KiDS and biases

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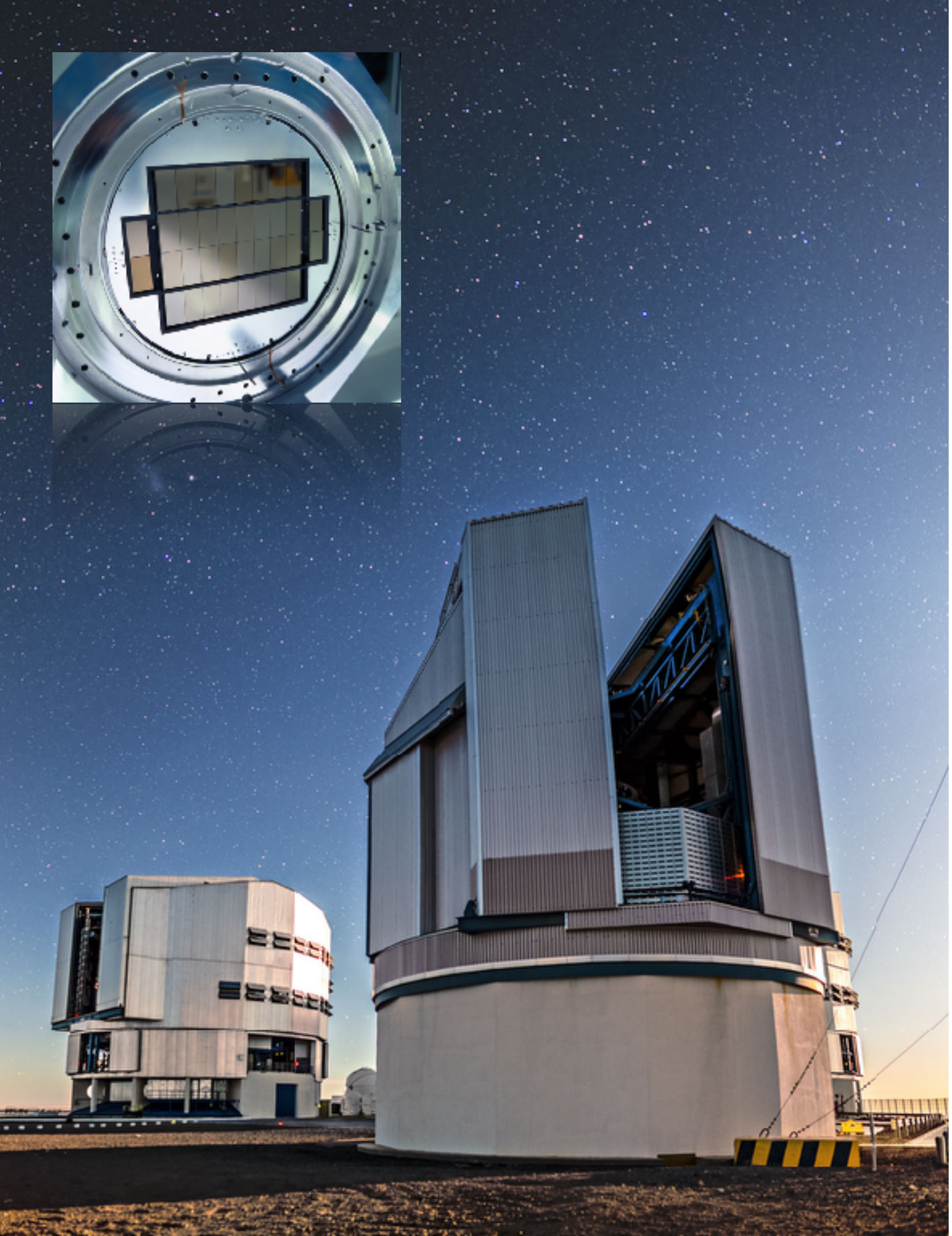
UC Berkeley/LBL, INPA, 19. 11. 2018
+ Marcello Cacciato, Massimo Viola, Konrad Kuijken, Henk Hoekstra & other KiDS

Universiteit Leiden
KiDS

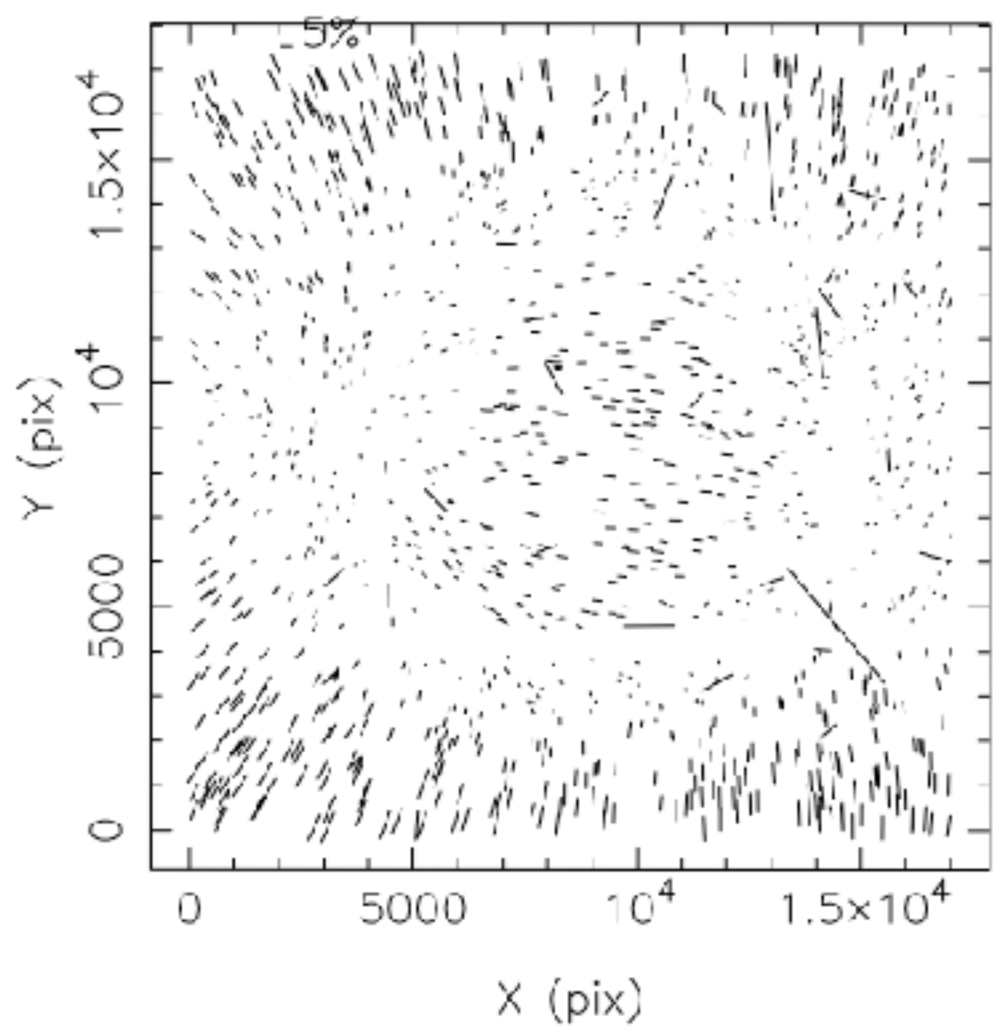
Picture credit: KiDS & Alex Tudorica

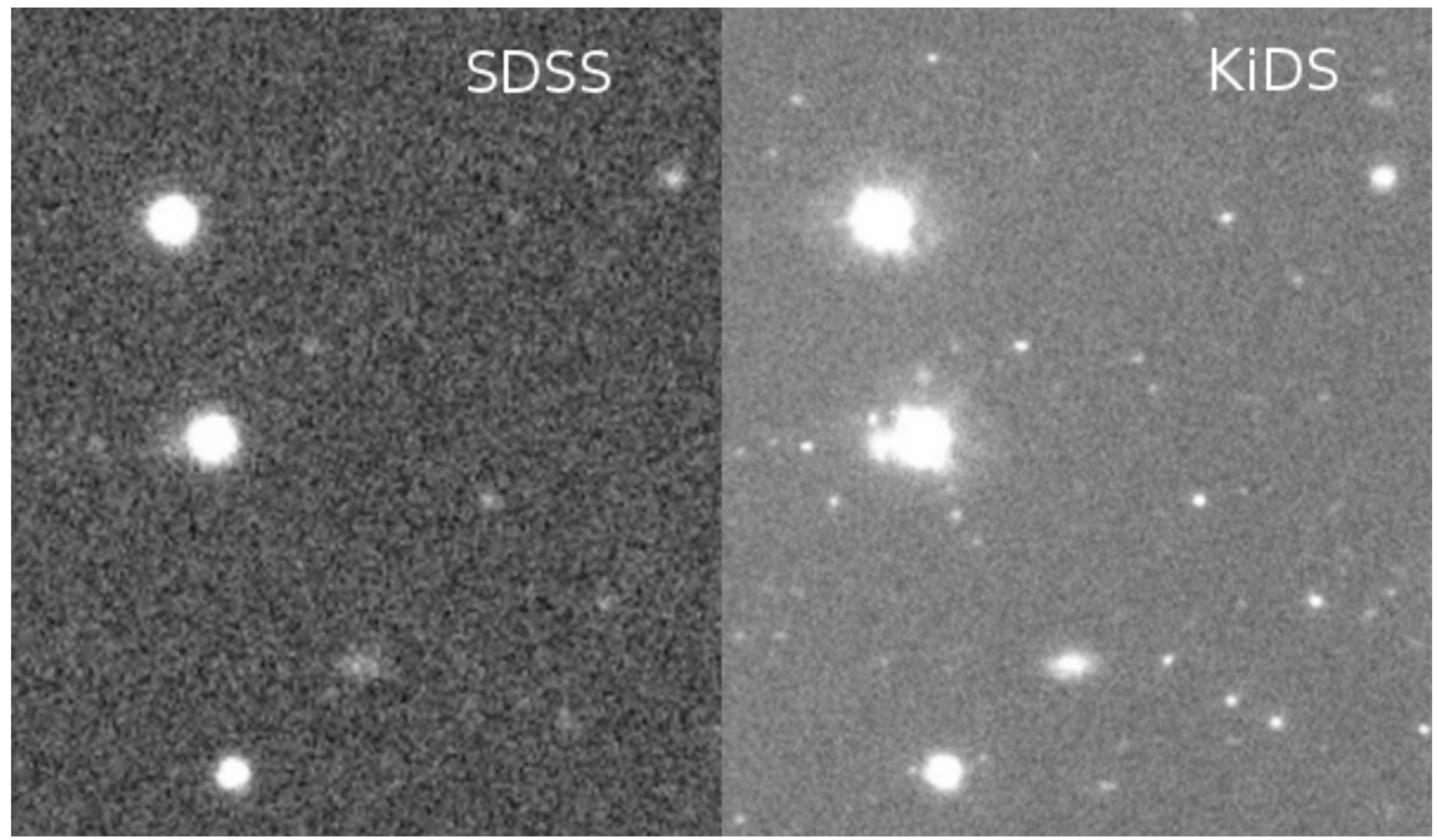


KiDS

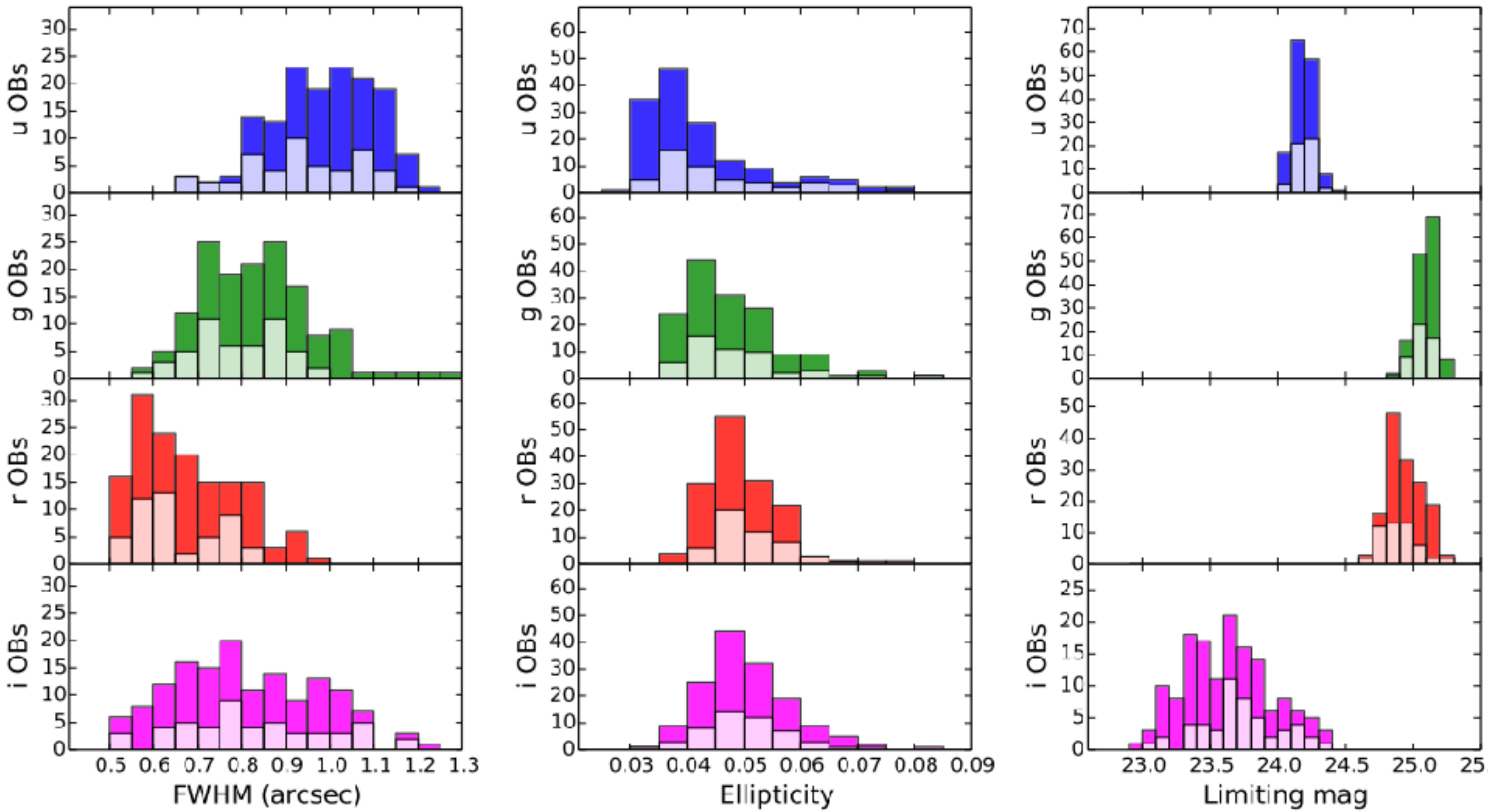
- 2.6m f/5.5 VST telescope, Paranal, Chile
- OmegaCAM: 32 CCD, 268 Mpix
- ~1350 deg^2 at the end
- u, g, r, i photometric bands
- Overlap with VIKING, SDSS, 2dF, COSMOS, GAMA, DEEP2

Designed with weak lensing in mind





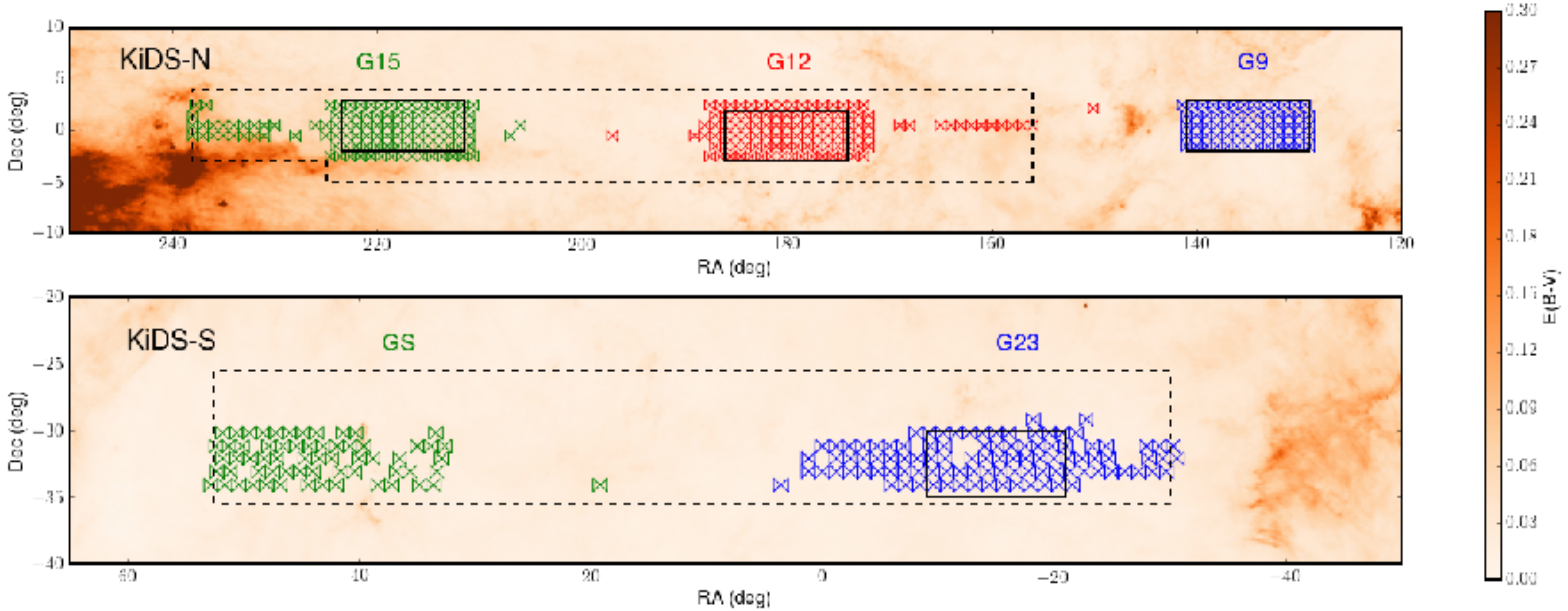
2 magnitudes deeper than SDSS (24.3, 25.1, 24.9, 23.8 in *ugri*), with sharper images



Seeing

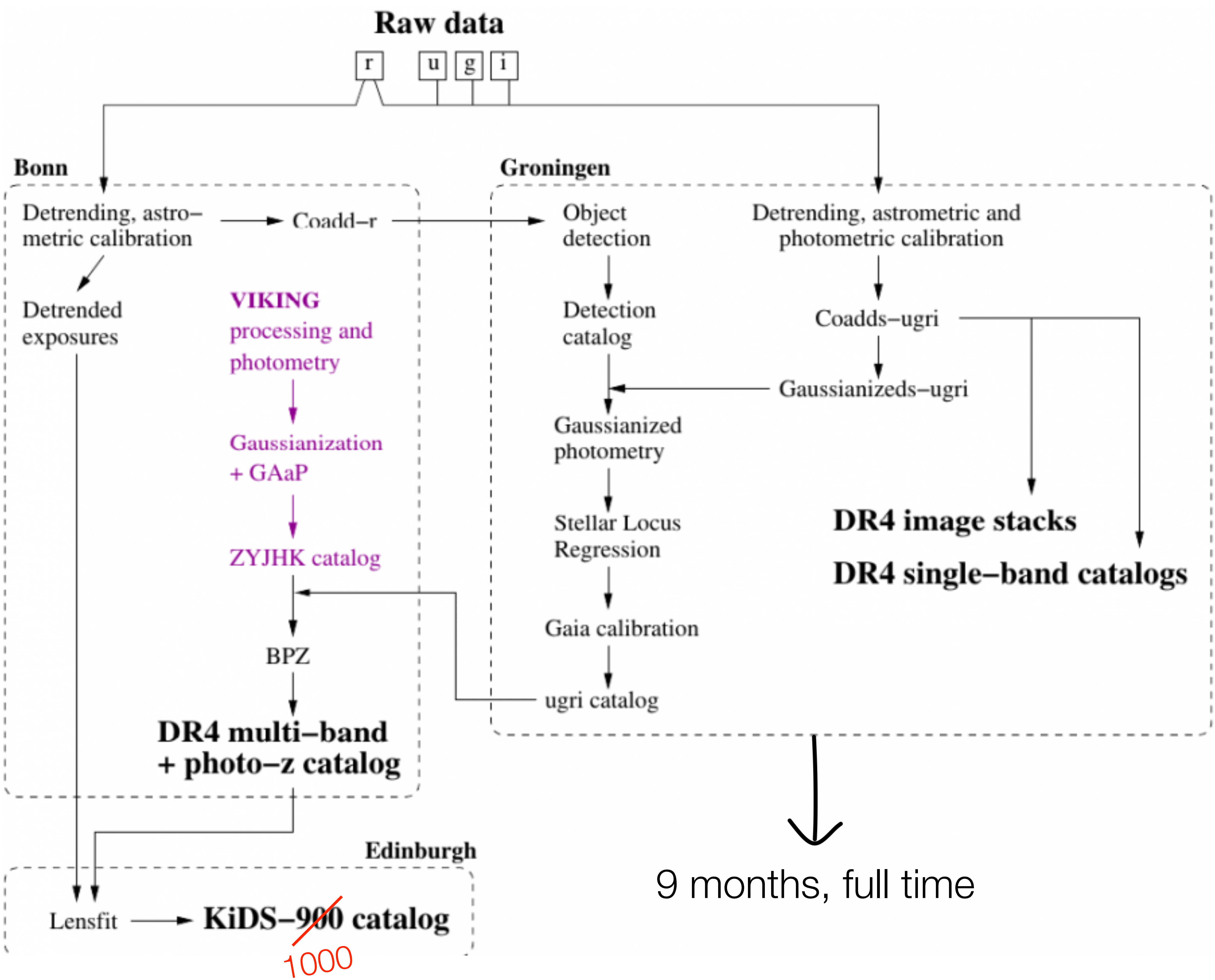
PSF

de Jong et al. 2017



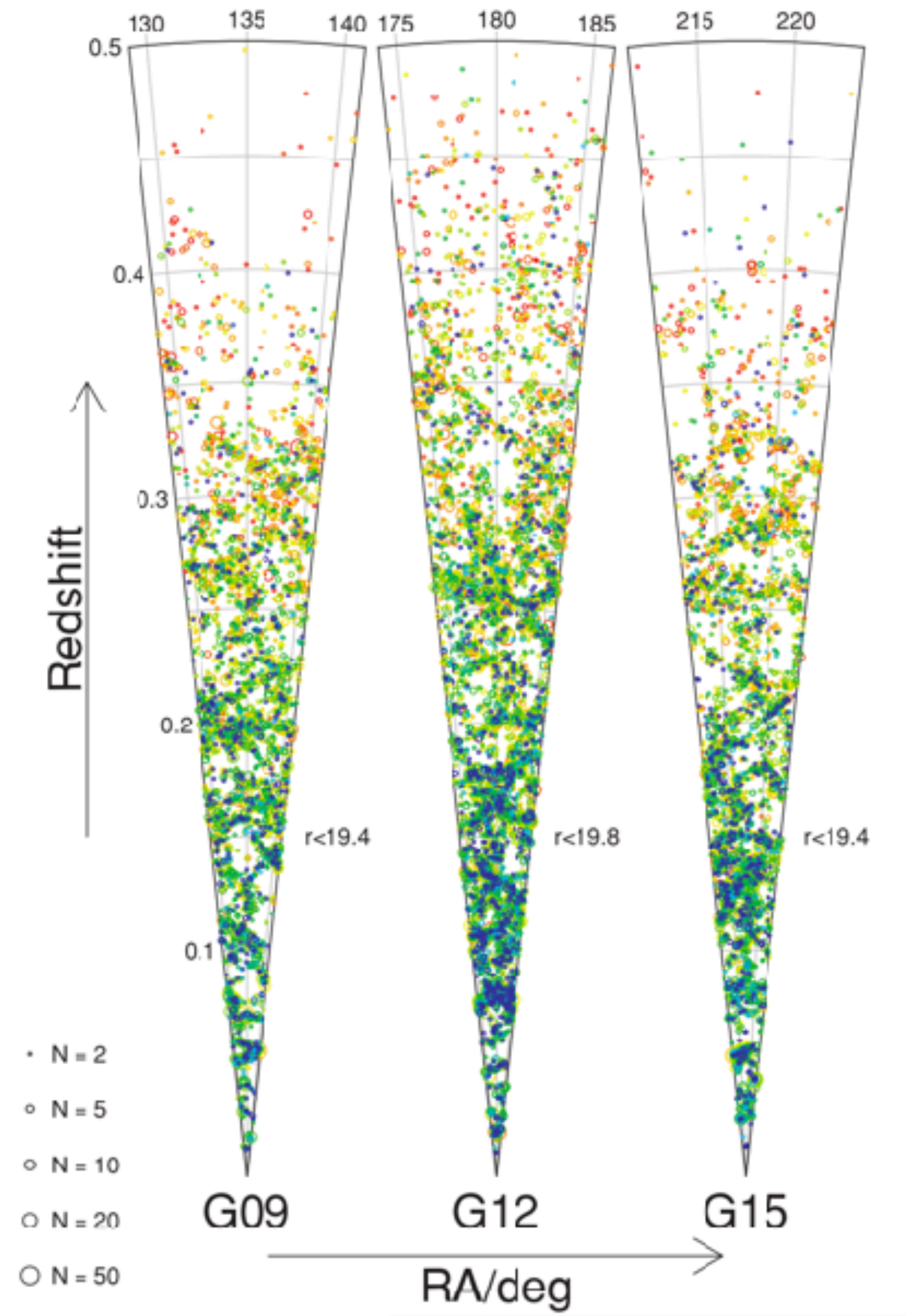
- Currently: 450 deg² (published, public), 1000+ deg²

- Redshift (median): ~0.6


Raw data
r
u
g
i
Bonn
Detrending, astro–metric calibration
Coadd–r
Detrended exposures
VIKING processing and photometry
Gaussianization + GAaP
ZYJHK catalog
BPZ
DR4 multi–band + photo–z catalog
Groningen
Object detection
Detection catalog
Gaussianized photometry
Stellar Locus Regression
Gaia calibration
ugri catalog
Detrending, astrometric and photometric calibration
Coadds–ugri
Gaussianizeds–ugri
DR4 image stacks
DR4 single–band catalogs
Edinburgh
Lensfit
KiDS–900 catalog
1000
9 months, full time

GAMA survey

- Spectroscopic survey on AAT
- Highly complete down to *r*-band magnitude of 19.8
- 180 deg^2 of overlap with KiDS
- Group information using FoF



Robotham et al. 2011

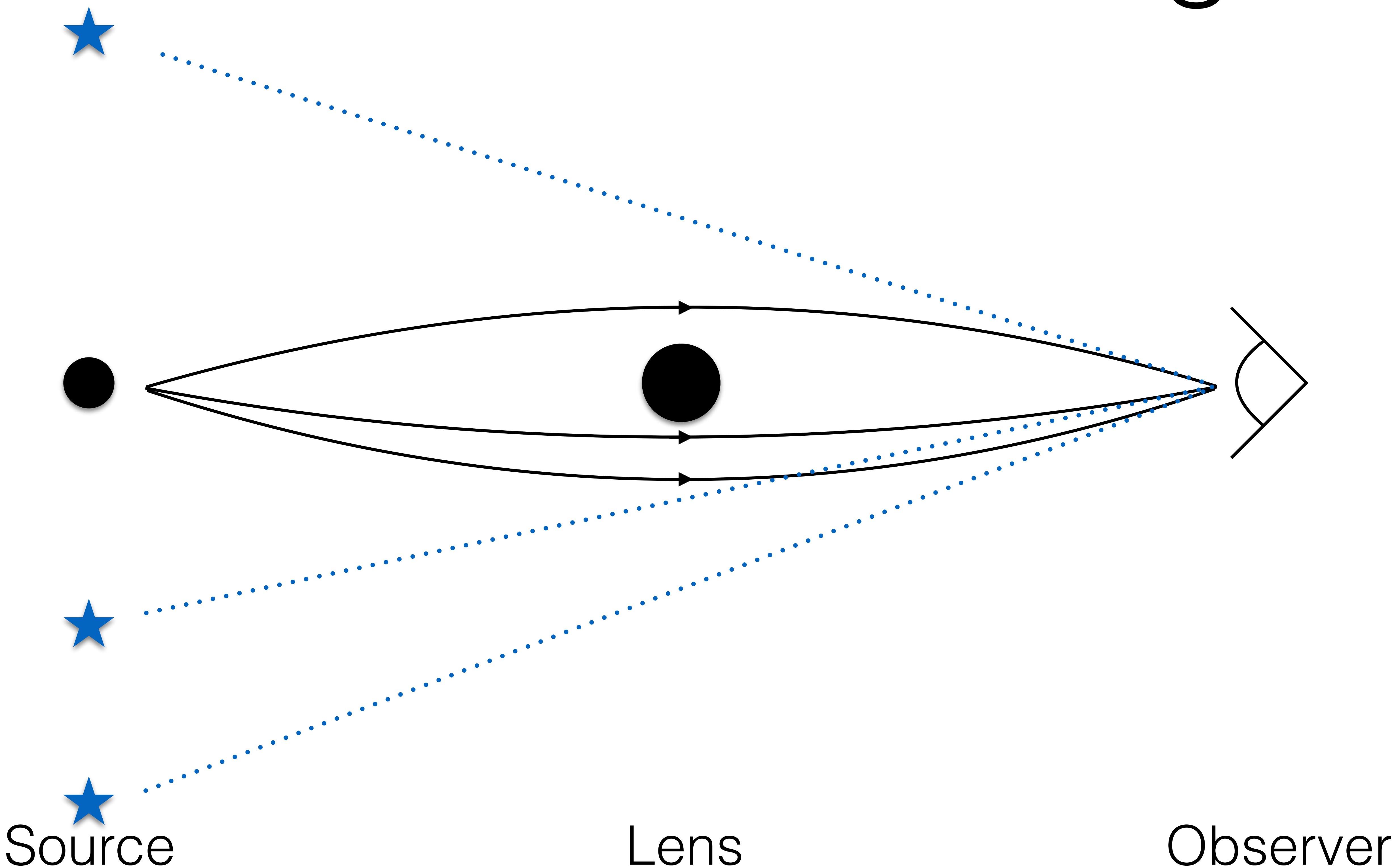
Why?

Cosmology!

Observational cosmology

- CMB (WMAP, Planck, Bicep, …)
- Distance measurements with supernovae
- Baryonic acoustic oscillations (WiggleZ, BOSS, …)
- Redshift space distortions (WiggleZ, 2dFLenS, …)
- Weak gravitational lensing (KiDS, CFHTLenS, DES, HSC, SDSS, …)

Gravitational lensing

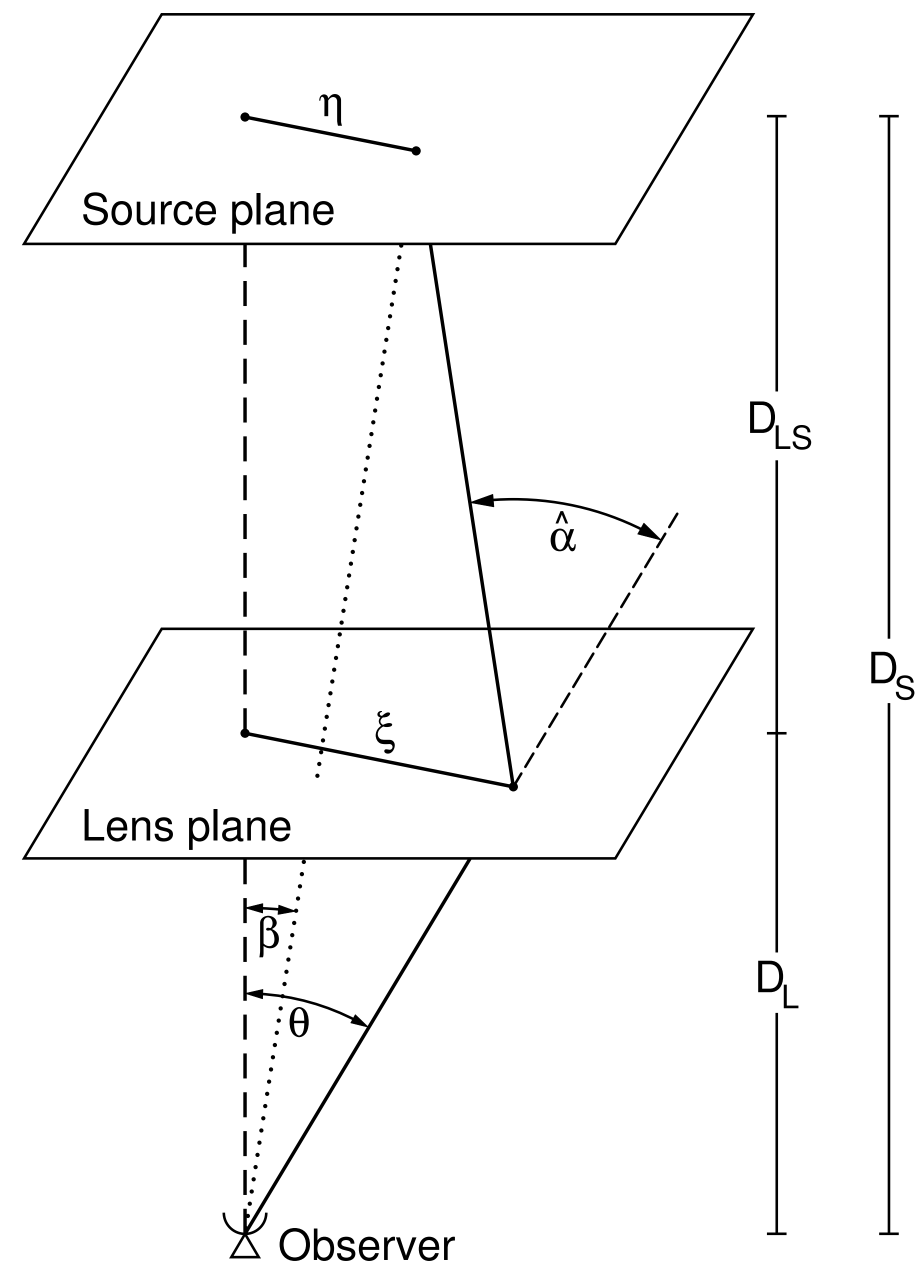


Gravitational lensing

- Lensing equation:

$$\vec{\beta} = \vec{\theta} - \frac{D_{LS}}{D_S}\hat{\vec{\alpha}} \equiv \vec{\theta} - \vec{\alpha}$$

- Non-linear: Strong lensing
- Linear: Weak lensing

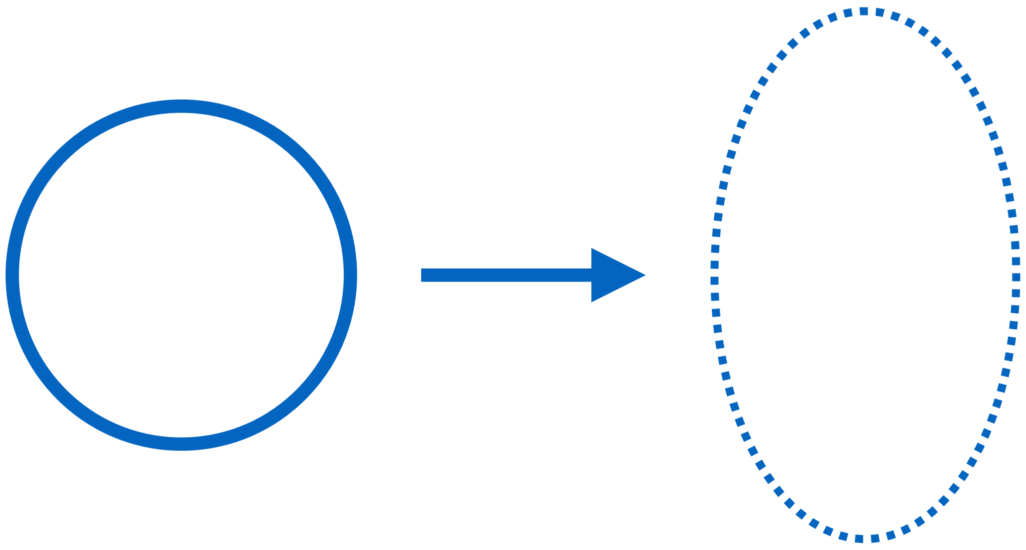


Gravitational lensing

$$\mathcal{A} = \begin{pmatrix} 1 - \kappa - \gamma_1 & -\gamma_2 \\ -\gamma_2 & 1 - \kappa + \gamma_1 \end{pmatrix}$$

- Shear

$$\gamma \equiv \gamma_1 + i\gamma_2 = \frac{1}{2}\left(\frac{\partial^2 \Psi}{\partial x_1^2} - \frac{\partial^2 \Psi}{\partial x_2^2}\right) + i\frac{\partial^2 \Psi}{\partial x_1 \partial x_2}$$



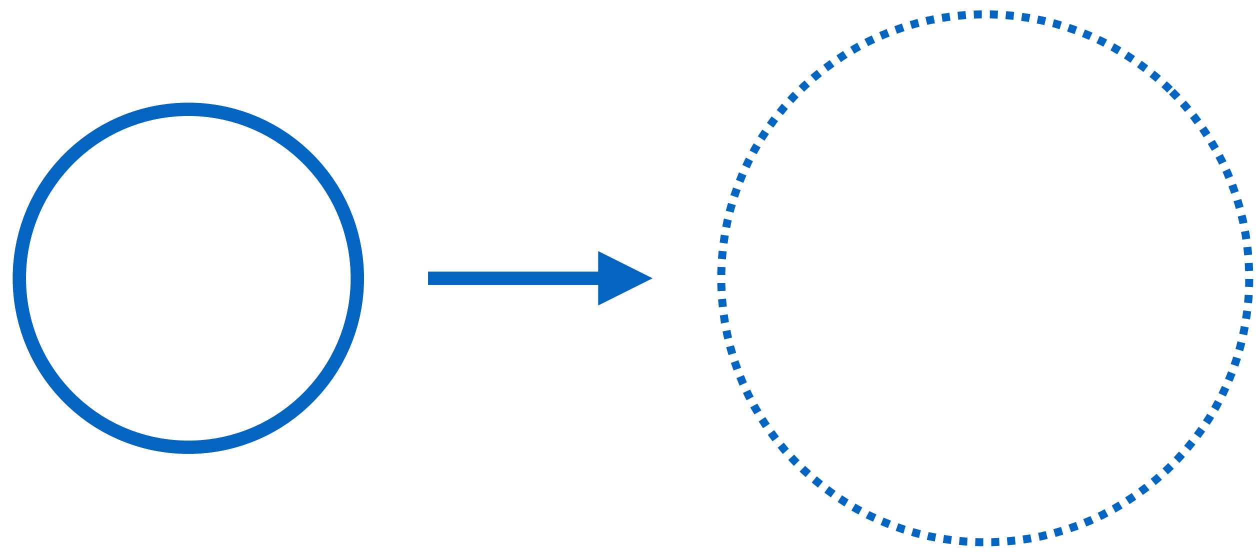
Gravitational lensing

- Dimensionless surface density (convergence):

$$\kappa(\vec{\theta}) = \frac{\Sigma(D_L\vec{\theta})}{\Sigma_{cr}}$$

where

$$\Sigma_{cr} = \frac{c^2}{4\pi G}\frac{D_S}{D_L D_{LS}}$$



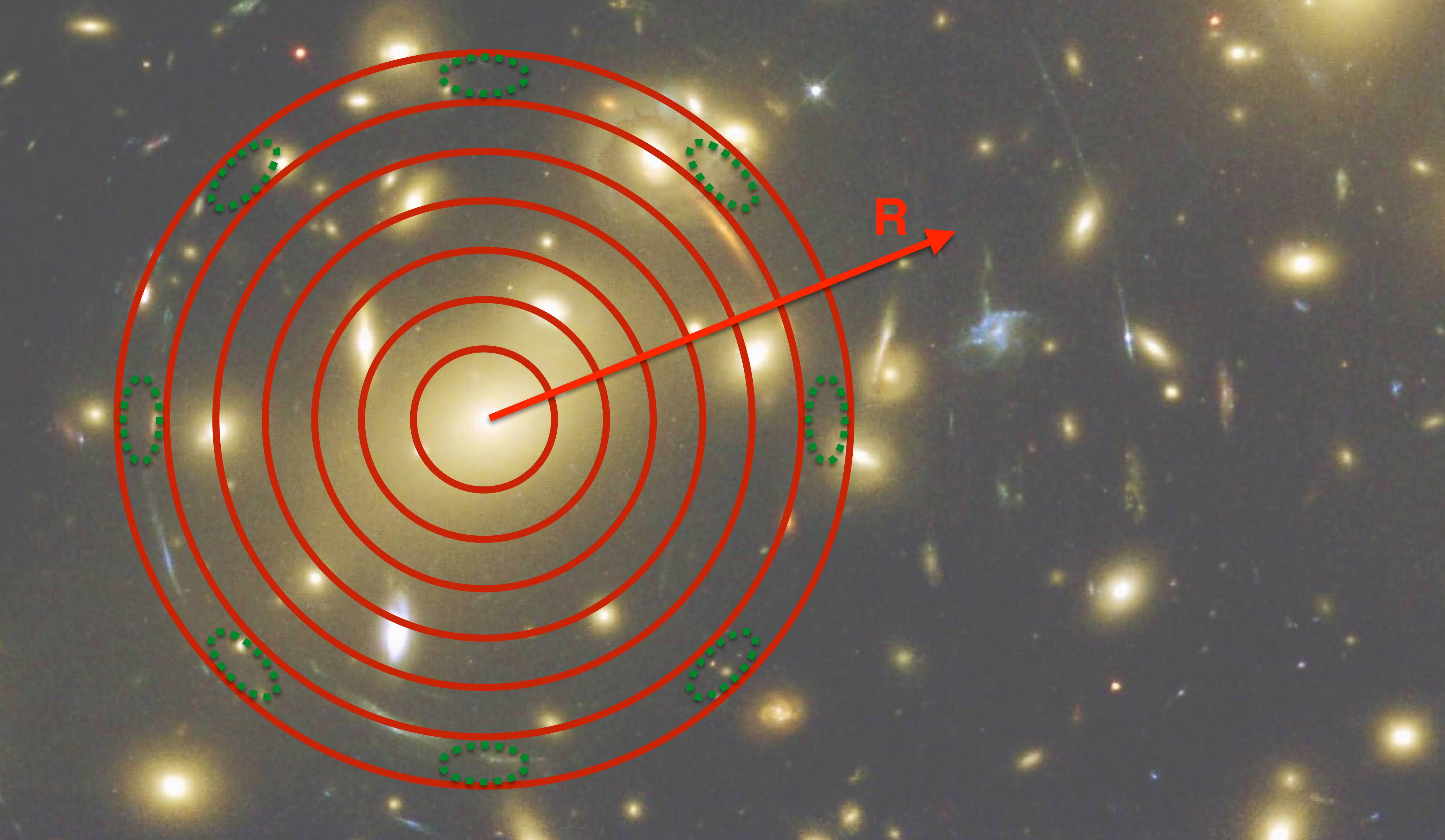
Shear measurements

$$\gamma \approx \langle \epsilon \rangle$$

$$\gamma_i^{\mathrm{obs}} = (1+m)\gamma_i^{\mathrm{true}} + c$$

+ additional complications

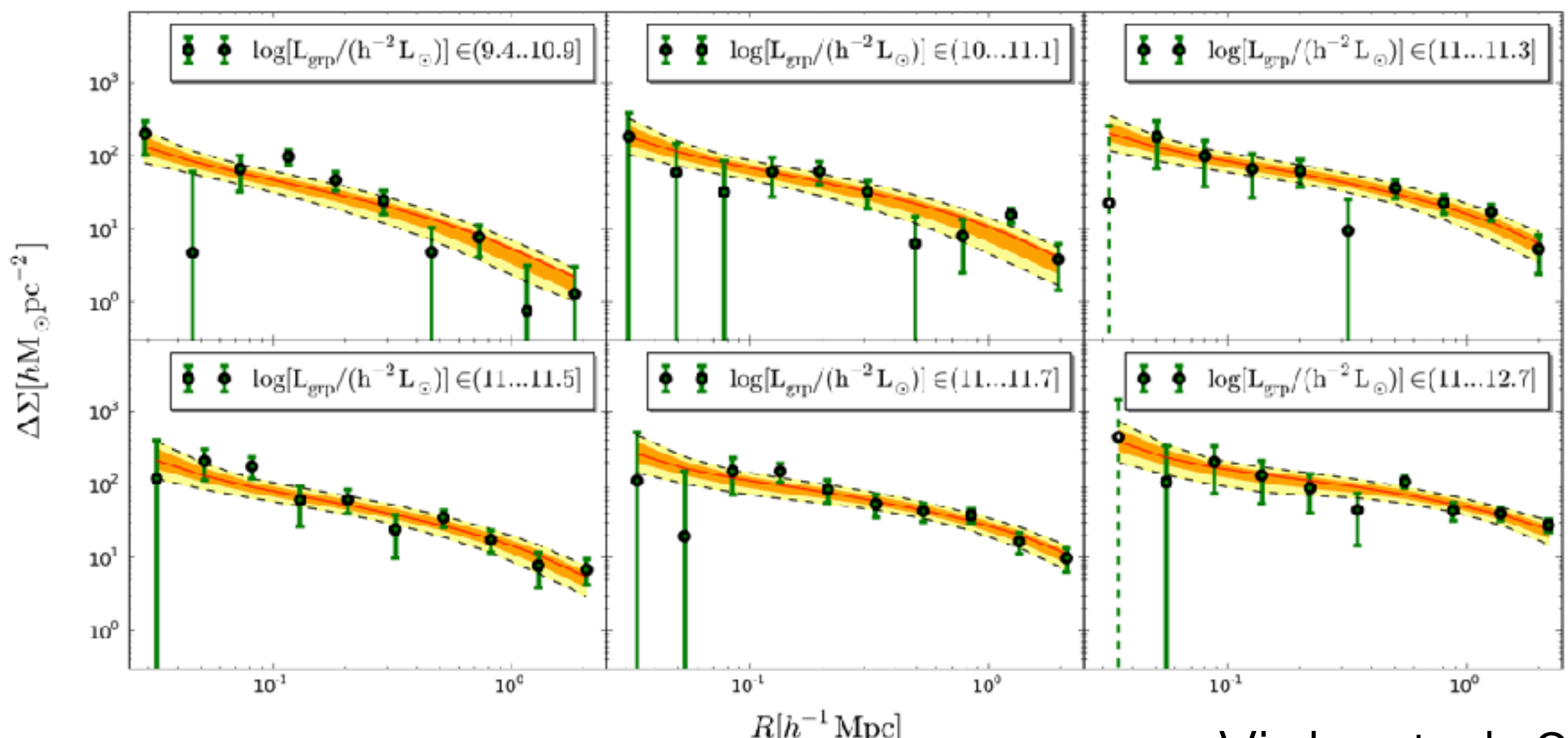
Galaxy-galaxy lensing



This allows us to

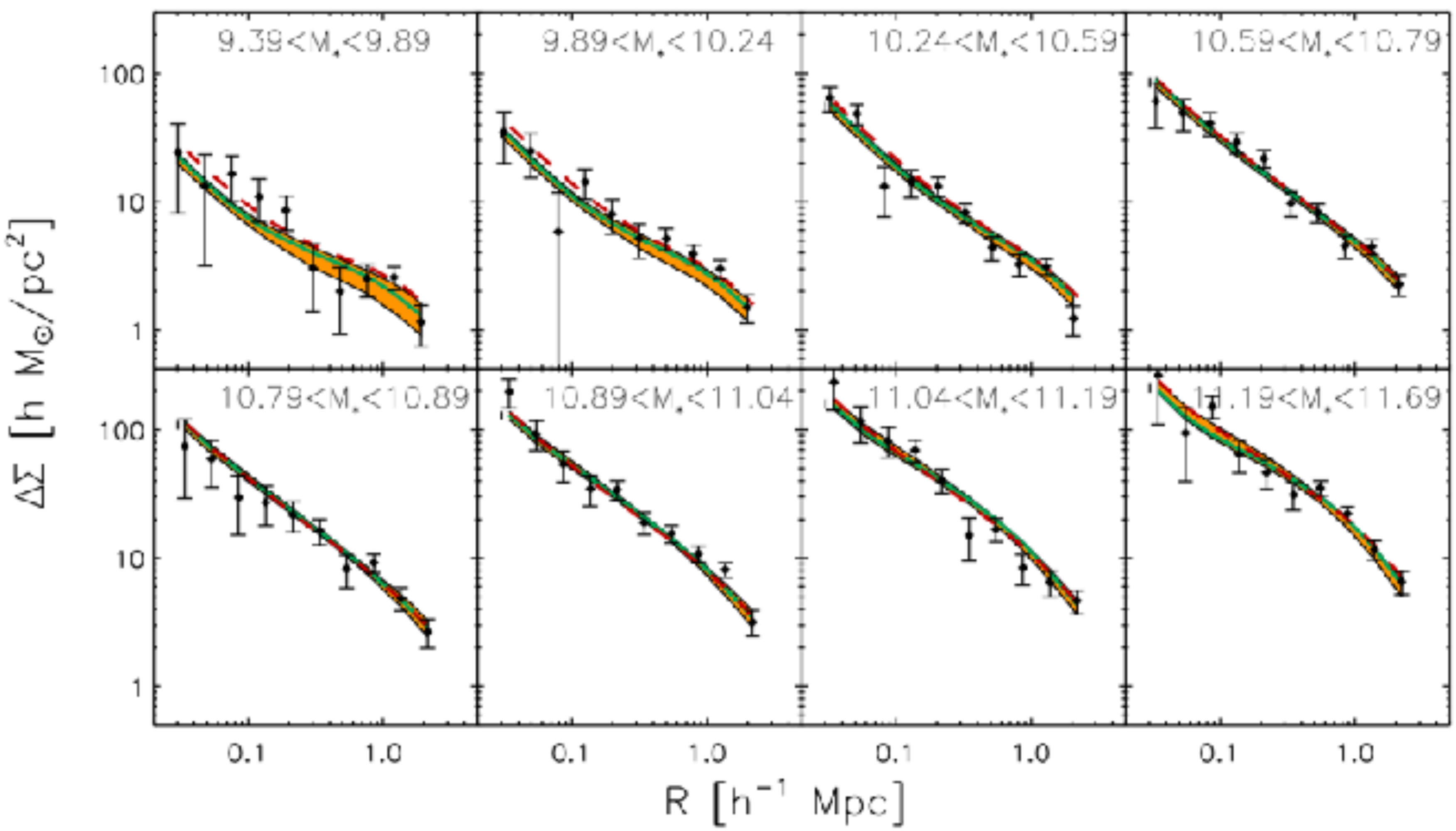
- Directly measure the mass of dark matter (all the matter in fact)
- Test the non-linear structure formation in the Universe (time dependent clustering, effect of baryons and neutrinos, …)
- Test the theory of gravity and it’s modifications

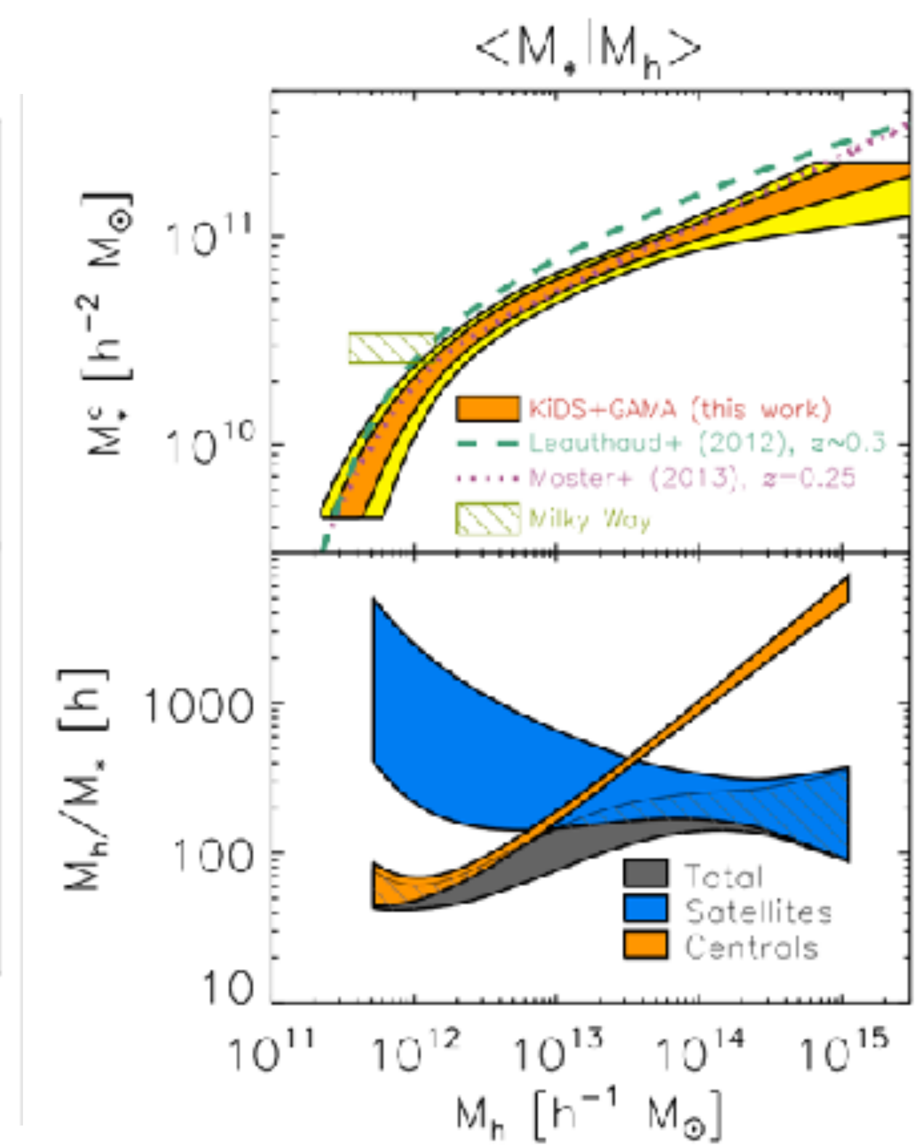
Scaling relations of GAMA groups



Viola et al. 2015

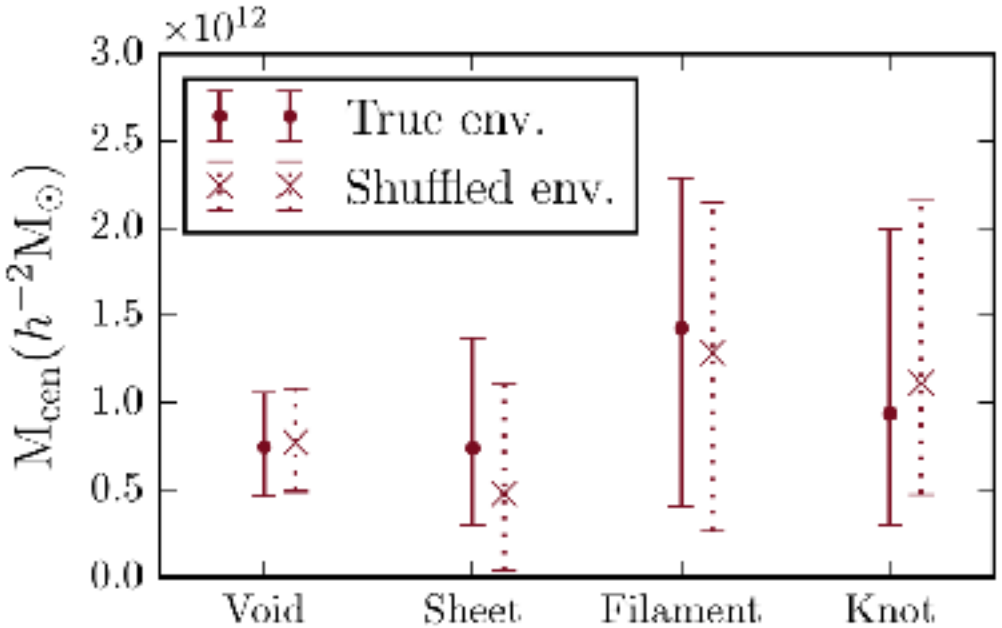
Probing the stellar-to-halo mass relation



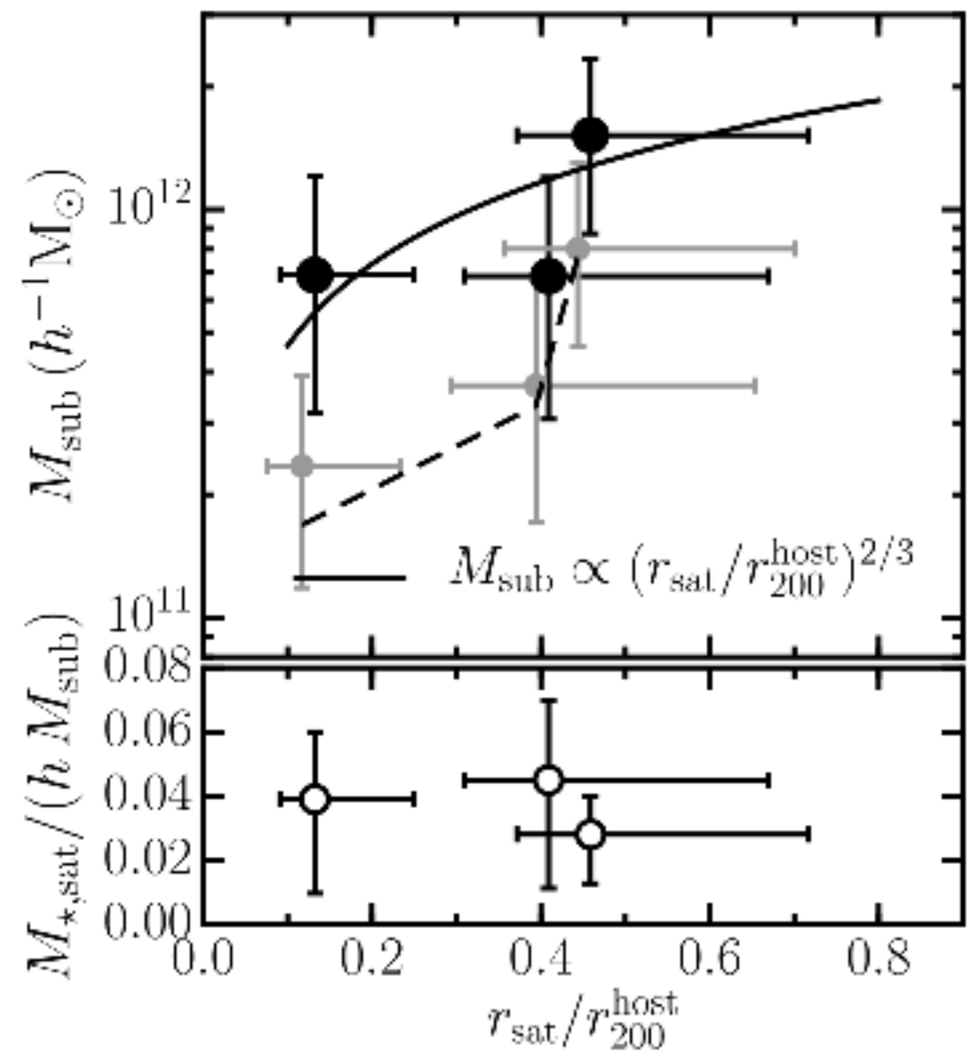


van Uitert et al. 2016

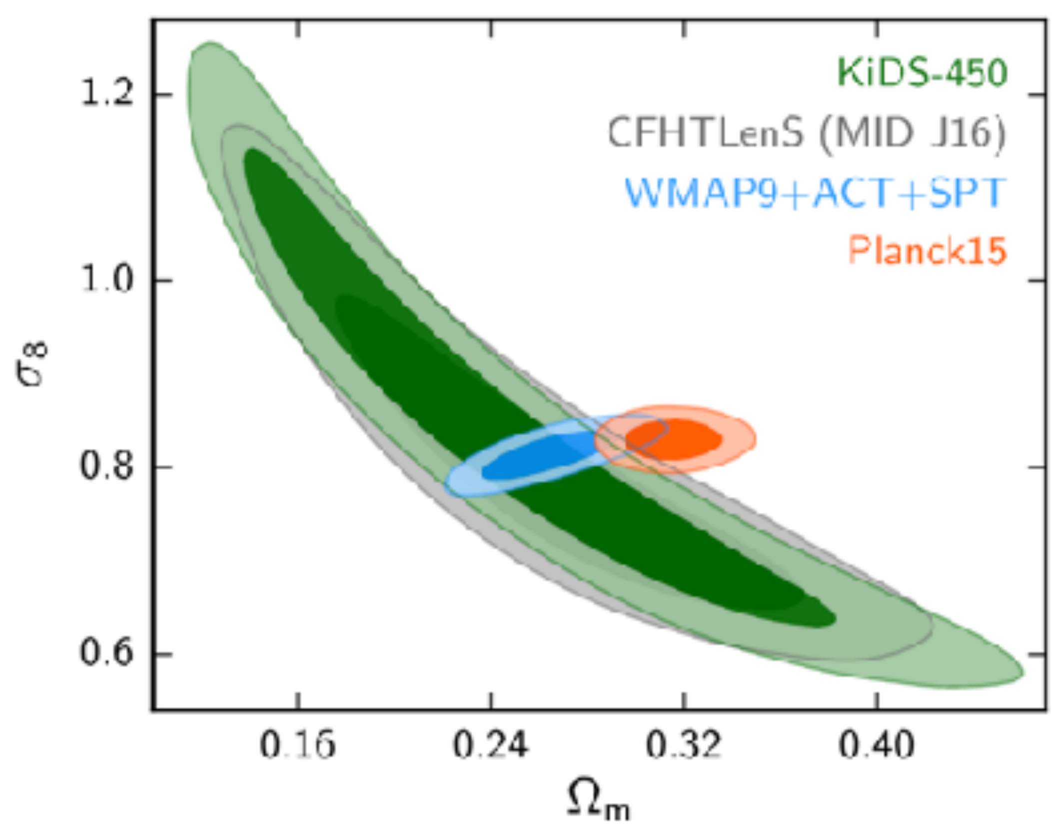
and many more ...



Brouwer et al. 2016



Sifón et al. 2015



Hildebrandt et al. 2017

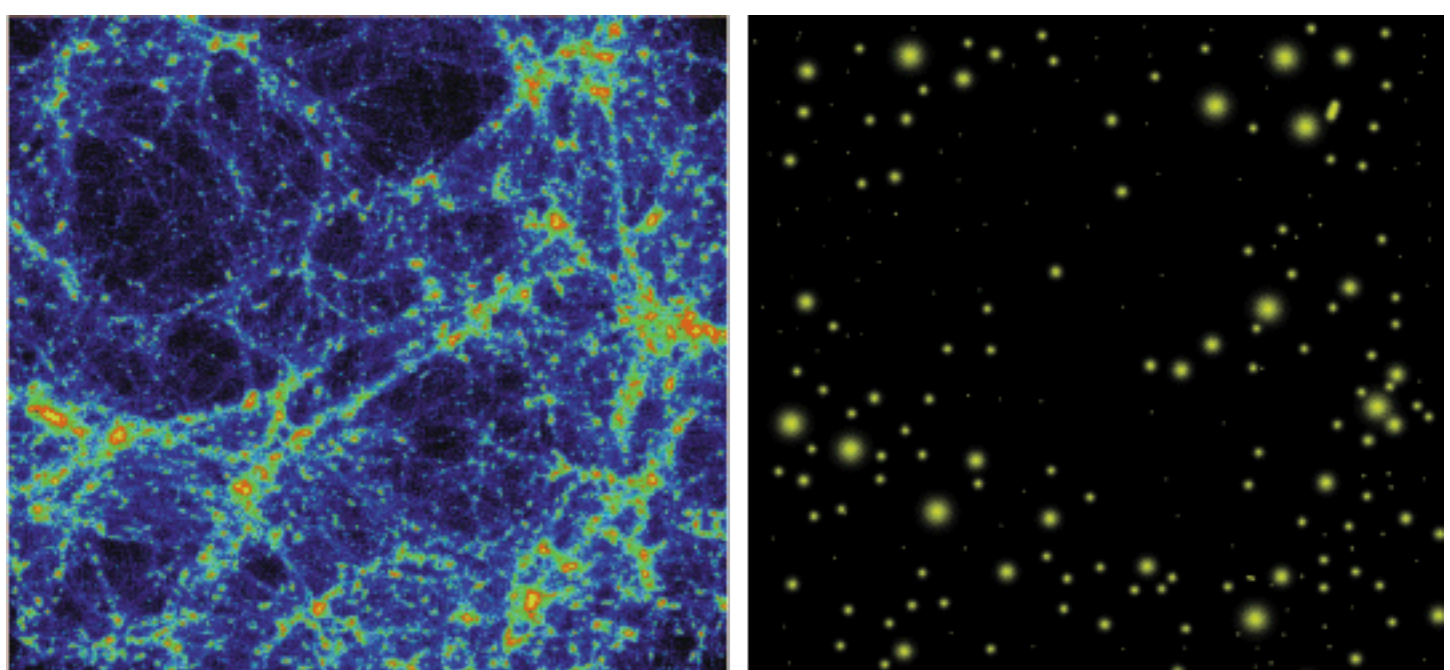
Halo model

Assumption

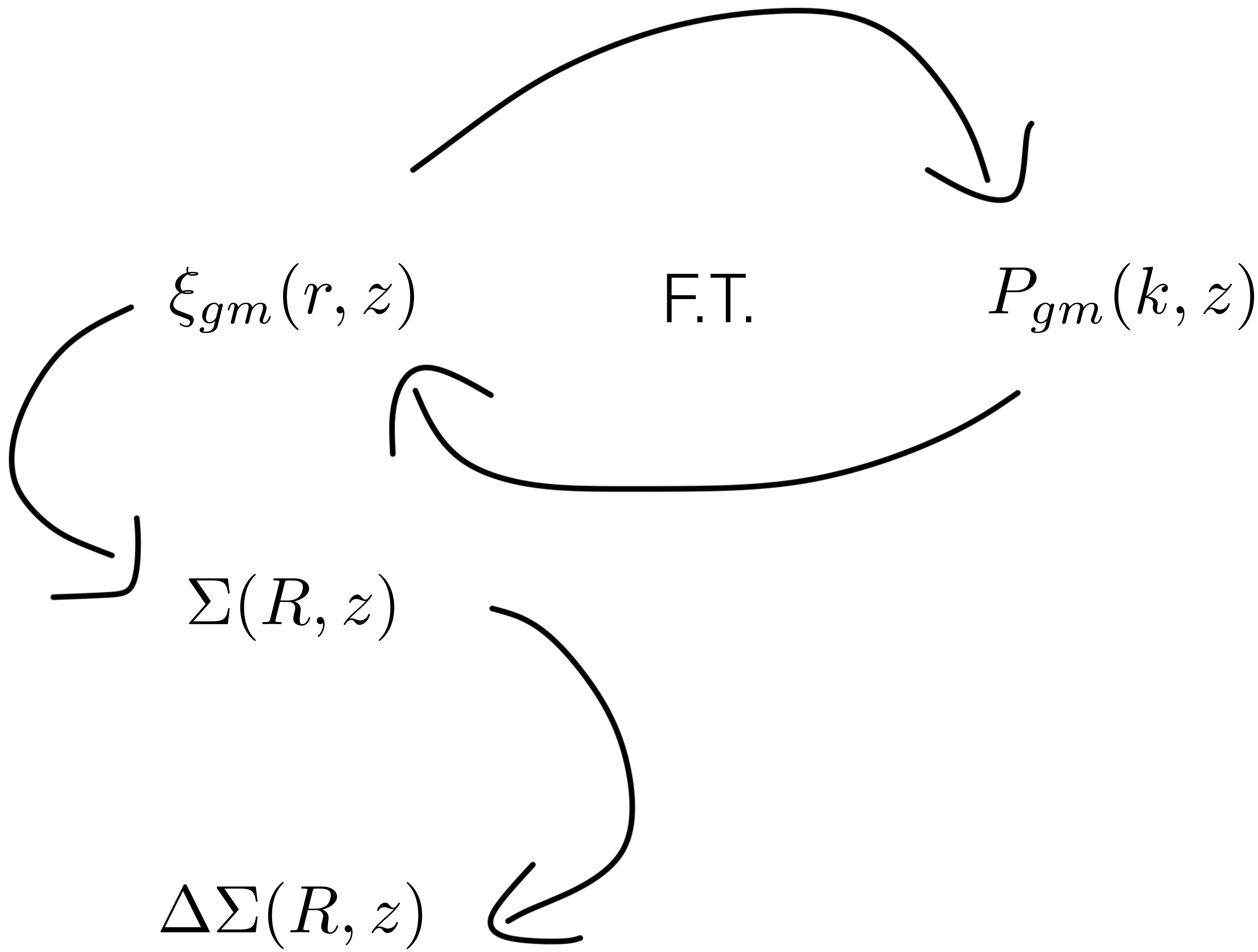
All the matter in the Universe is in haloes

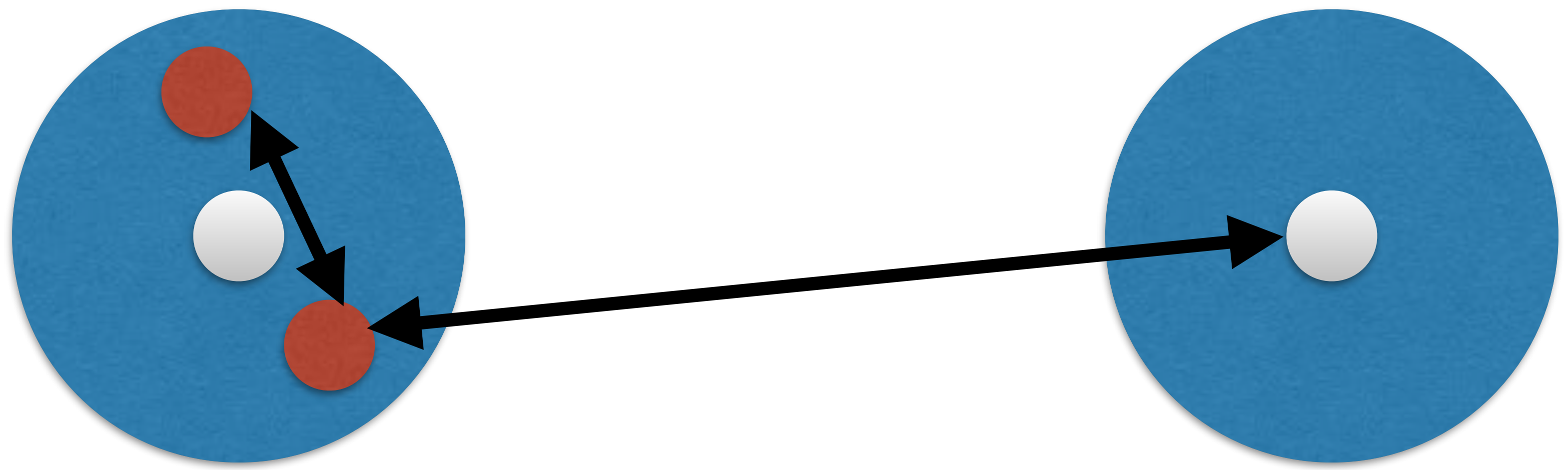
↓

Use the halo properties to describe the statistical properties of observed matter distribution



Cooray & Sheth (2002)


$\xi_{gm}(r, z)$
F.T.
$P_{gm}(k, z)$
$\Sigma(R, z)$
$\Delta\Sigma(R, z)$



$$P(k,z) \propto \int \mathrm{d}M\, n(M)\, u(k\,|\,M)\, \langle N\,|\,M\rangle$$

Halo mass function

Density profile

HOD

Halo Assembly Bias

- Halo mass - property of halos that most strongly influences the properties of galaxies within them

- But! - as seen in simulations, spatial distribution depends also on other properties (i.e. formation time, concentration, star formation rate, …)

- Dependence of the spatial distribution of DM halos upon properties beside mass

Assembly Bias

What we are after

↓

Violation of standard halo model assumption

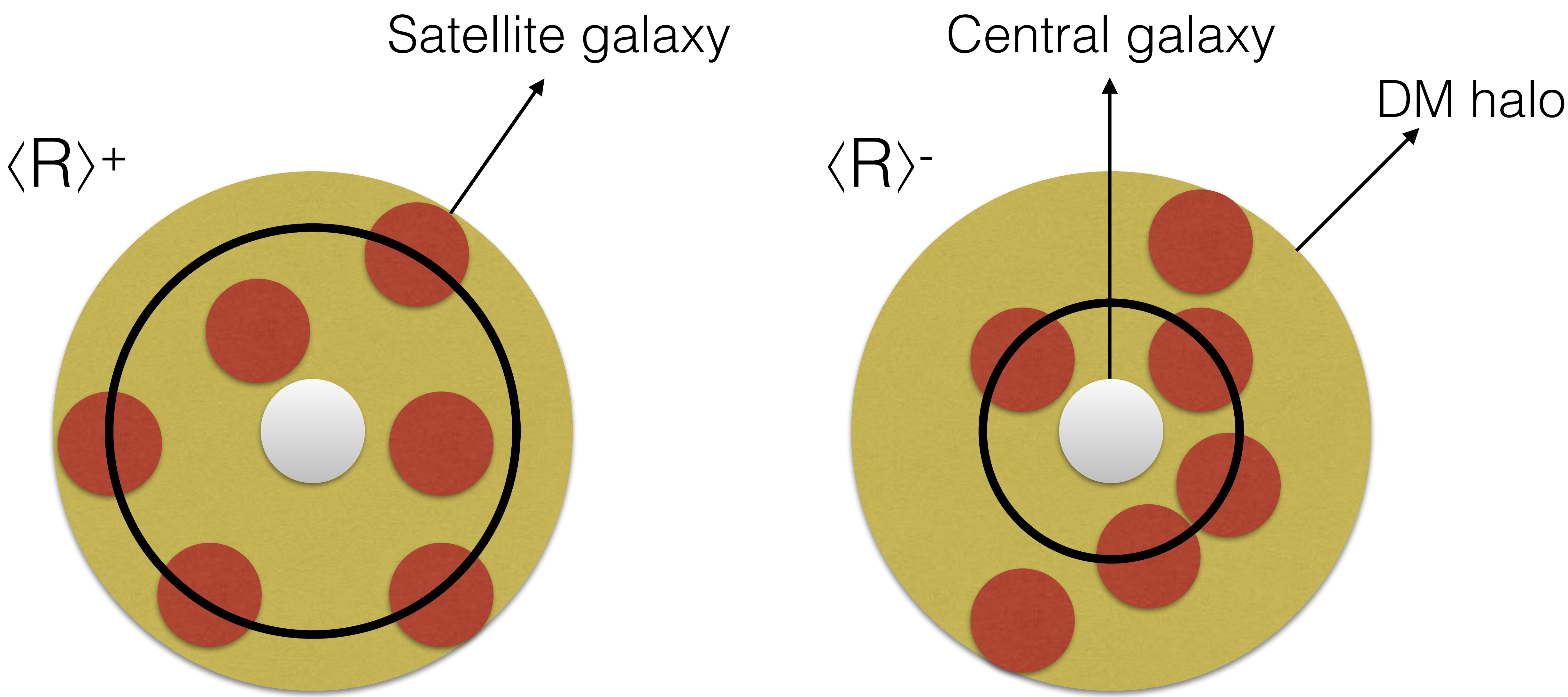
↓

Halo model not able to predict the lensing and clustering correctly

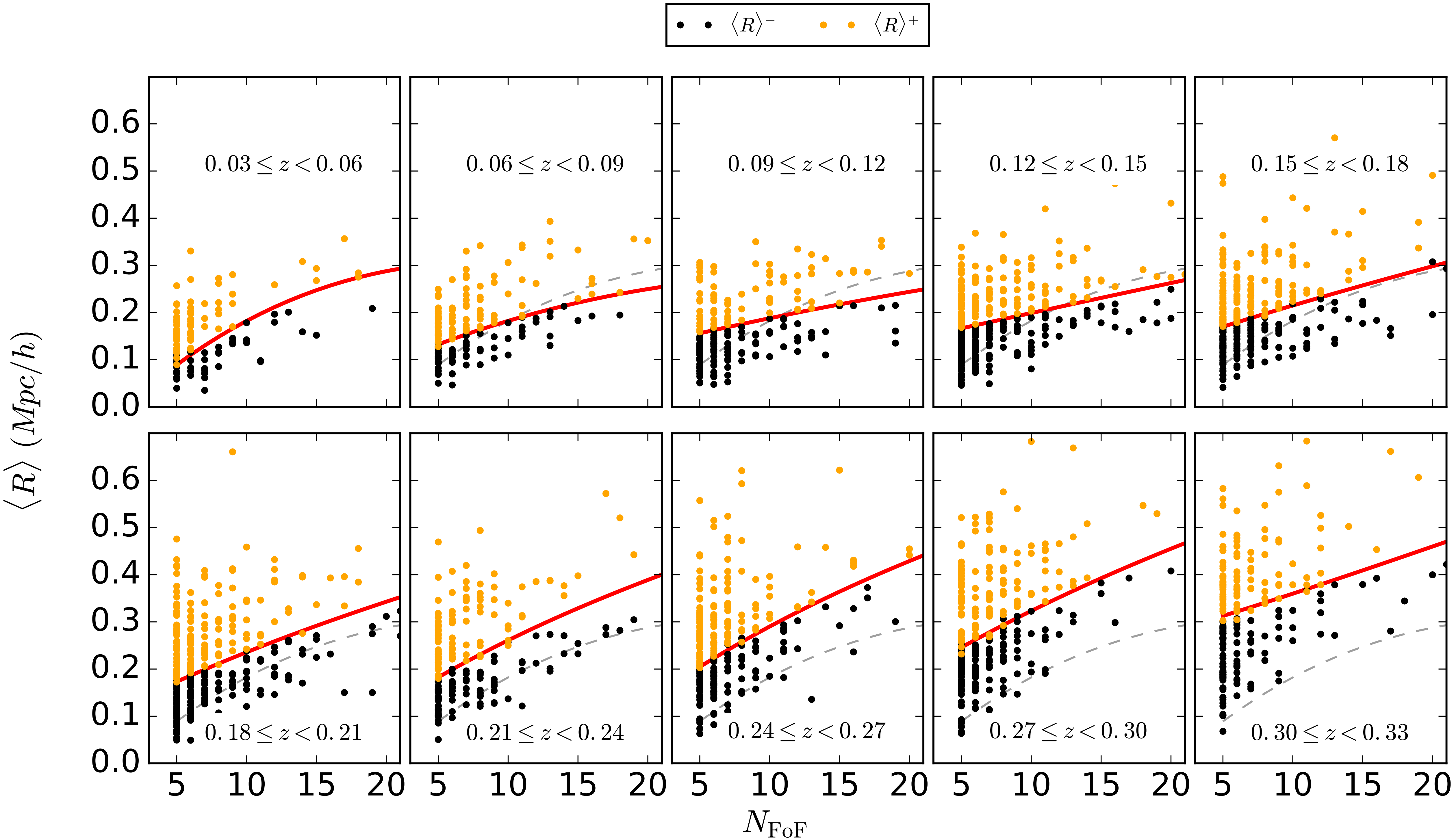
↓

Manifestation in the data as different lensing profiles

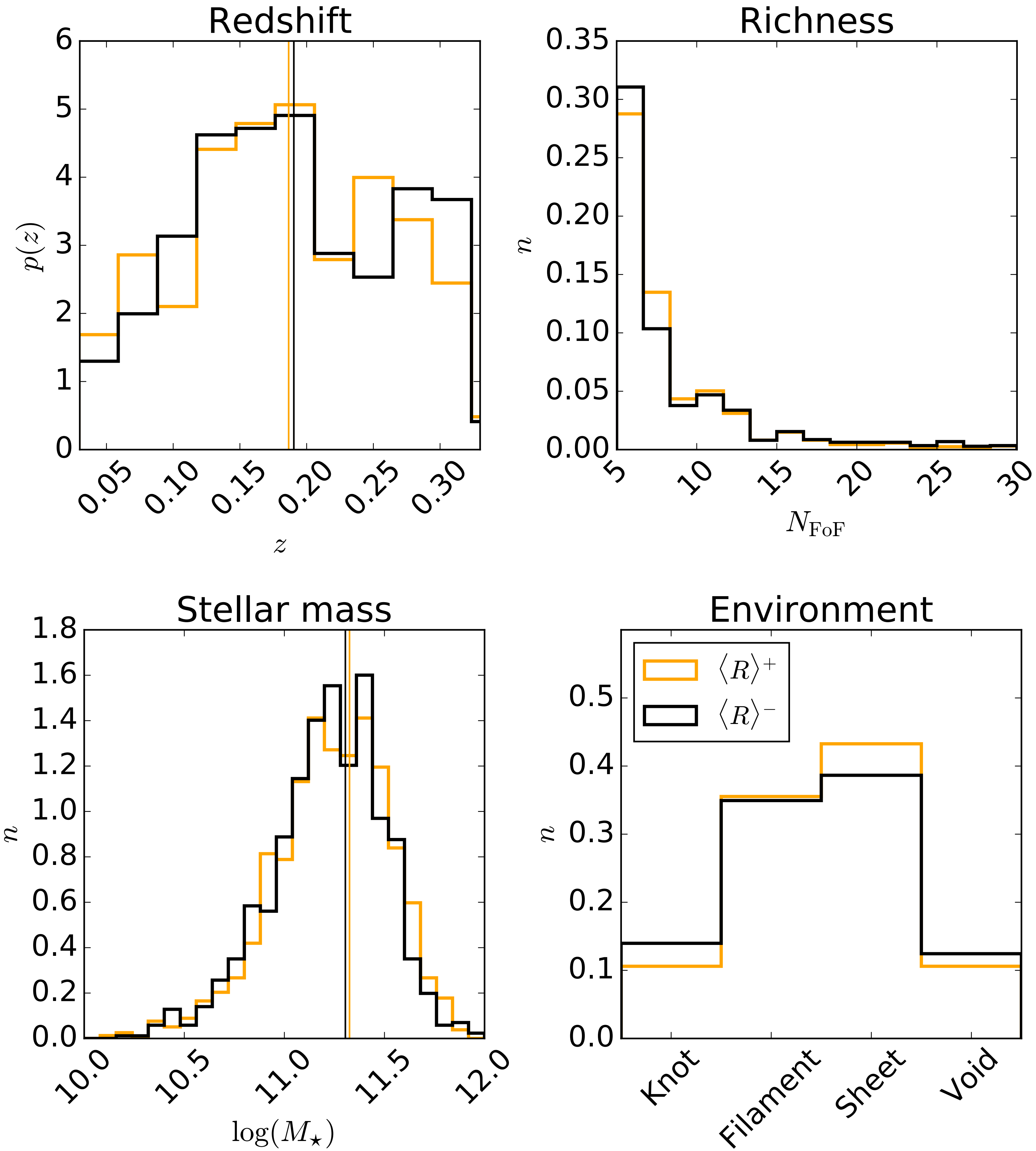
Inspired by the work of Miyatake et al. 2016 …



Selection of galaxy groups



Dvornik et al. 2017

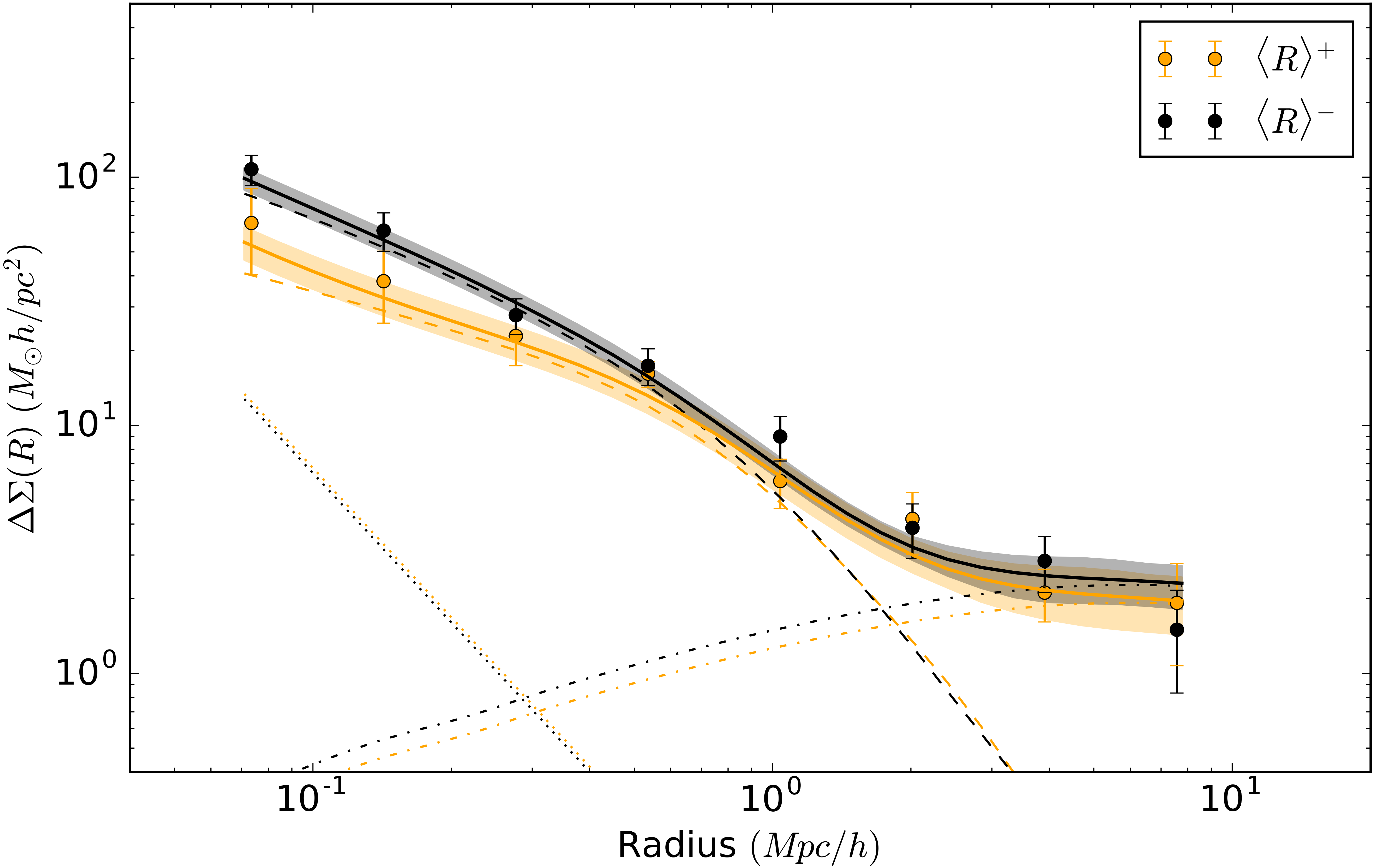


Redshift
Richness
Stellar mass
Environment
$p(z)$
z
n
$N_{\rm FoF}$
$\log(M_\star)$
$\langle R\rangle^+$
$\langle R\rangle^-$
Knot
Filament
Sheet
Void

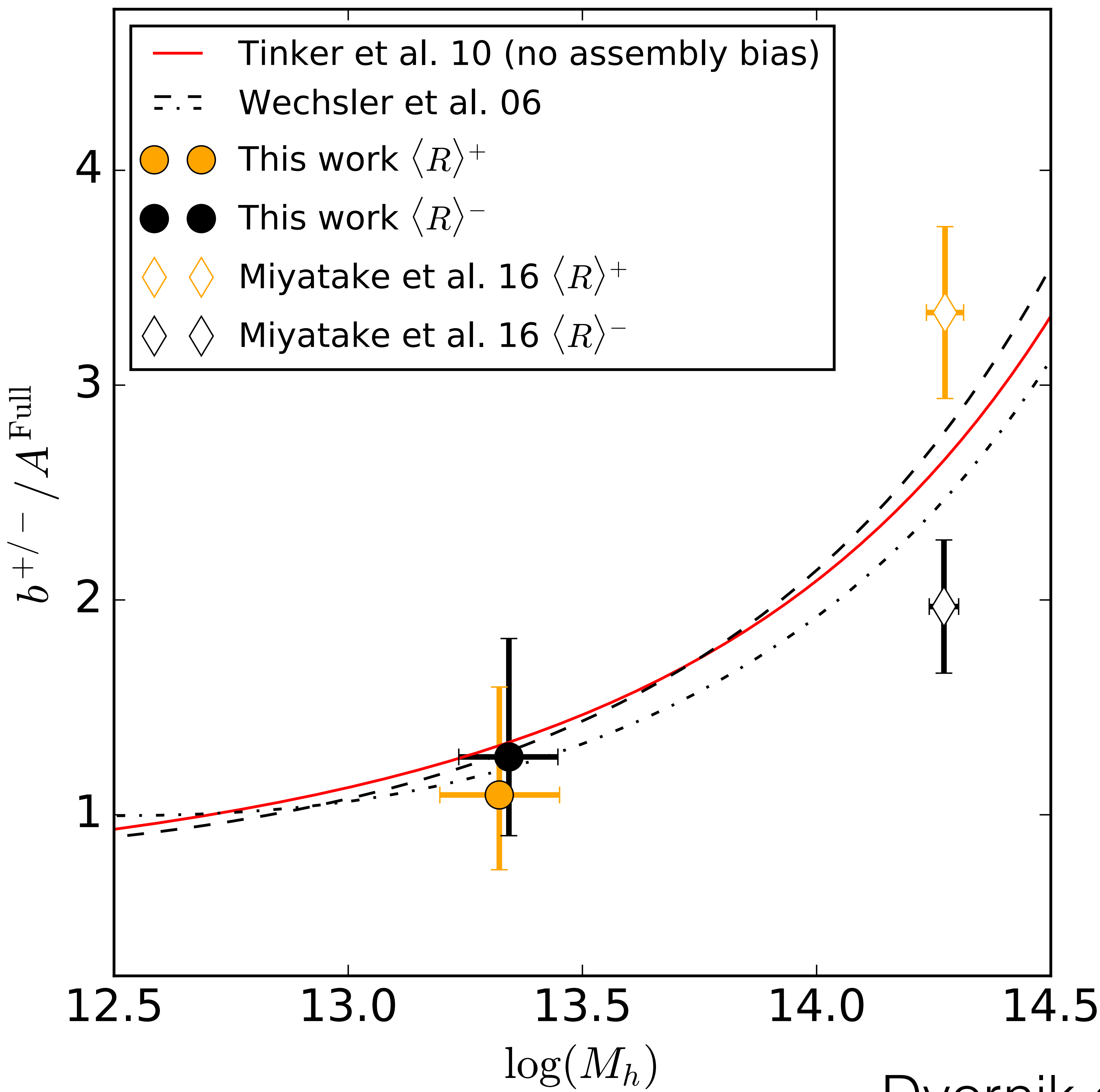
… and

We still use the
standard halo model

Lensing results

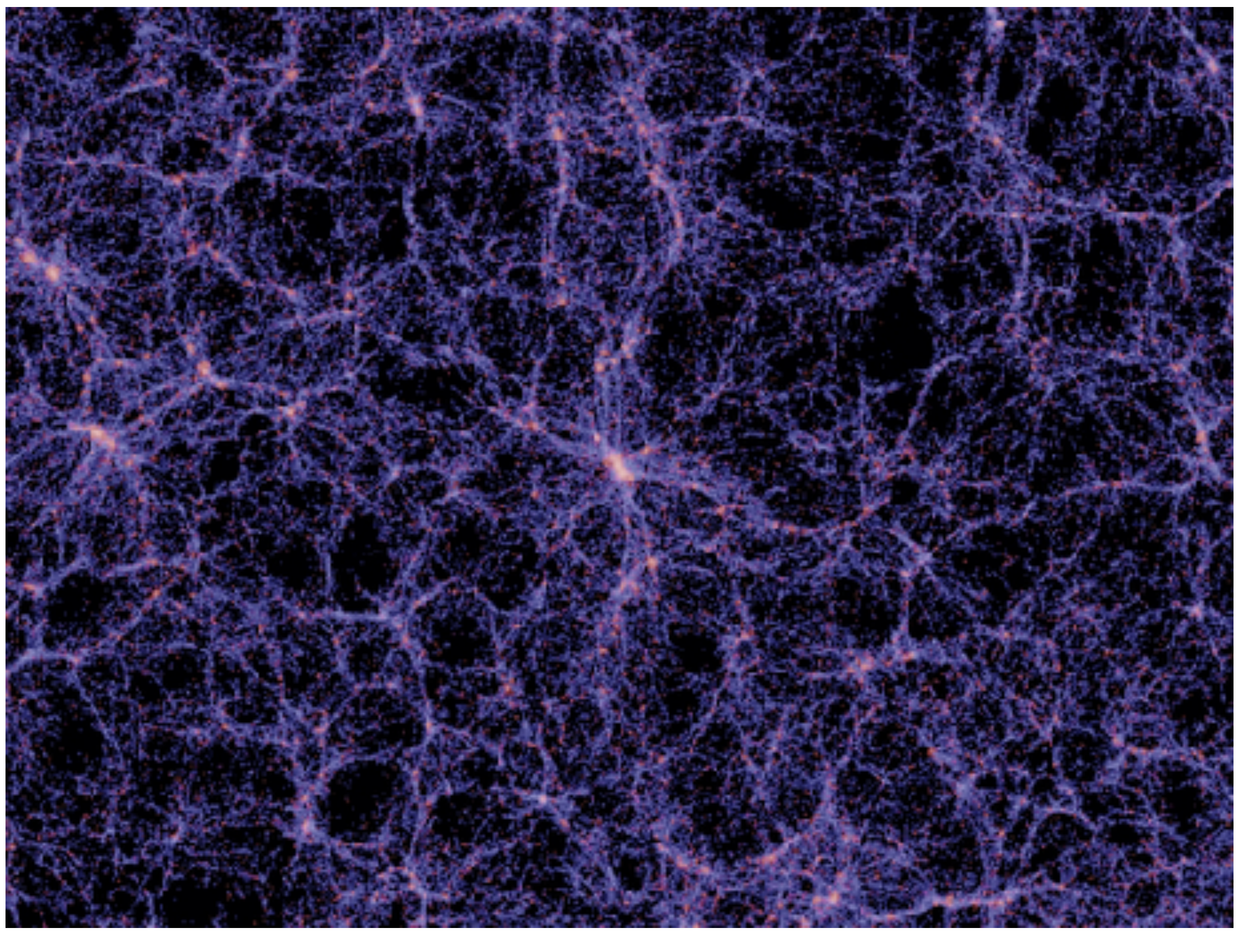


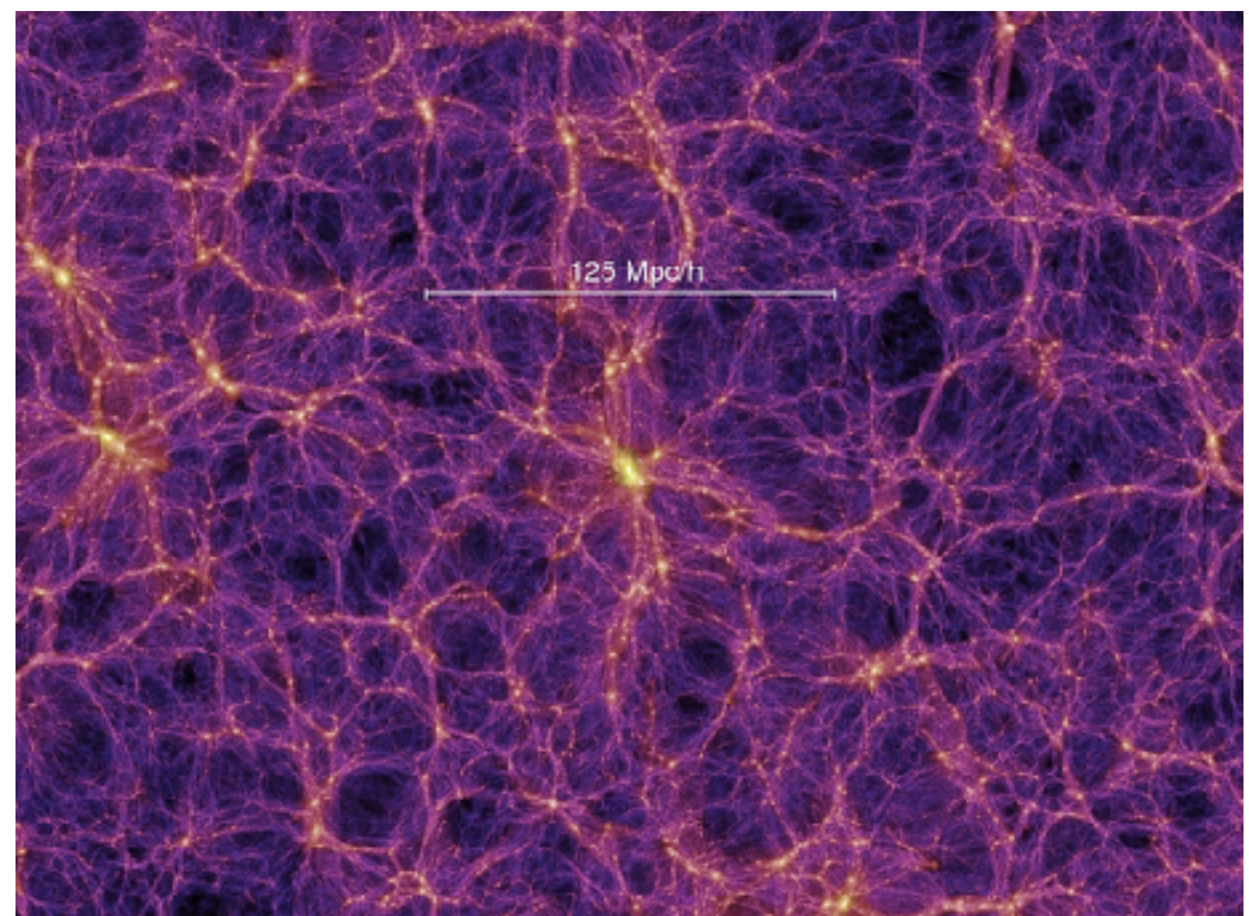
Dvornik et al. 2017



Dvornik et al. 2017

Galaxy bias





Galaxy bias

$$\delta_{\mathrm{g}} = f(\delta_{\mathrm{m}})$$

Linear

Non-linear

Deterministic

Stochastic

$$\delta_{\mathrm{g}} = b \cdot \delta_{\mathrm{m}}$$

Defining it with density contrast is a bit awkward …

- Wouldn’t it be better to used something that we can directly measure, like:
  - Number of galaxies N
  - Halo mass M

$$\implies b(M) \propto \frac{\langle N|M \rangle}{M}$$

Advantage of this:

- Use everything we know about halo occupation distributions (HOD's) to figure out the nature of galaxy bias
- We can use the ever so popular halo model to link it with observations
- Halo model then gives us power spectra
  - And from this also the weak lensing signal and galaxy clustering

$$b(k) = \sqrt{\frac{P_{\mathrm{gg}}}{P_{\mathrm{mm}}}} \qquad b(r) = \sqrt{\frac{\Delta\Sigma_{\mathrm{gg}}}{\Delta\Sigma_{\mathrm{mm}}}}$$

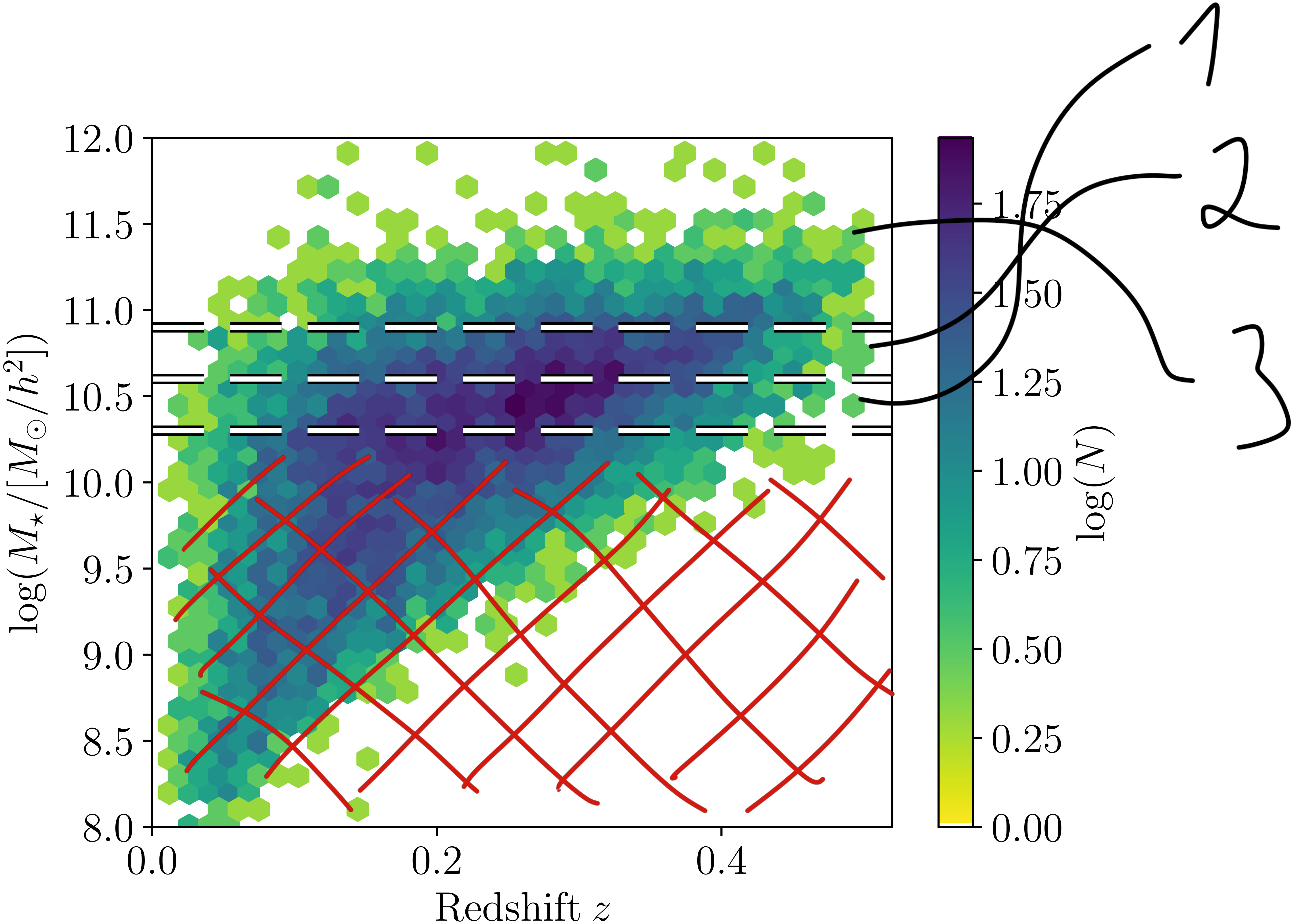
To the Γ

$$b(r) = \sqrt{\frac{\Delta\Sigma_{\mathrm{gg}}}{\Delta\Sigma_{\mathrm{mm}}}}$$

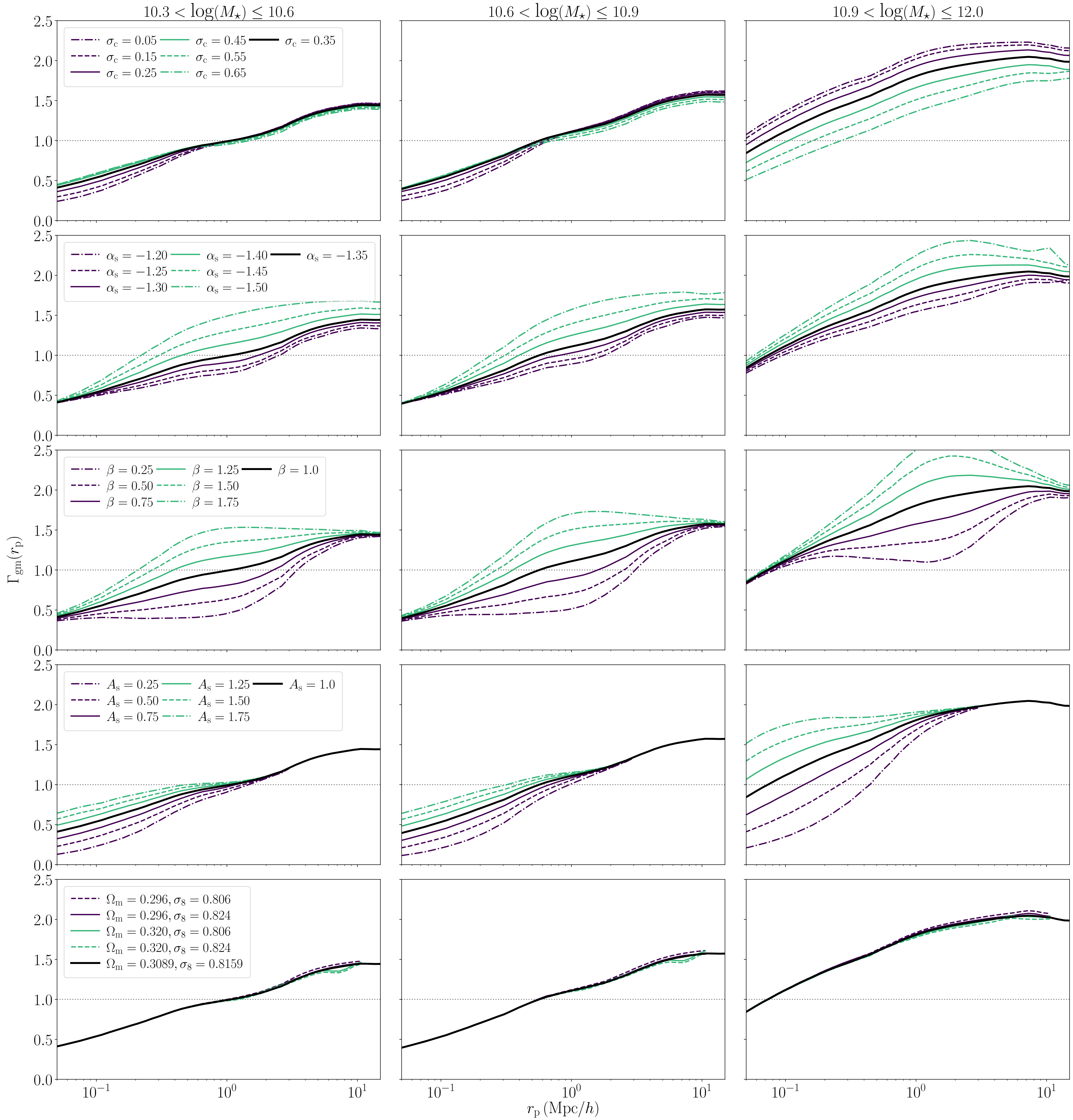
$$R(r) = \frac{\Delta\Sigma_{\mathrm{gm}}}{\sqrt{\Delta\Sigma_{\mathrm{gg}} \cdot \Delta\Sigma_{\mathrm{mm}}}}$$

$$\Gamma(r) = \frac{\Delta\Sigma_{\mathrm{gg}}}{\Delta\Sigma_{\mathrm{gm}}}$$

- Observationally it is easier to measure Γ, than b or R directly
  - we only need clustering and galaxy-galaxy lensing

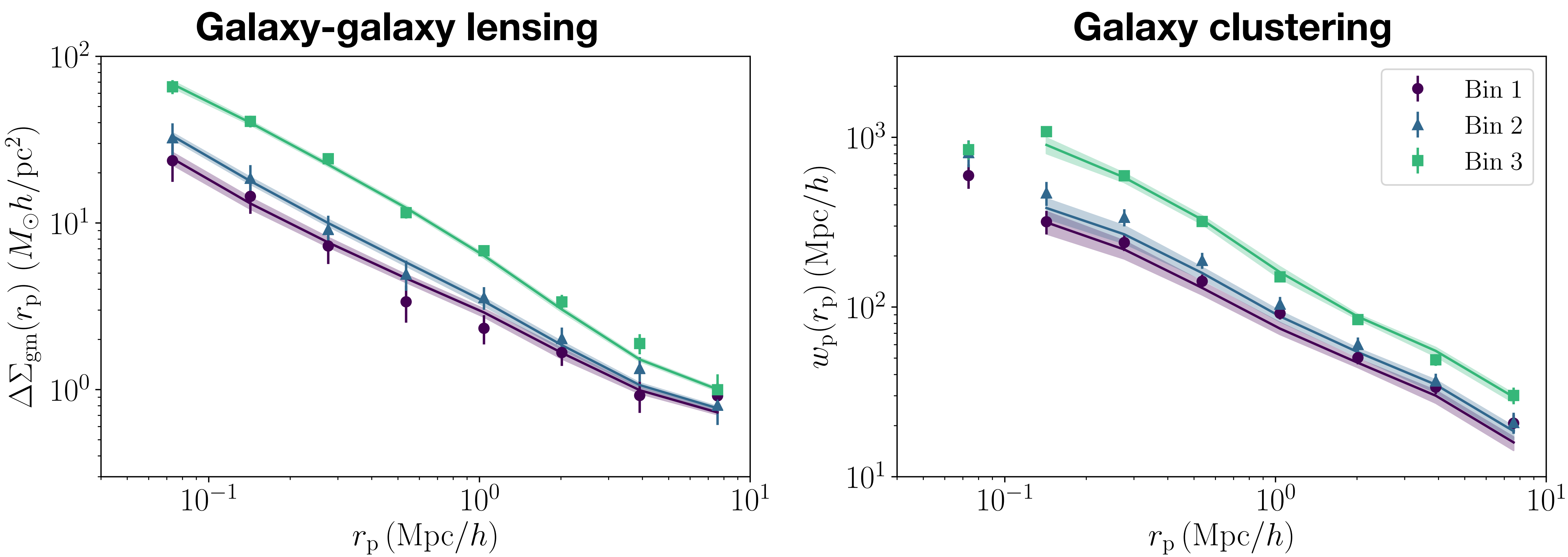


Dvornik et al. 2018



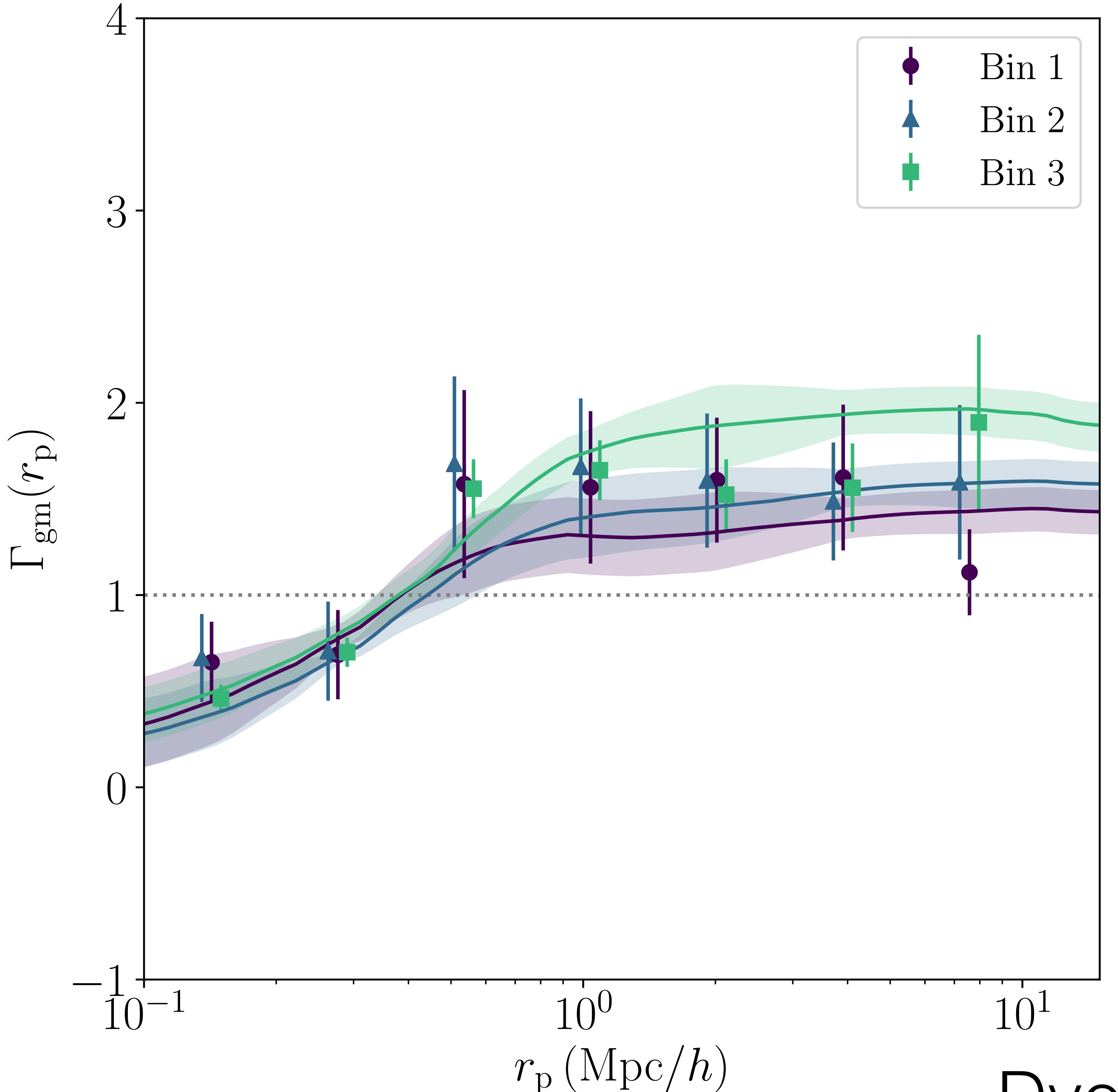
Dvornik et al. 2018

Now, let's see the measurements …



Dvornik et al. 2018

Back to the Γ

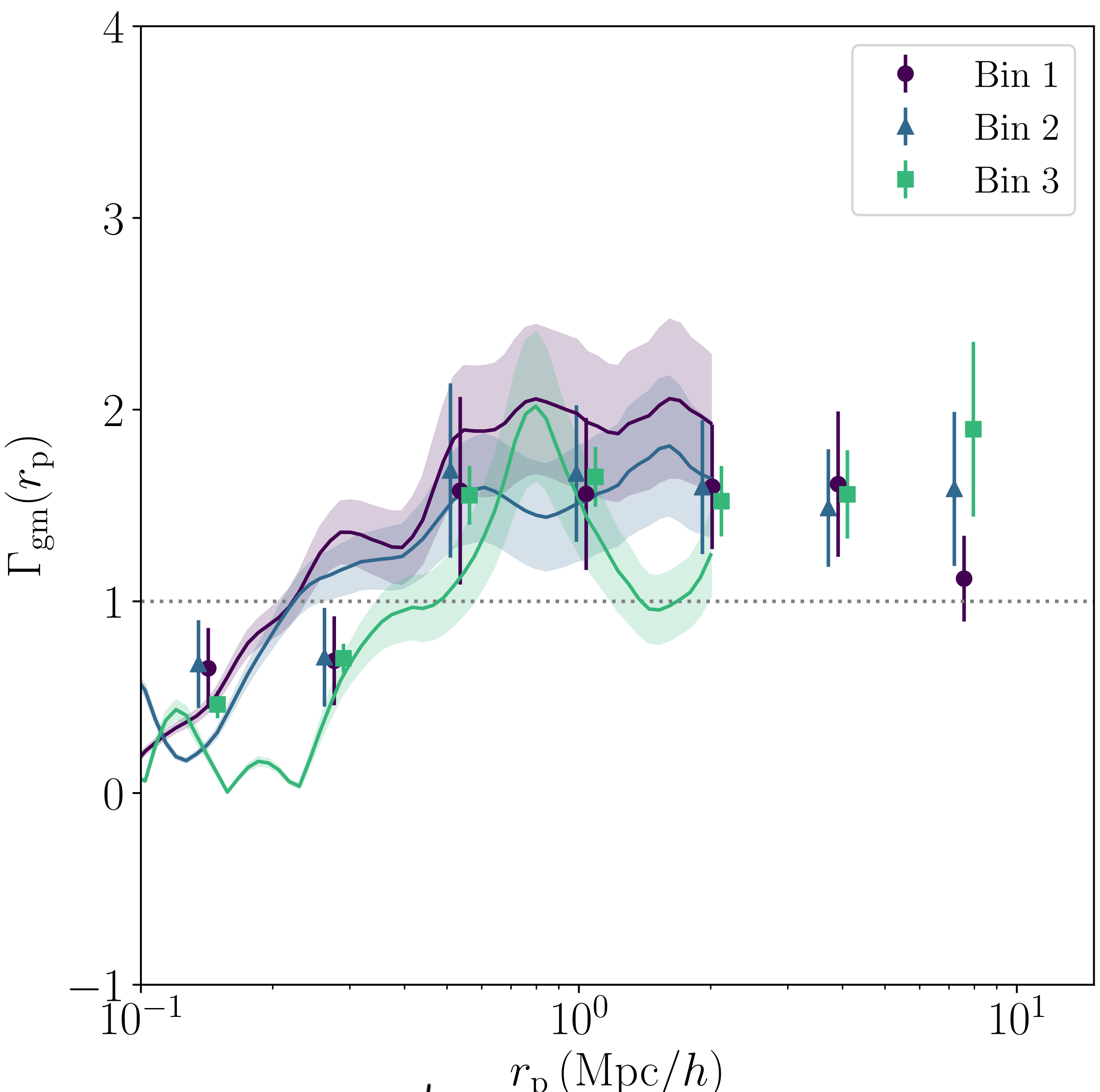


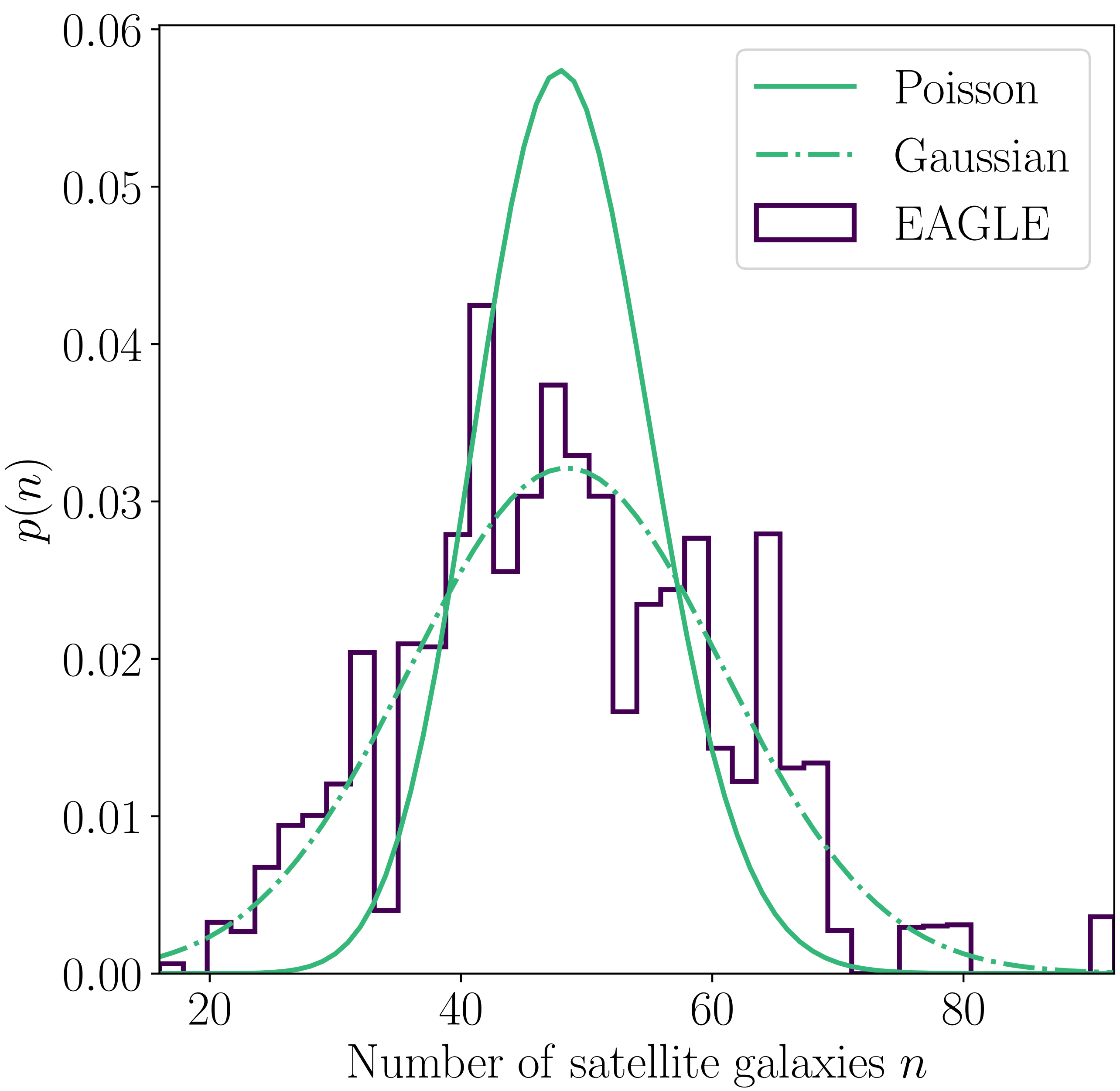
Dvornik et al. 2018

Results

- Given the constrained HOD parameters, galaxy bias is:
  - non-linear (due to presence of central galaxies)
  - stochastic (satellite galaxies are not following Poisson distribution and do not quite follow the DM density profile)

Similar trends are spotted with an EAGLE eye*





* pun intended

Conclusions

- Assembly bias
  - Halo assembly bias not detected on galaxy group scales
  - It still needs to be considered in halo models (due to Euclid, LSST and WFIRST)
  - Lensing is not a limiting factor - spectroscopic information on galaxy groups/clusters
- Galaxy bias
  - We have measured the Γ bias function for KiDS & GAMA galaxies
  - Constrained the HOD parameters responsible for the scale-dependence of the same Γ bias function and showed that galaxy bias is non-linear and stochastic
  - Results can be used for cosmological analysis that uses galaxies as a main tracer (cosmic shear)