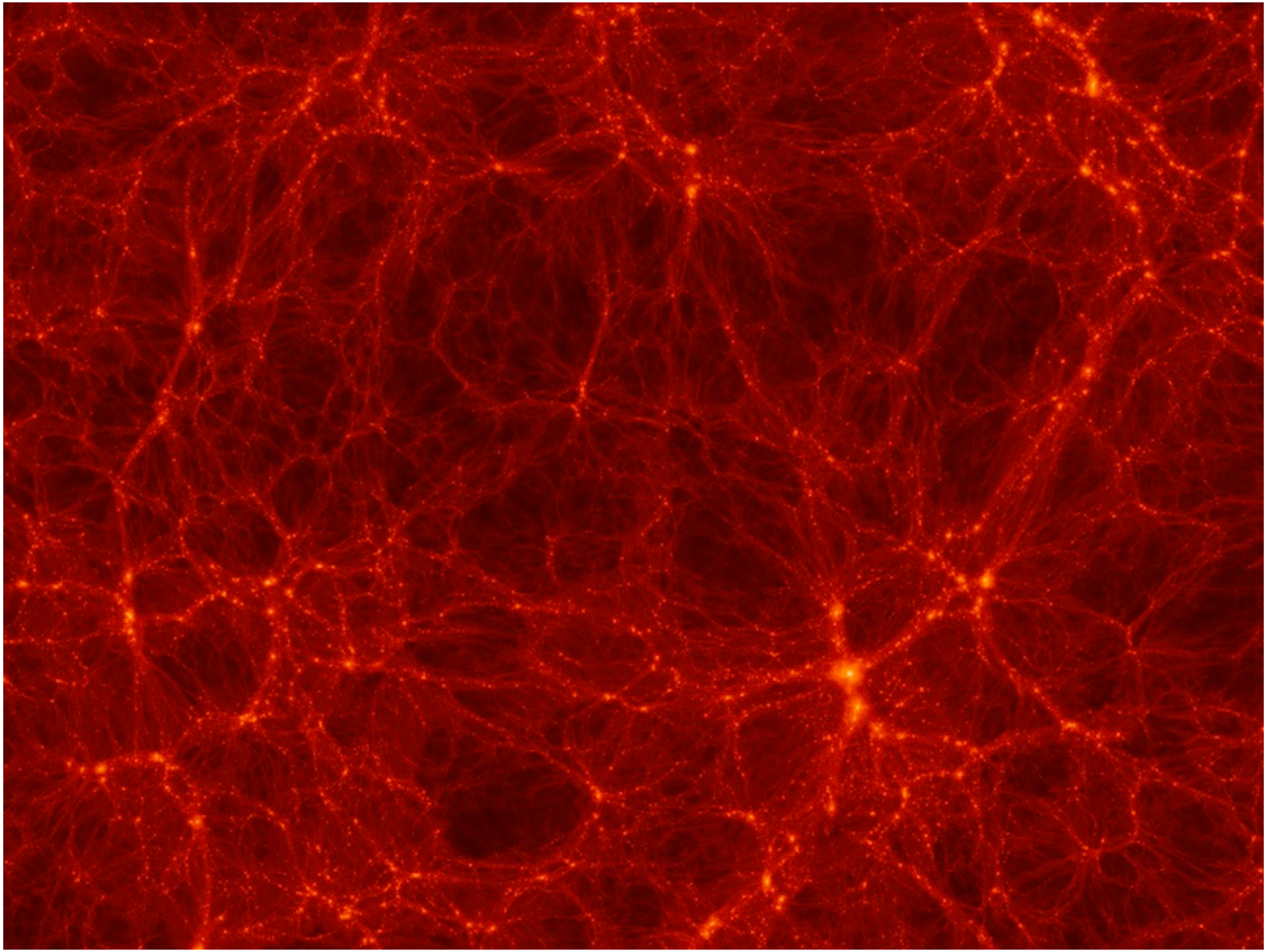
Cosmology: a precision probe of fundamental physics





Planck Collaboration 2015

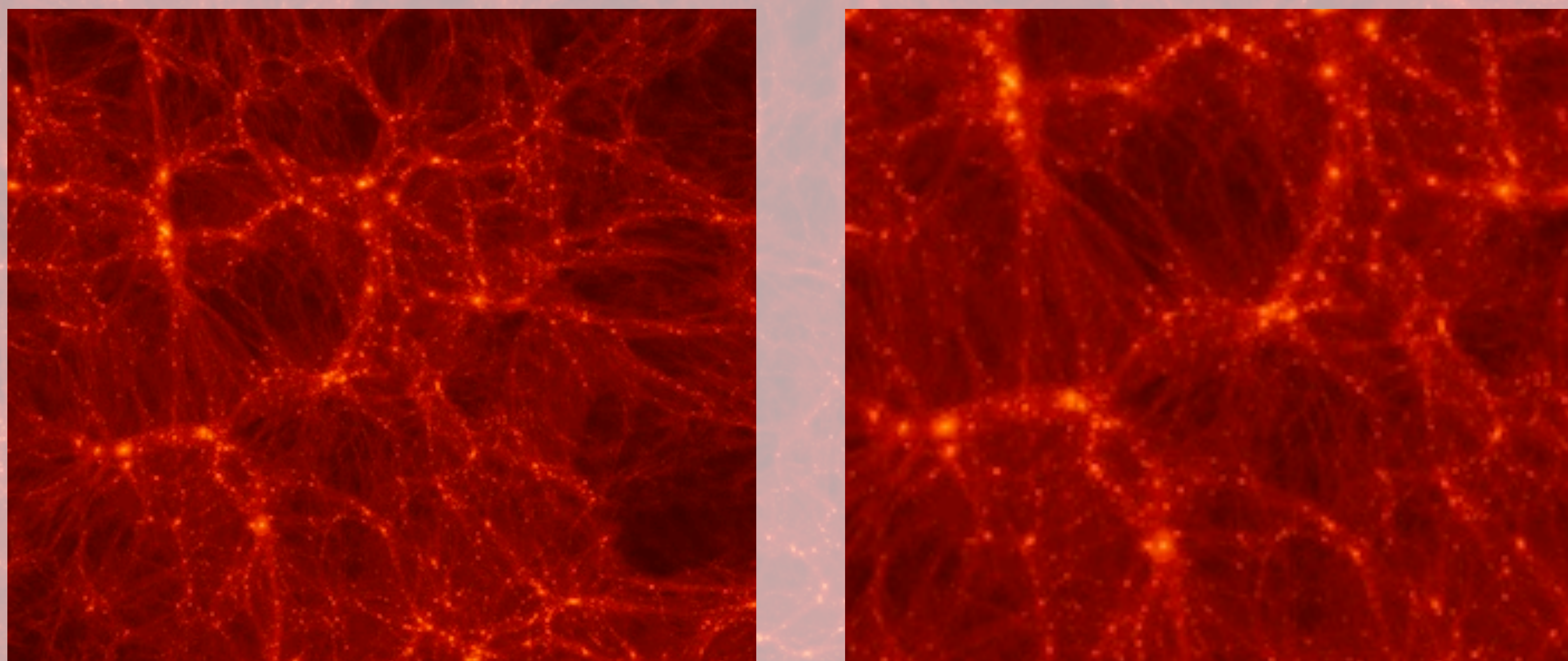
What can we measure?



(Bolshoi simulation: Klypin+ 2011) (250 Mpc across)

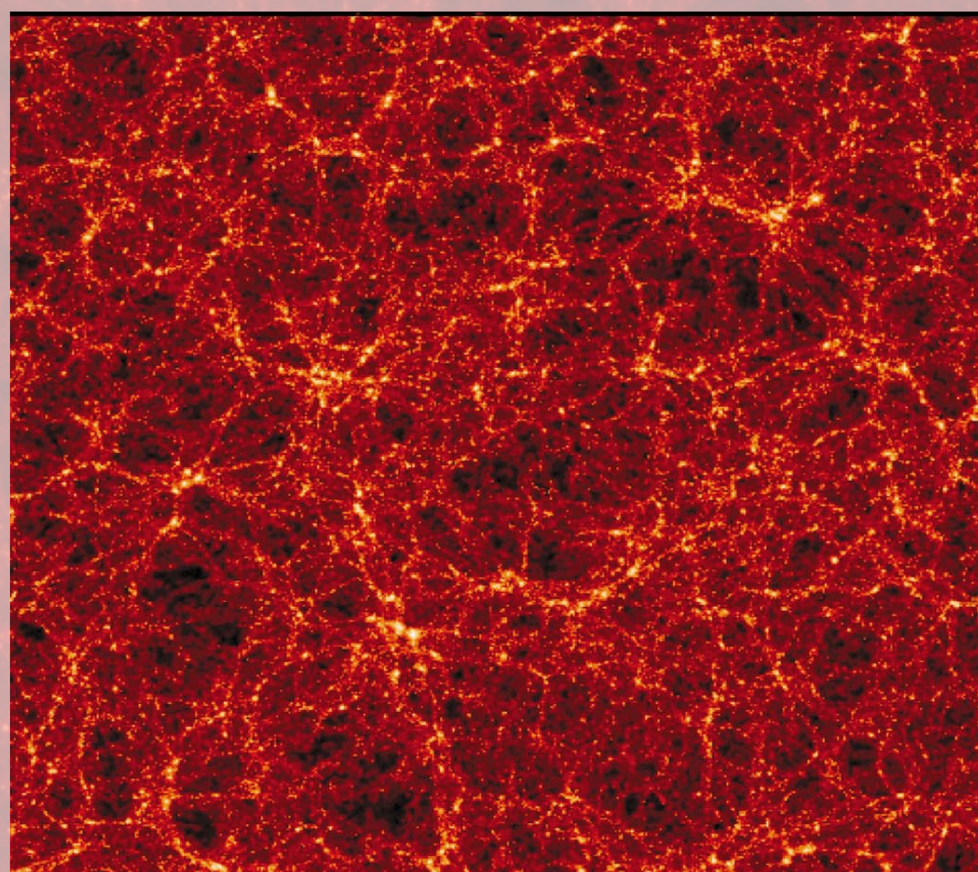
What can we measure?

“geometry”

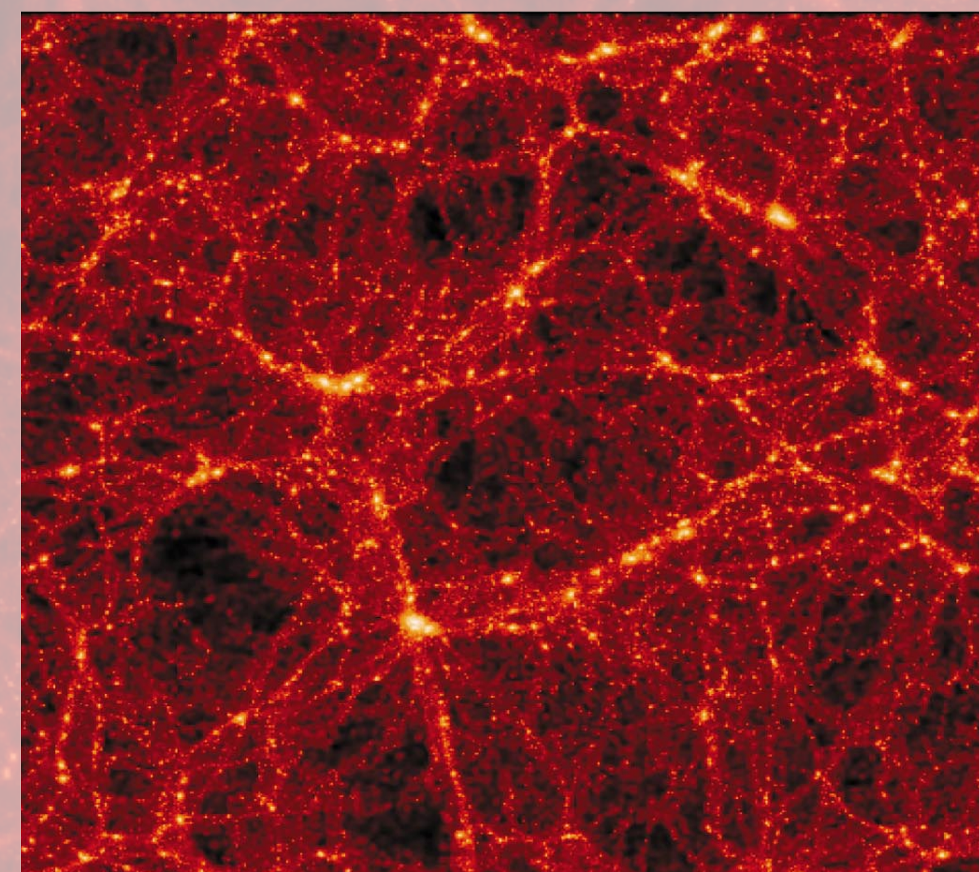


What can we measure?

“growth”



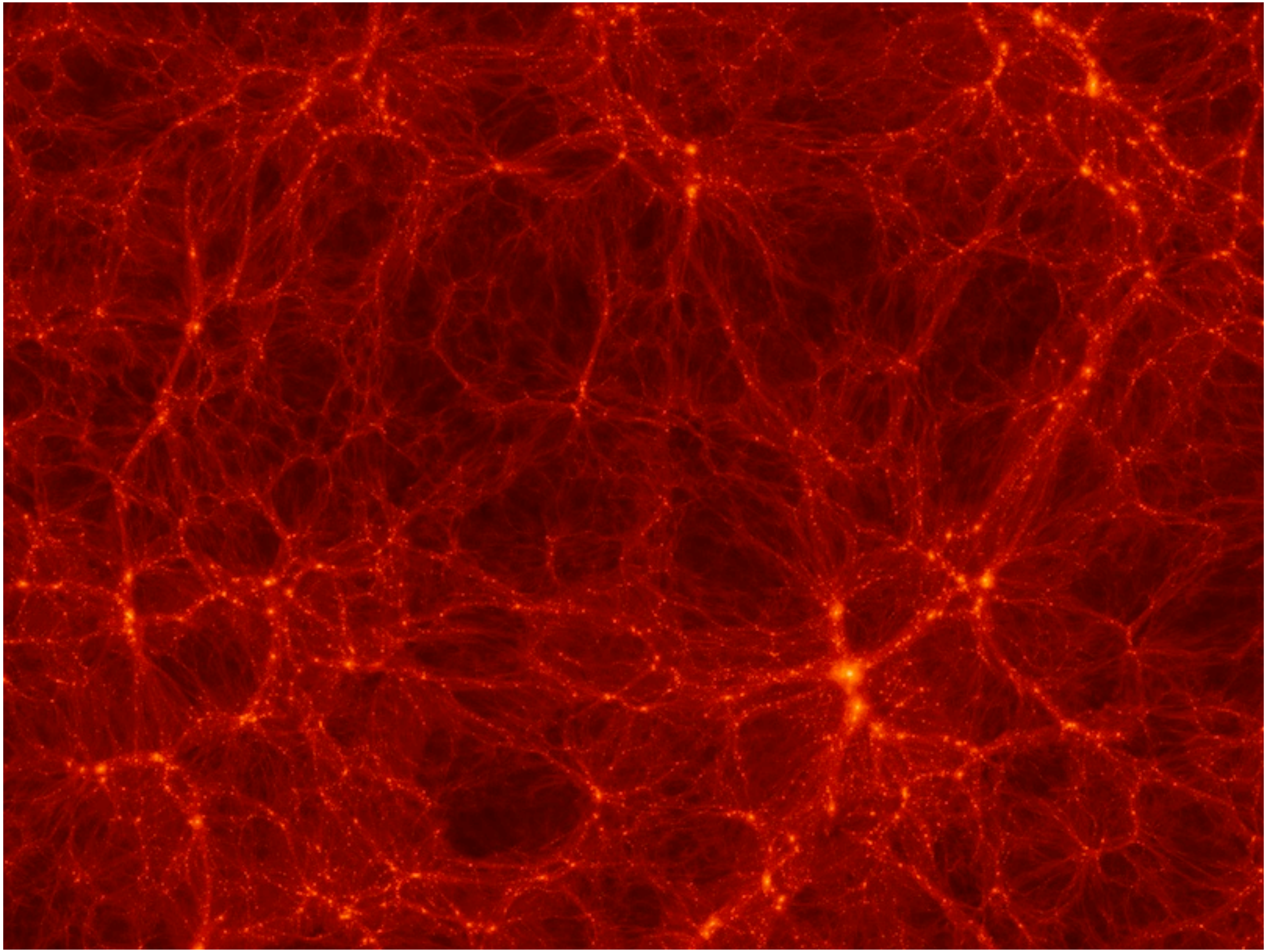
No Dark Energy



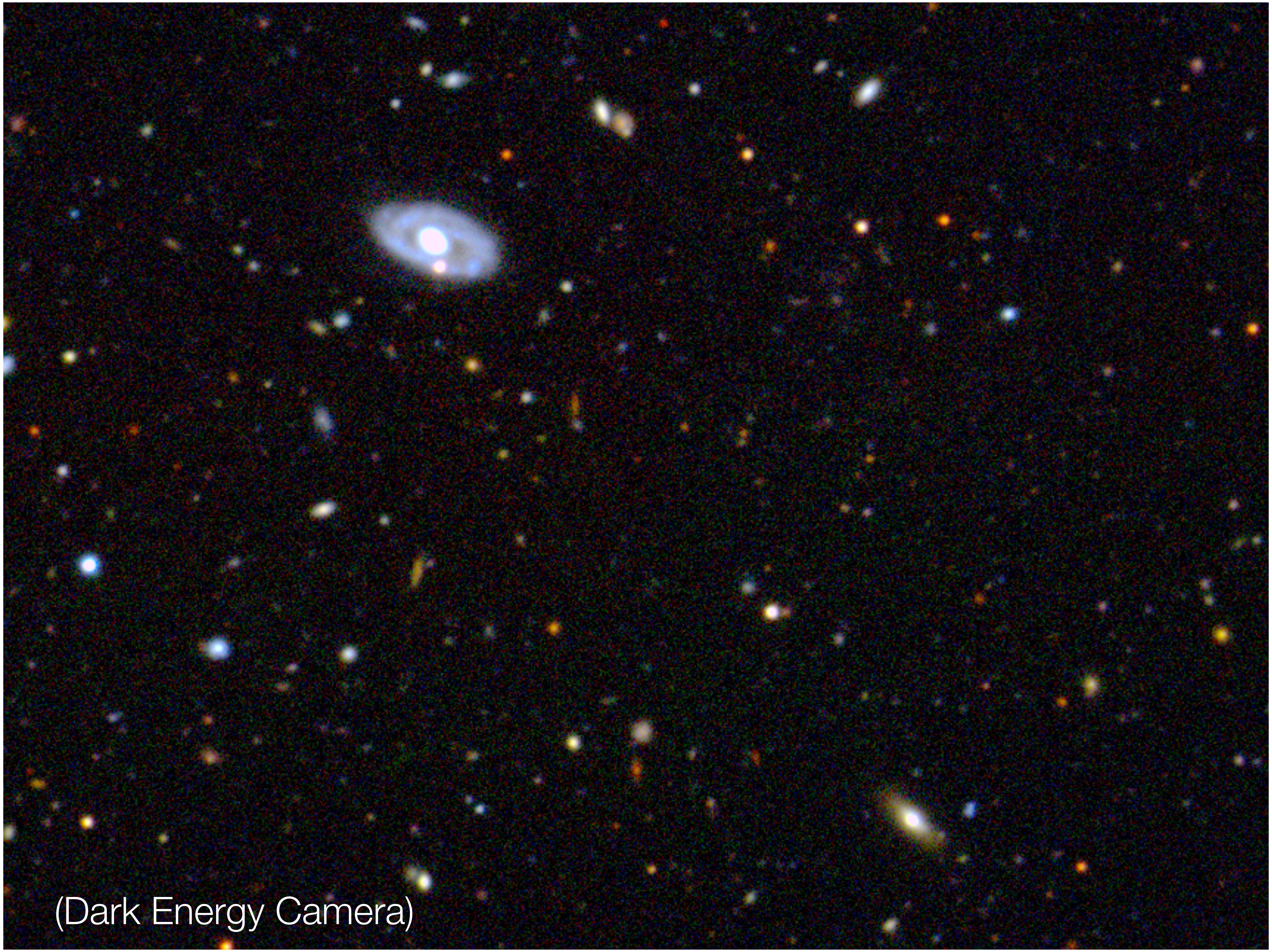
Dark Energy

(Virgo simulations: Jenkins+ 1998)

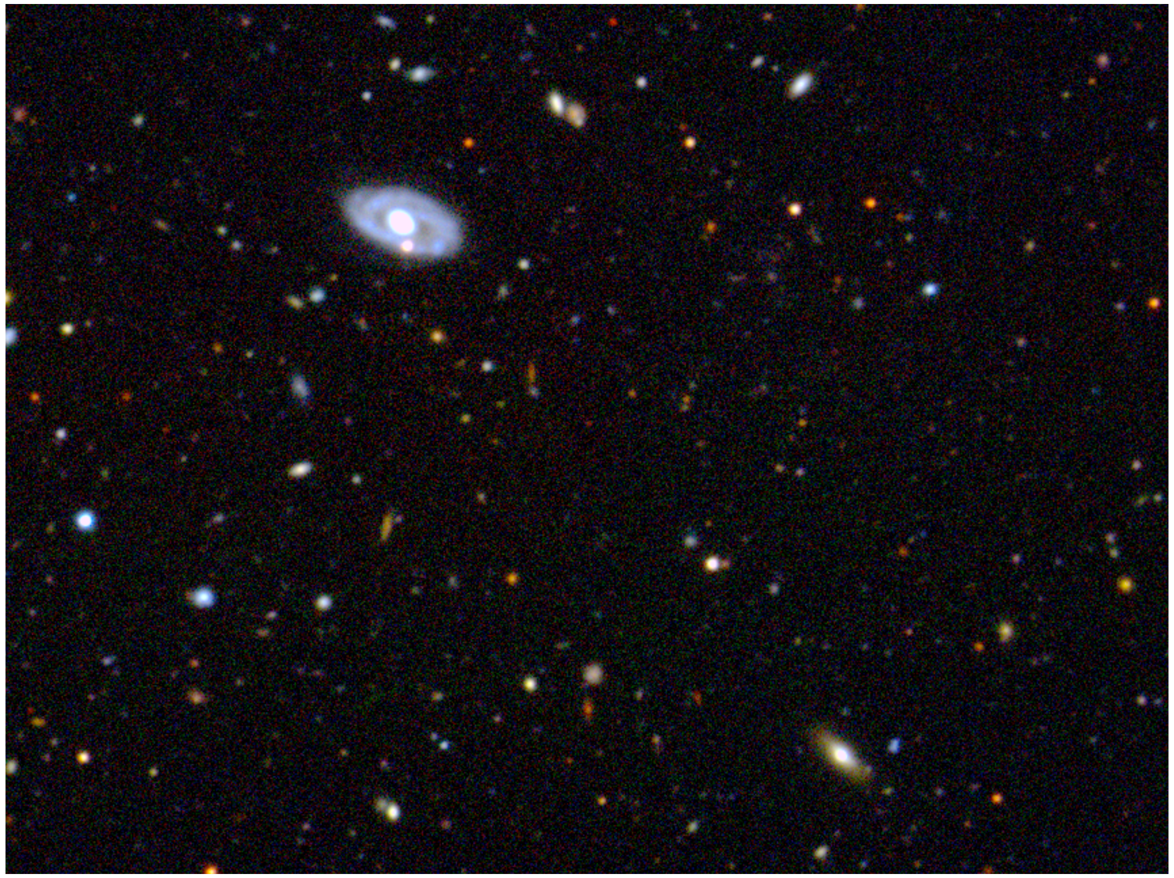
What can we measure?

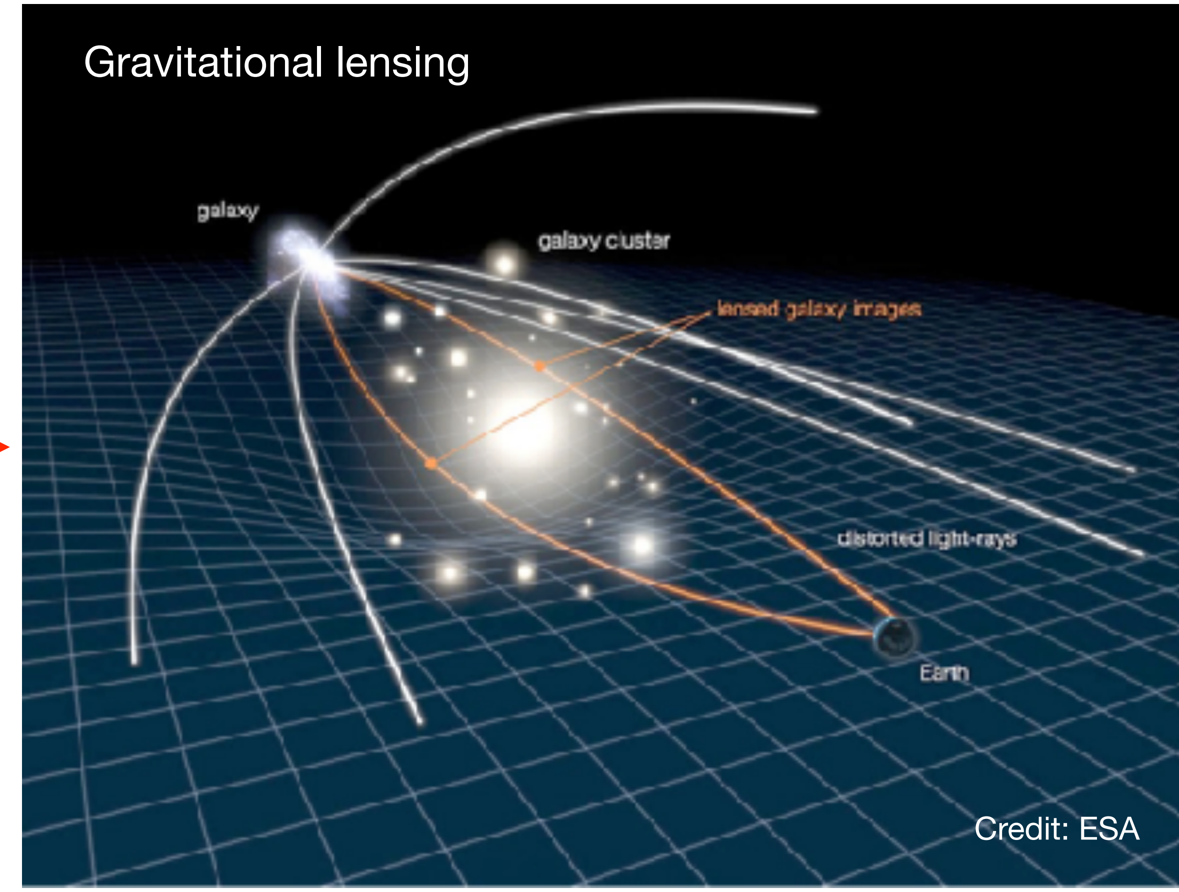


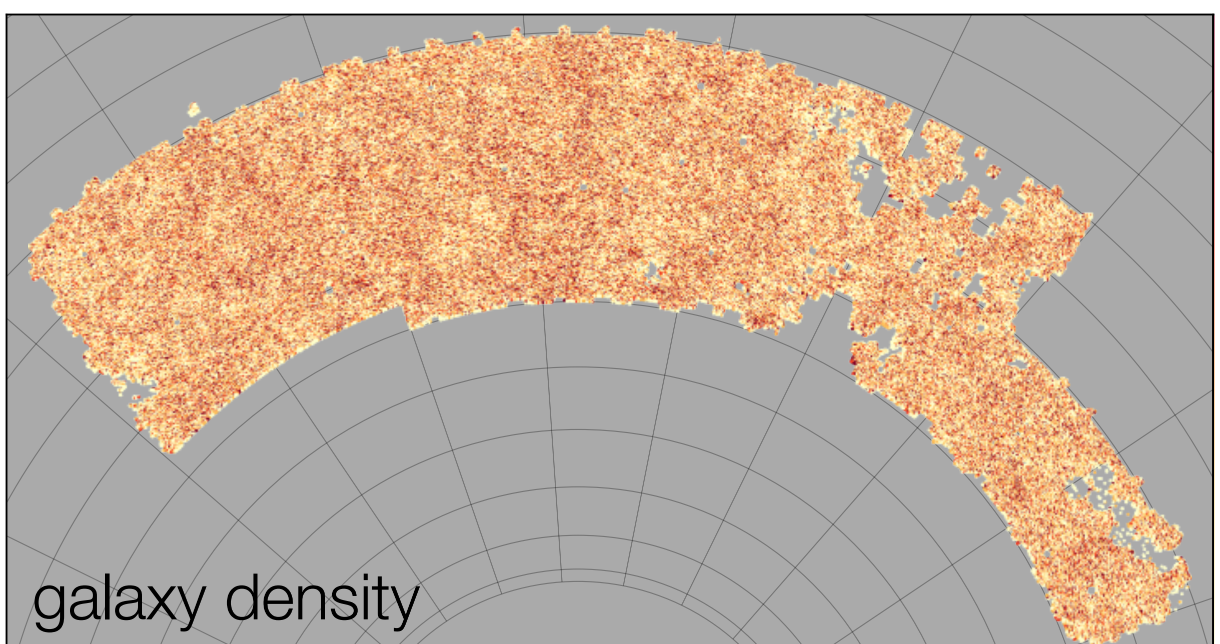
What can we measure?

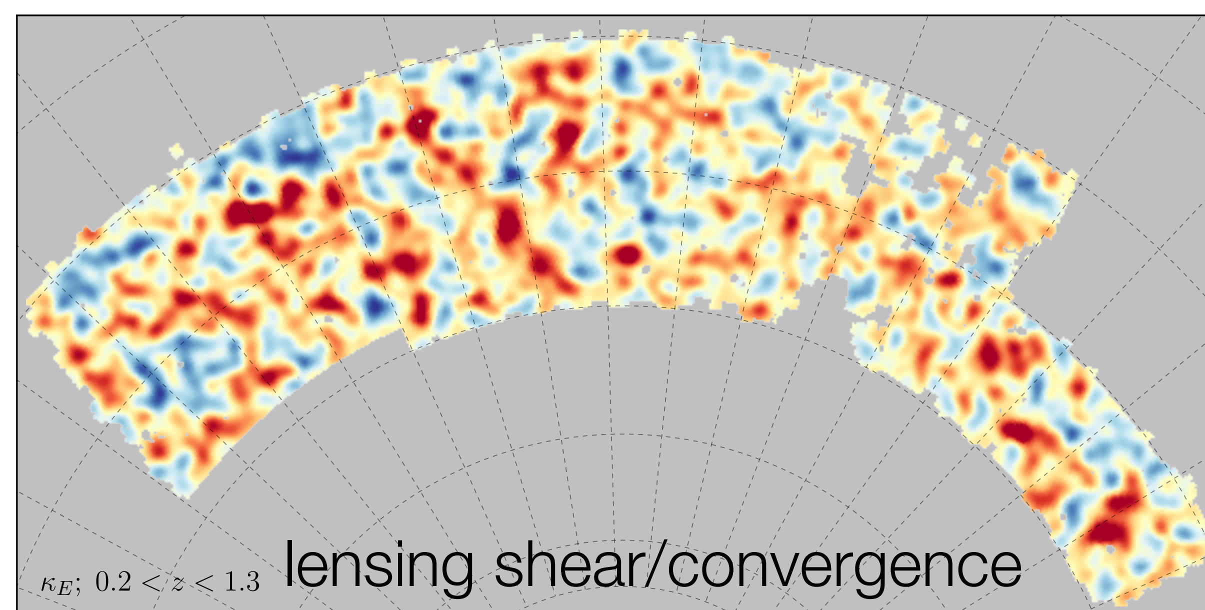


Observables



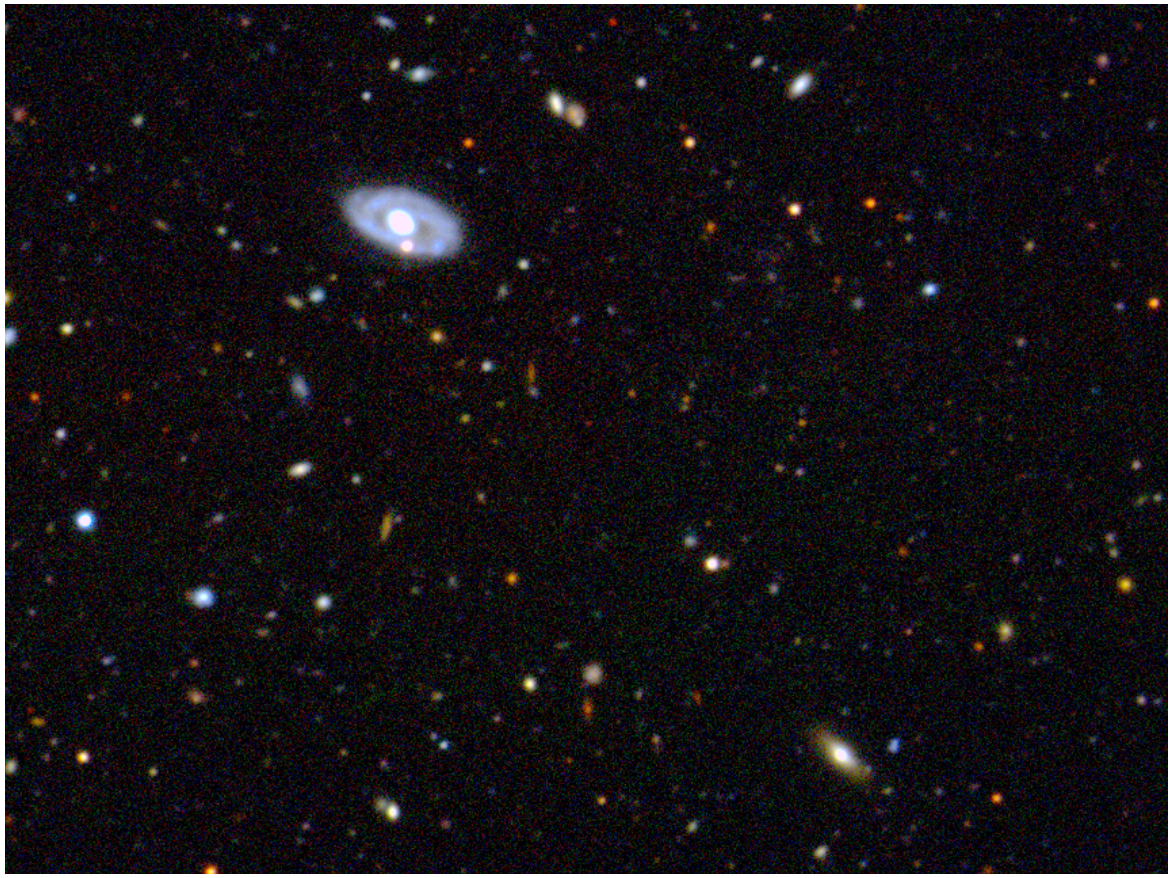


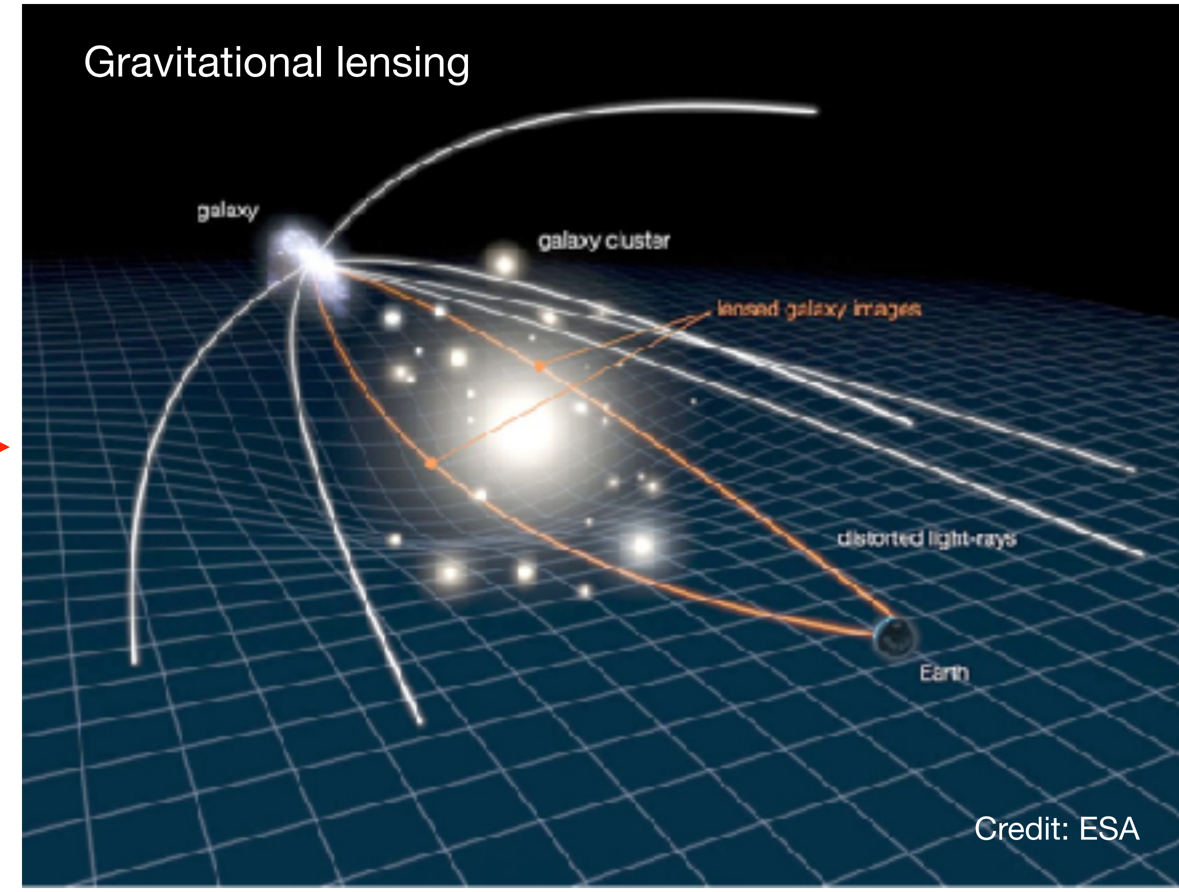


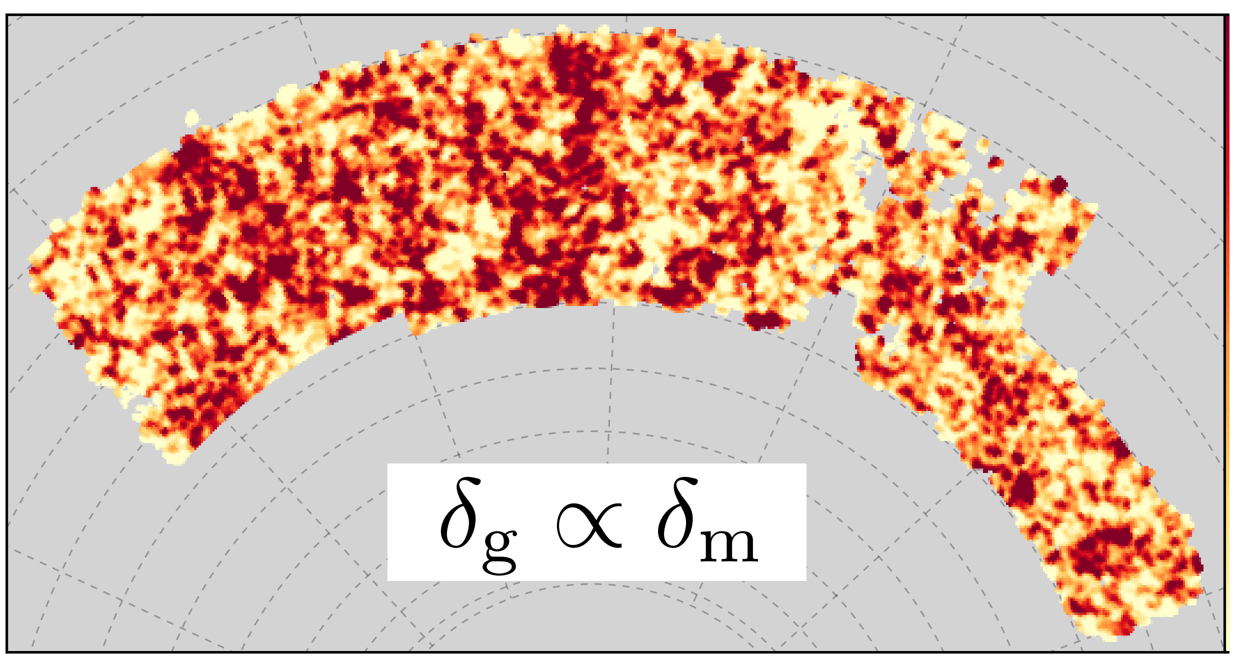


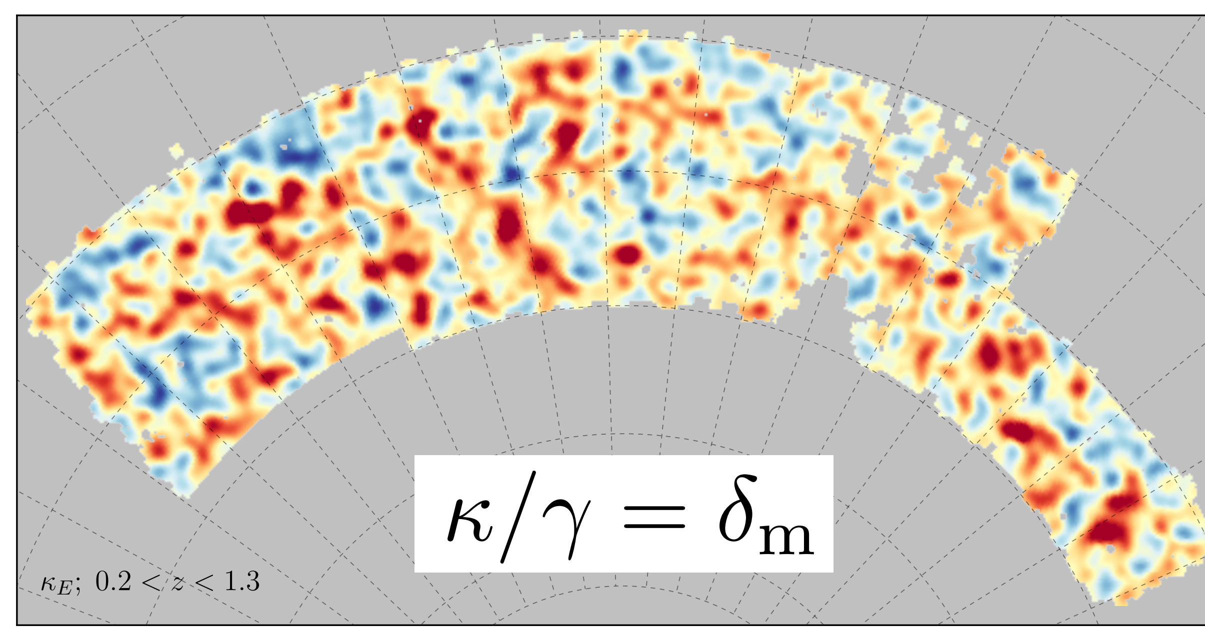
DES Year 1: Elvin-Poole+ 2017; Chang+ 2018

Observables









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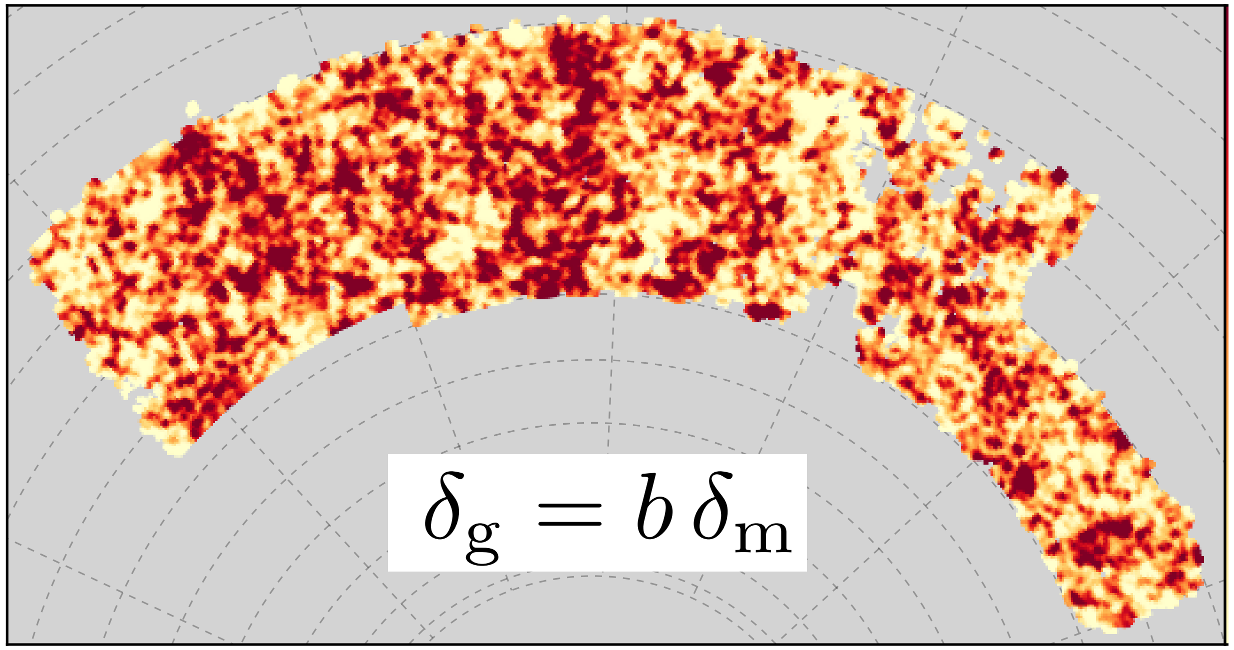
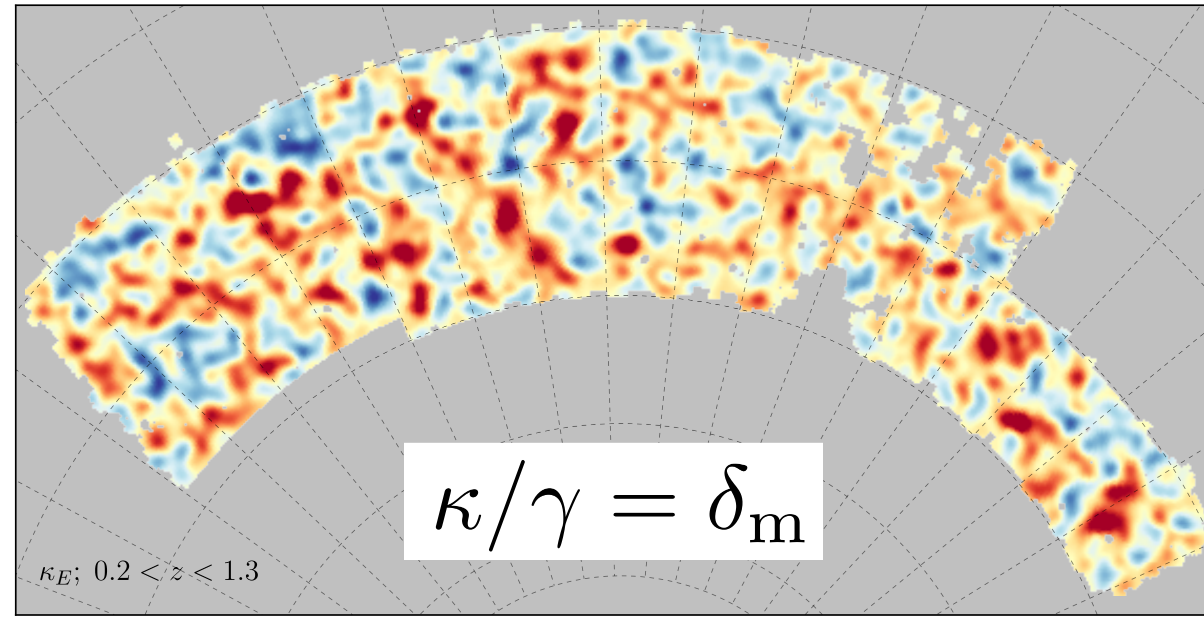
Combining probes





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

"3x2"

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

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

Challenges

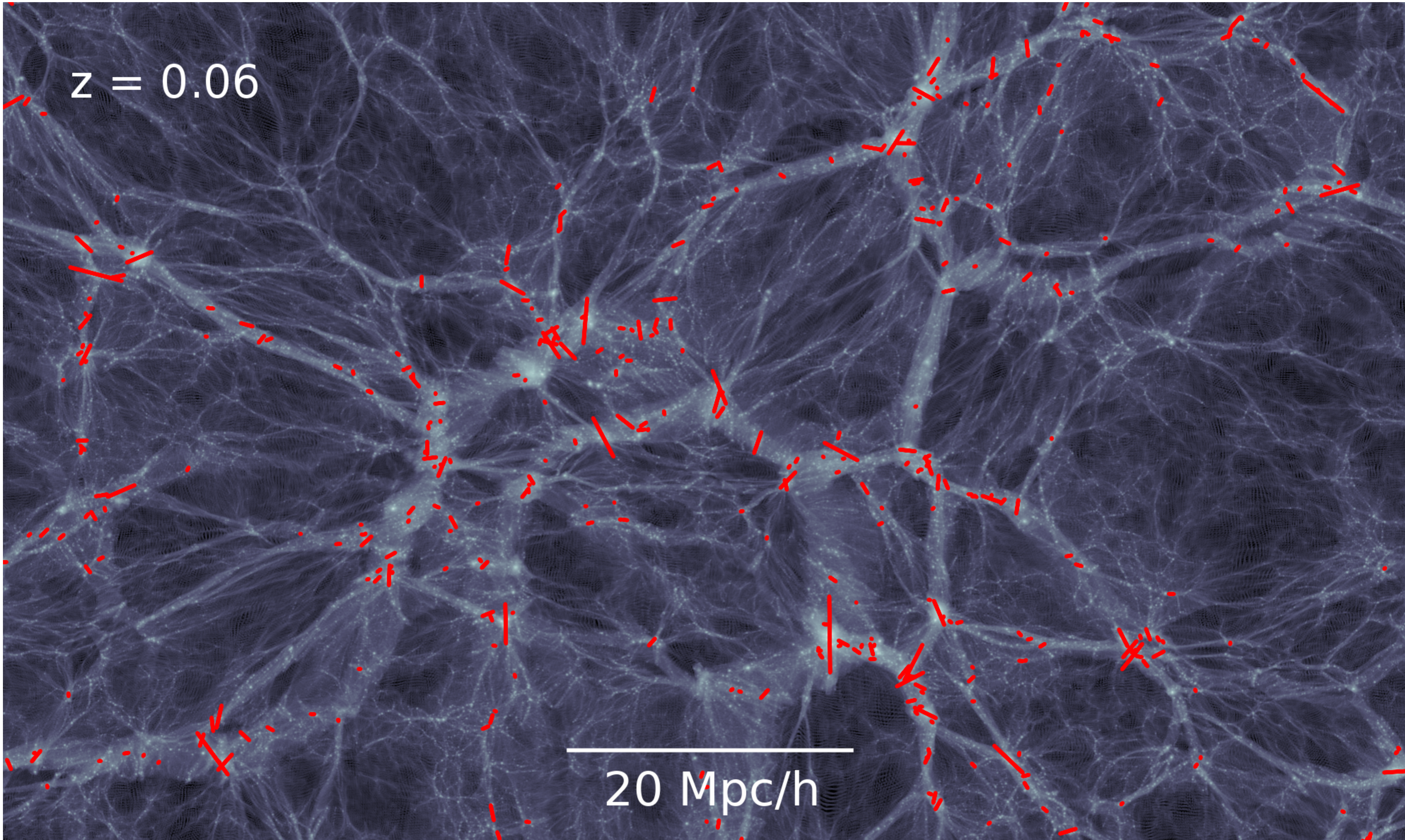
Measurement systematics

- photometric redshift uncertainties
- shear calibration and source blending
- PSF modeling
- details of survey selection and completeness

Astrophysical systematics

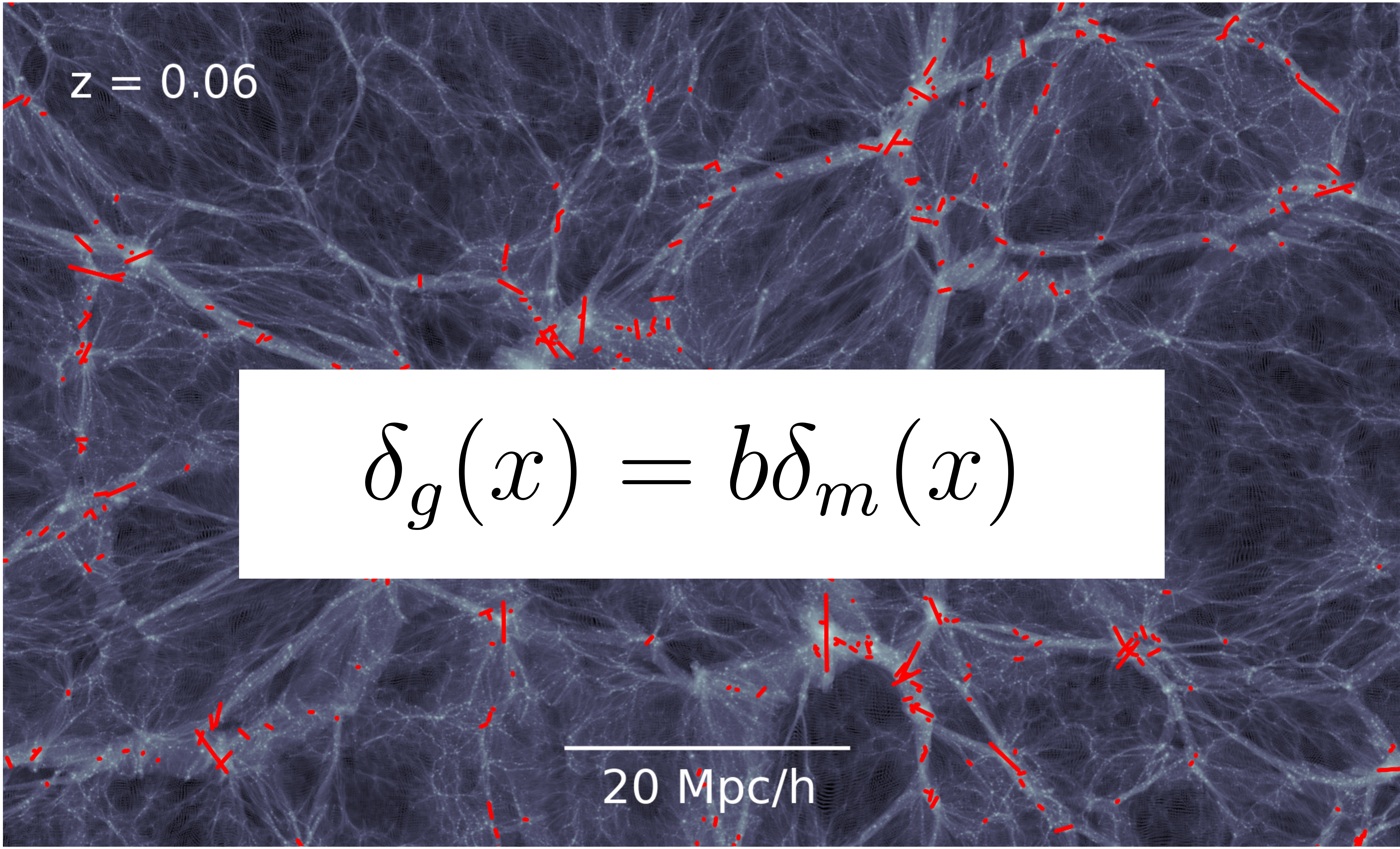
- galaxy/tracer formation and relationship to dark matter
    - shape/size correlations (e.g. “intrinsic alignments”)
    - biasing and peculiar velocities
- nonlinear structure growth
- “baryonic effects” on matter clustering

Modeling the observables:
galaxy positions and shapes



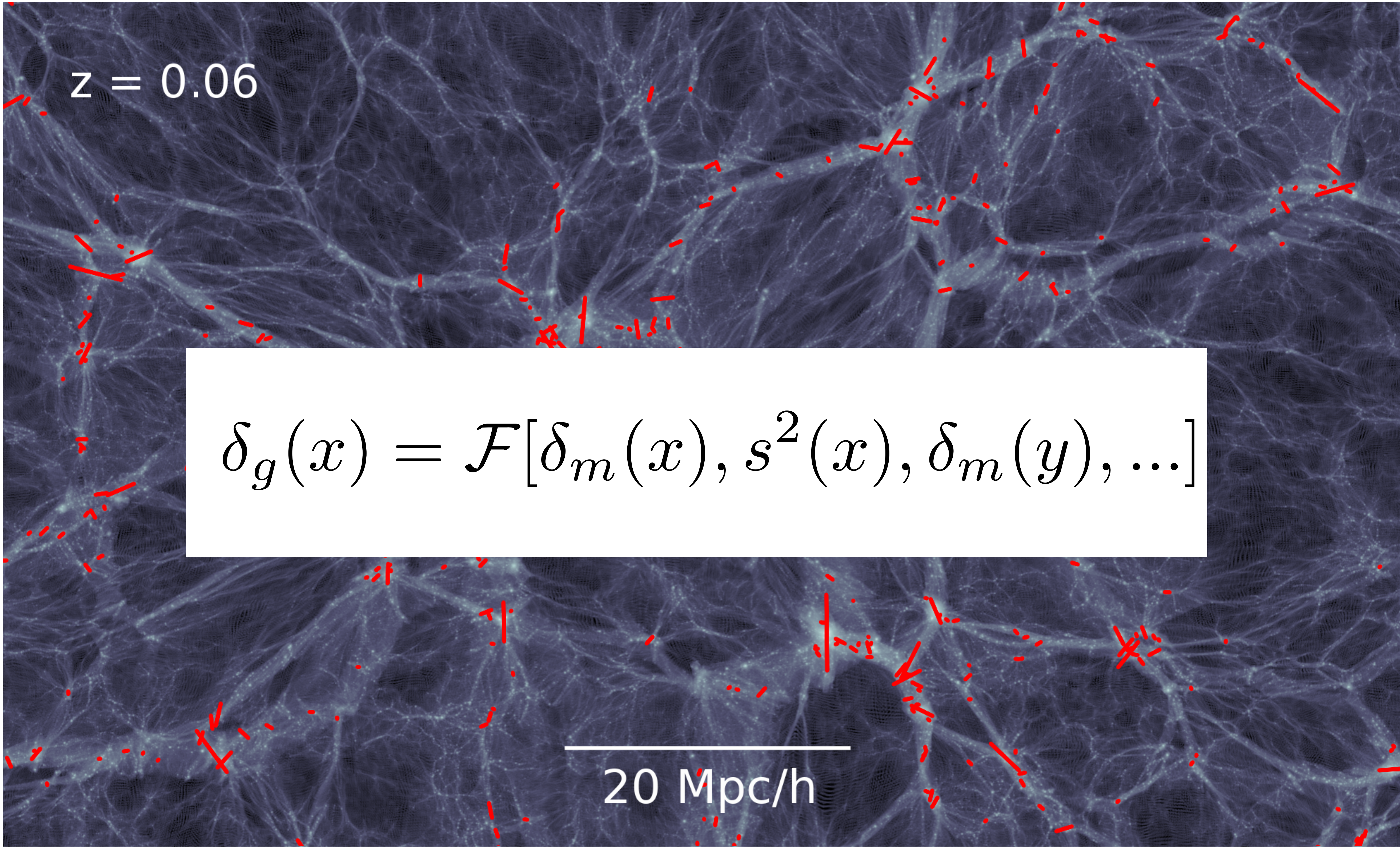
(MassiveBlack II: Khandai+ 2014; Tenneti+ 2014a,b)

Galaxy positions ("bias")



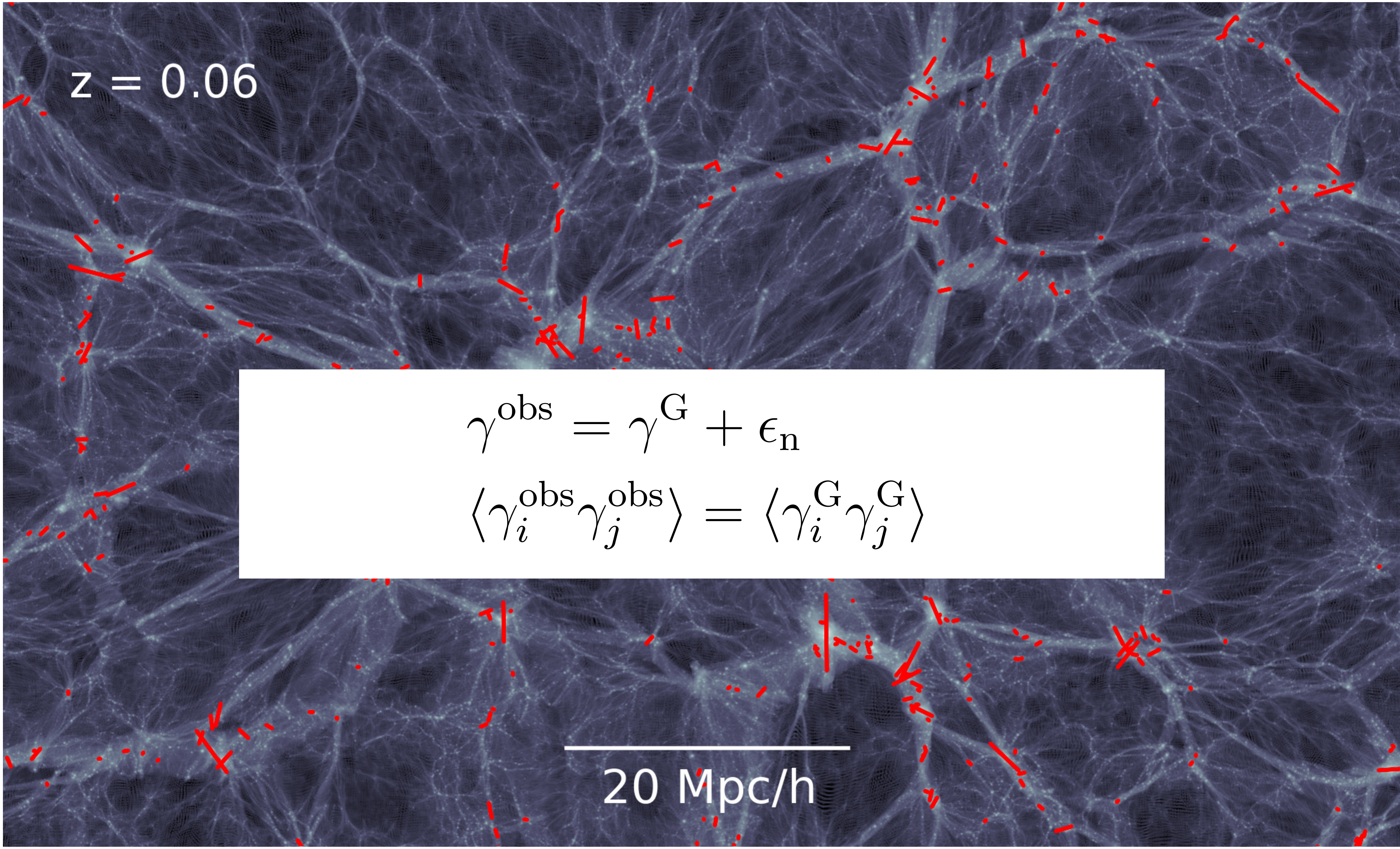
$$\delta_g(x) = b\delta_m(x)$$

Galaxy positions (“bias”)



$$\delta_g(x) = \mathcal{F}[\delta_m(x), s^2(x), \delta_m(y), \ldots]$$

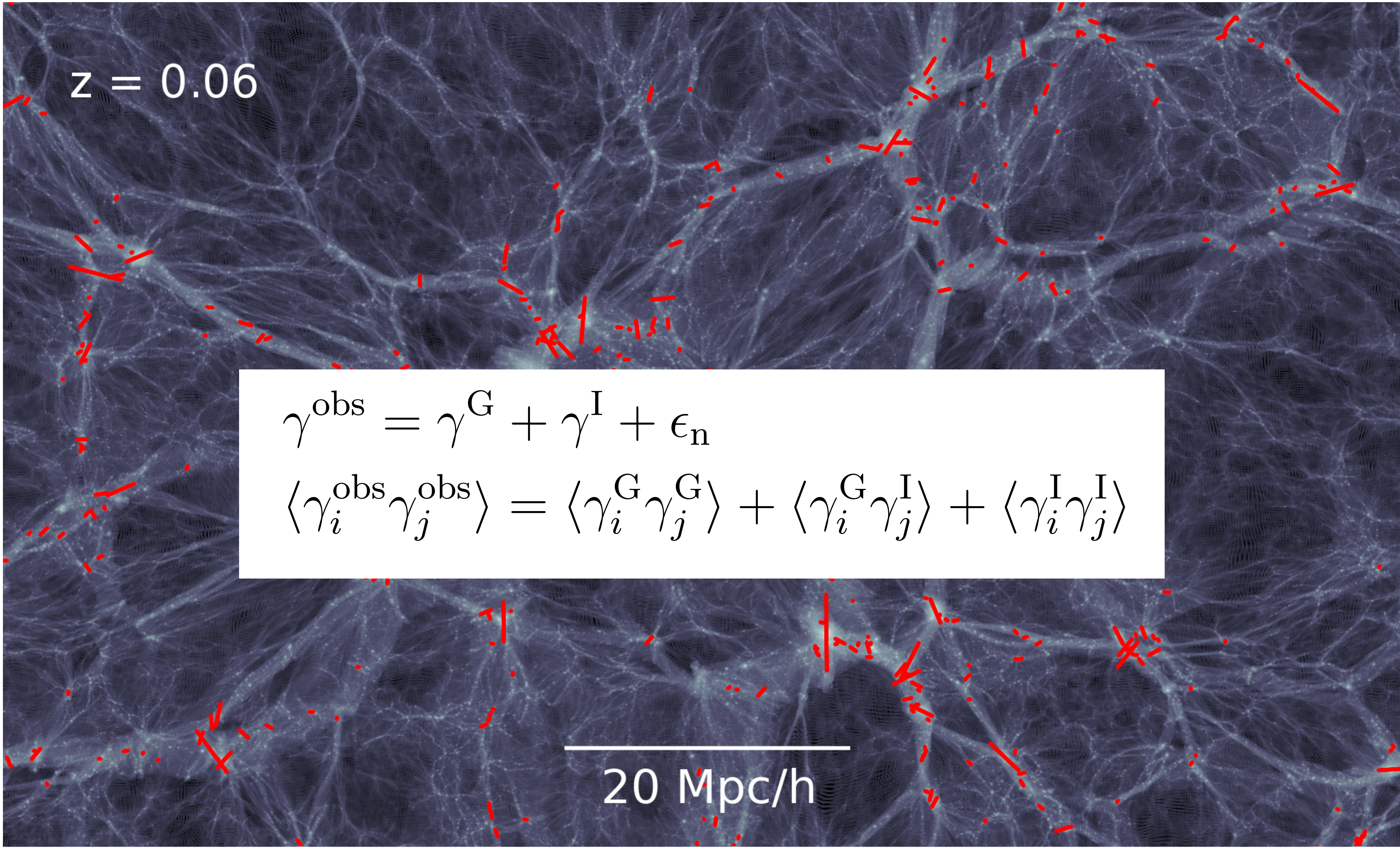
Galaxy shapes (“intrinsic alignments”)



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

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

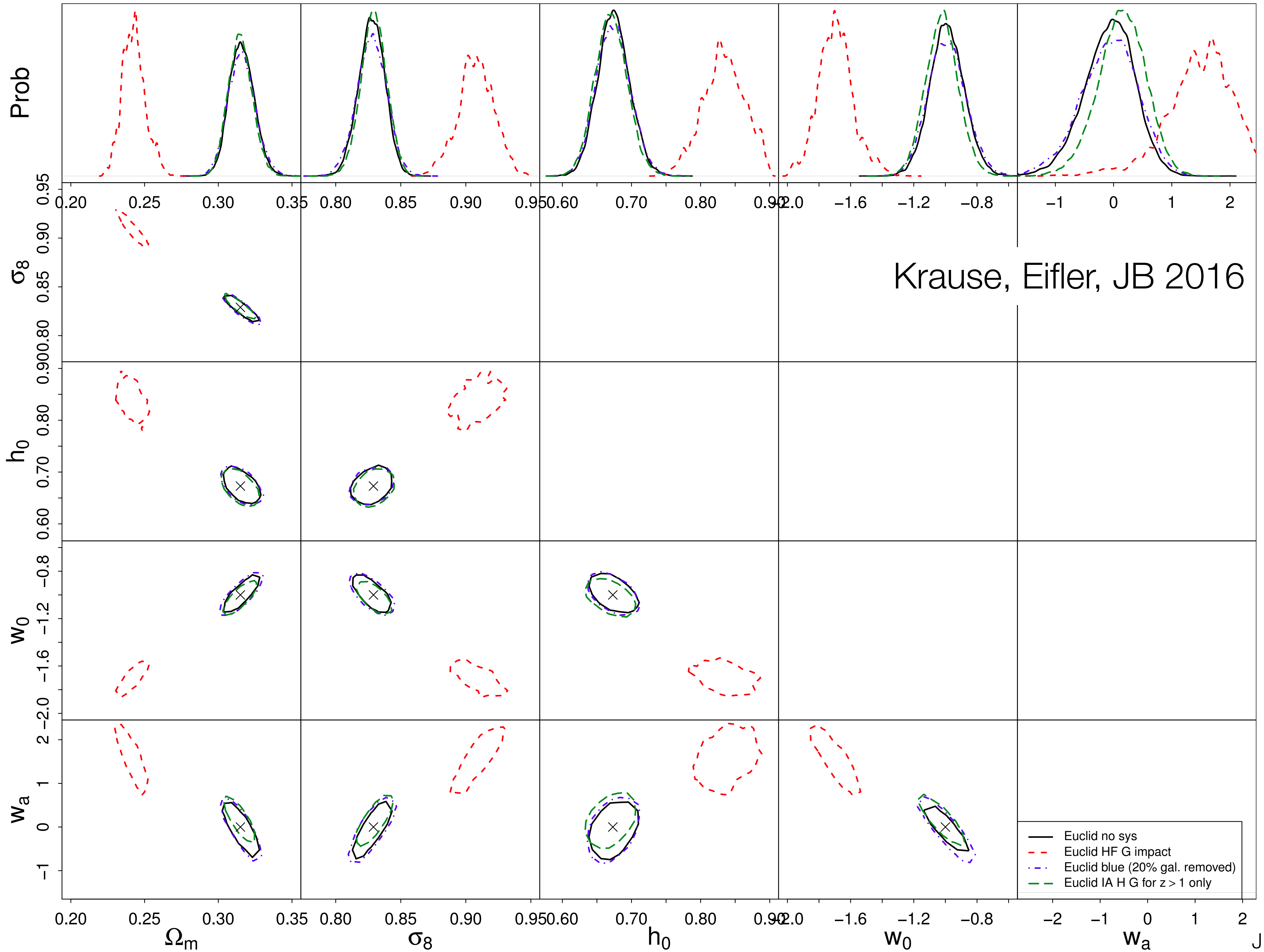
Galaxy shapes ("intrinsic alignments")



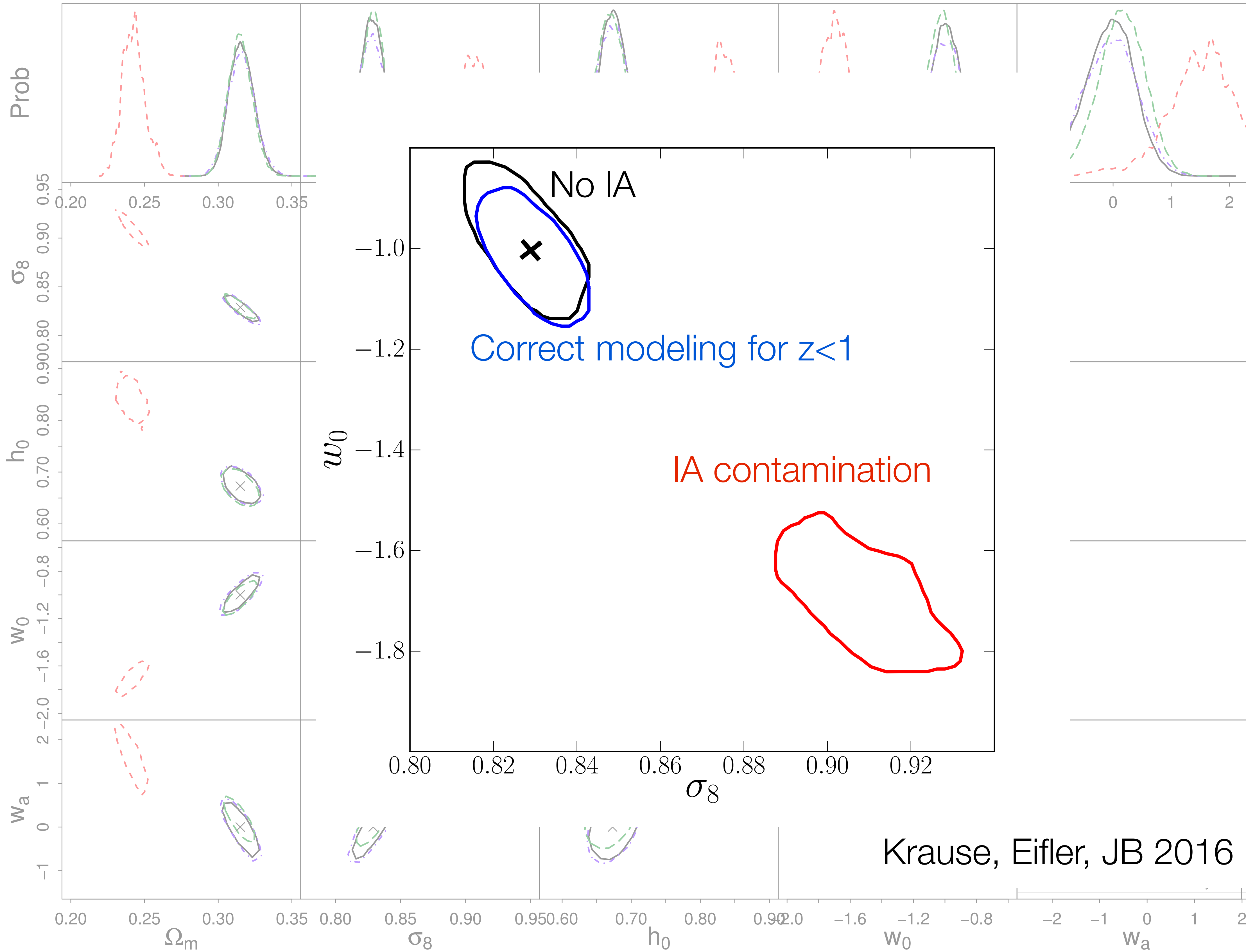
$$\gamma^{\mathrm{obs}} = \gamma^{\mathrm{G}} + \gamma^{\mathrm{I}} + \epsilon_{\mathrm{n}}$$

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

Precision vs accuracy: IA in Euclid

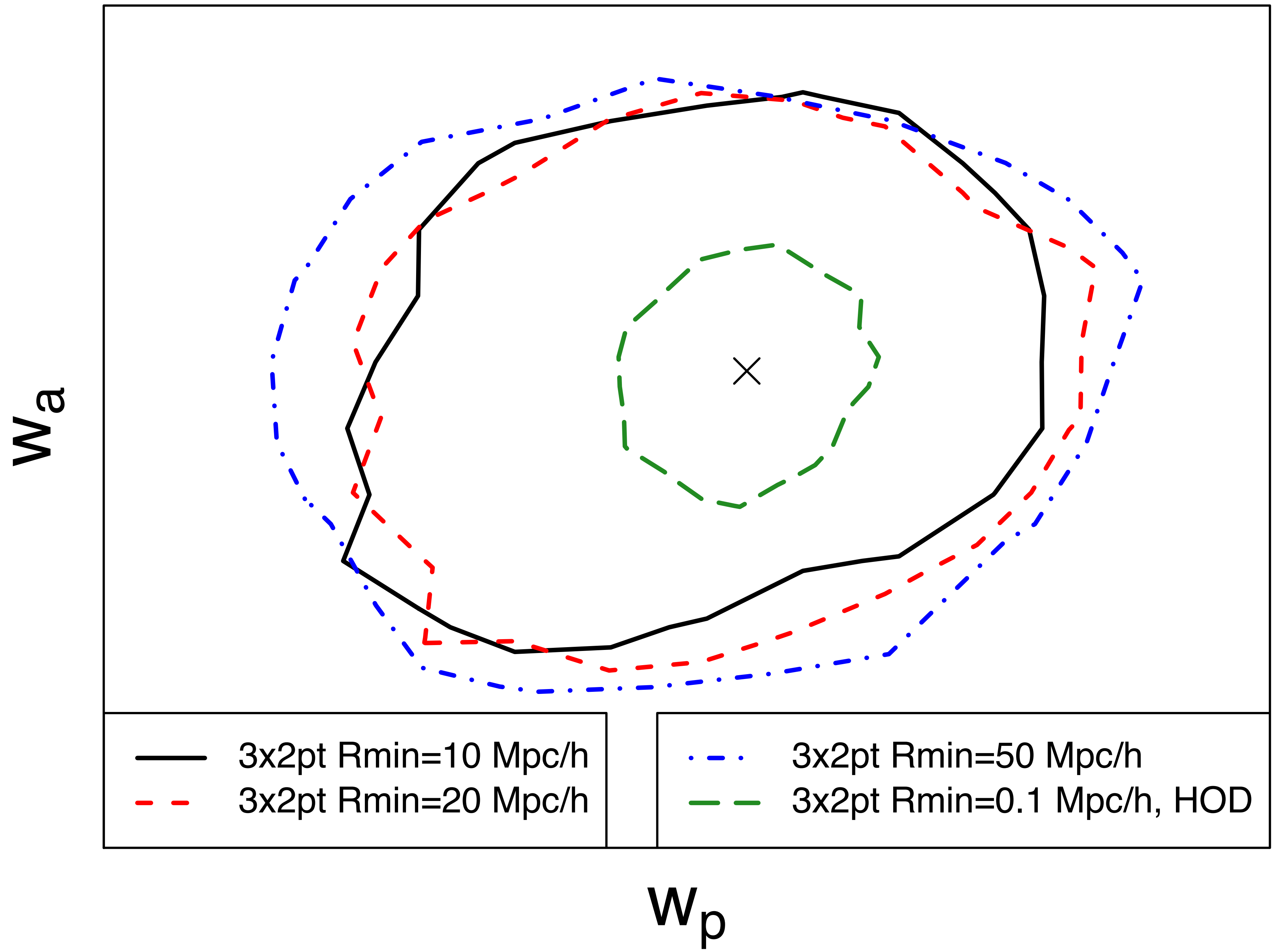


Precision vs accuracy: IA in Euclid



Krause, Eifler, JB 2016

Why go beyond linear theory?



LSST-like forecast: Krause & Eifler 2017

Unified description in effective perturbative expansions

galaxy bias (McDonald & Roy 2009; Assassi+ 2014; Angulo+ 2015; Desjacques, Jeong, Schmidt 2016)

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

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

galaxy intrinsic alignments
(JB+ 2015; Schmidt+ 2015; JB+ 2017 arXiv:1708.09247; Schmitz, Hirata, JB, Krause 2018 arXiv:1805.02649)

- cosmological quantities directly connect to underlying model
- effective parameters receive contributions from small scales
- new probes of large-scale structure and fundamental physics

Power law and FFT methods

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

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

↓

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

↓

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

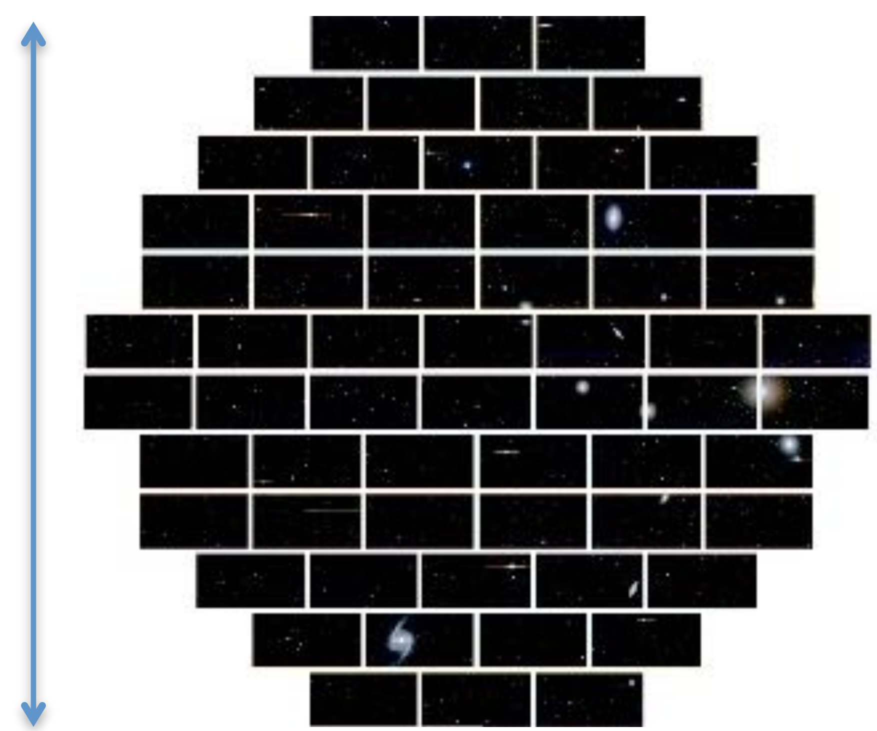
(e.g. **`FFTLog`**: Talman 1978, Hamilton 2000)

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

Dark Energy Survey

- DECam on Blanco Telescope, Cerro Tololo, Chile
- 5000 sq degrees
- 5 year mission
  525 nights (+extension)
- 300 million galaxies
  ($0 < z < 2$)
- overlap with SPT and ACT

2.2 deg



Survey Progress

Results in Aug 2017

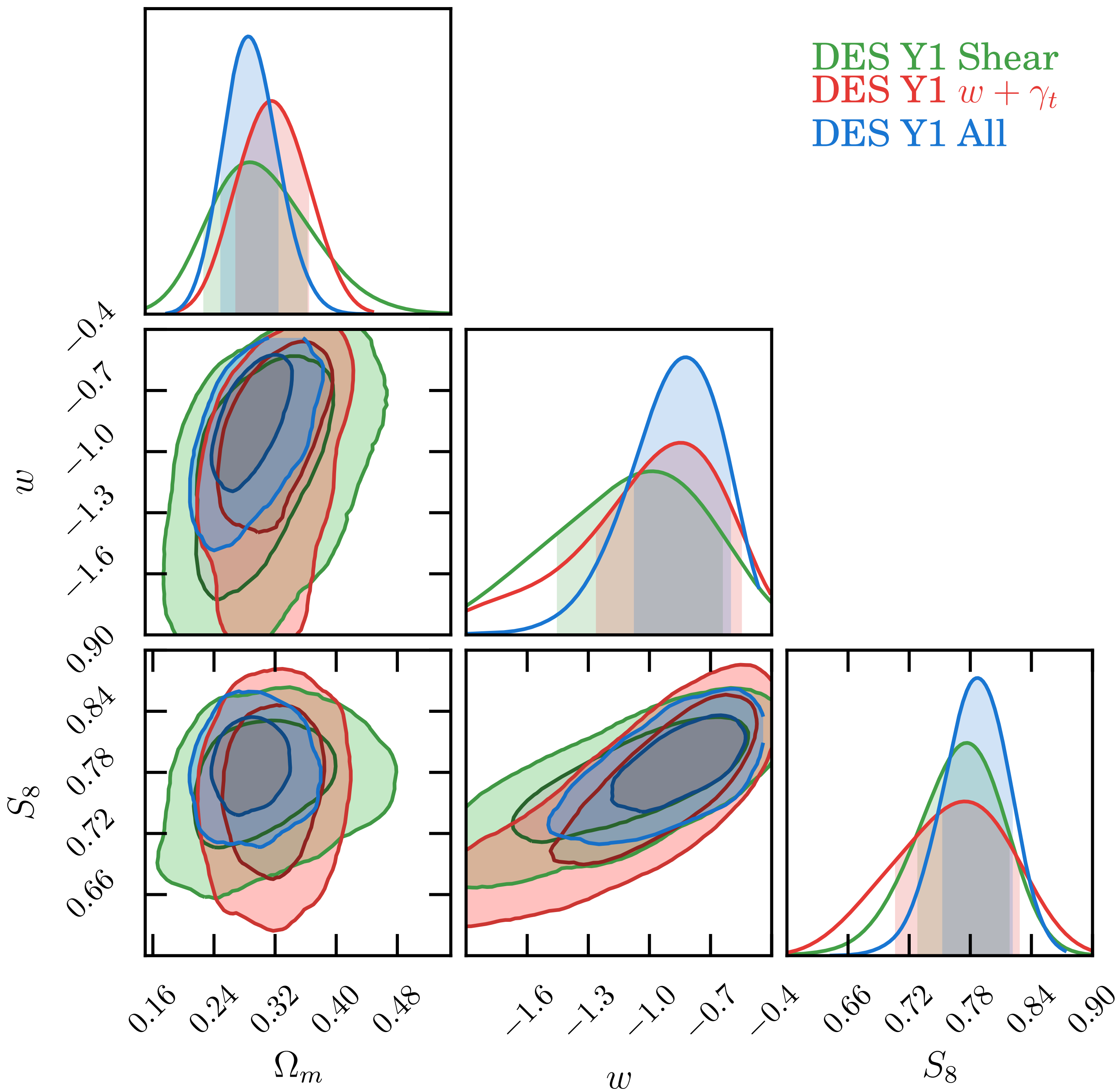
Data taking nearly complete

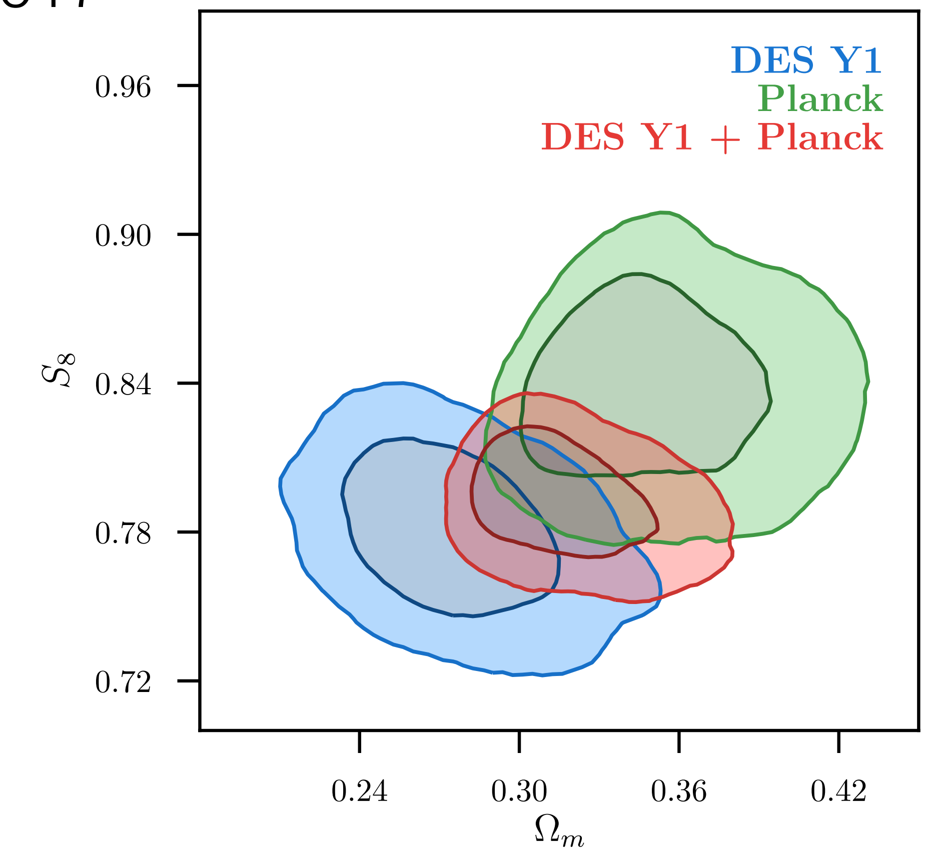
DES Year 1 cosmology papers

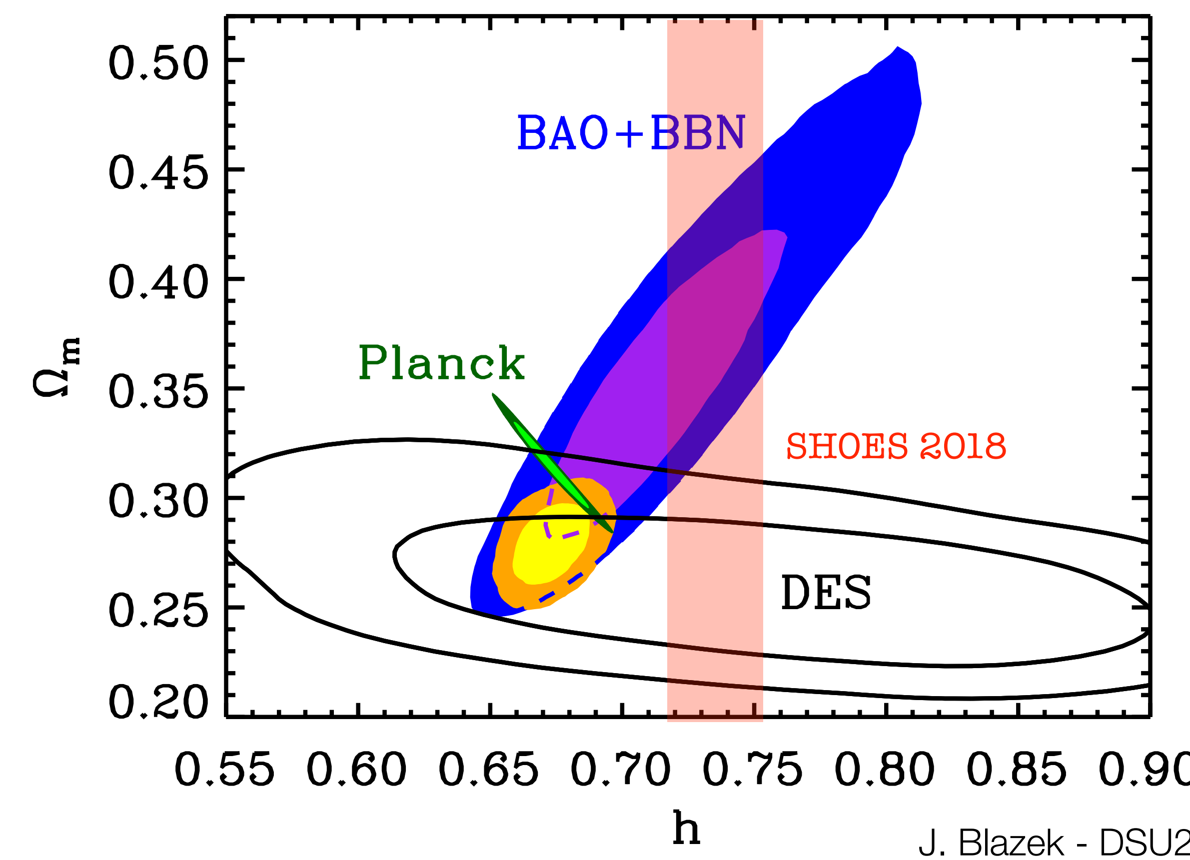
- Galaxy catalog & reduction
- The Y1 shear catalogs
- Cross-correlation redshifts methodology
- Cross-correlation redshifts on Y1 data
- Source redshifts
- redMaGiC redshifts
- Galaxy-galaxy lensing
- Cosmic shear
- Galaxy clustering
- Mass mapping
- Key Project methodology & covariances
- Key Project on simulations
- Key Project Results
- Key Project with CMB lensing

DES Year 1 Results

DES Collaboration 2017







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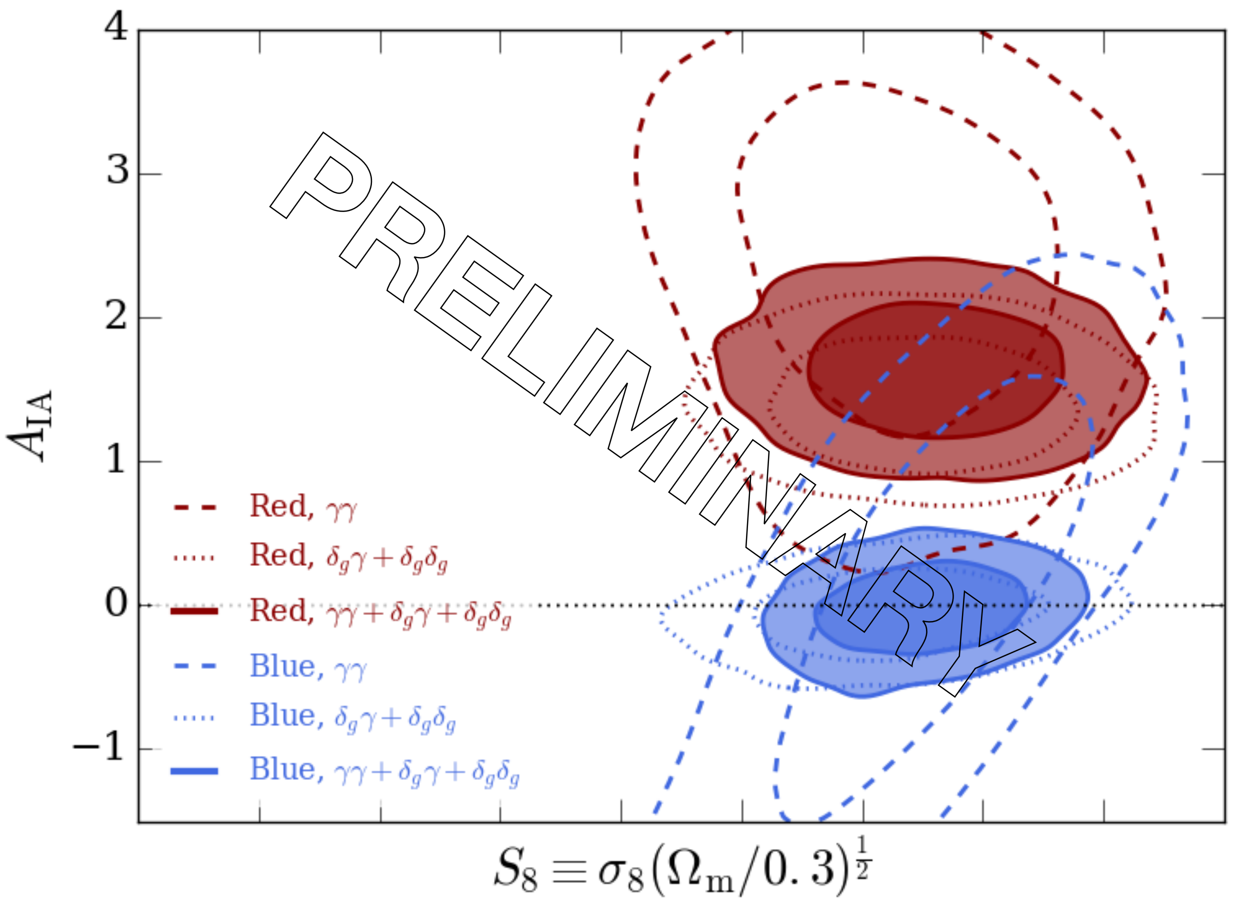
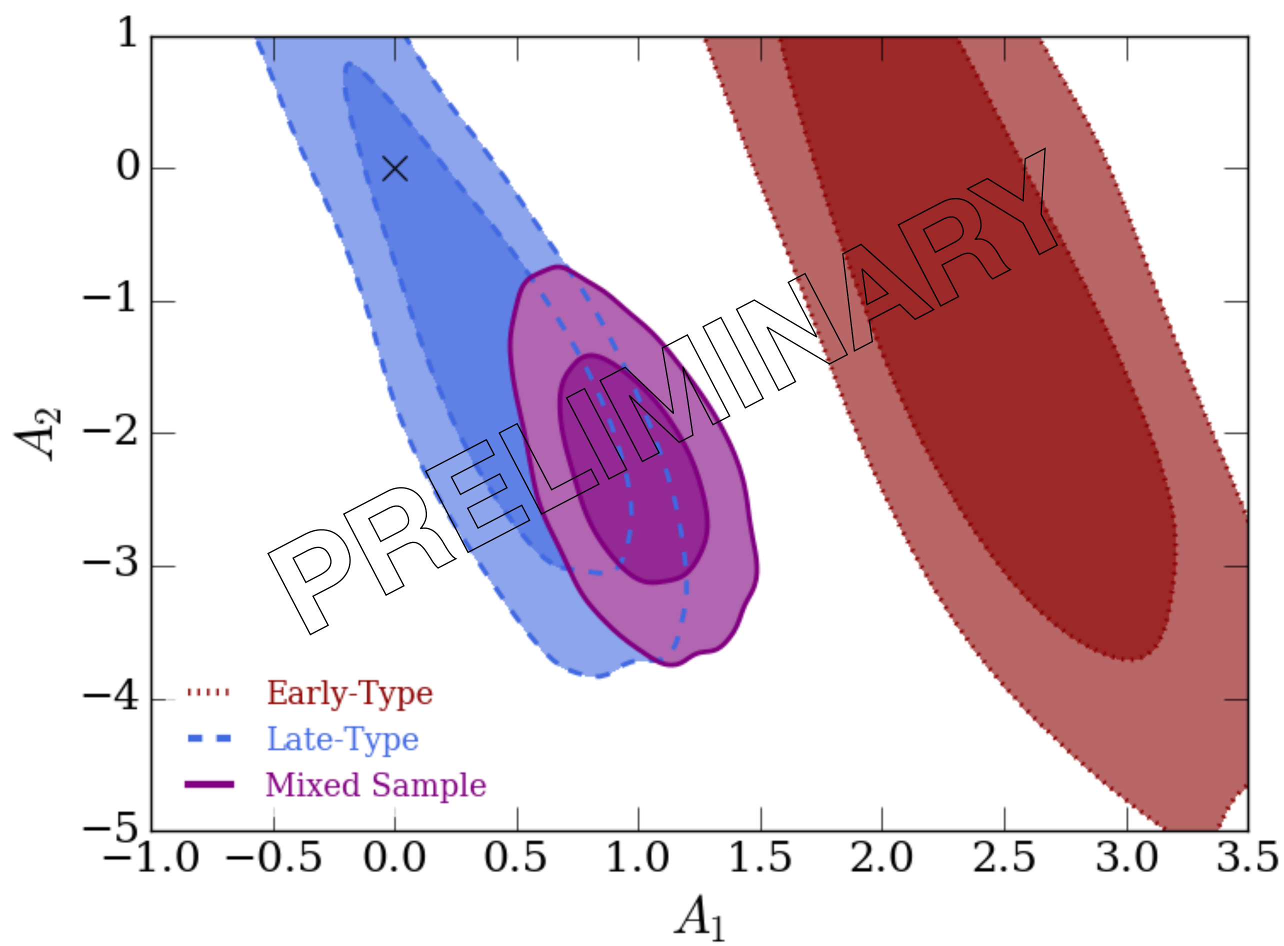
Probing IA with DES

Samuroff, JB + DES Collaboration, in prep.

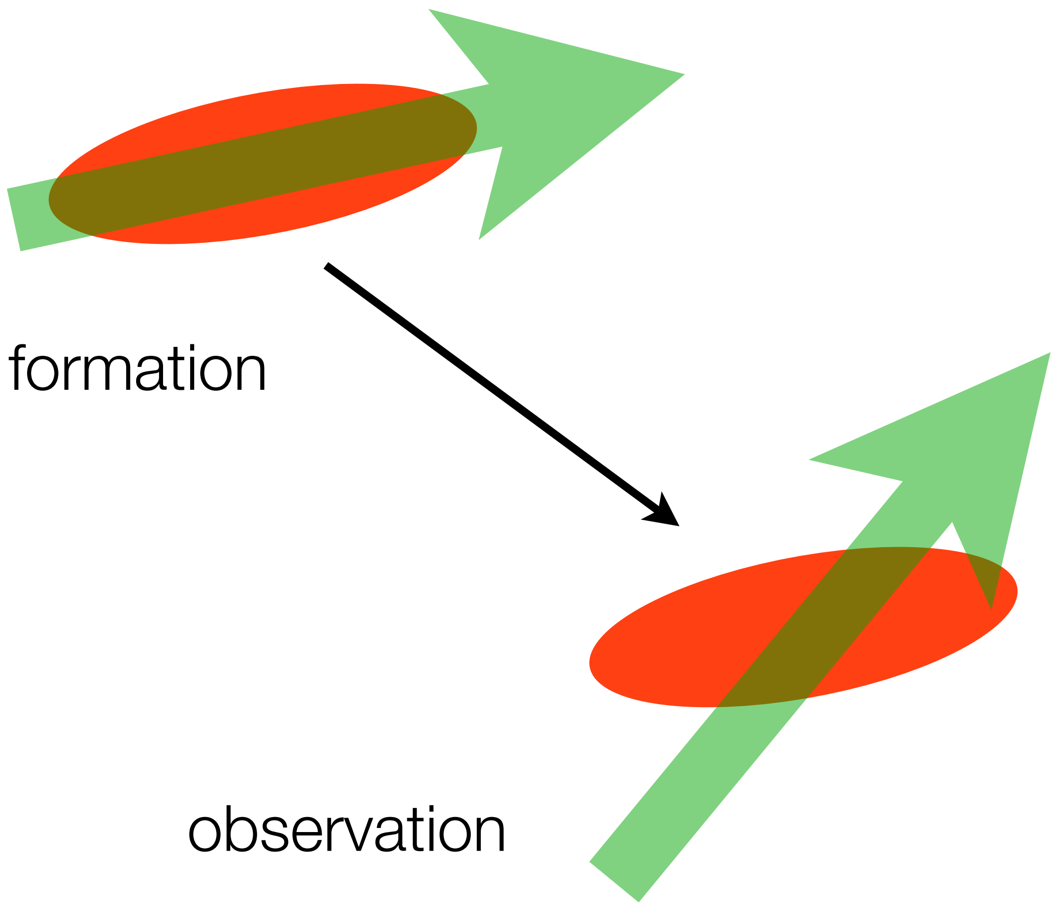


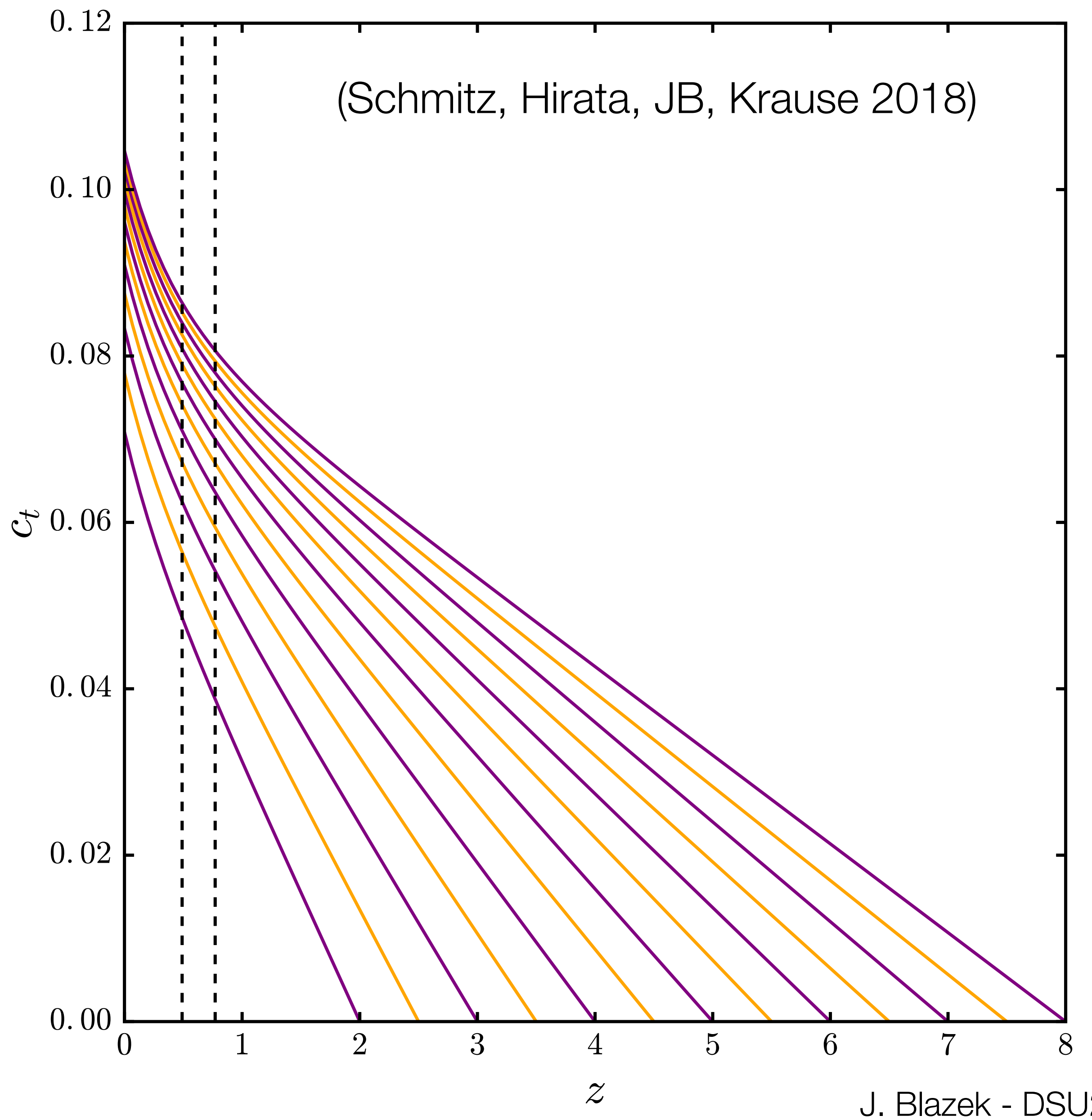


Beyond systematics

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

- Probe of LSS
- Test inflation (e.g. Schmidt+ 2015)
- Modified gravity, LIV dark matter, preferred frame
- **Galaxy formation and evolution**





Summary

- Improved modeling of observables needed for optimal multi-probe cosmological analyses.
- Effective perturbative expansions can be applied to galaxy biasing and IA, providing systematics control and novel probes of fundamental physics.
- Can we introduce parameters without losing too much information? Informative priors from sims or observations?
- DES Y1 results demonstrate methods - we are learning! Y3 analyses underway. We are preparing for the next-generation of surveys (LSST, Euclid, DESI, WFIRST, …).