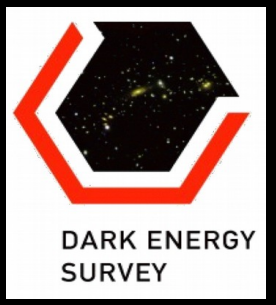
Tunnel vision:
Weak lensing by galaxy troughs

Daniel Gruen

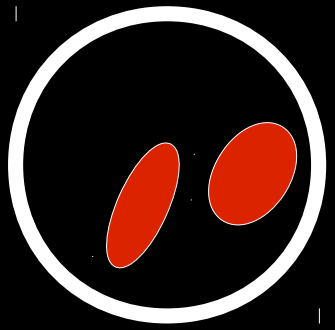


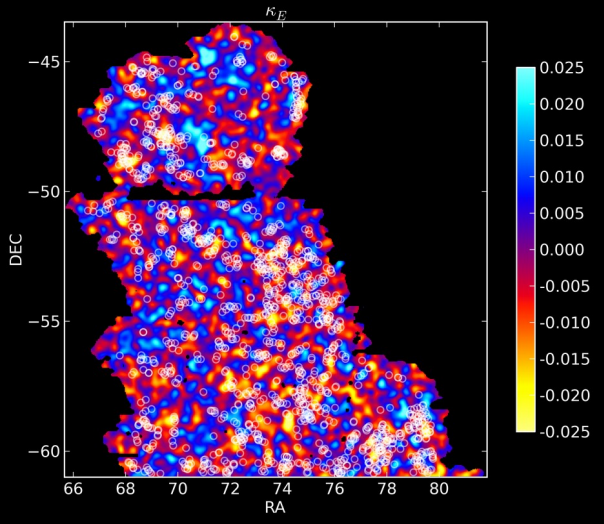
with Oliver Friedrich, Bhuvnesh Jain, Annalisa Mana, Eduardo Rozo, Eli Rykoff, Stella Seitz, Vinu Vikram, and the DES Collaboration

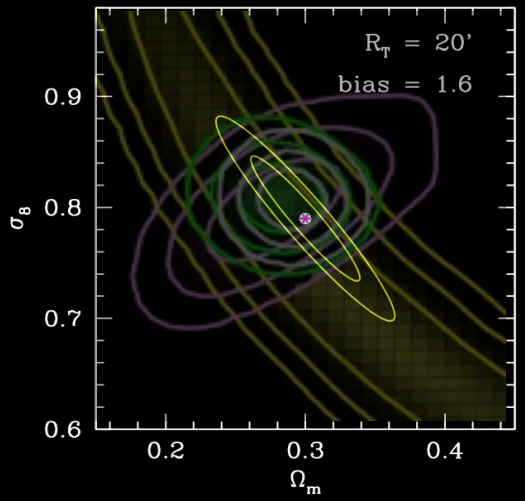
MPA Cosmology Seminar, Nov 10 2015

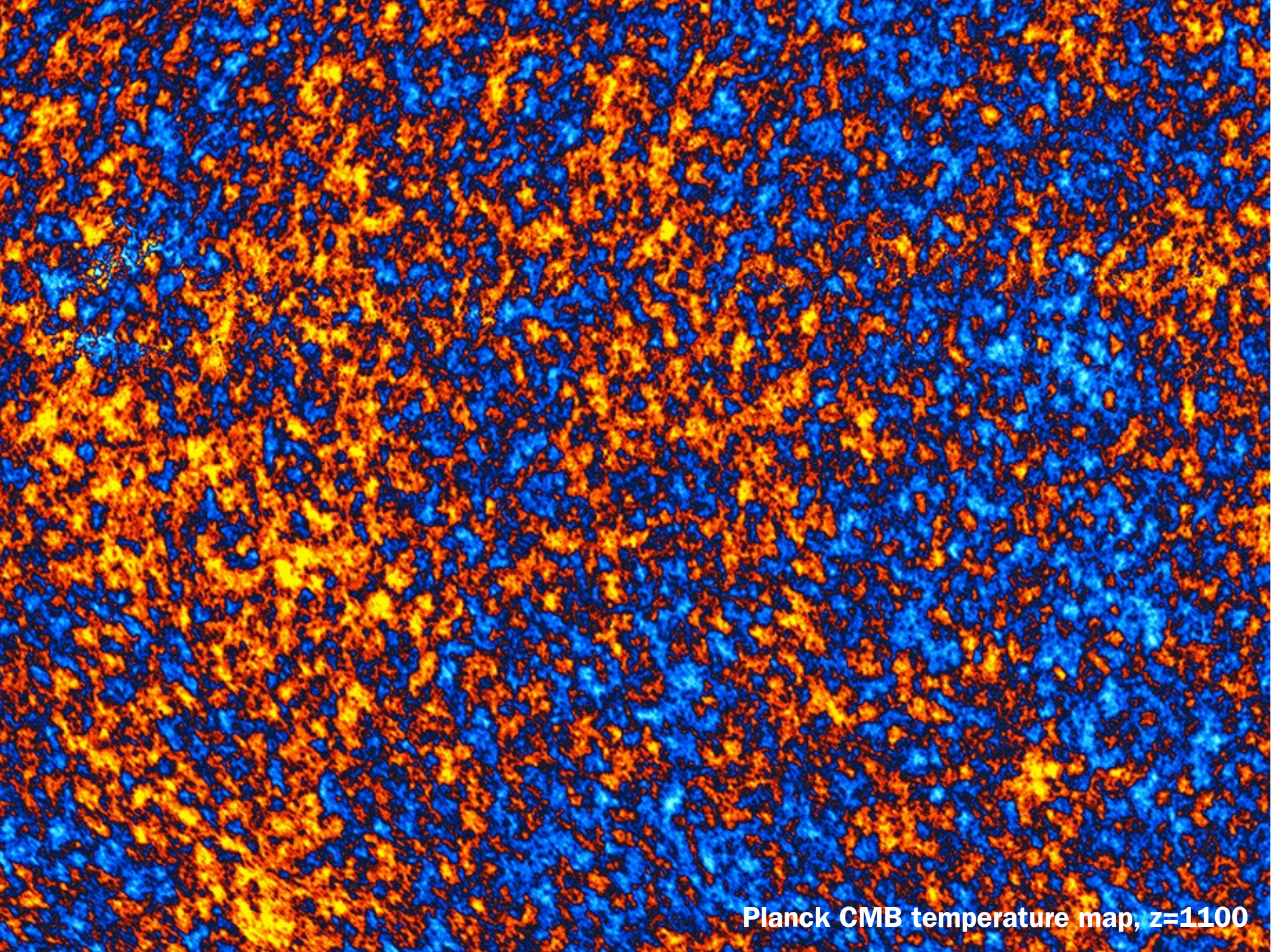
Structure

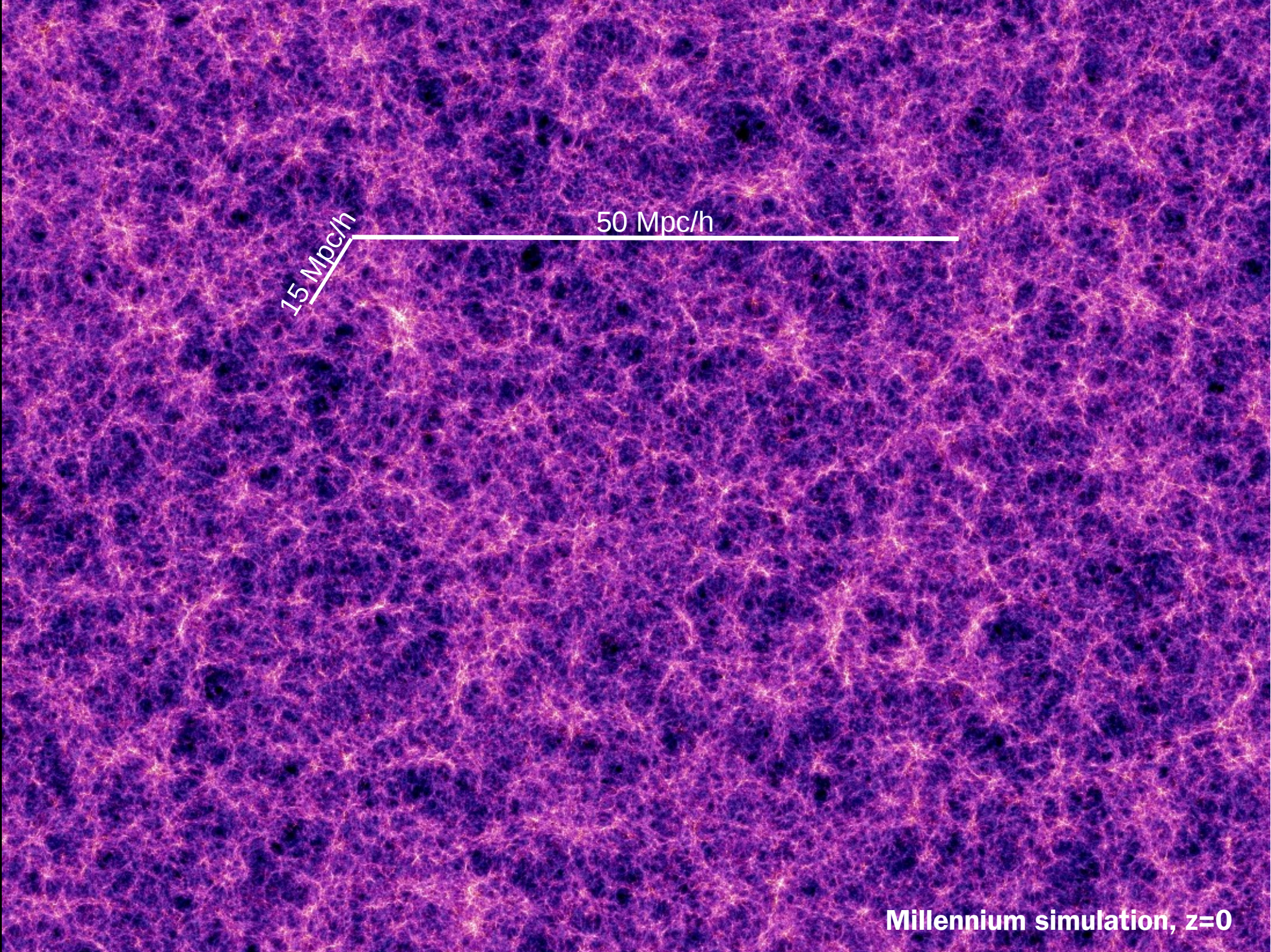
- Introduction
- Theory & Measurement
- Outlook



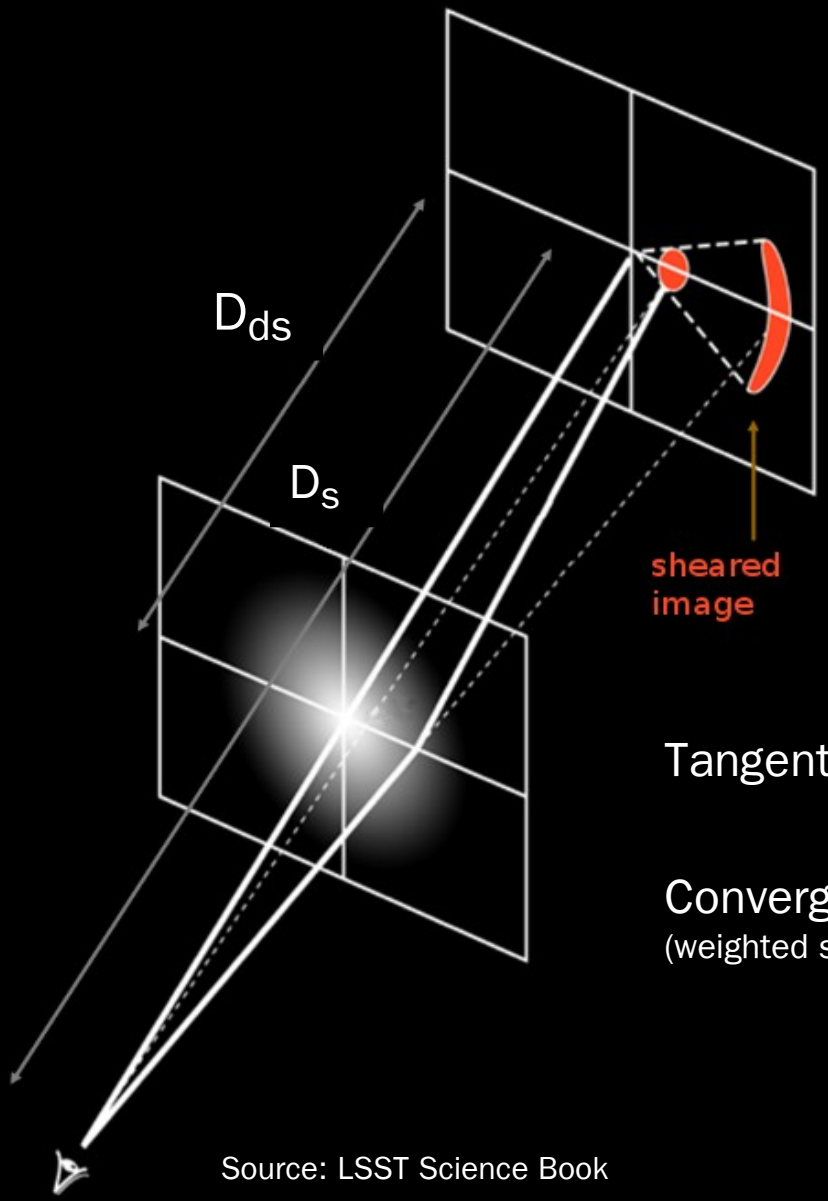





Planck CMB temperature map, z=1100


50 Mpc/h
15 Mpc/h
Millennium simulation, z=0

Weak Lensing



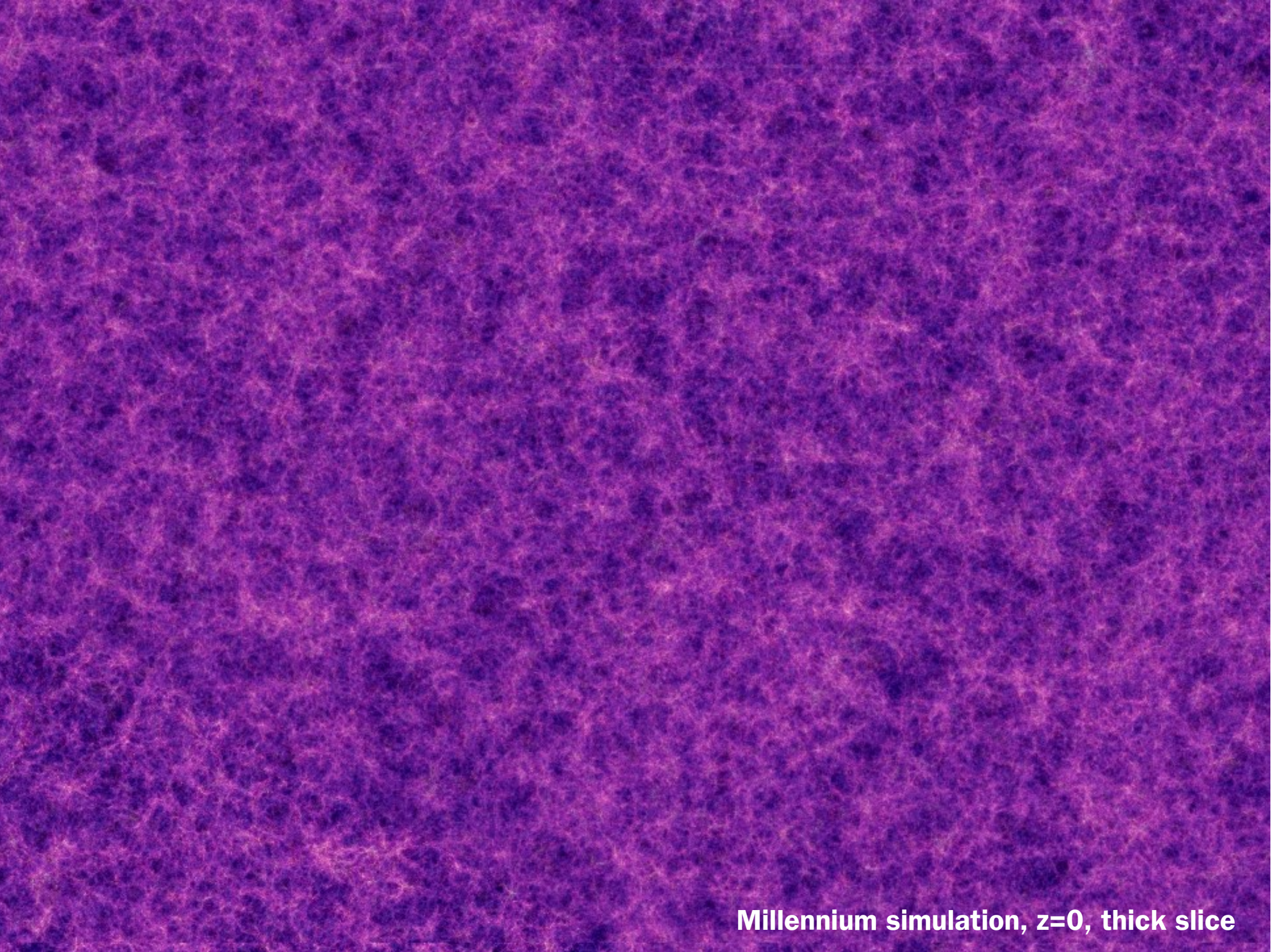
Source: LSST Science Book

- Matter inhomogeneities (also dark) bend metric (and therefore light rays)
- Weak effect: ~% distortion
- Tangential distortion $\propto$ overdensity

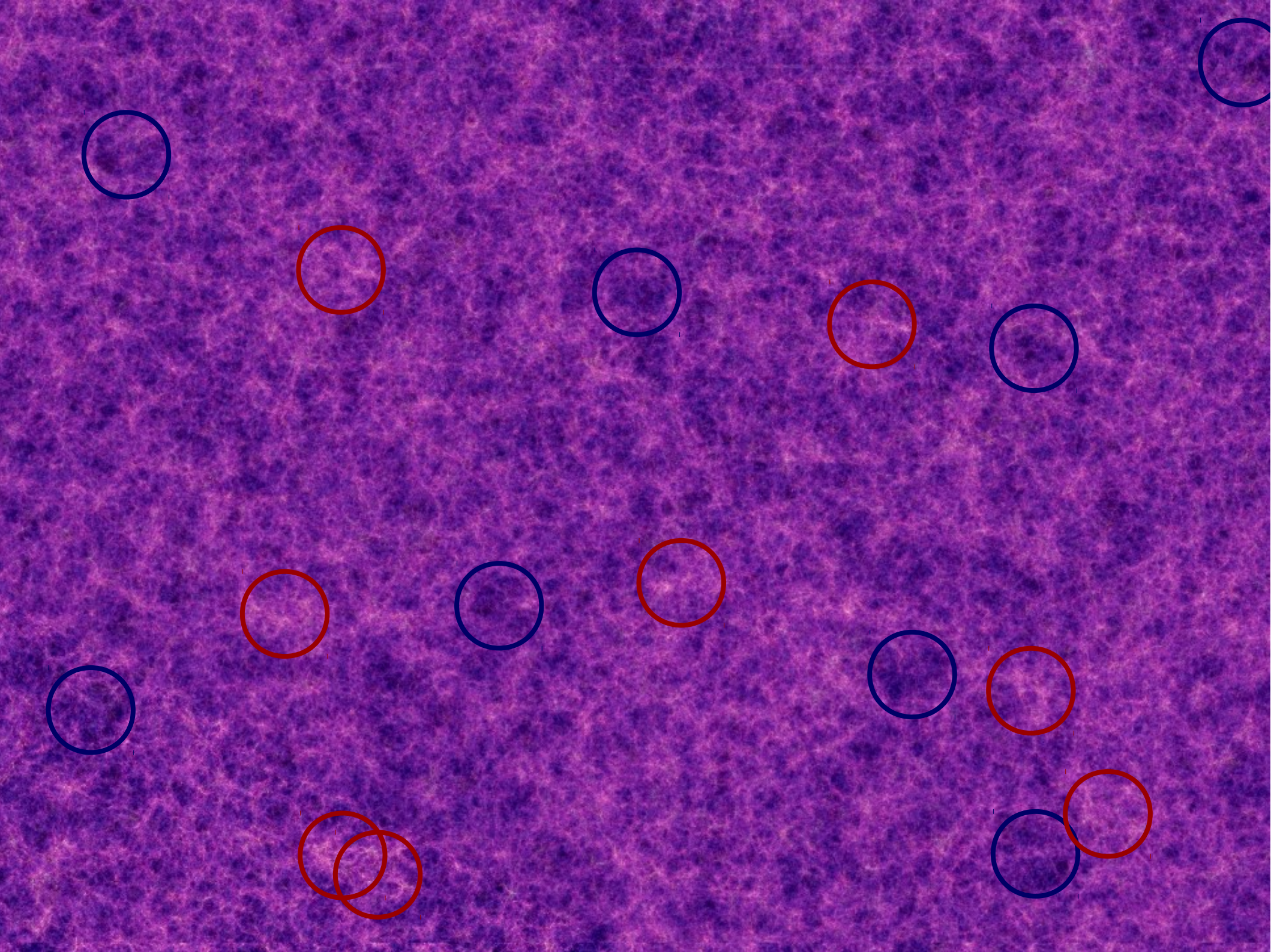
Tangential shear $\gamma_t(\theta) = \langle\kappa(\theta')\rangle_{\theta'<\theta} - \kappa(\theta)$

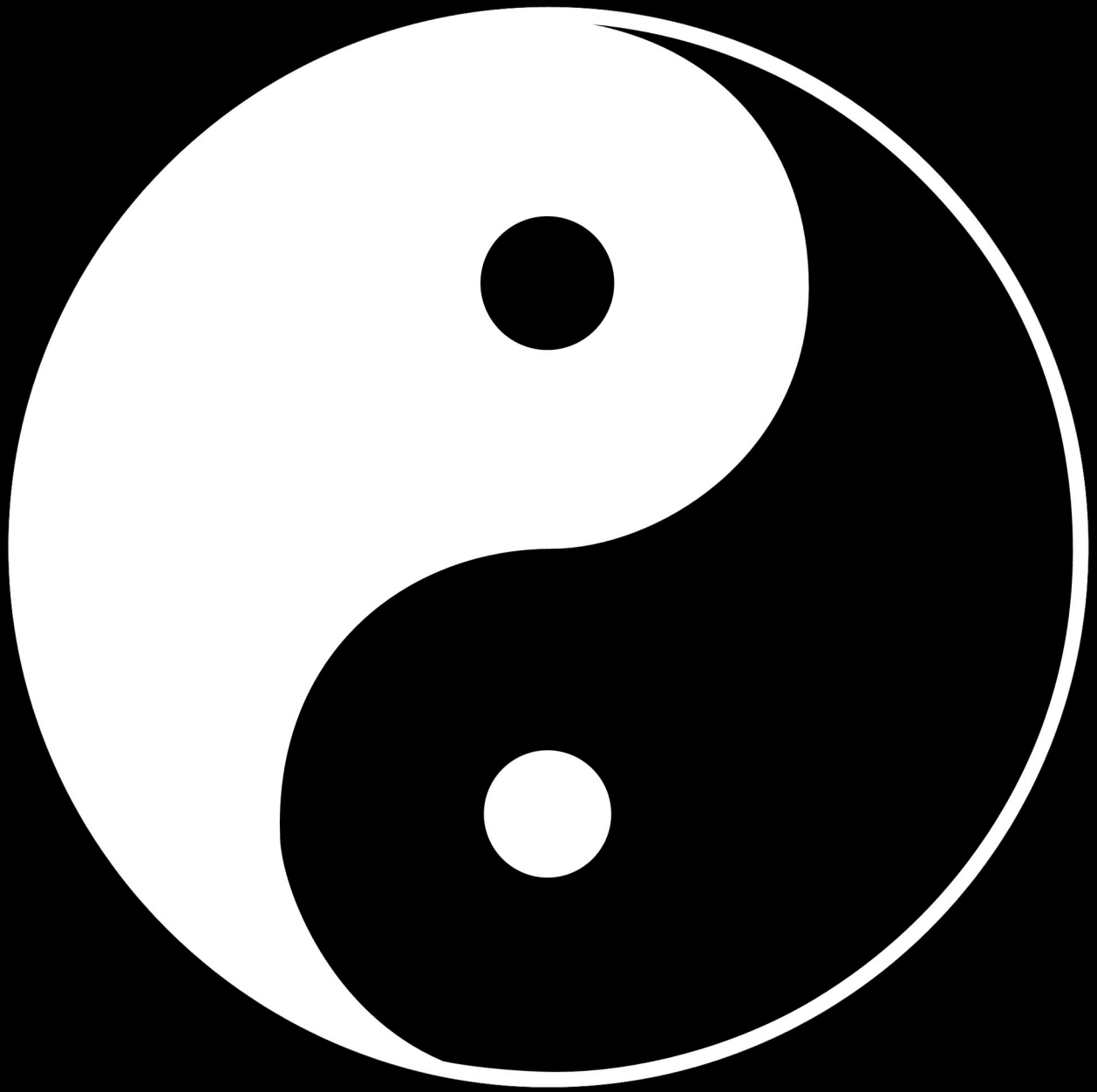
Convergence (weighted surface mass density) $\kappa = \Sigma / \left[\frac{c^2}{4\pi G}\frac{D_s}{D_d D_{ds}}\right]$

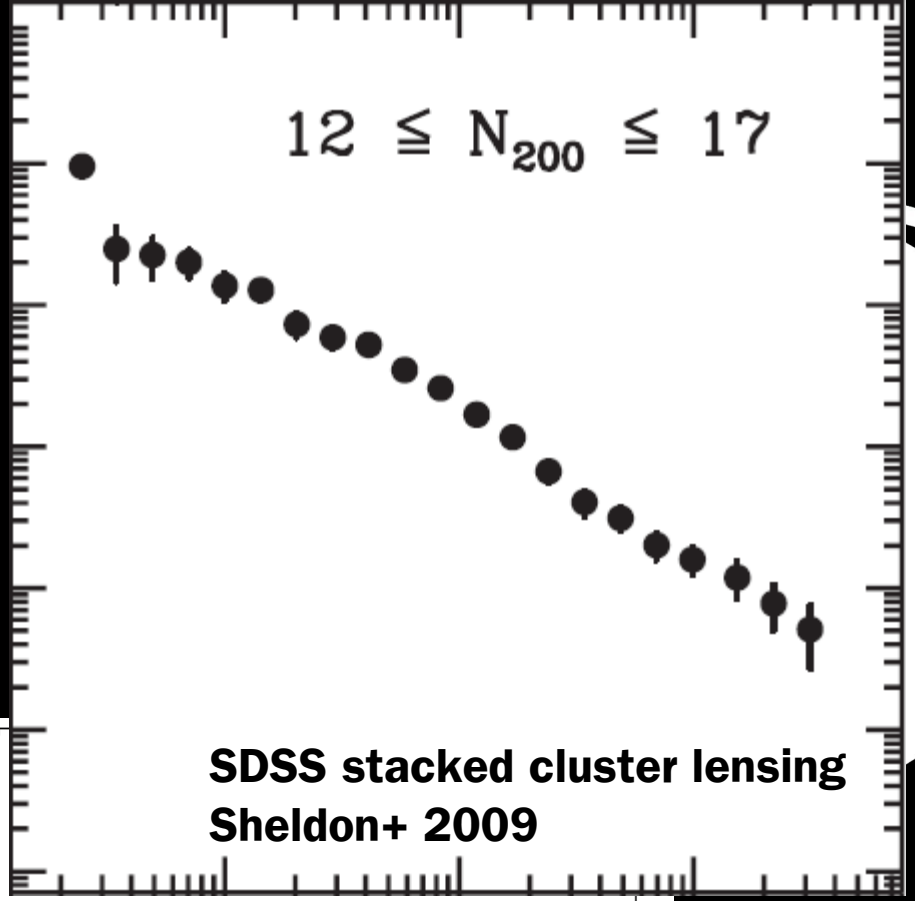
- broad lens z dependence: this is little more than 2D



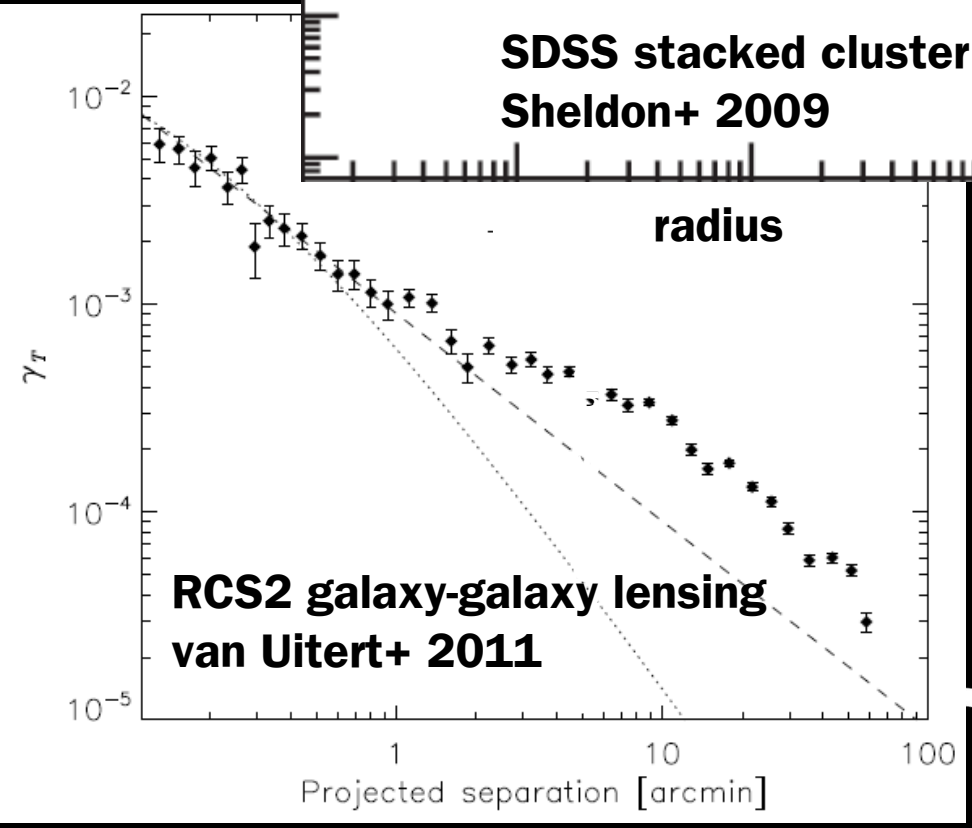
Millennium simulation, z=0, thick slice



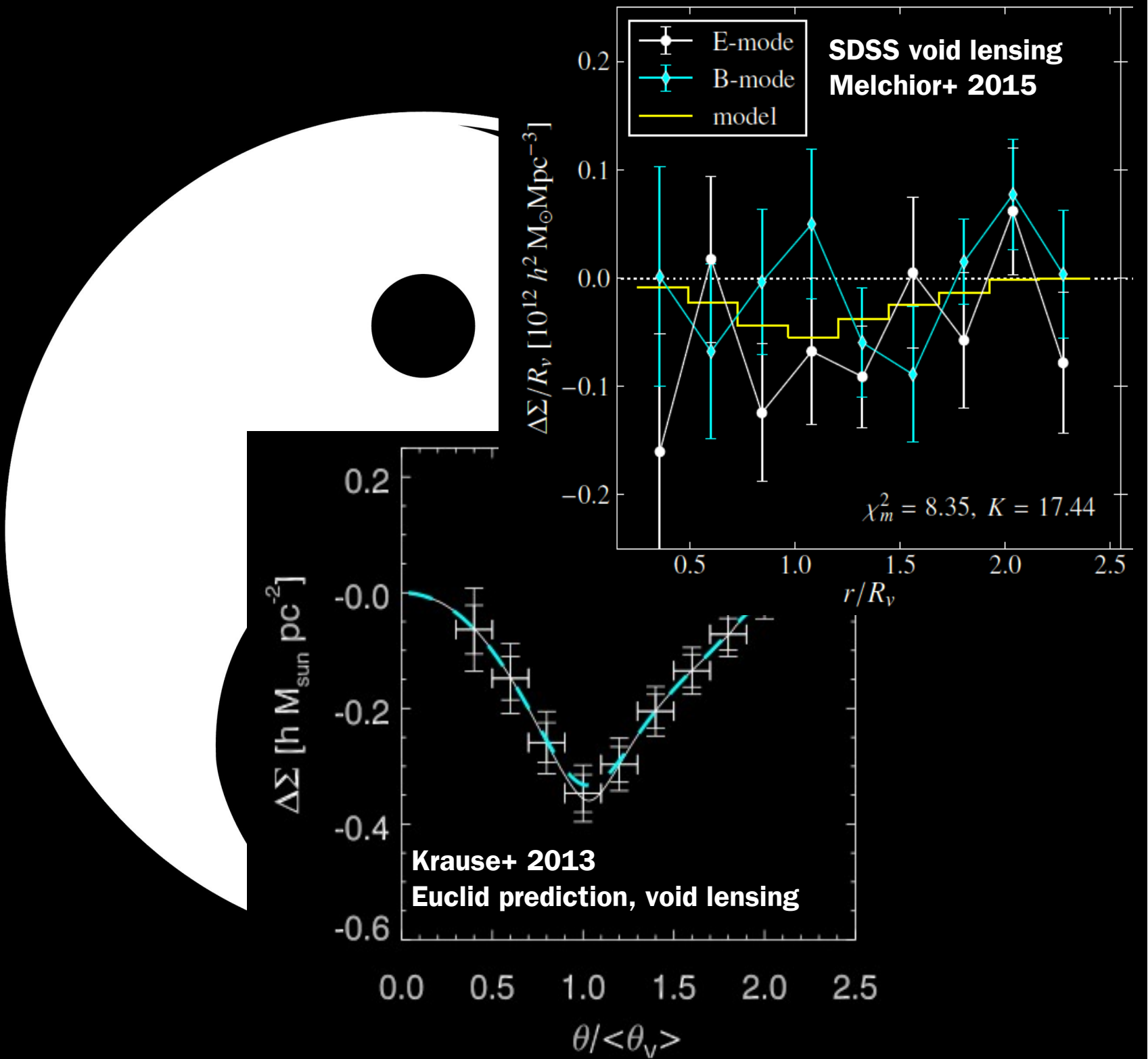




SDSS stacked cluster lensing
Sheldon+ 2009



RCS2 galaxy-galaxy lensing
van Uitert+ 2011


E-mode
B-mode
model
SDSS void lensing
Melchior+ 2015
$\Delta\Sigma/R_v$ [$10^{12}\,h^2\,M_\odot Mpc^{-3}$]
$\chi^2_m = 8.35,\ K = 17.44$
r/R_v
$\Delta\Sigma$ [h M_{sun} pc^{-2}]
Krause+ 2013
Euclid prediction, void lensing
$\theta/<\theta_v>$

Matter density

$$\delta(\chi) = \frac{\rho(\chi)}{\langle\rho\rangle} - 1$$

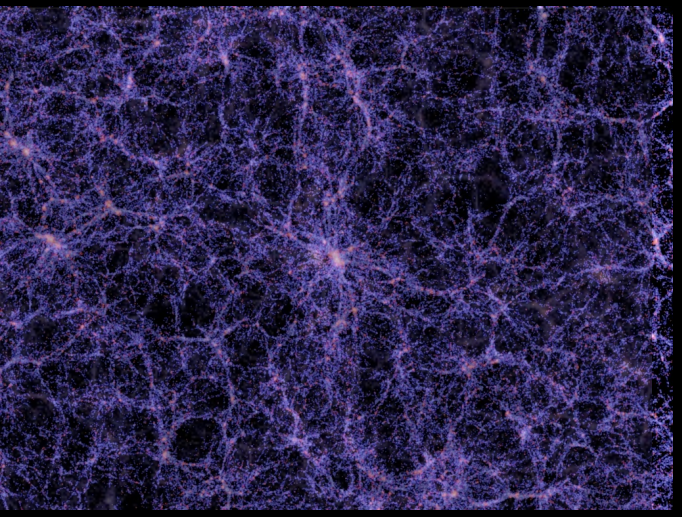
- not observable

Galaxy field

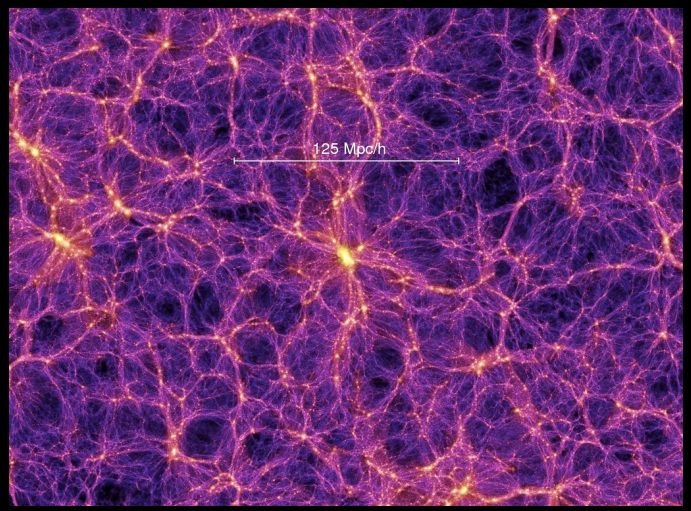
- high S/N
- sparse
- modelling issues w.r.t. matter field
- z direction difficult

Convergence κ

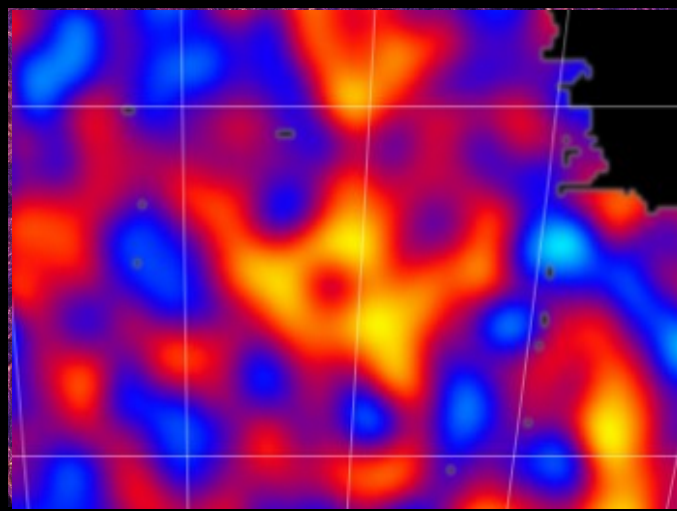
- low S/N
- projected only
- simple connection to matter field
- extra gravity test



Millennium galaxies + blur



Millennium dark matter



DES κ map, Vikram++ 2015

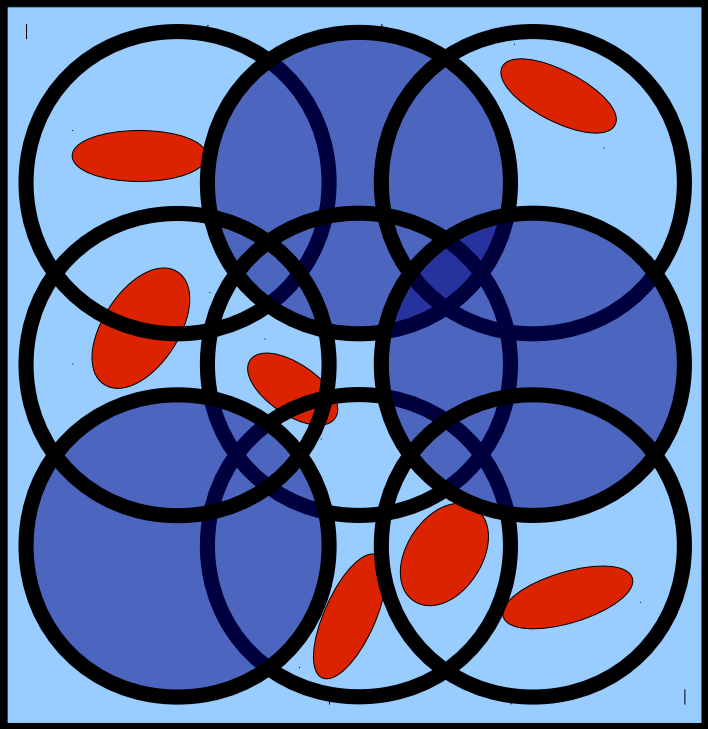
Galaxy troughs

- Trough: (long) cylinder* with galaxy count below some threshold
- Goals: statistics of matter field around underdense lines of sight

\+ easy to find in photo-z, high S/N of lensing due to suppression of LSS noise,

\+ new way of probing structure and gravity

– not actual individual physical entities



Theory & Measurement

DG, Oliver Friedrich, Bhuvnesh Jain, Annalisa Mana, Eduardo Rozo,
Eli Rykoff, Stella Seitz, Vinu Vikram++, arXiv:1507.05090

Theory: galaxy count to lensing κ

Galaxy count N in trough

$$p(N|\delta_T) = \frac{1}{N!}\left(\bar{N}\left[1+b\delta_T\right]\right)^N \exp\left(-\bar{N}\left[1+b\delta_T\right]\right)$$

$$\langle\delta_T|N\rangle = \int_{-1}^{\infty} \mathrm{d}\delta_T \; \delta_T \; \frac{p(N|\delta_T)\, p(\delta_T)}{P(N)}$$

Matter contrast δ_T in trough

$$C_{\kappa,\Sigma}(\ell) = \int_0^{\infty} \mathrm{d}w \; \frac{q_1(w)\, q_2(w)}{w^2} \; P_\delta\left(\frac{\ell}{w}, w\right)$$

Convergence κ / shear g_t around trough

Oliver Friedrich

Theory: prediction

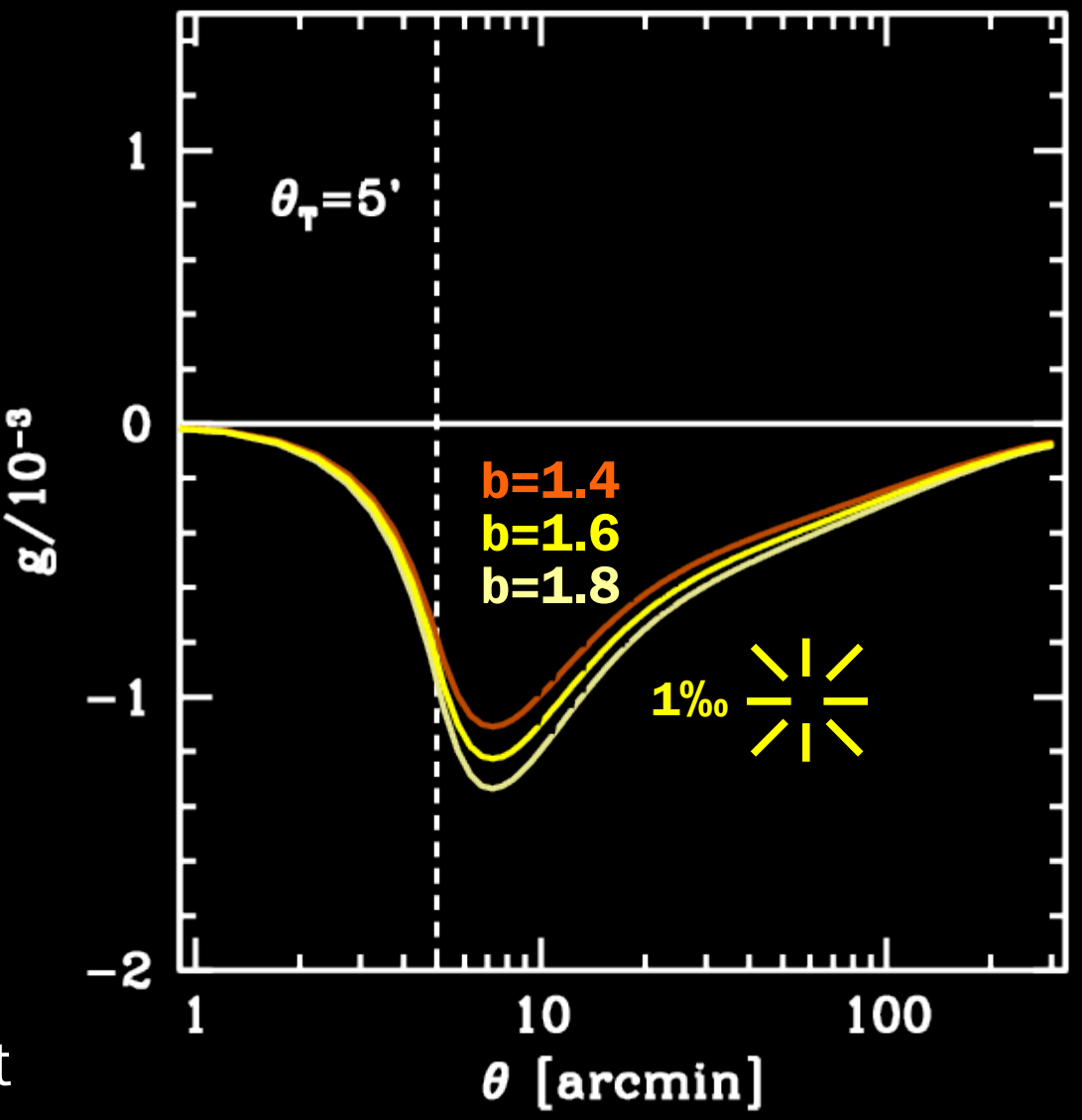
Galaxy count N

↓

Matter contrast δ_T

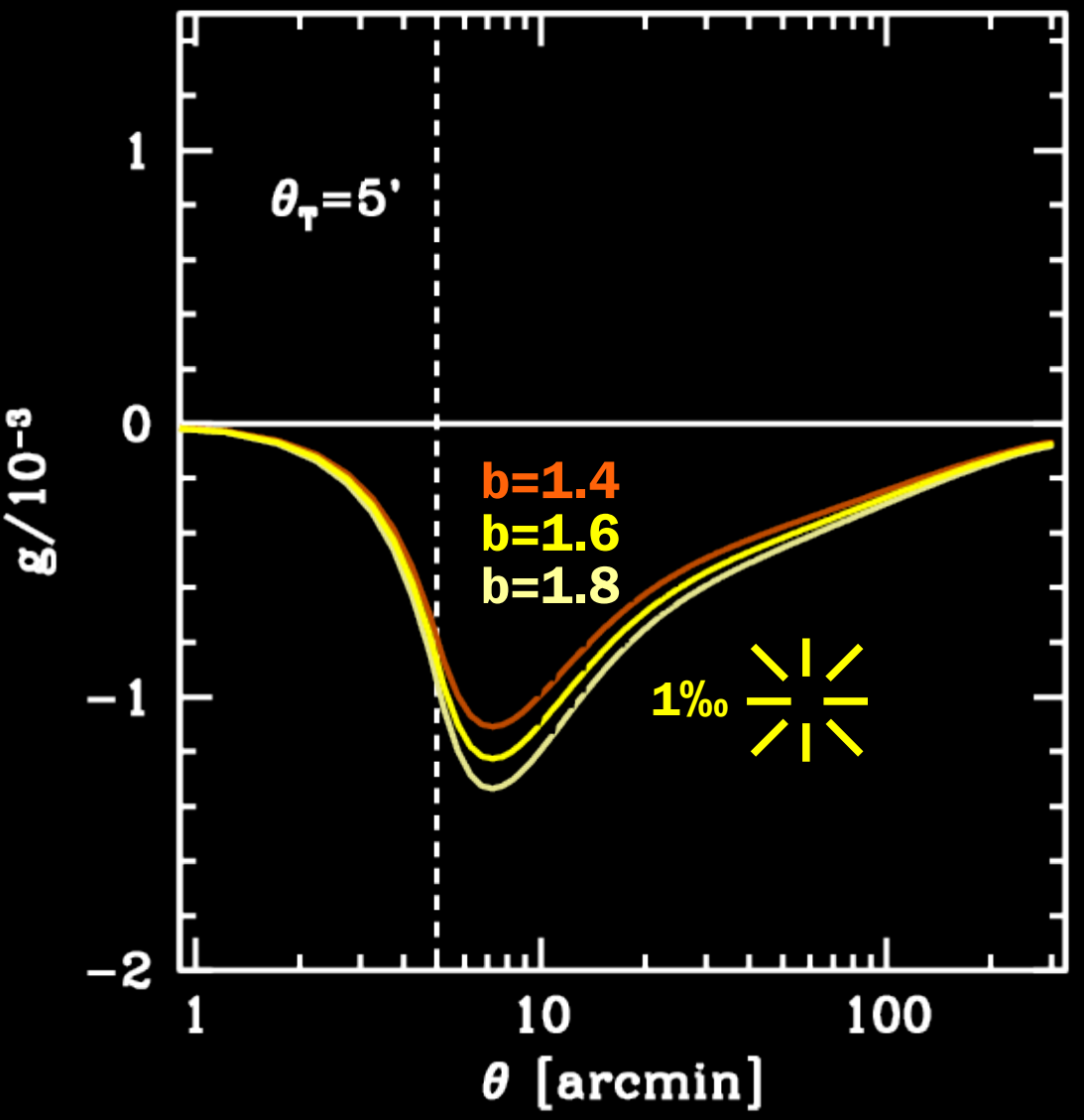
↓

Convergence κ / shear g_t



Measurement

- DES Science Verification: ~150 sq. deg, grizY, full DES depth
- tracers: Rykoff/Rozo redMaGiC galaxies, 0.2<z<0.5, L>0.5L*, 1/[1000 Mpc^3]
- troughs = lower 20th percentile in galaxy count
- sources:~2x10^6 at z>0.6



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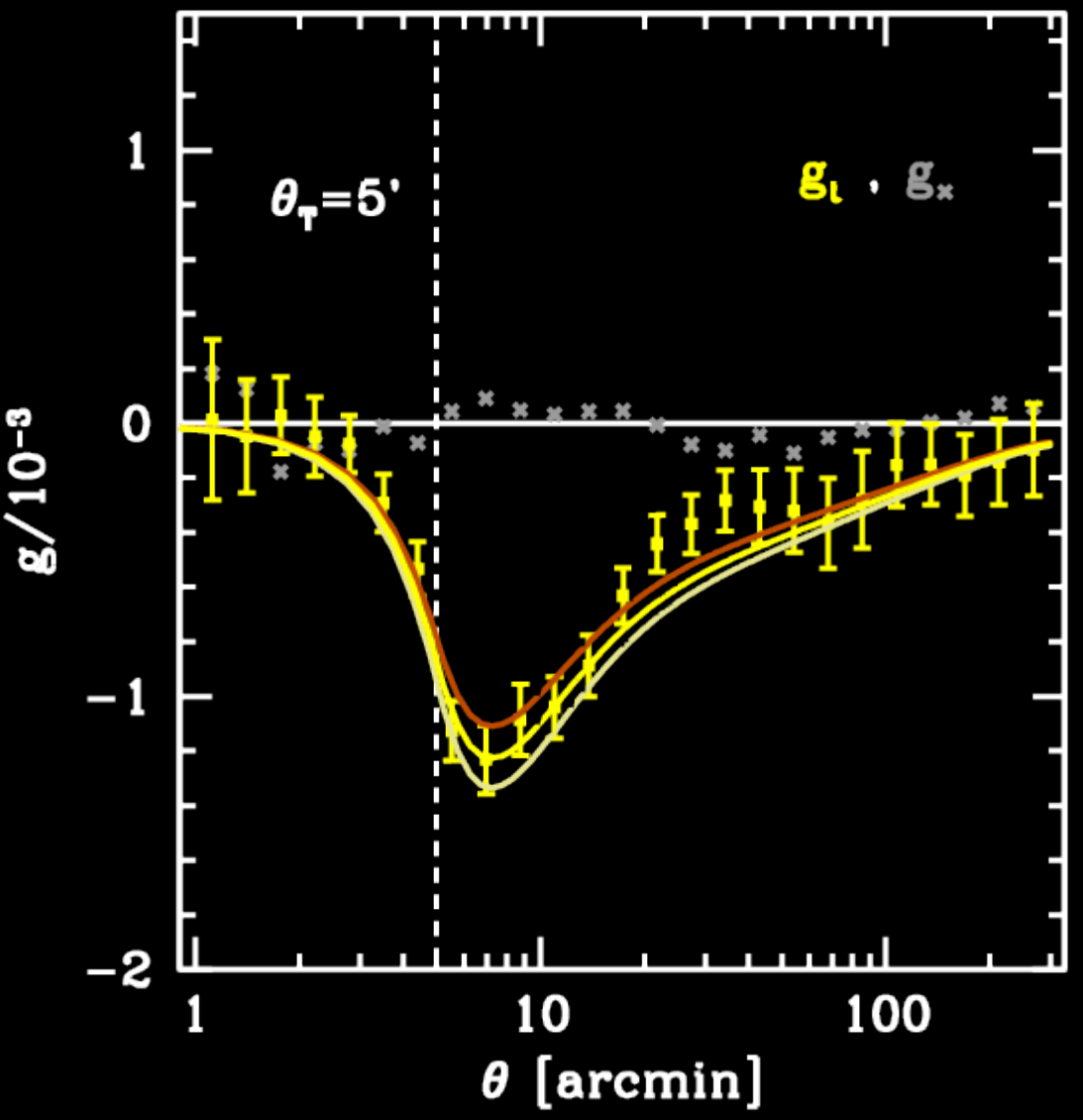
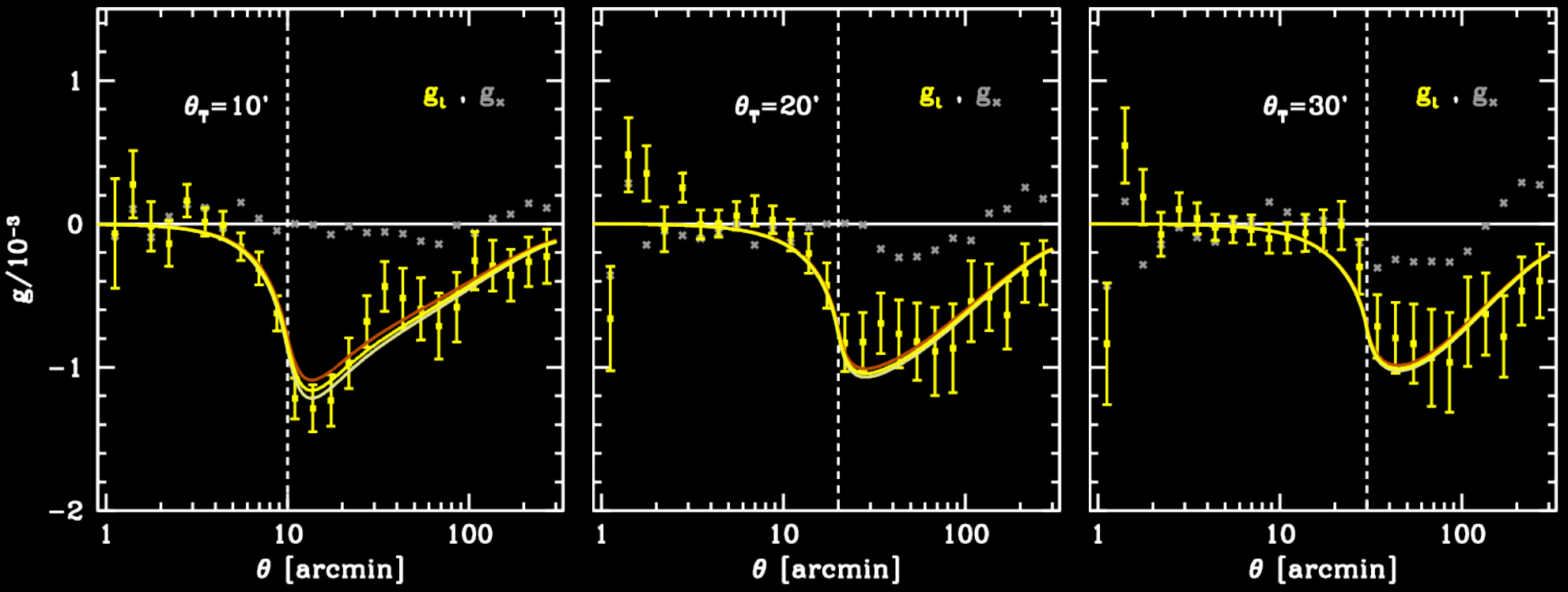
- troughs = lower 20th percentile in galaxy count
- sources:~2x10^6 at z>0.6
- S/N ~ 15!

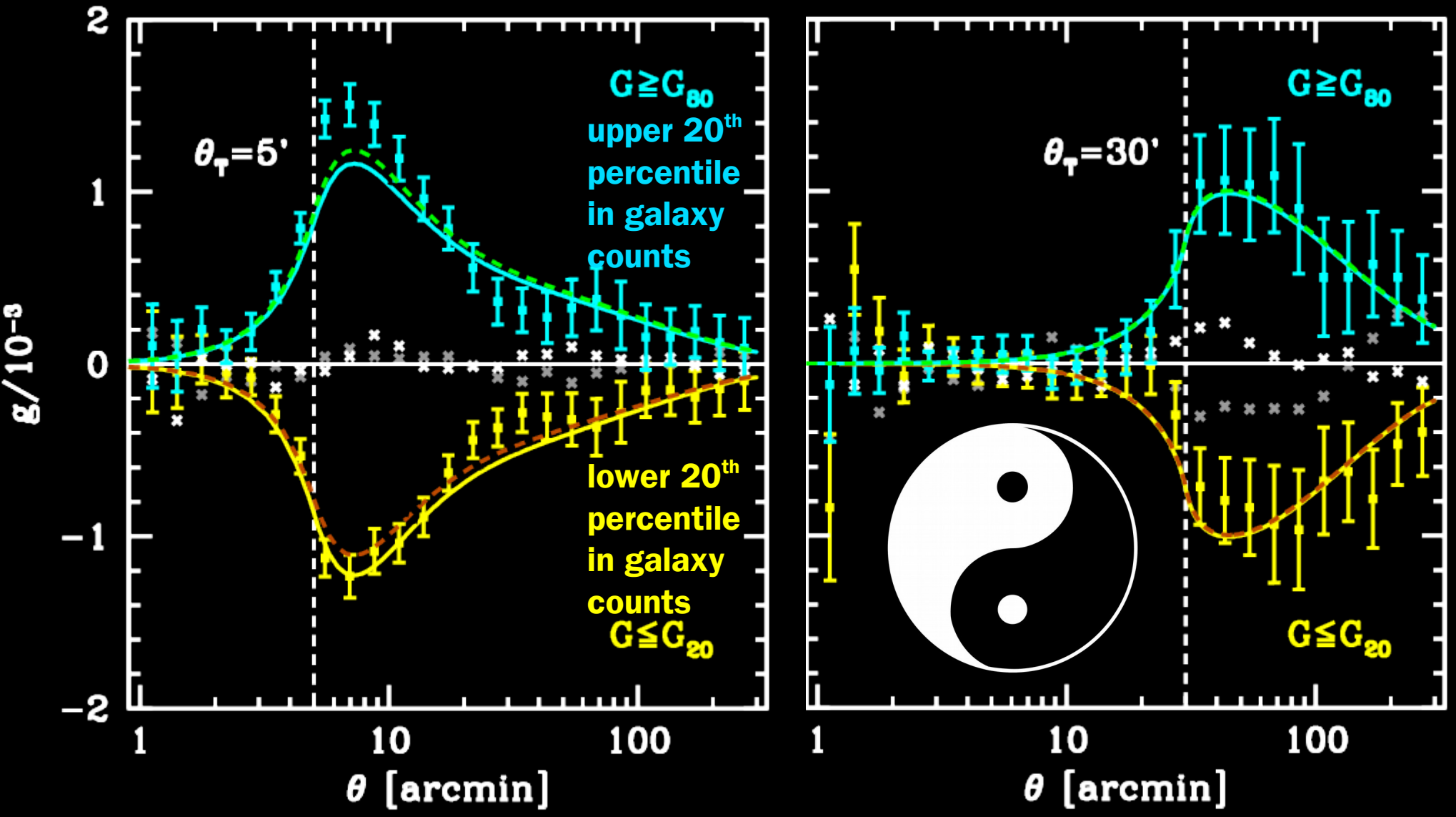


Measurement: larger radii



- reduced S/N due to cosmic variance
- in the dense tracer limit independent of bias model: galaxies only have to trace matter *somehow*

Measurement: under/overdensity



Outlook

Trough lensing for cosmology

Friedrich+ in prep.

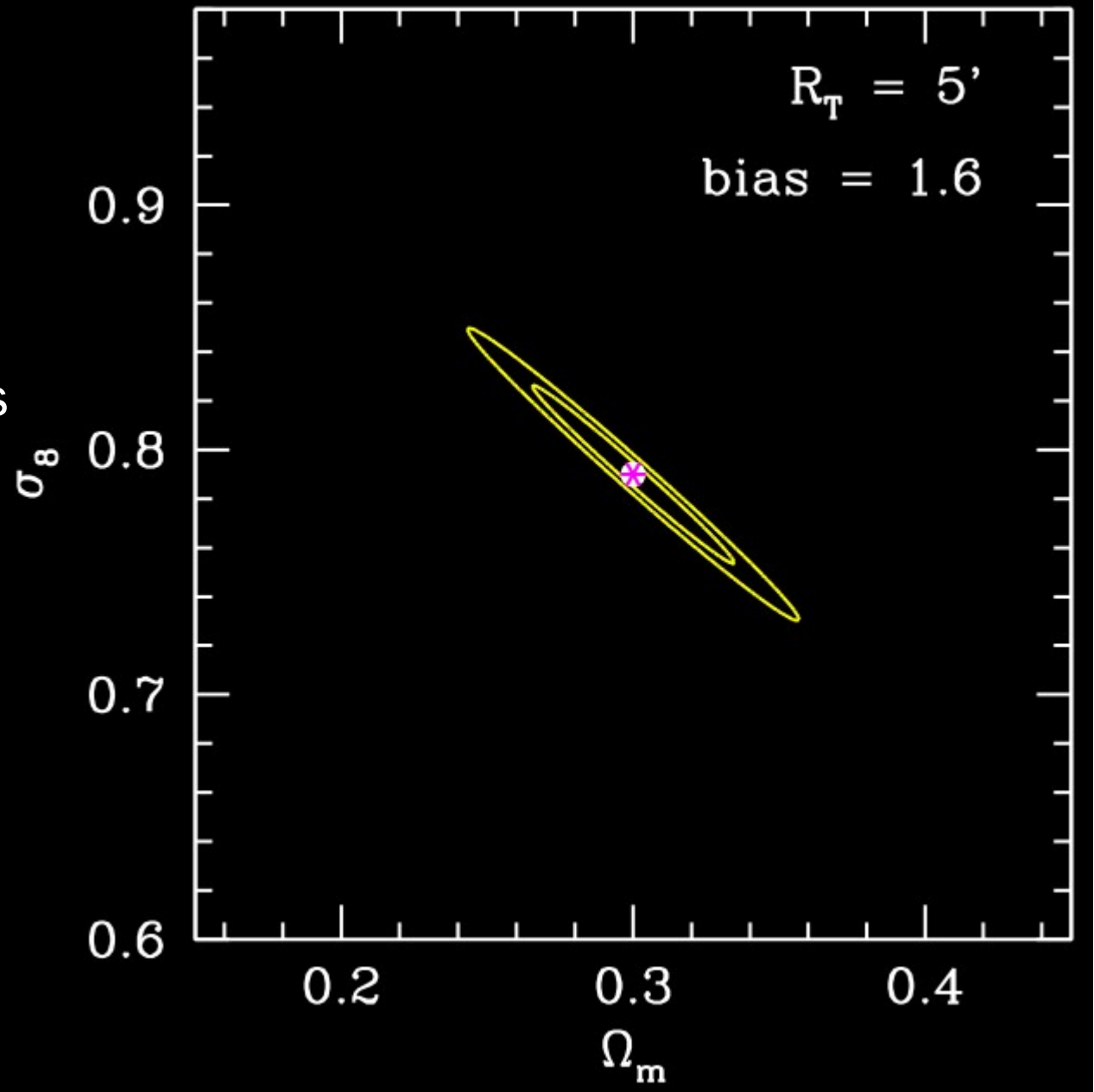
- Goal: prediction for cosmological constraints from trough lensing in final DES data
  - 5000 sq. deg.
  - depth comparable to science verification
- Method: Fisher analysis of troughs of single radius with sources in two redshift bins
  - cosmology dependence from matter and tomographic convergence power spectrum
  - covariance from log-normal mock surveys

Trough lensing for cosmology

Friedrich+ in prep.

Constraints on

- Ω_m and σ_8
  - Degeneracy as in other lensing probes
  - Not marginalized over bias



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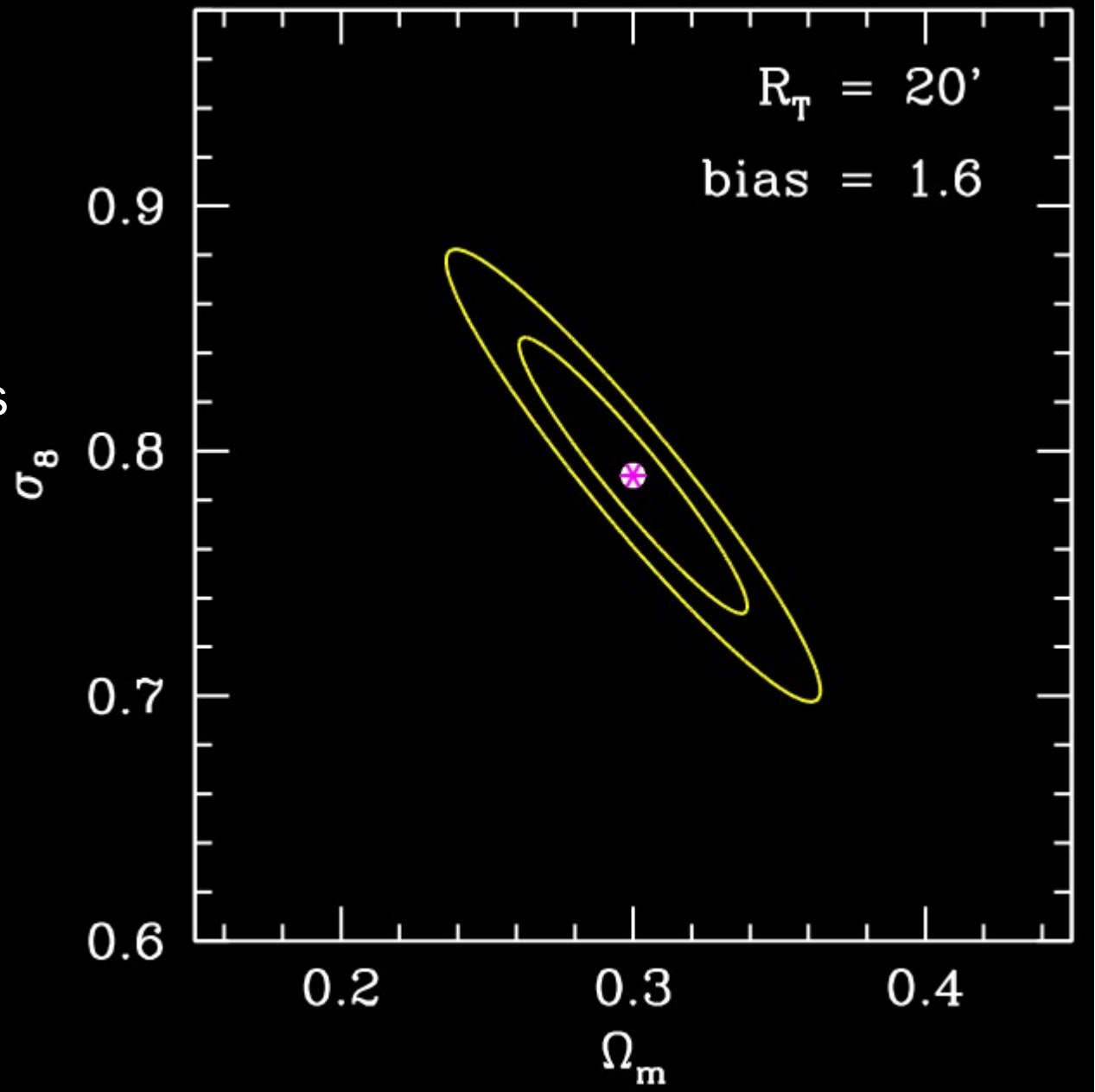

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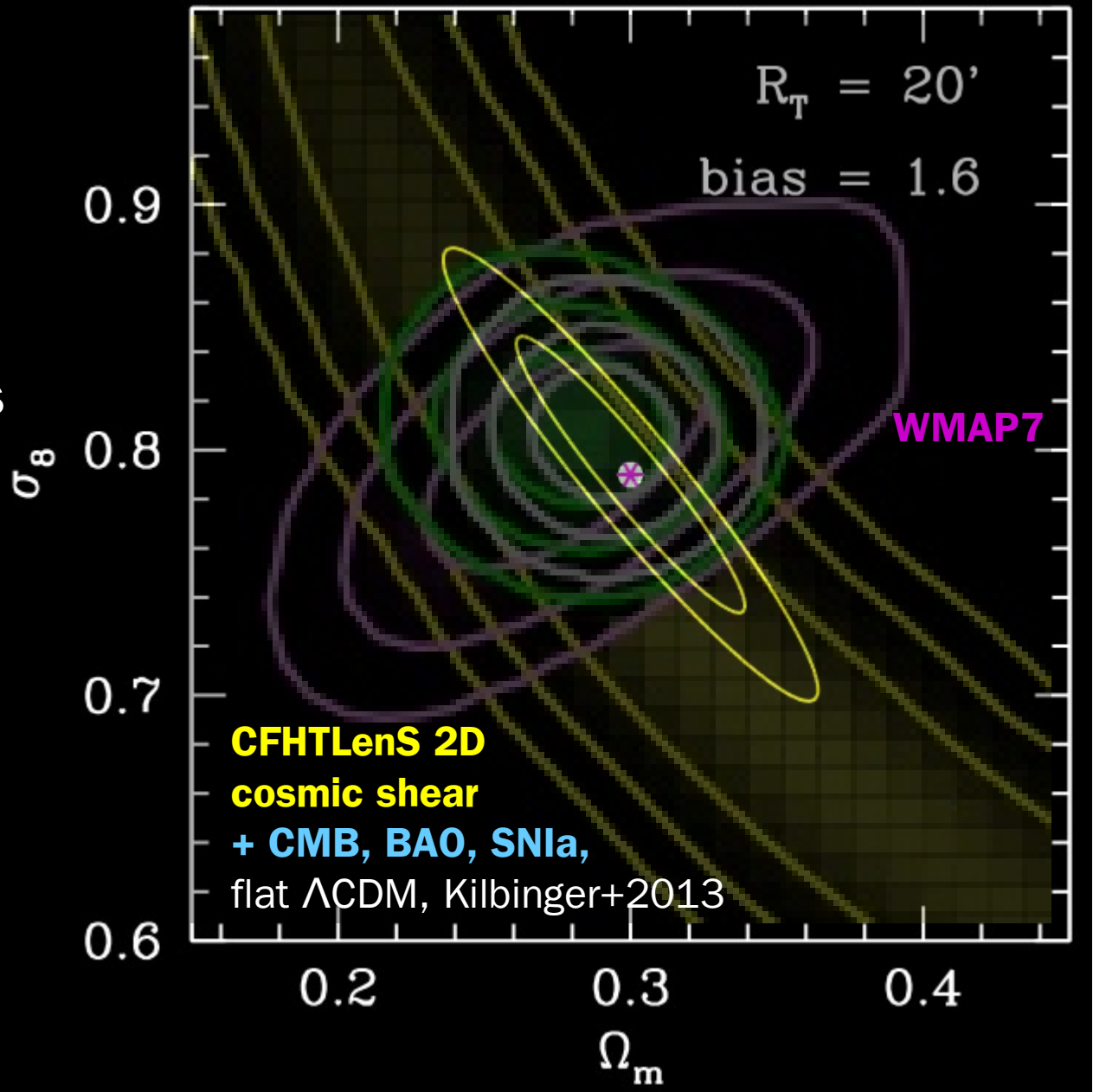

Trough lensing for cosmology

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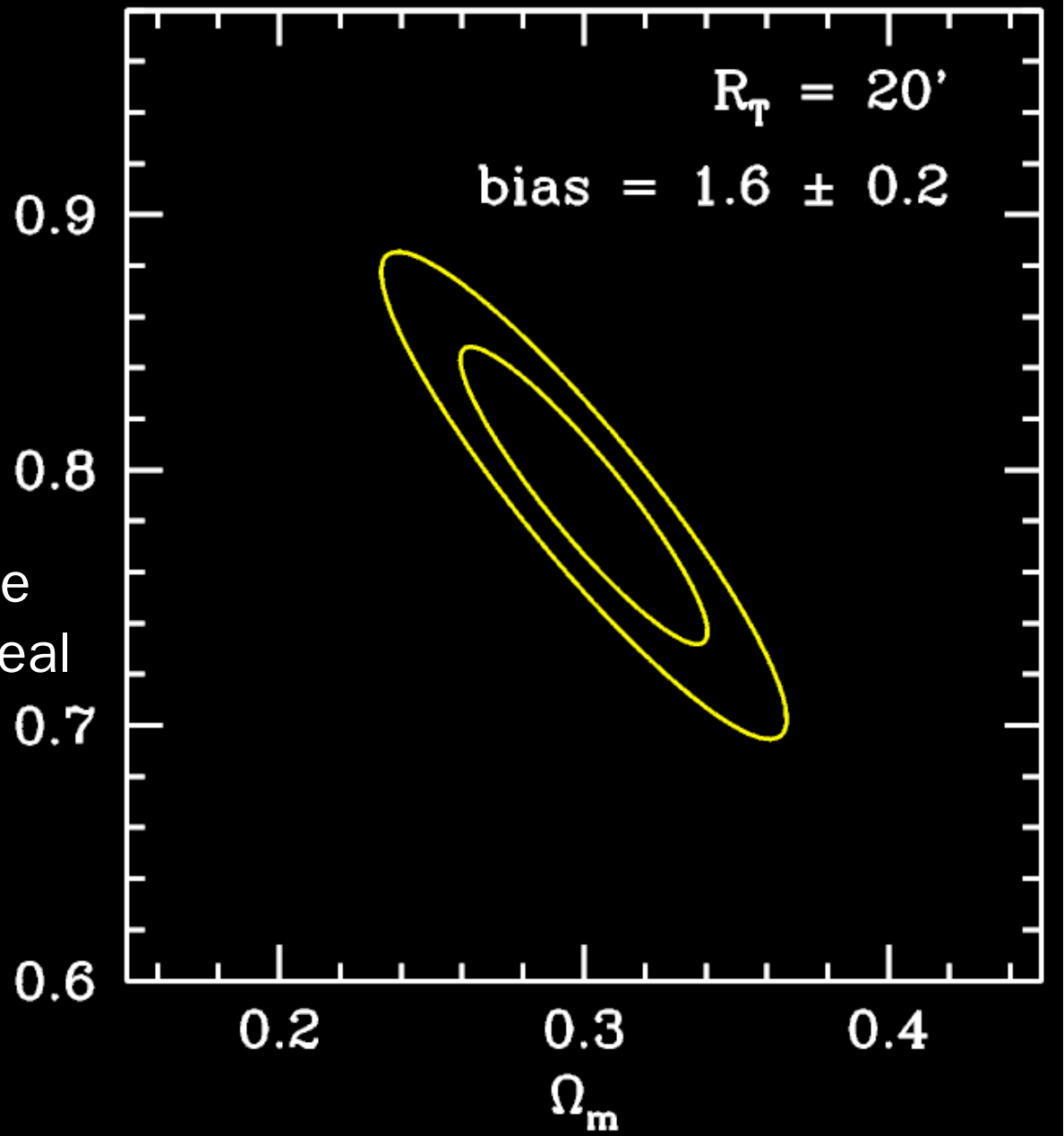
Constraints on

- Ω_m and σ_8
  - Degeneracy as in other lensing probes
  - Not marginalized over bias ⋯ but at large radii, that's not a big deal



Trough lensing for cosmology

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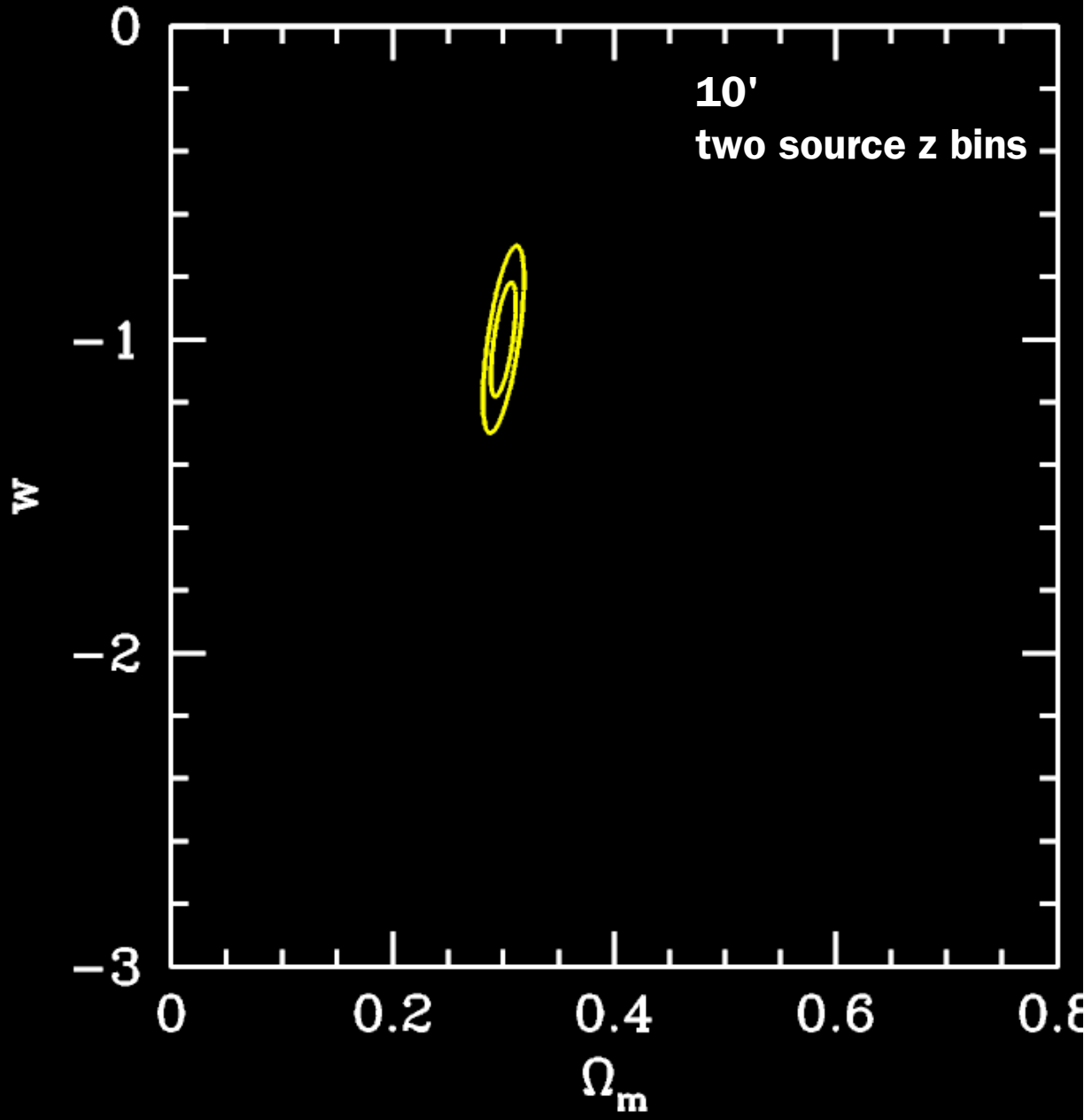
- Dark energy w
  - non-marginalized



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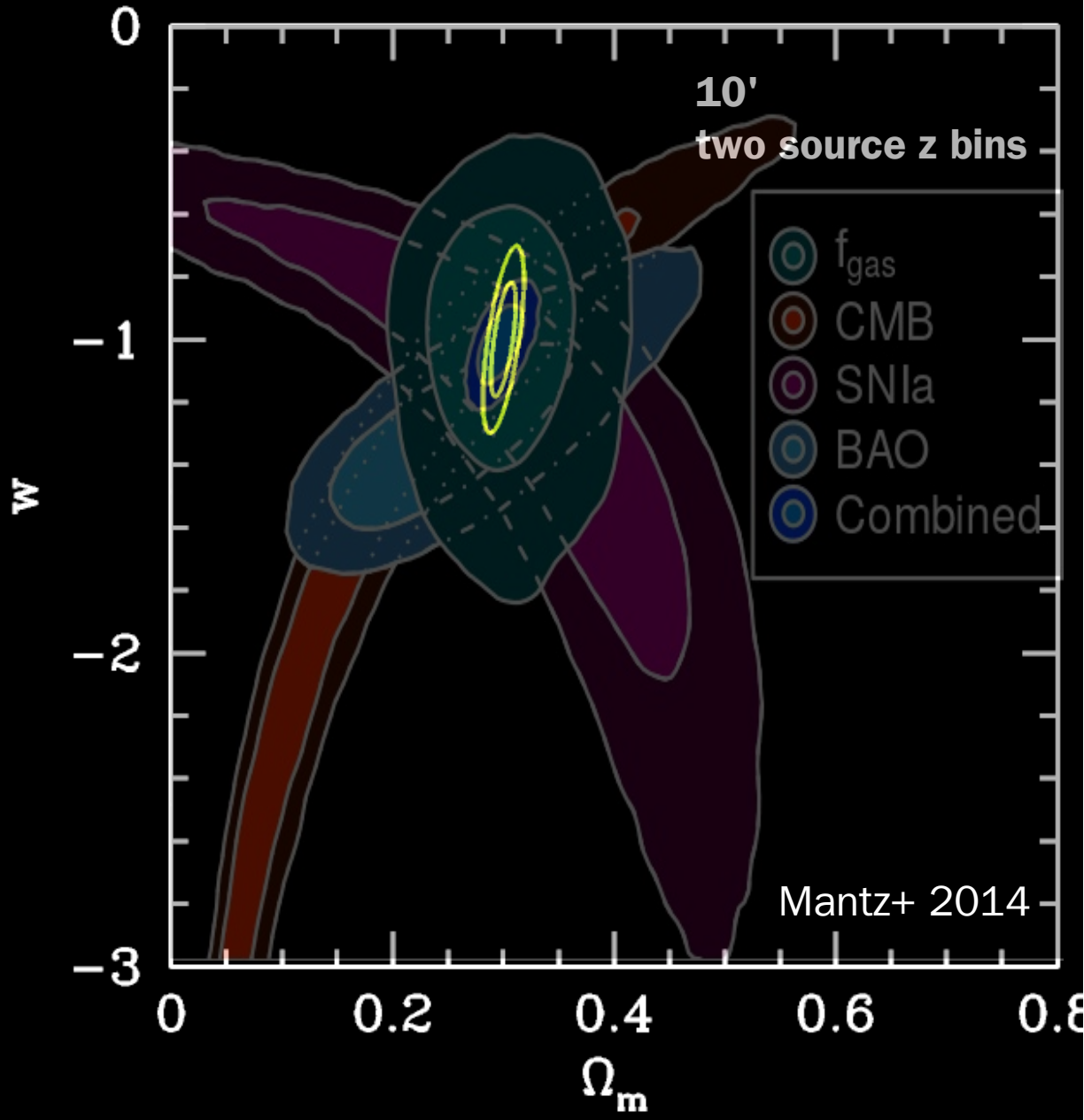

Summary

- Troughs are a new way of probing
  - gravity in the low-density universe
  - structure in general
  - with favorable lensing S/N
- First lensing measurements are consistent with a simple model and ΛCDM cosmology, but much better data coming soon
- Ongoing work on
  - Modelling and predictions
  - Simulations
  - Cosmological constraints
  - Cross-correlation with other fields
  - ...