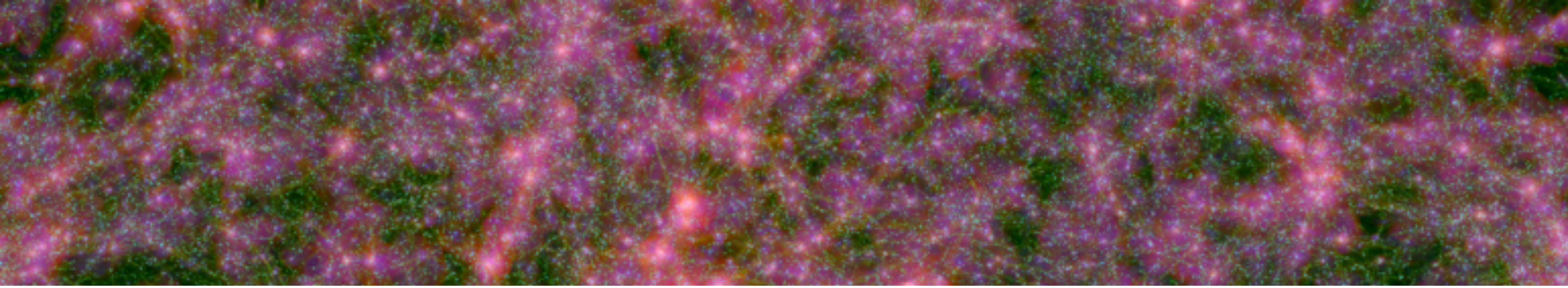


The Horizon-AGN Simulation

Effect of baryons on small scale weak lensing statistics

Raphaël Gavazzi (IAP)

Collaborators: *C. Gouin, C. Pichon, C. Laigle, Y. Dubois, S. Codis, E. Chisari...*

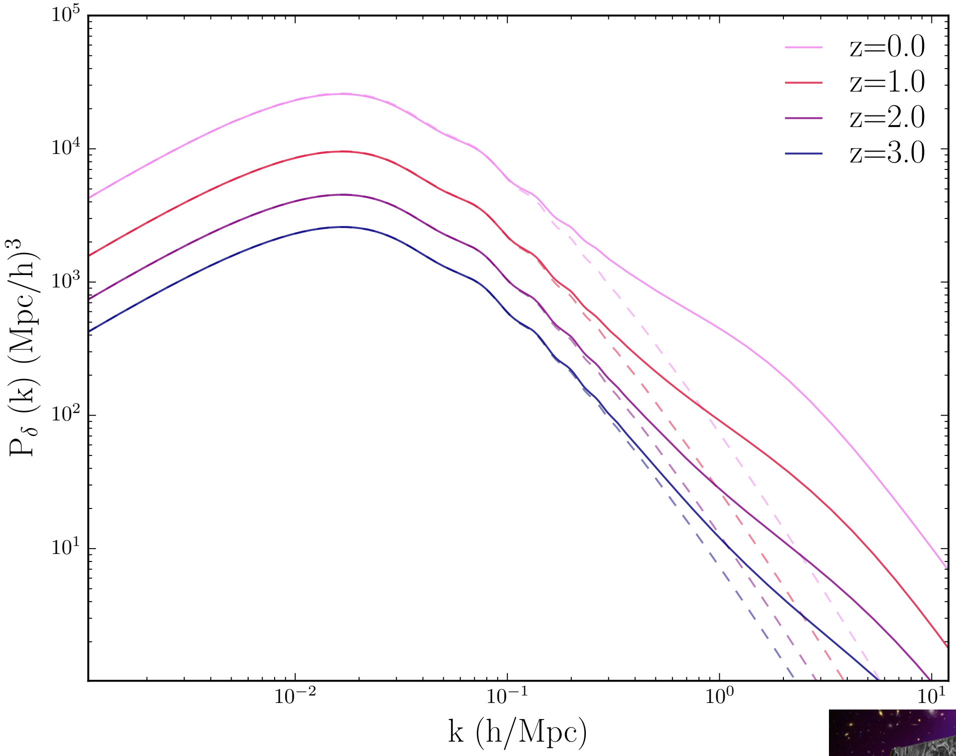
PTchat@Kyoto

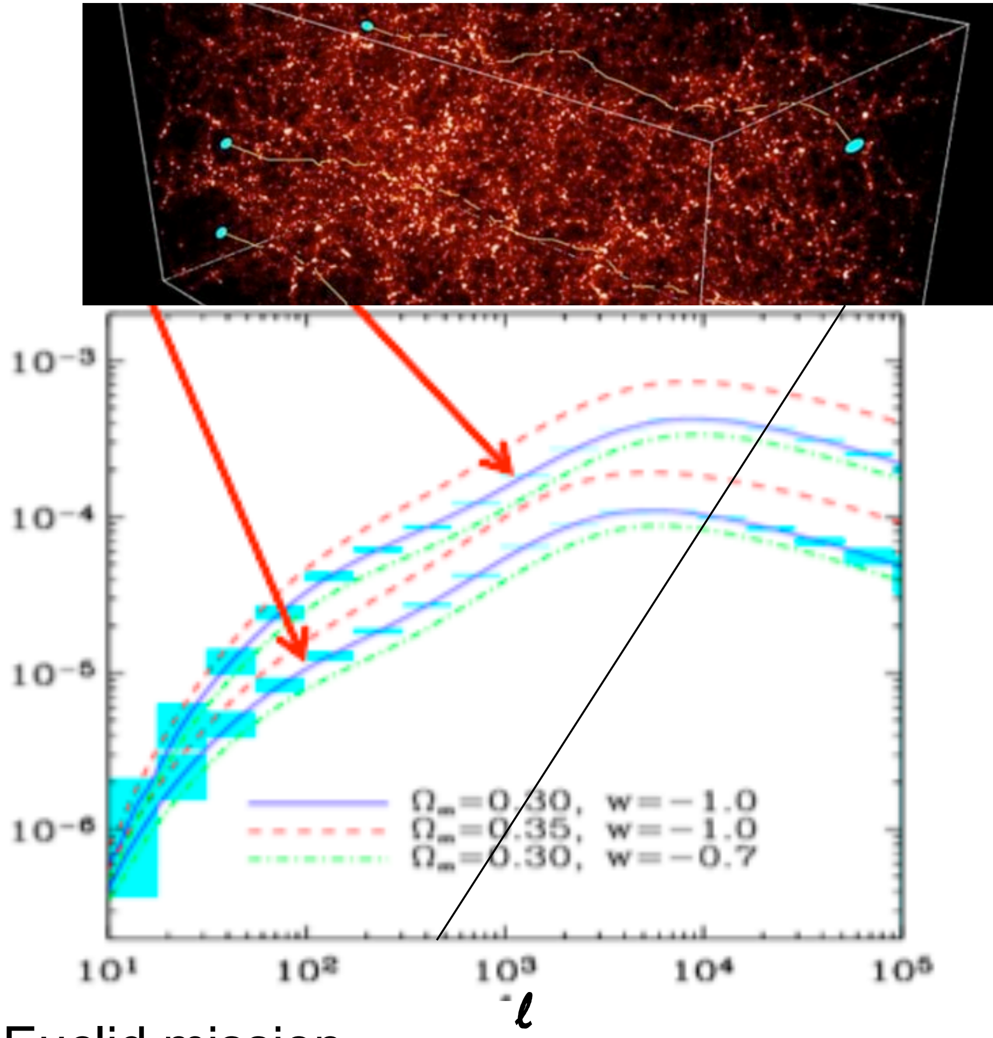
8-12 April 2019 Yukawa Institute for Theoretical Physics

Gouin et al. 2019, submitted to A&A
⋯ this week on arXiv

Baryons may matter

Small non-linear scales contribute to cosmic shear signal.
As we get close to (1-)halo scales, baryons do not behave exactly like DM



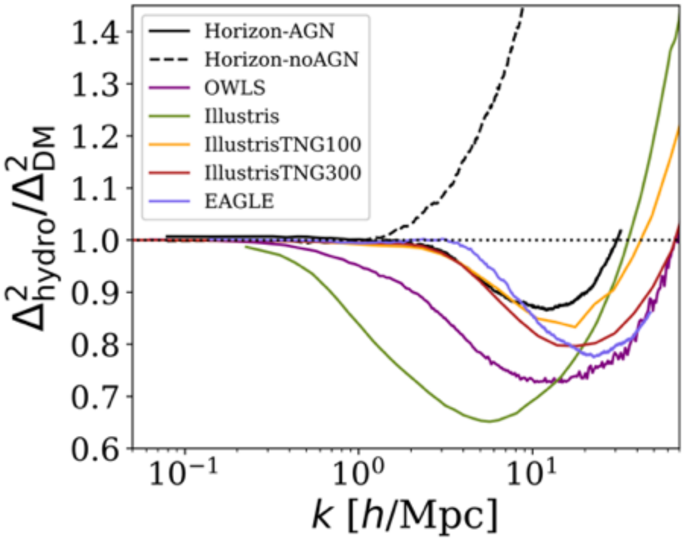



Euclid mission

Hydrodynamical simulations

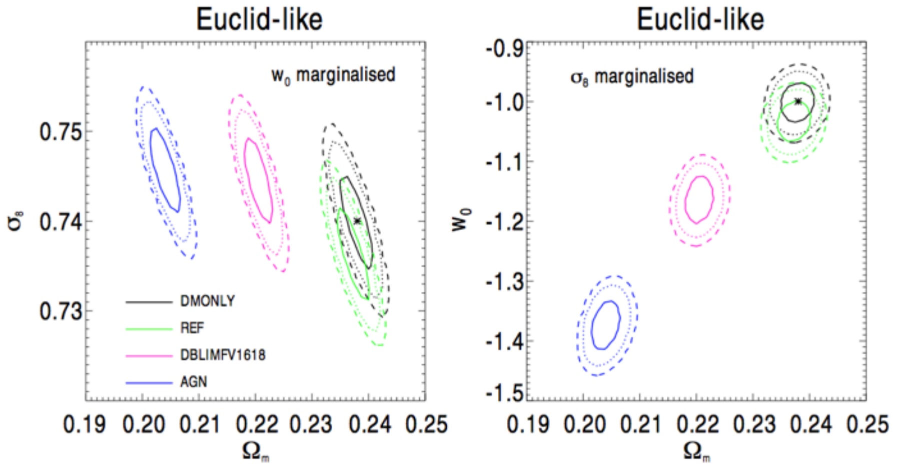
Ratio of two point total matter density power spectra

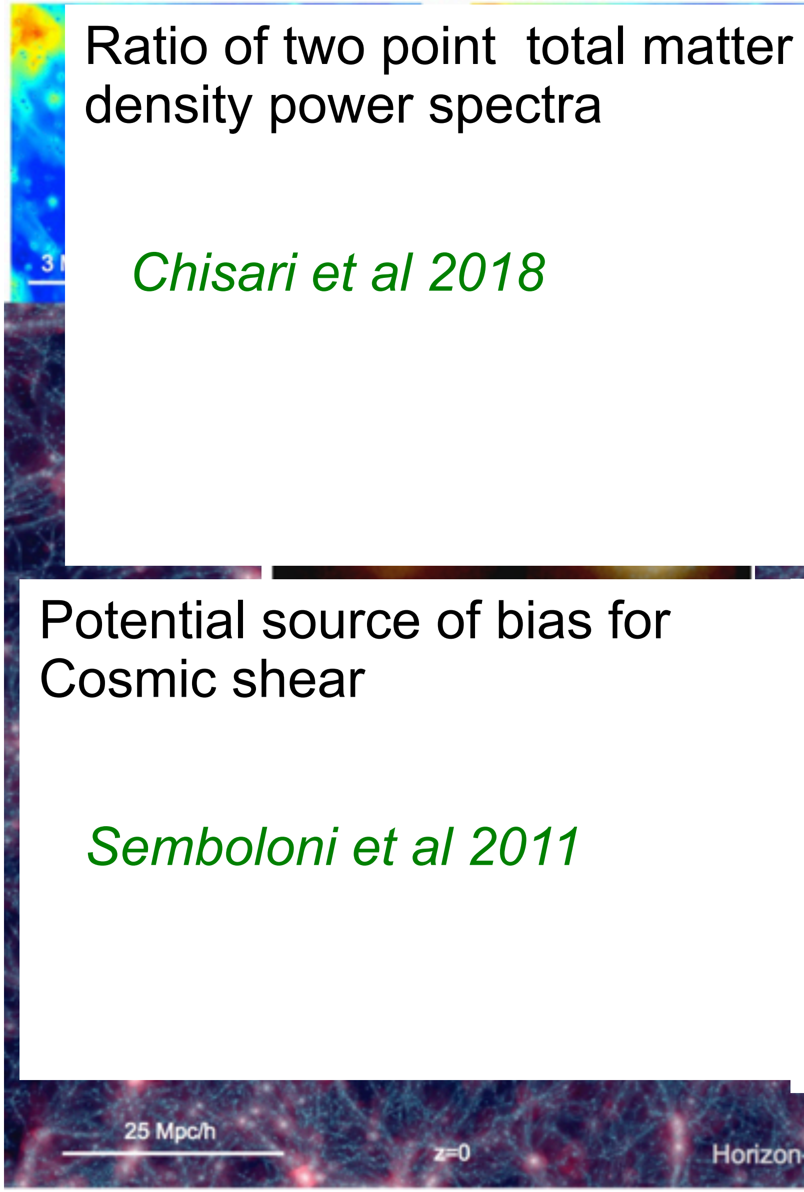
Chisari et al 2018

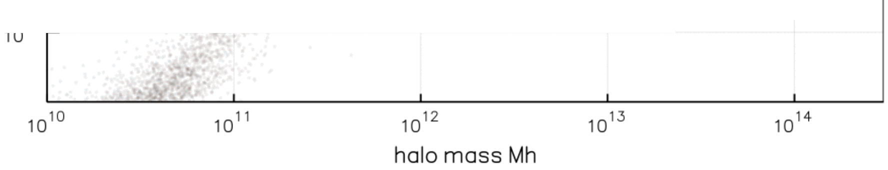


Potential source of bias for Cosmic shear

Semboloni et al 2011





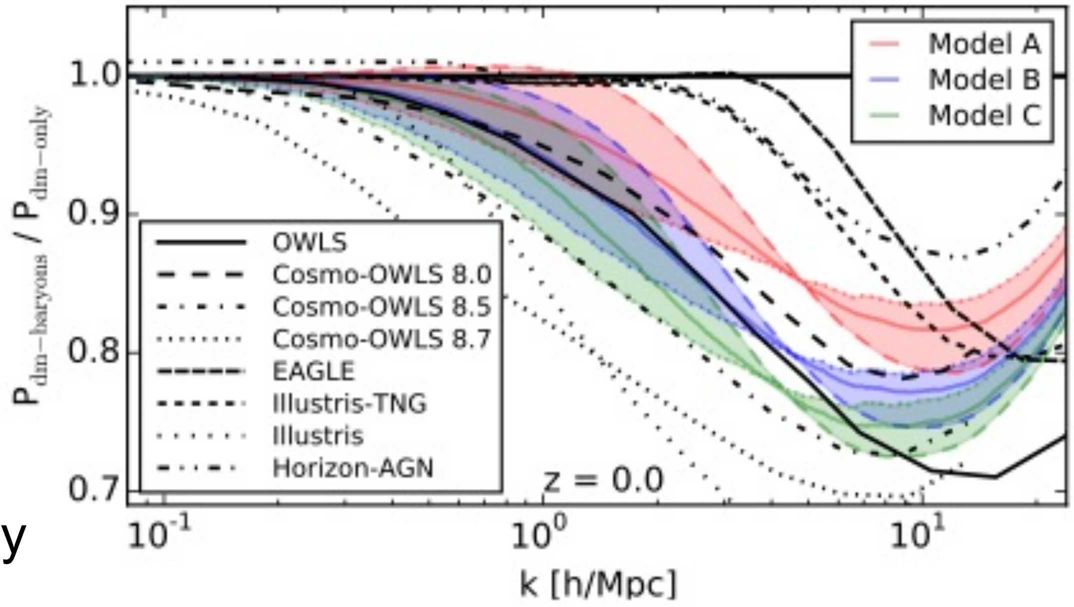


Baryons in halos

Schneider, Teyssier et al 2015, 2019

Prescriptions on how gas (and stars) will be distributed inside halos and how DM particles in DM-only sims will respond.

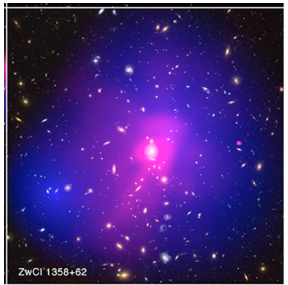
Main degrees of freedom: slope of gas density profile and outermost radius of ejection)… and stellar mass of central



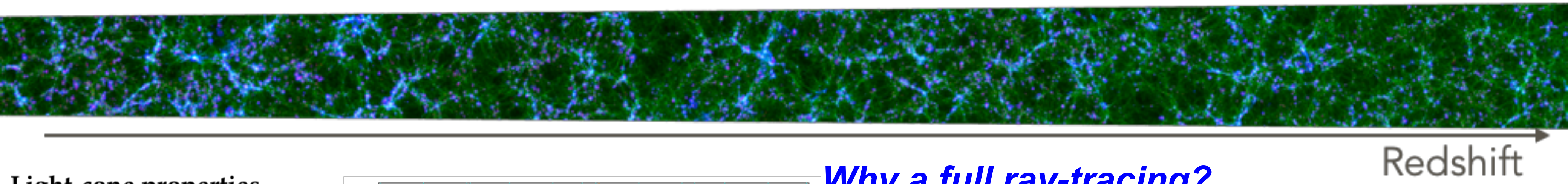
Can capture results of hydro-sims (H-AGN, Illustris*, EAGLE, OWLS) and mimic the impact on matter PS.

Observations easily set $M_* \mid M_{\rm halo}$

X-ray clusters can constrain slope and outermost radius but the main uncertainty is the hydrostatic mass bias
(ie what is the actual halo mass of a cluster with a given observed gas profile?
→ related to cluster lensing mass modeling)

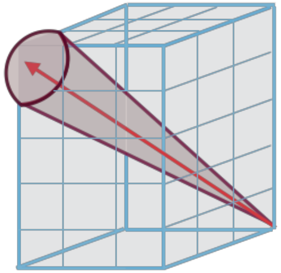


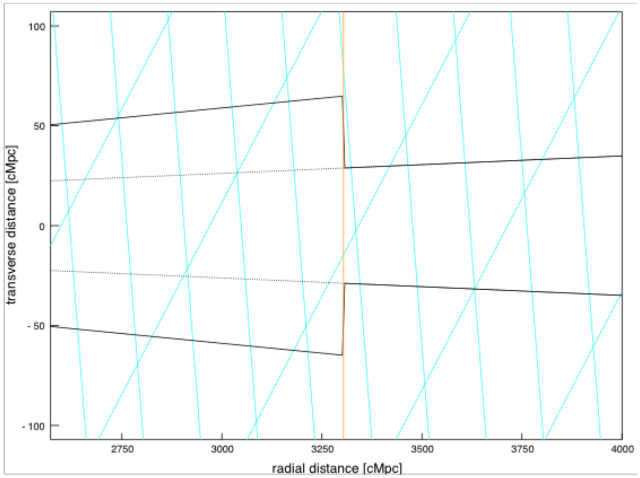
Horizon-AGN past lightcone



Light-cone properties

- ✓ 5 square degrees until z~1
- ✓ 1 square degree until z~7





Why a full ray-tracing?

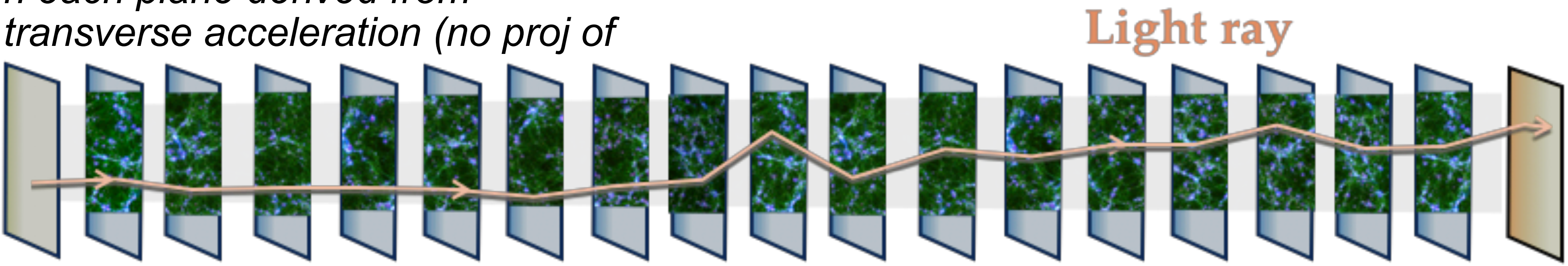
Compare amplitude of baryonic effects with small scale effects (γ→g, beyond Born, magnification bias)

Insights on Stellar-to-halo mass relations:
gal-gal lensing (weak and strong)

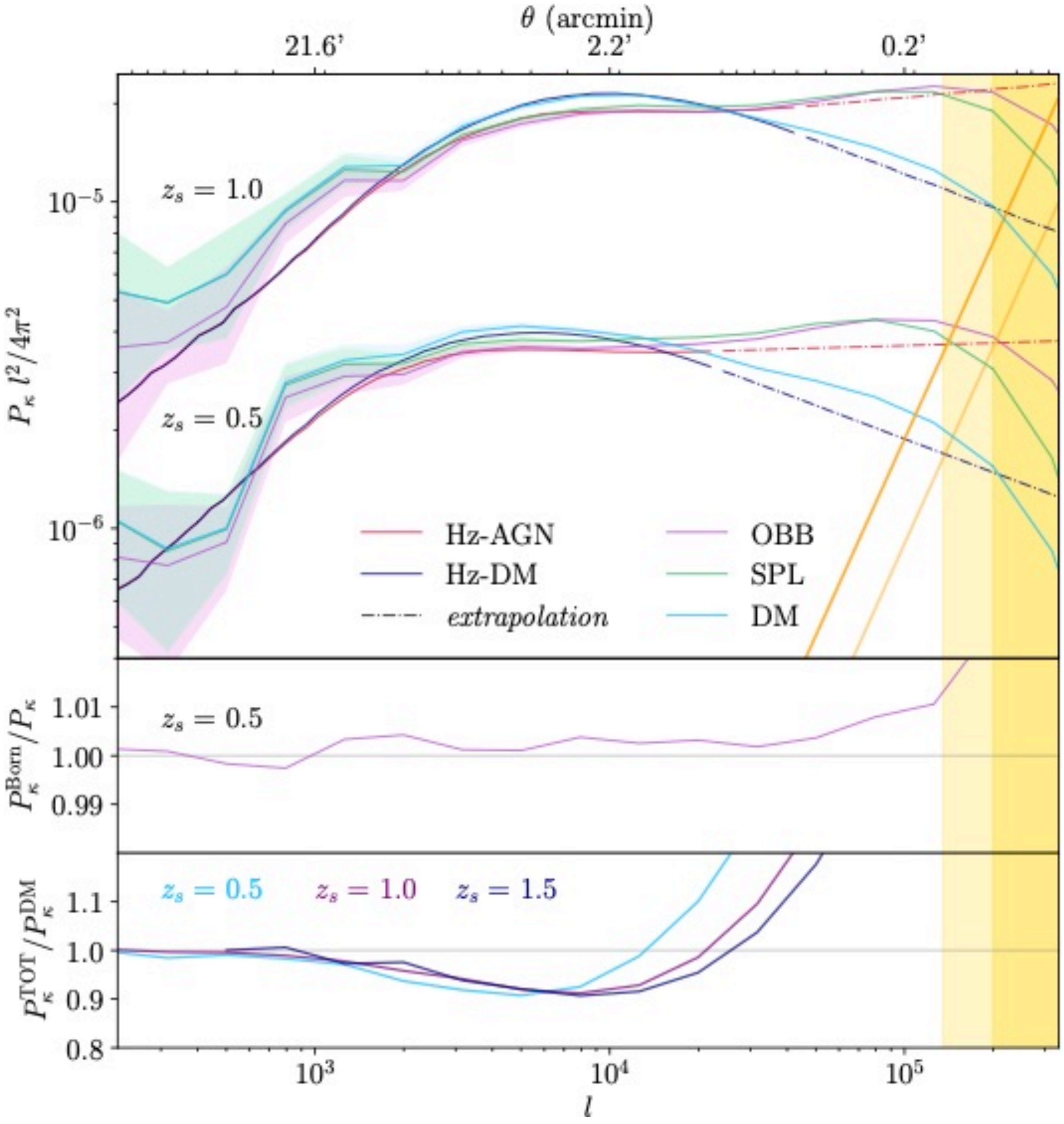
Mock lensed galaxy catalogs (gal evolution)

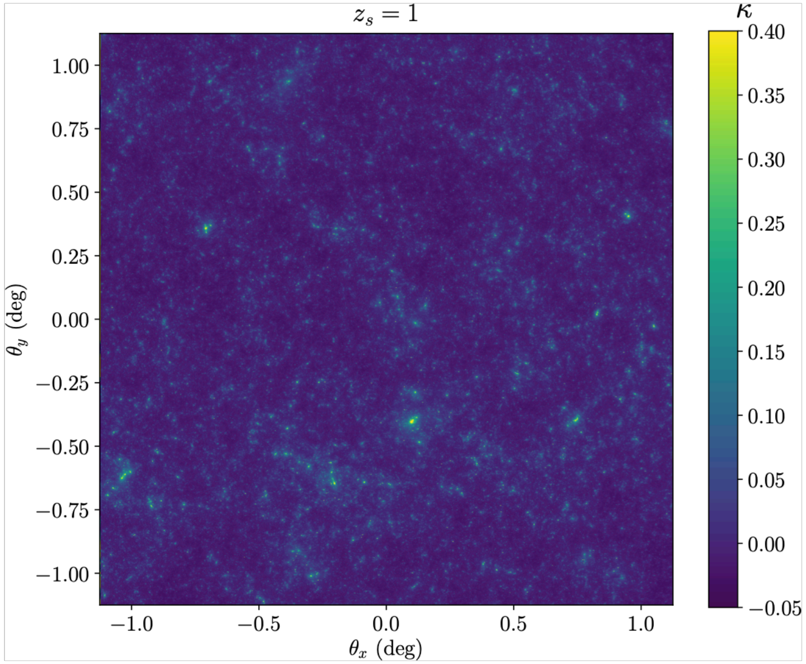
Mock lensed images ("end-to-end" studies)

Deflection in each plane derived from Simulation transverse acceleration (no proj of particles)



Convergence Power Spectrum

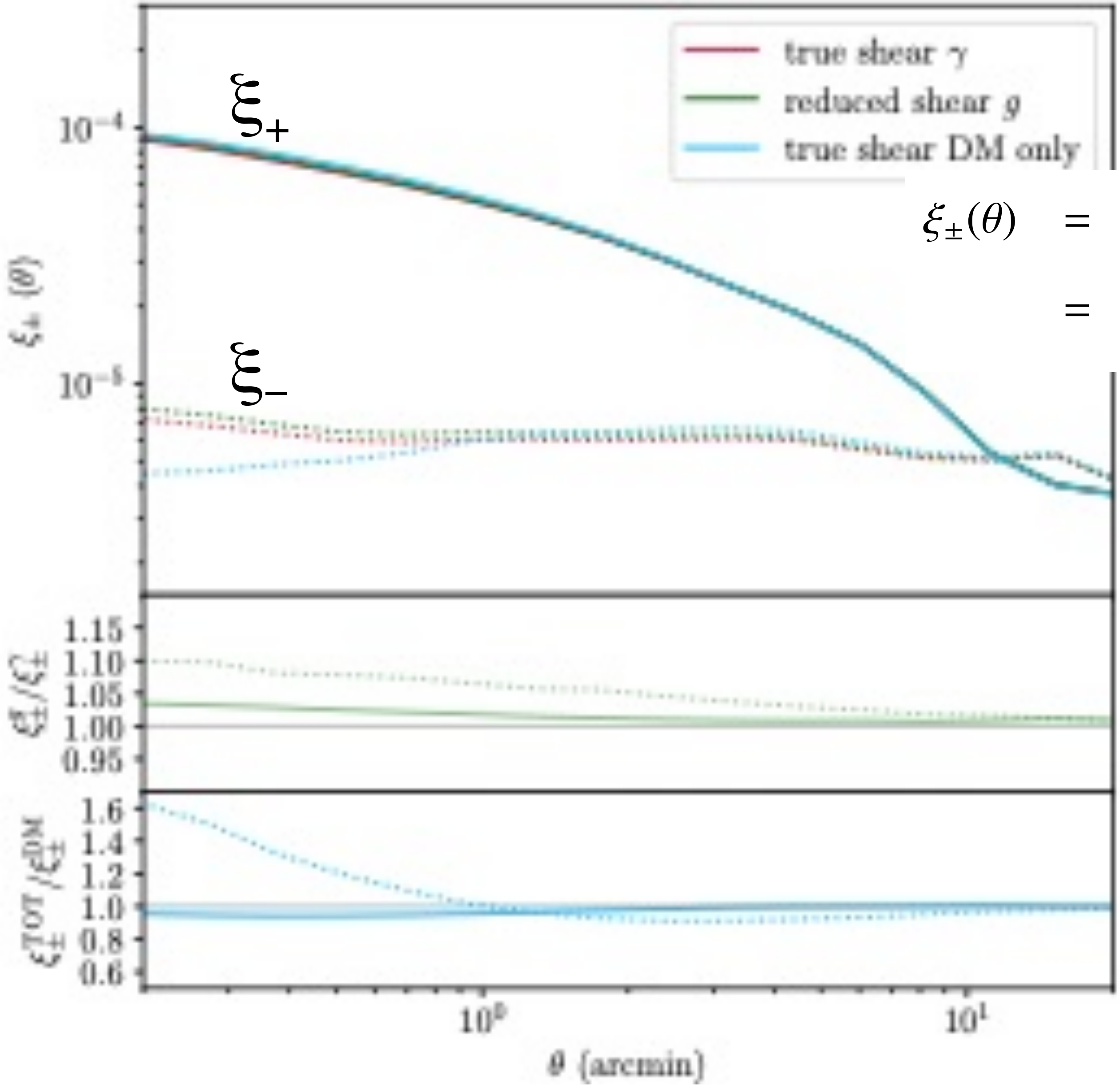




Born approximation
1% valid up to ℓ~10^5 !

For 0.5< z_s <1.5 , ΔPκ/Pκ
-2% for ℓ >10^3
-10% for 4000<ℓ <2000
Then cooled baryons kick in

Shear correlation functions



$$\begin{aligned}\xi_\pm(\theta) &= \langle\gamma_+(\vartheta+\theta)\gamma_+(\vartheta)\rangle_\vartheta \pm \langle\gamma_\times(\vartheta+\theta)\gamma_\times(\vartheta)\rangle_\vartheta \\ &= 2\pi\int \mathrm{d}\ell\,\ell J_{0/4}(\theta\ell)P_\kappa(\ell)\,,\end{aligned}$$

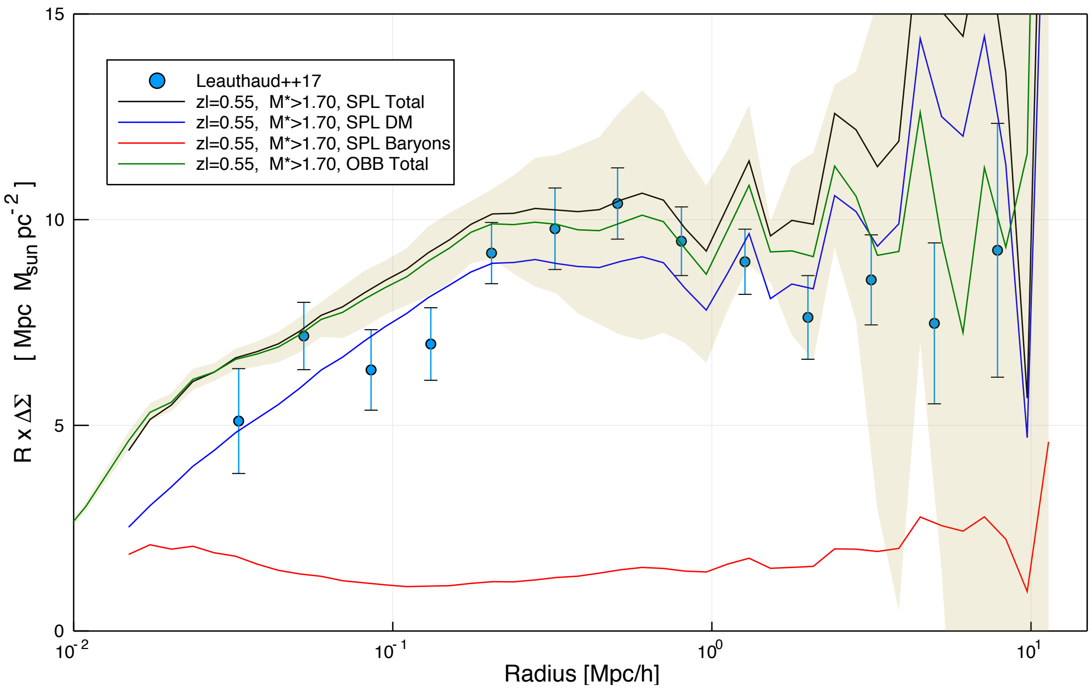
$$g \equiv \frac{\gamma}{1-\kappa}$$

1-5% increase on few arcmin angular scales

Baryons → 10% depletion on few arcmin angular scales

(+large boost from stars below 1arcmin)

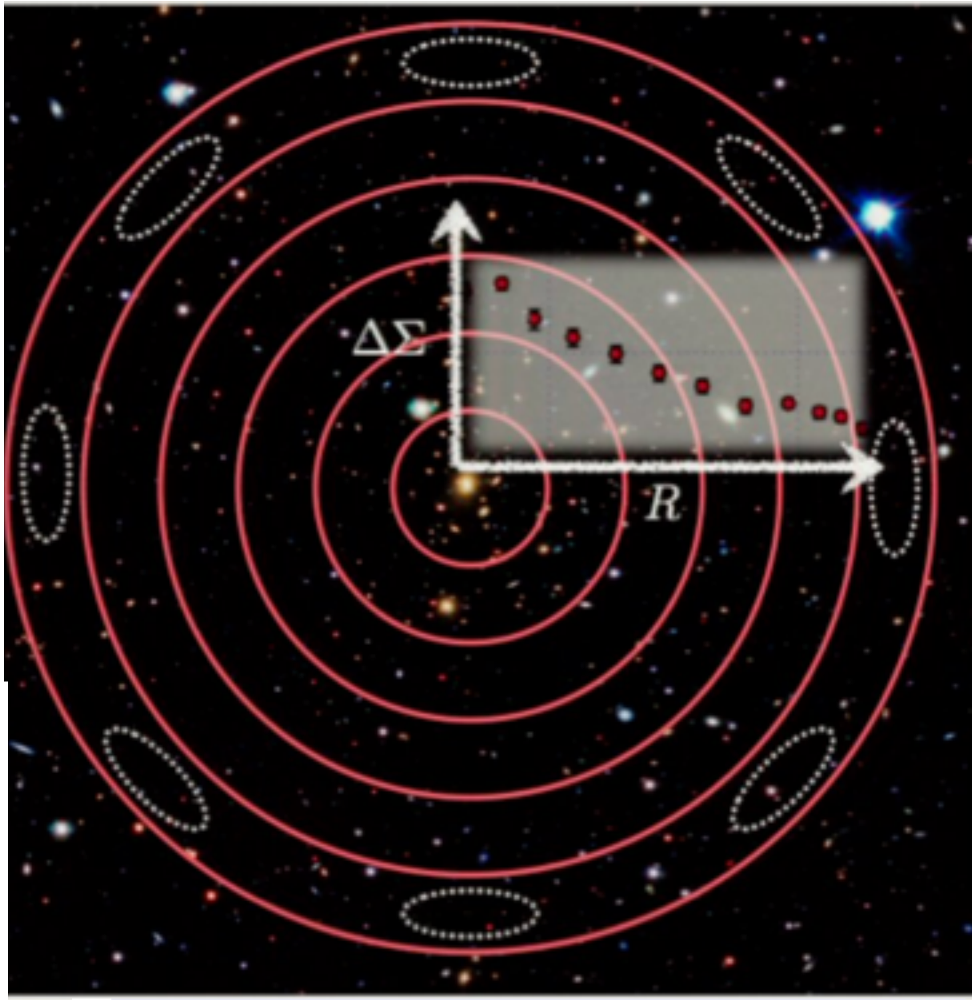
Galaxy-Galaxy lensing (GGL)



Good agreement with
CMASS lenses x CFHTLenS+CS82 sources

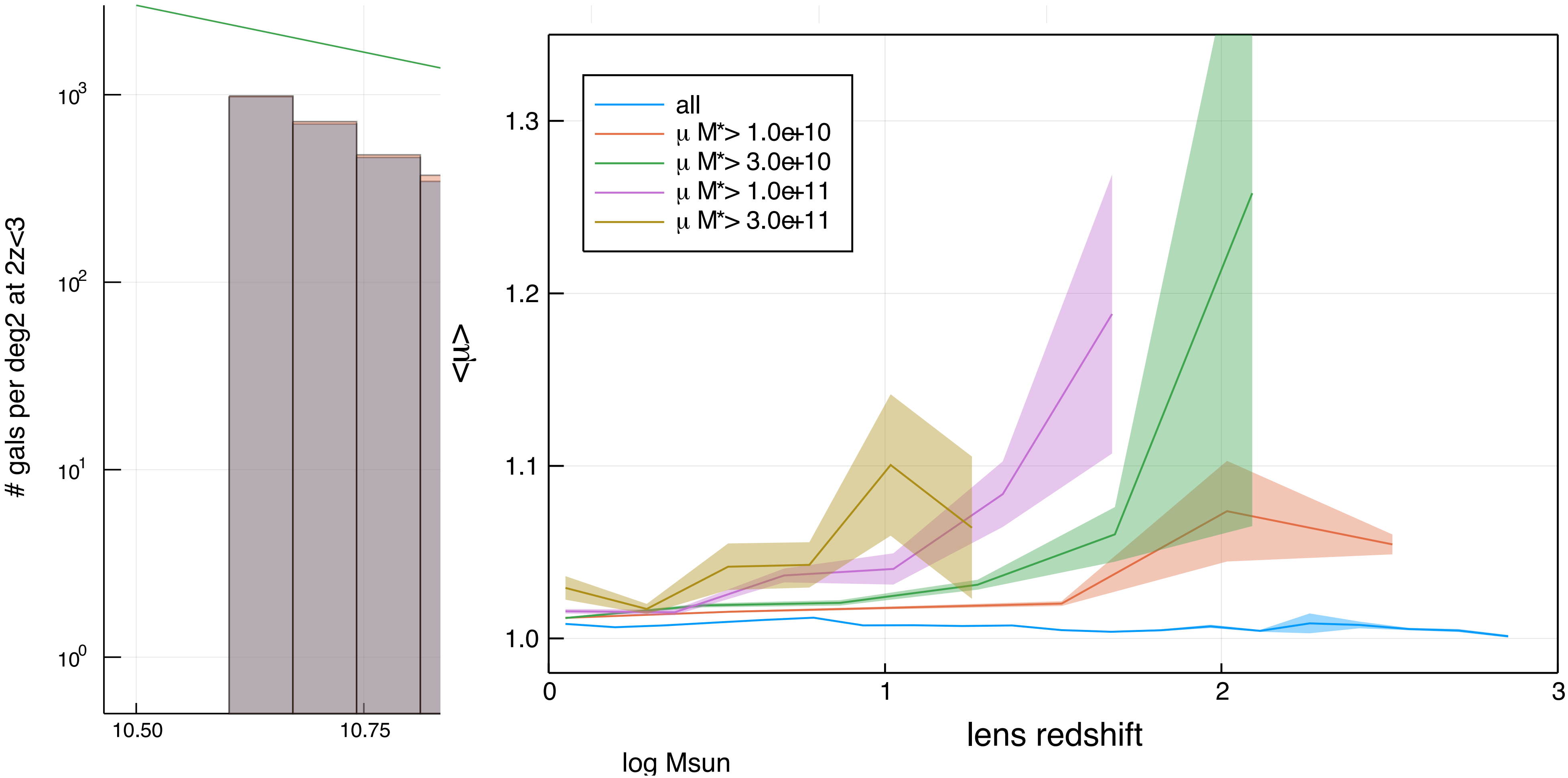
→ H-AGN M*-M$_{halo}$ relation consistent

Small excess below 200 kpc:
??gas not sufficiently pushed out??



$$\gamma_t \propto \Delta\Sigma(R) = \int \mathrm{d}z\,\overline{\rho}\xi_{g,m}(r)$$

Magnification bias

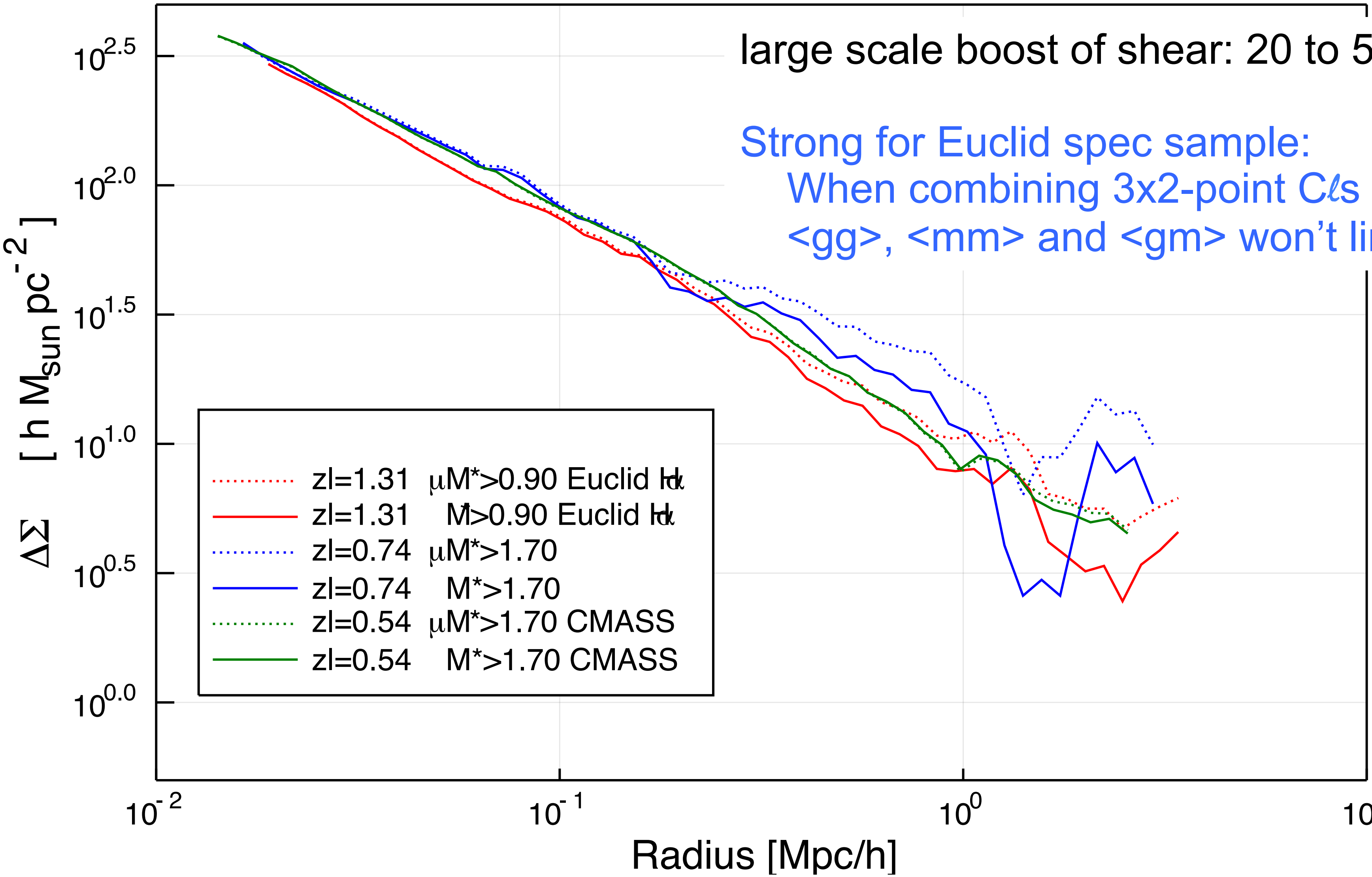


Bright objects with material along the line of sight get preferentially selected…

Also true for foreground lenses if zl is large enough (>0.6)

Effect of Magnification bias on GGL

High- z magnif bias impact (see also Ziou&Hui 08)

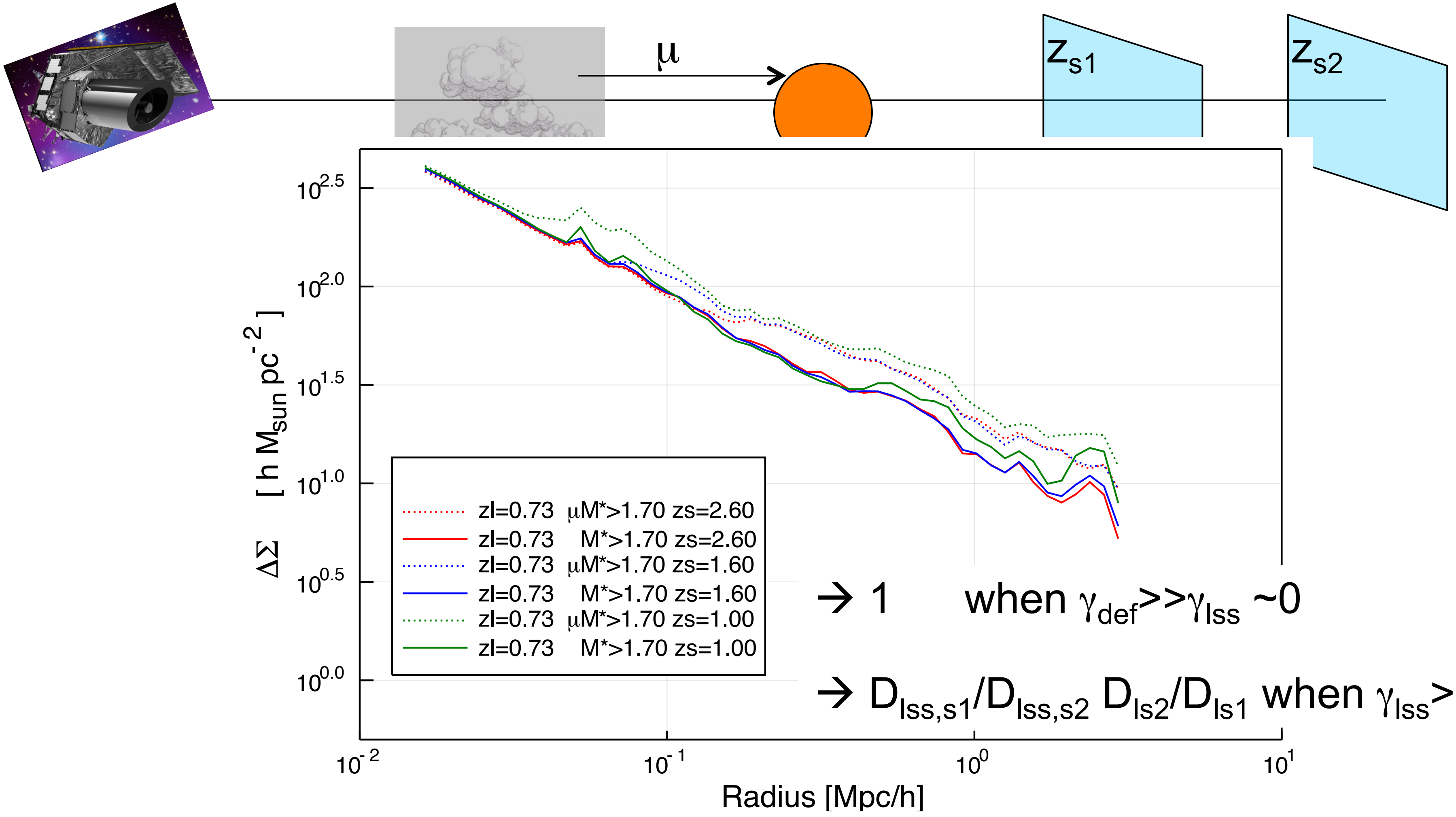


large scale boost of shear: 20 to 50%

Strong for Euclid spec sample:
When combining 3x2-point Cℓs
<gg>, <mm> and <gm> won’t line up!

Effect of Magnification bias on GGL

Shear ratio tests : $\gamma(zl,zs1)/\gamma(zl,zs2) = (D_{ls1}/D_{s1}) / (D_{ls2}/D_{s2})$ → *cosmography* tests are in trouble because intervening matter causing mag bias will act differently on source planes z_{s1} and z_{s2}

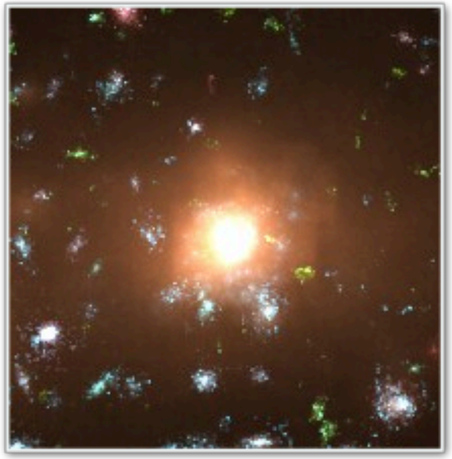


→ 1 when $\gamma_{def} >> \gamma_{lss} \sim 0$

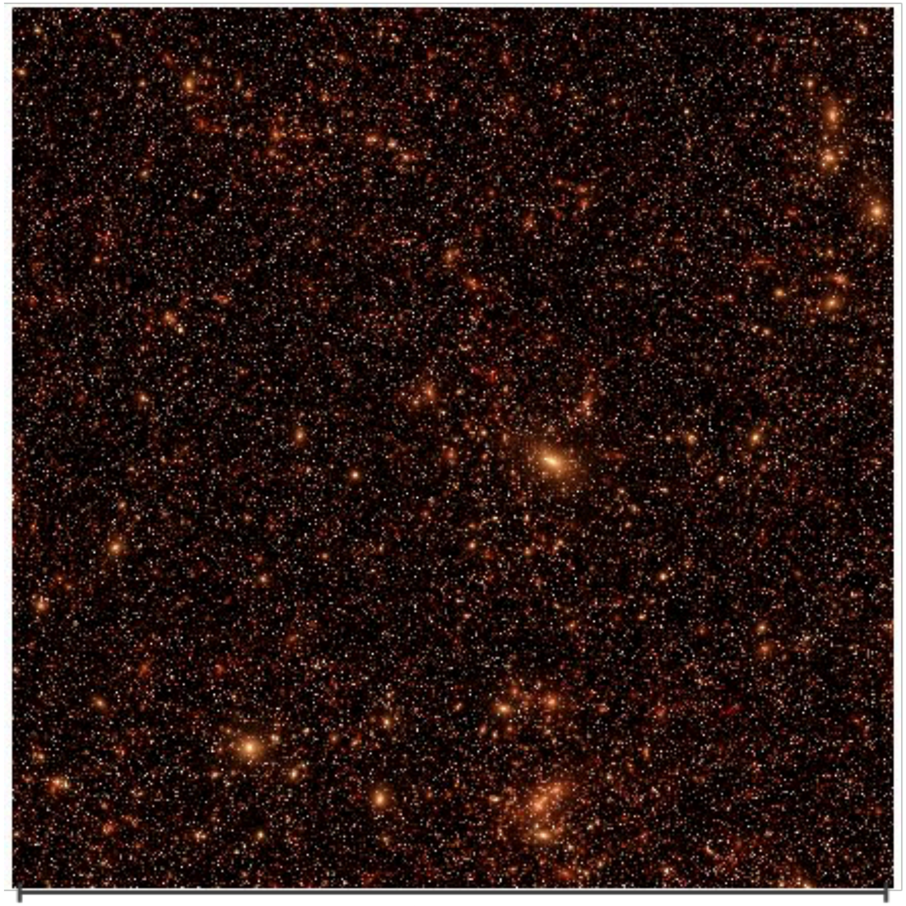
→ $D_{lss,s1}/D_{lss,s2}\ D_{ls2}/D_{ls1}$ when $\gamma_{lss} >> \gamma_{def} \sim 0$

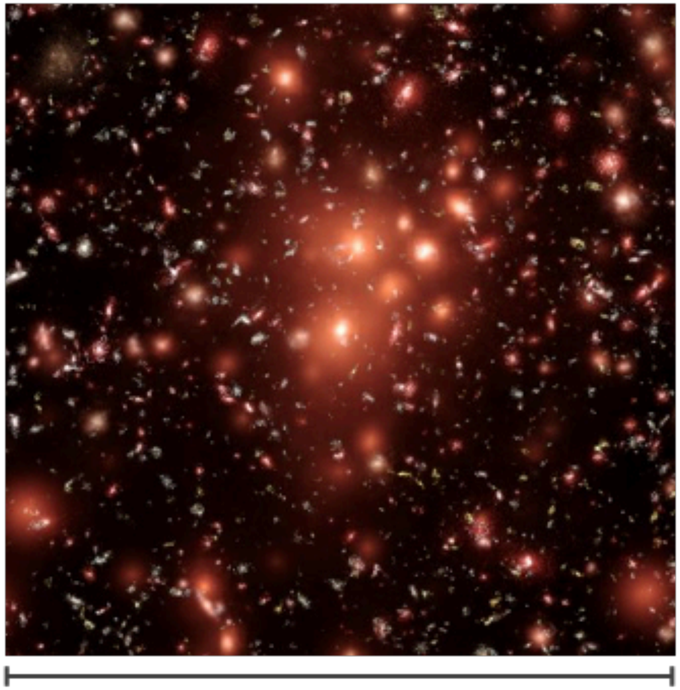
Mock images

before lensing

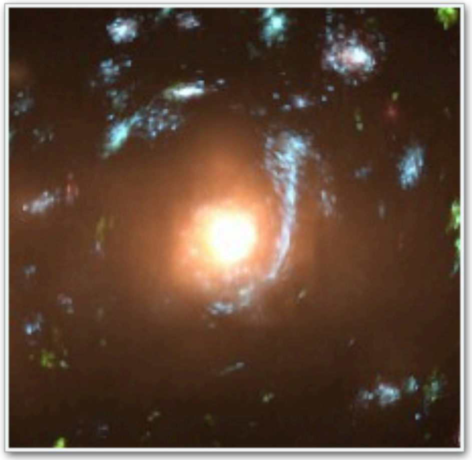


Band u,g,z



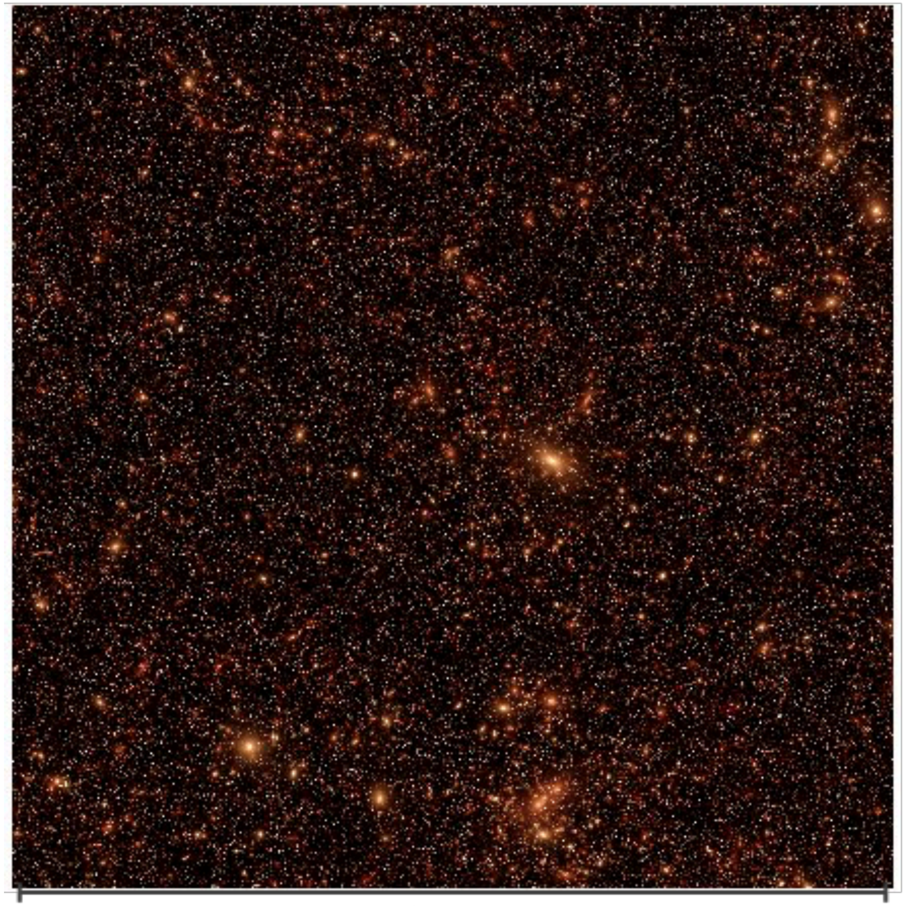


Mock images

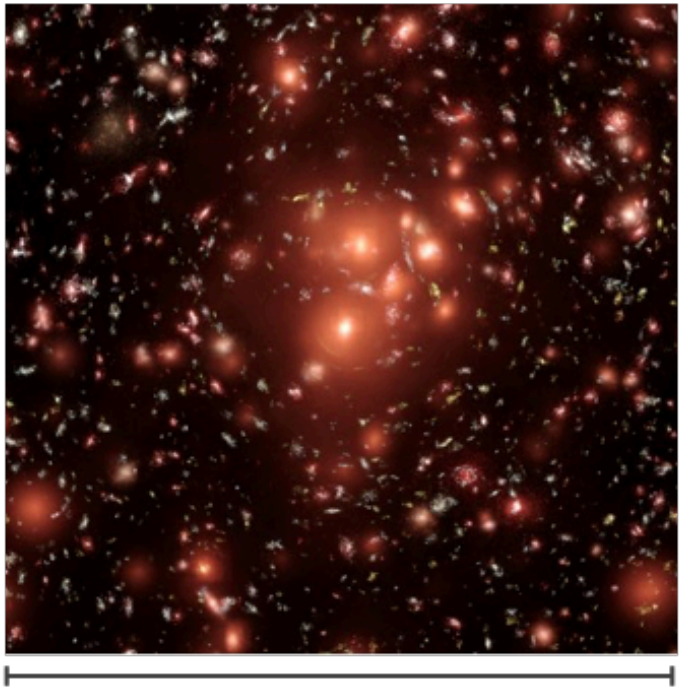


after lensing

Band u,g,z



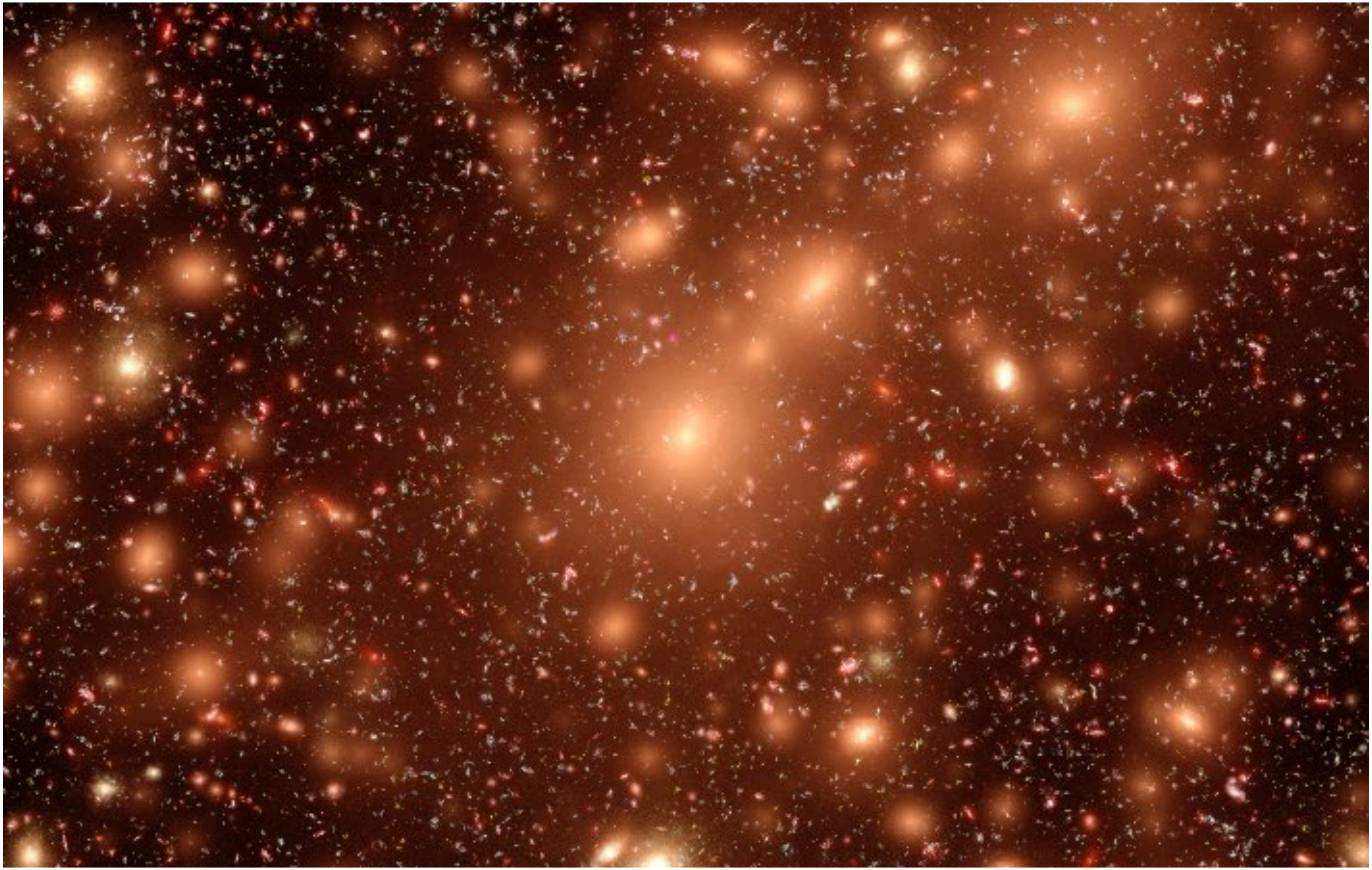
1 degree



~ 1 arcmin

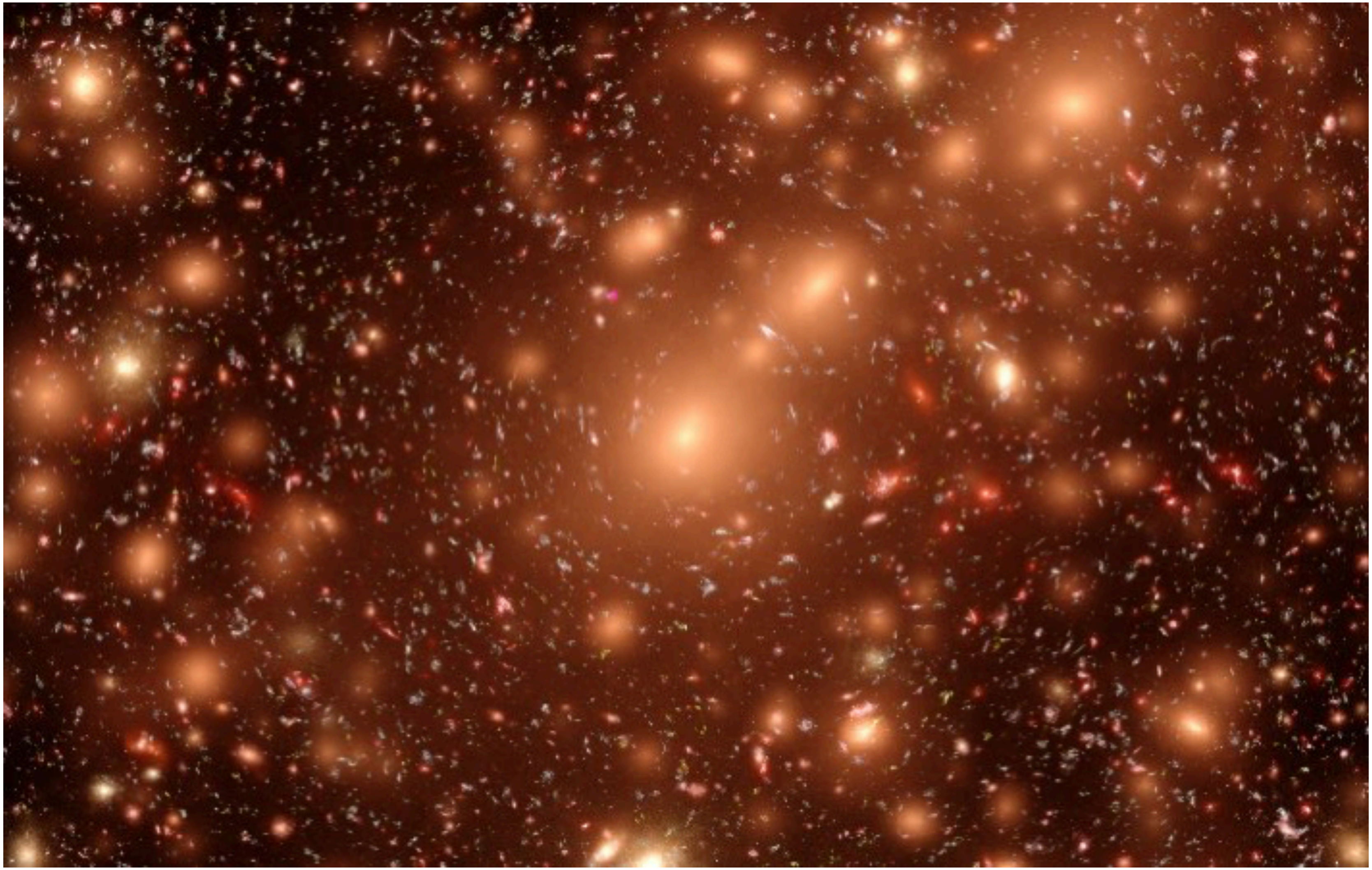
Mock images

No Lensing



Mock images

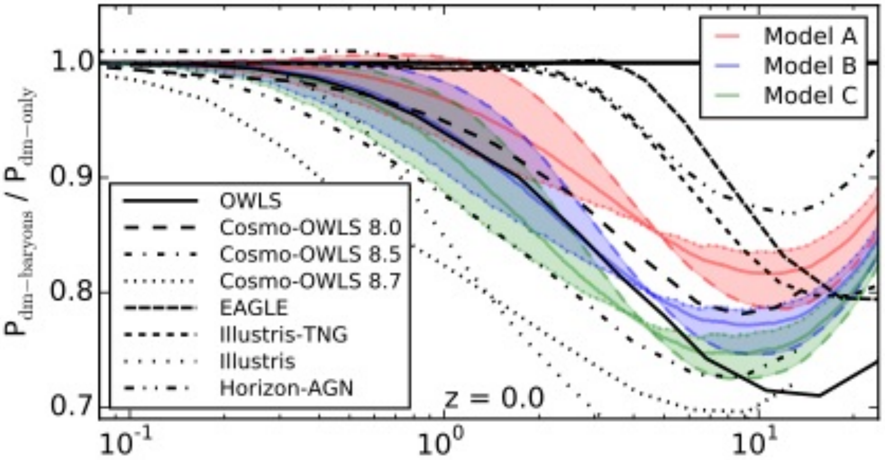
Lensing

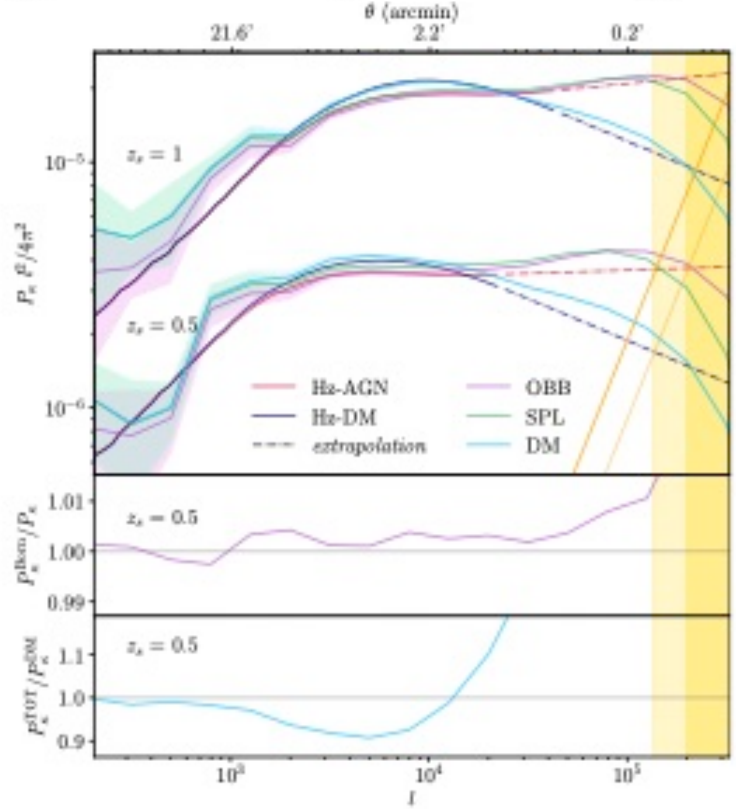


Conclusion

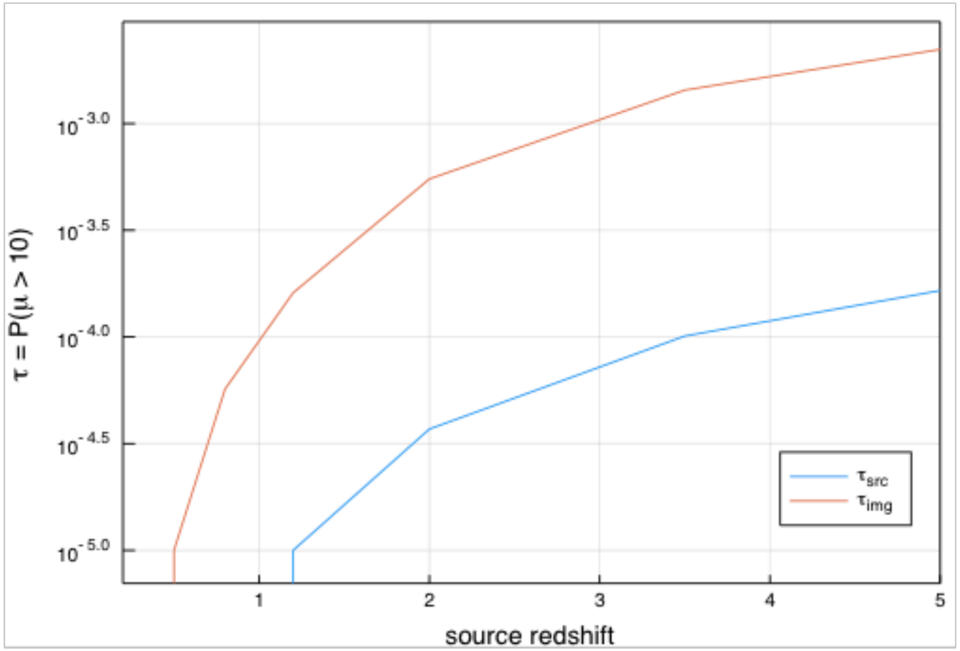
Baryons: significant role in 2-pt shear statistics

- >1% for k>0.1 h/Mpc, as high as 25% at 10 h/Mpc
- Gas distribution in clusters and groups (expelled fraction, how far?) captures main features (Schneider, Teyssier et al. 2015, 2019)
- Room for improvement in “Baryonic corrections”:
  - Cluster lensing to calibrate mass-observables
  - Diffuse gas distribution at $r>r_{500}$
  - Sub-grid physics and larger hydro-simulation boxes
- 3D→2D full raytracing: does not change picture
  - beyond-Born
  - reduced-shear
- Galaxy-Galaxy Lensing:
  - Magnification bias can bias 3x2pt high-z analyses and shear ratio tests.
- Wealth of information in mock images for end-to-end studies

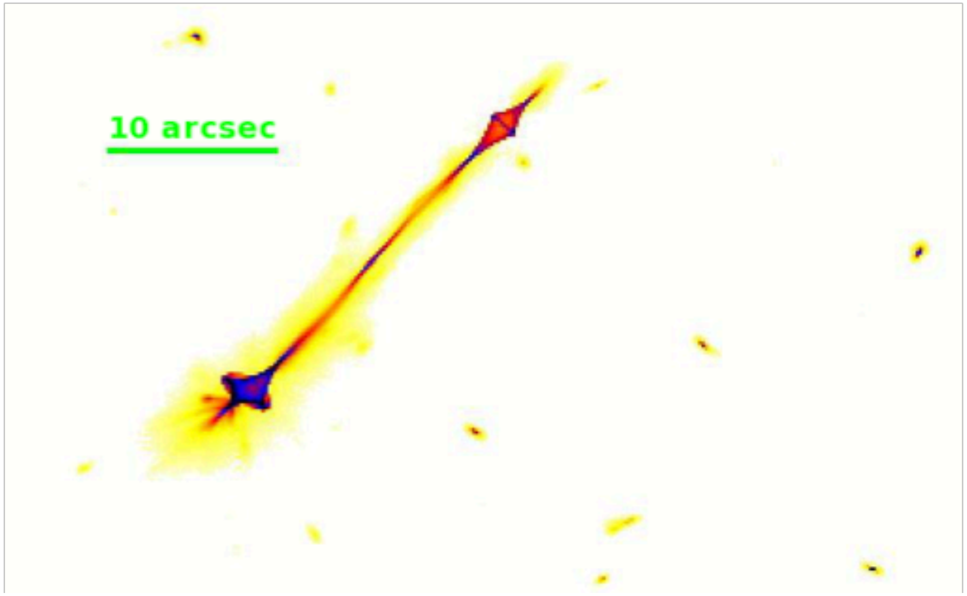




Strong lensing



Horizon-AGN has the resolution to probe internal structure of galaxies



$$\rho_{\rm dmo}(r) = \rho_{\rm nfw}(r) + \rho_{\rm 2h}(r).$$

$$\rho_{\rm dmb}(r) = \rho_{\rm gas}(r) + \rho_{\rm cga}(r) + \rho_{\rm clm}(r) + \rho_{\rm 2h}(r),$$

$$\rho_{\rm gas}(r) = \frac{\rho_{\rm gas,0}}{(1+u)^{\beta}(1+v^2)^{(7-\beta)/2}}$$

$v=r/r_{ej}$,
$r_{ej}= \theta_{eq}\, r_{200}$

$$\beta(M_{200}) = 3 - \left(\frac{M_{\rm c}}{M_{200}}\right)^{\mu}$$

Name	Comp.	Description	Equation	Status
$\theta_{\rm ej}$	Gas	Parameter specifying the maximum radius of gas ejection relative to the virial radius.	(2.12)	free
$\theta_{\rm co}$	Gas	Parameter specifying the core radius of the gas profile relative to the virial radius.	(2.12)	fixed
M_c	Gas	Parameter related to the slope of the gas profile: defines the characteristic mass scale where the slope becomes shallower than minus three.	(2.16)	free
μ	Gas	Parameter related to the slope of the gas profile: defines how fast the slope becomes shallower towards small halo masses.	(2.16)	free
A, M_1	Star	Parameters related to the stellar fractions: normalisation and slope of the power-law describing the halo mass dependence.	(2.11)	fixed
$\eta_{\rm star}$	Star	Parameter specifying the total stellar fraction within a halo (including central galaxy, satellites, and halo stars).	(2.11)	free
$\eta_{\rm cga}$	Star	Parameter specifying the stellar fraction of the central galaxy.	(2.11)	free
R_h	Star	Parameter specifying the truncation radius of the central galaxy.	(2.10)	fixed
ε	DM	Parameter specifying the truncation radius of the NFW profile.	(2.6)	fixed
a, n	DM	Parameters related to adiabatic relaxation of the dark matter (including galaxy satellites and halo stars).	(2.17)	fixed
q, p	2-halo	Standard parameters specifying the 2-halo term (excursion-set modelling).	(2.9)	fixed

Born approximation

Implicit equation for the source plane angular coordinates:
Integrates deflections along perturbed light rays

$$\boldsymbol{\beta}(\boldsymbol{\theta},\chi_{\rm s}) = \boldsymbol{\theta} - \frac{2}{c^2}\int_0^{\chi_{\rm s}} {\rm d}\chi\, \frac{\chi_{\rm s}-\chi}{\chi_{\rm s}\,\chi} \boldsymbol{\nabla}_{\beta}\phi\,(\boldsymbol{\beta}(\boldsymbol{\theta},\chi),\chi)$$

Born Approximation: Integrates deflections along unperturbed light rays

$$\boldsymbol{\beta}(\boldsymbol{\theta},\chi_{\rm s}) = \boldsymbol{\theta} - \frac{2}{c^2}\int_0^{\chi_{\rm s}} {\rm d}\chi\, \frac{\chi_{\rm s}-\chi}{\chi_{\rm s}\,\chi} \boldsymbol{\nabla}_{\theta}\phi\,(\boldsymbol{\theta},\chi)$$