Overview of CFIS weak lensing

French-Chinese days on WL

CEA, 04/10/2018

CANADA-FRANCE IMAGING SURVEY

CosmoStat WL group

CEA

CFIS, Euclid - but not only!

Martin Kilbinger	- **WL data analysis, cross-correlations**
Florent Sureau	- **pipeline architecture, shape measurement**
Jean-Luc Starck	- **mass mapping, PSF**
Sandrine Pires	- **mass mapping**
Jérôme Bobin	- **machine learning, redshift estimation**
Jean-Charles Cuillandre	- **Data analysis**
Sam Farrens	- **PSF, pipeline architecture**
Arnau Pujol (left for Barcelona)	- **shear calibration, cross-correlations**
Austin Peel	- **mass mapping, peak counts**
Axel Guinot	- **CFIS data analysis, redshift estimation**
Morgan Schmitz	- **PSF**
Alexandre Bruckert	- **blended objects**

External collaborators

EPFL (CH)

Marc Gentile
Frédéric Courbin

IAP WL group

Raphaël Gavazzi
Henry McCracken
Emmanuel Bertin

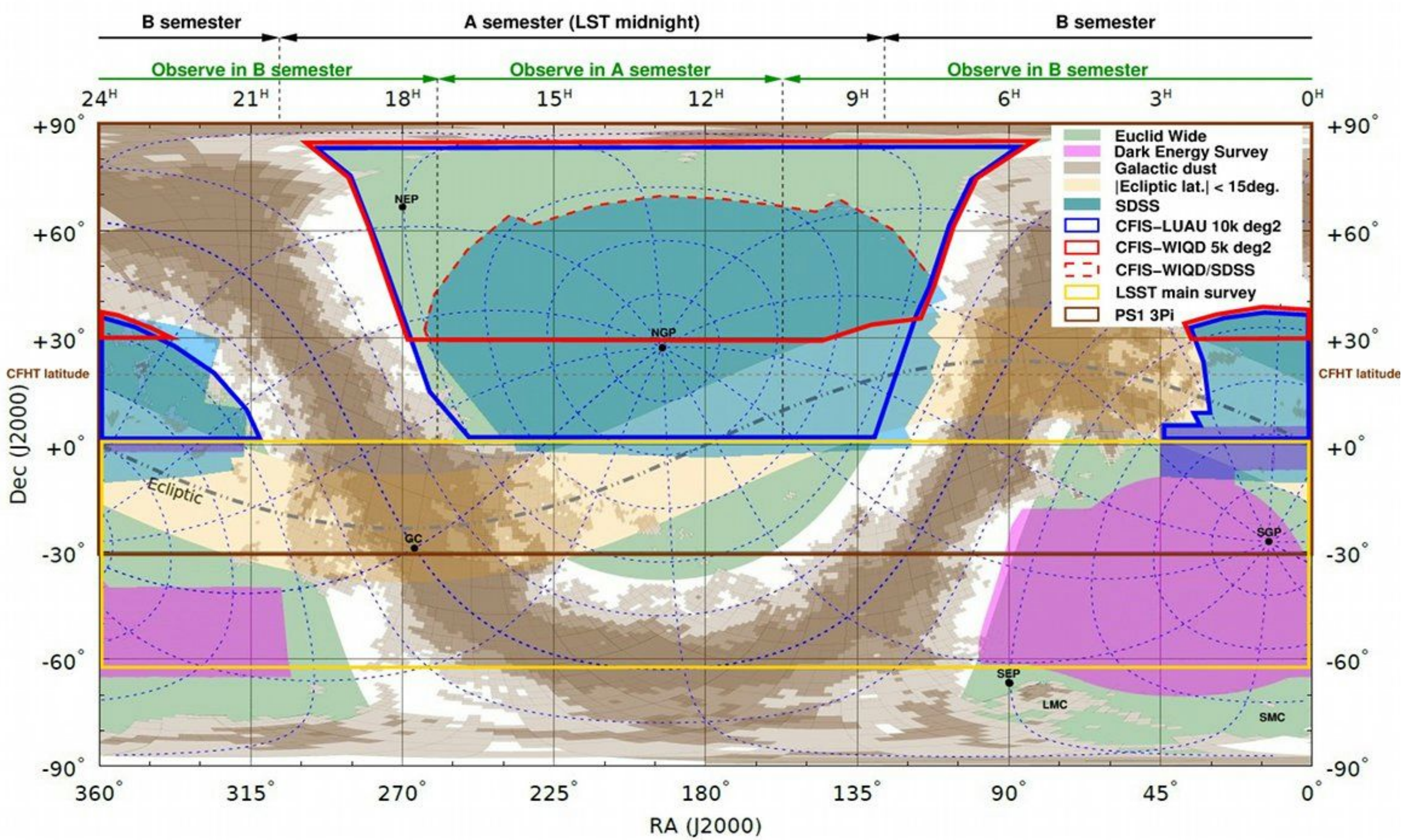
Waterloo

Mike Hudson (**CFIS WL lead**)
Isaac Spitzer

LenS team (DE/CA/UK)

Ludo van Waerbeke (UBC)
Hendrik Hildebrandt (Bonn)
Thomas Erben (Bonn)
Catherine Heymans (Edinburgh)

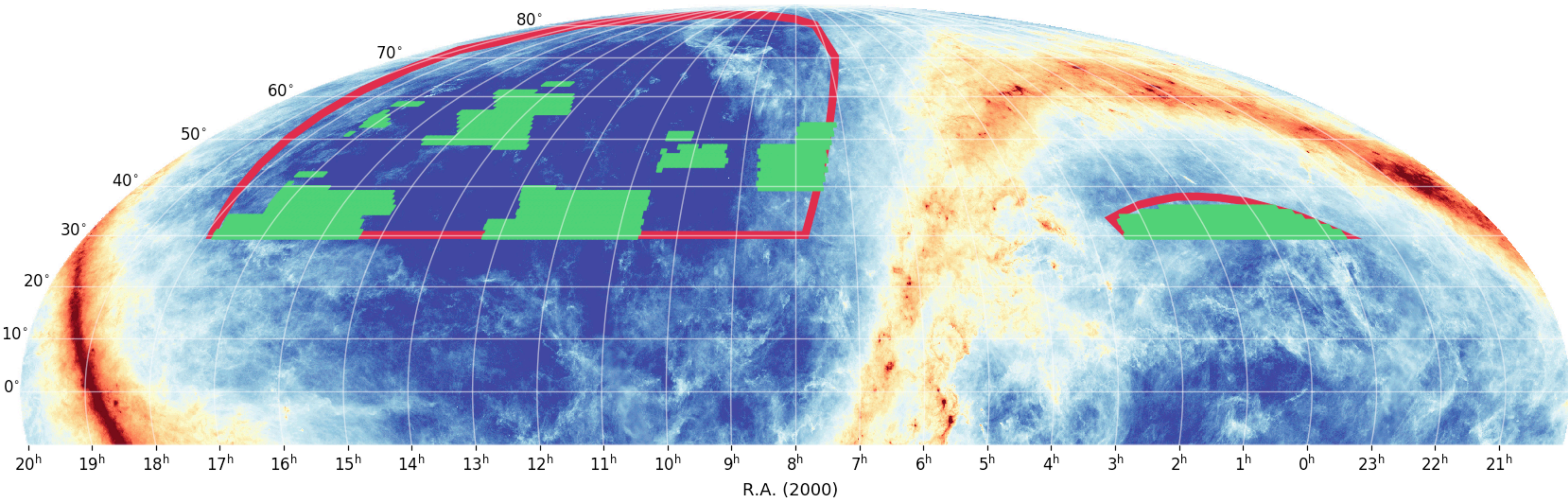
The CFIS survey



MegaCAM/CFHT, 2017 - 2019, u=24.5, r=24.1 (10s extended obj).

CFIS data status

http://www.cfht.hawaii.edu/Science/CFIS-DATA



CFIS-r survey area and realized coverage as of May 2018

Total survey area: 4.800 deg.^{2}

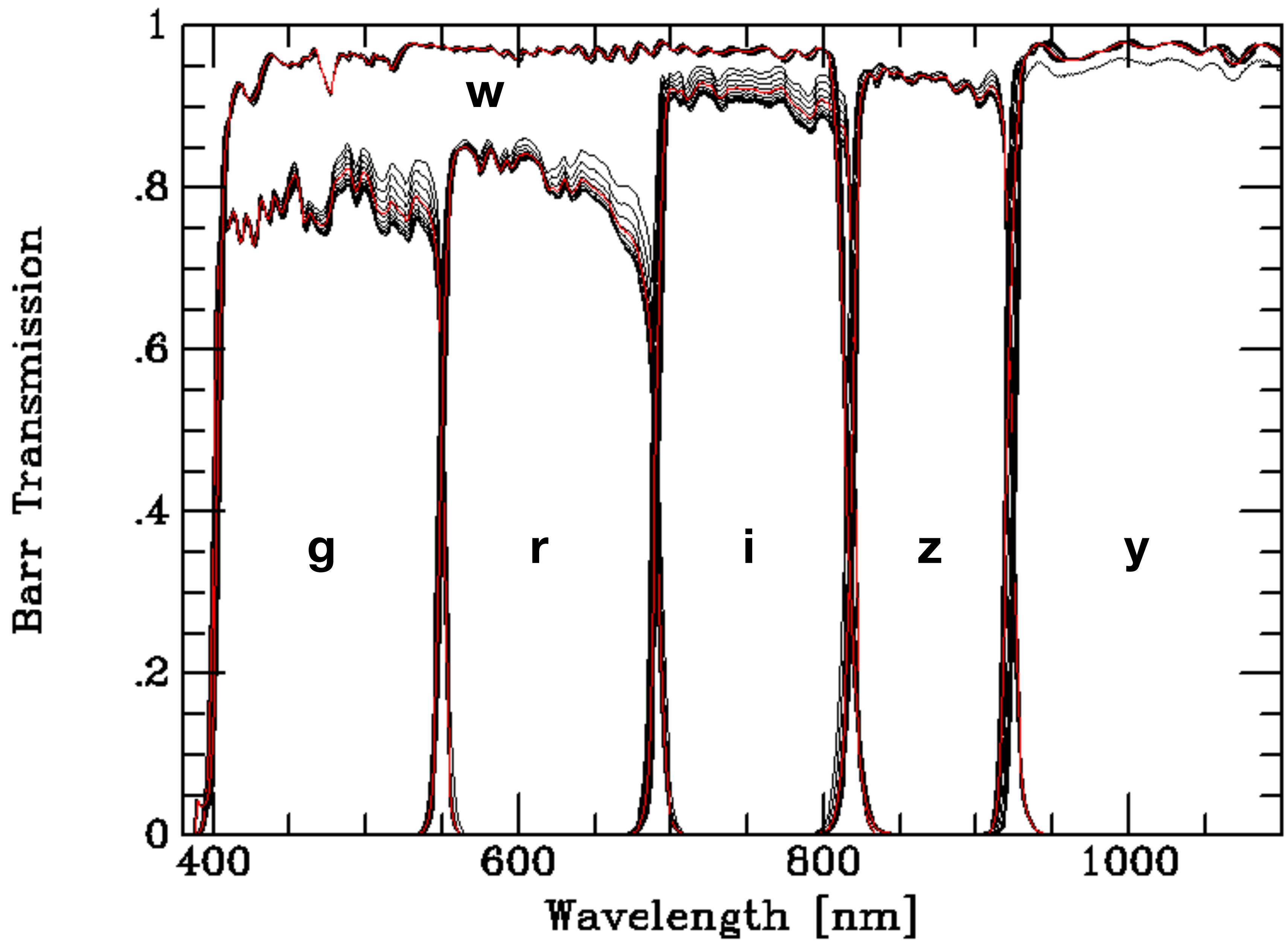
Covered area: 1337 deg.^{2} (27%), left to cover: 3463 deg.^{2} (73%)

CFIS + Pan-STARRS = Unions

- Pan-STARRS-w survey for NEOS in dark time which has uneven sky coverage that is most heavily weighted on the ecliptic but which will be roughly uniform going forward. The mode of the PSF distribution in w-band is 1.2 arcsec. Pan-STARRS-w is within the CFIS-u footprint.
- Pan-STARRS-i survey for NEOS in grey time has uneven sky coverage. The mode of the distribution in i-band is 1.0 arcsec. Pan-STARRS-i is within the CFIS-u footprint
- Pan-STARRS-z survey for NEOS in bright time will have roughly uniform coverage, and is entirely in the northern 5000 square degree CFIS-r footprint.

Pan-STARRS: 2018 - 2022, existing grizy, new, deep i, y over CFIS footprint.

Pan-STARRS filters



Pan-STARRS data

- DR1
  - September 2018
  - Pan-STARRS, all Pan-STARRS Medium-Deep fields within the CFIS footprint, the following products will be produced independently of the CFIS dataset:
    - *g, r, i, z, y*-band stack images (full depth available)
    - stack source catalogs (photometry, astrometry, galaxy models)
- DR2
  - June 2019
  - Pan-STARRS, within the CFIS sky coverage only, the following products will be produced independently of the CFIS dataset:
    - *i* & *z*-band stack images (full depth available)
    - *w*-band stack images from best image quality subset, using ~⅓ of w-band exposures
    - Stack source catalogs (photometry, astrometry, galaxy models)
    - Mean Forced Warp Photometry
    - Metadata
- DR3 (extra versus DR2 besides gain in sky coverage and overall depth)
  - January 2021
  - Pan-STARRS:
    - Forced chips (mean of the individual frame photometry)
    - Includes Pan-STARRS photometry of CFIS-u, CFIS-r
- DR4 (extra versus DR2/3 besides gain in sky coverage and overall depth)
  - June 2022
  - Pan-STARRS:
    - The Tractor or equivalent forced photometry

CFIS WL science

CFIS is part of the Euclid survey. Ground-based optical bands for photo-z
in Northern hemisphere,
with Pan-STARRS, JST.

Stand-alone science with CFIS:

- Testing General Relativity
- Dark-matter halo properties
- Tidal stripping of satellite galaxies

Modified gravity

Friedmann-Lemaître-Robertson-Walker metric with perturbations:

$$\mathrm{d}s^2 = \left(1 + \frac{2\Psi}{c^2}\right)c^2\mathrm{d}t^2 - a^2(t)\left(1 - \frac{2\Phi}{c^2}\right)\mathrm{d}l^2$$

time dilation

spatial curvature

Gravitational action on**:**

- non-relativistic objects (galaxies):
  Newtonian potential $\boldsymbol{\Psi}$
- relativistic objects (photons; light deflection):
  travel equal parts of space and time → sum $\boldsymbol{\Psi}+\boldsymbol{\Phi}$

GR: $\boldsymbol{\Psi} = \boldsymbol{\Phi}$, but $\boldsymbol{\Psi} \neq \boldsymbol{\Phi}$ in most **MoG**!

Density δ related to potentials with Poisson equation.

Observable is density power-spectrum $P_\delta = \langle\delta\delta\rangle$ or related.

Modified gravity

- Measure different types of power spectra to measure differences between **Ψ** and **Φ**.
  - Galaxy clustering measures **Ψ** and bias b: $\langle\delta_{\mathrm{g}}\delta_{\mathrm{g}}\rangle \propto b^2 P_{\Psi}$
  - Galaxy-galaxy lensing measures **Ψ**+**Φ**: $\langle\delta_{\mathrm{g}}\delta_{\mathrm{m}}\rangle \propto b\, P_{\Psi+\Phi}$
- Take ratios to minimize sensitivity to cosmological parameters.
- Need another observable to eliminate (linear) bias.
  - RSD anisotropy parameter

growth factor

$$\beta = \frac{1}{b}\frac{\mathrm{d}\ln D_+}{\mathrm{d}\ln a}$$

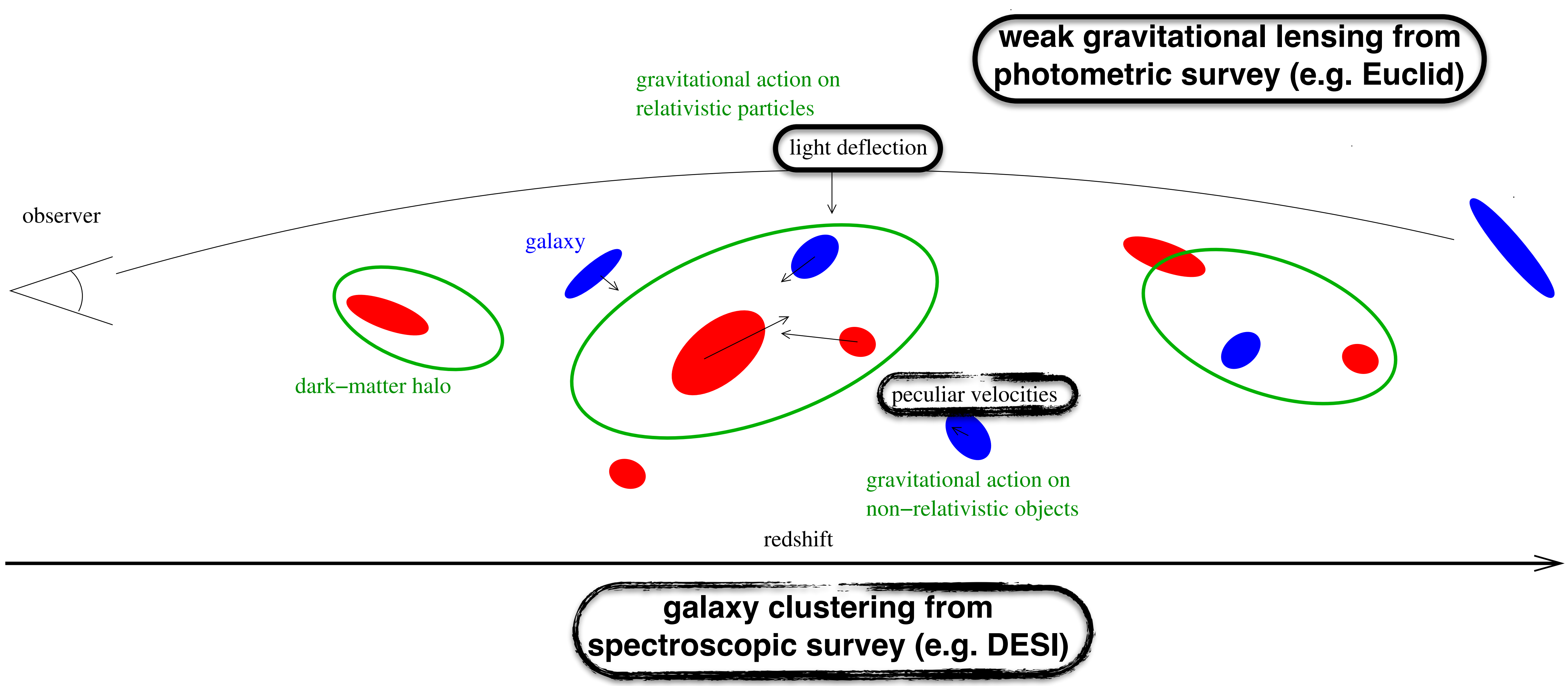
$$\boxed{E_{\mathrm{G}} \cong \frac{1}{\beta}\frac{\langle\delta_{\mathrm{m}}\delta_{\mathrm{g}}\rangle}{\langle\delta_{\mathrm{g}}\delta_{\mathrm{g}}\rangle}}$$

Zhang et al. (2007)

Testing General Relativity on cosmological scales

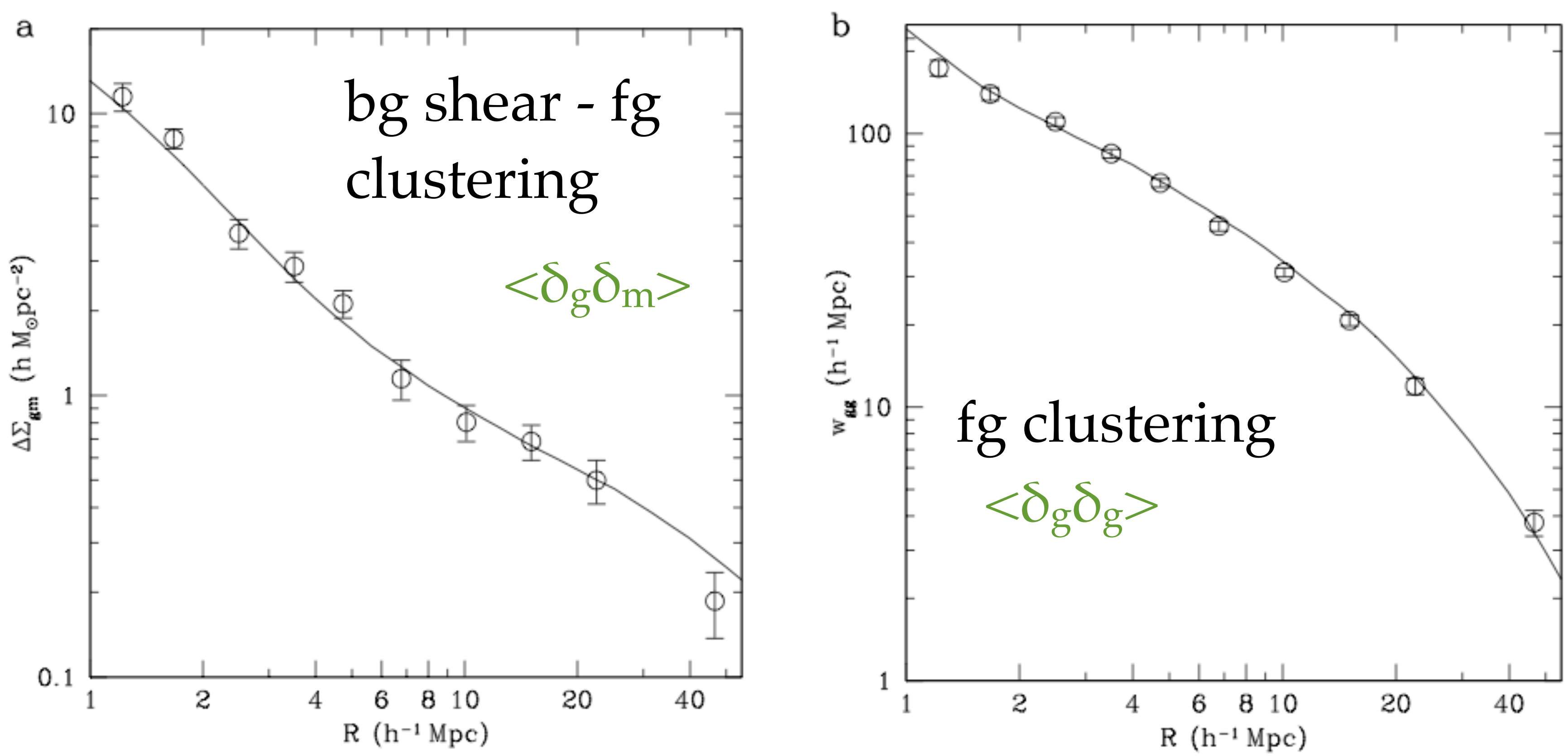
Measuring gravitational action on light and galaxies:
Equal in General Relativity, **different** in modified gravity theories.

Modified gravity affects differently mass (galaxy clustering, non relativistic) and light (weak lensing, relativistic), measuring the difference with both probes will test GR.



Testing General Relativity on cosmological scales

SDSS (Reyes et al. 2010)

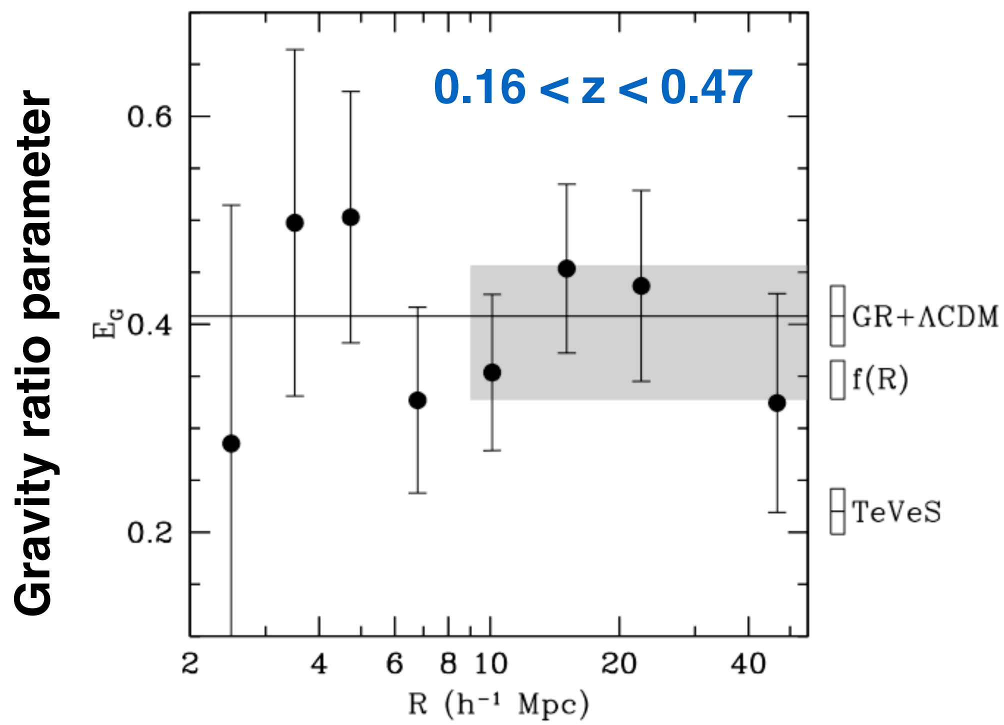


$\beta = 0.309 \pm 0.035$

from SDSS galaxy clustering
(redshift-space distortions)
Tegmark et al. (2006)

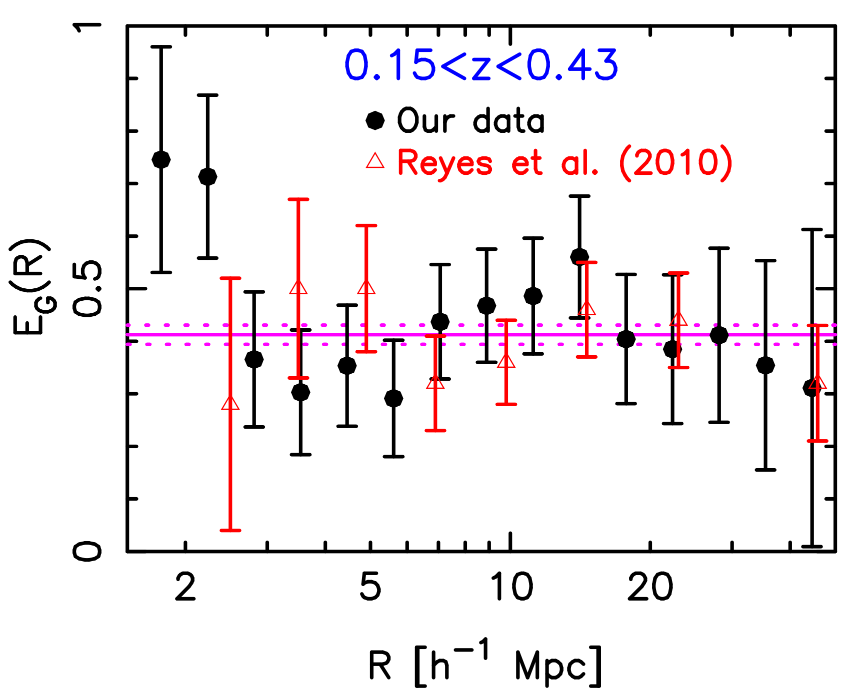
Testing General Relativity on cosmological scales

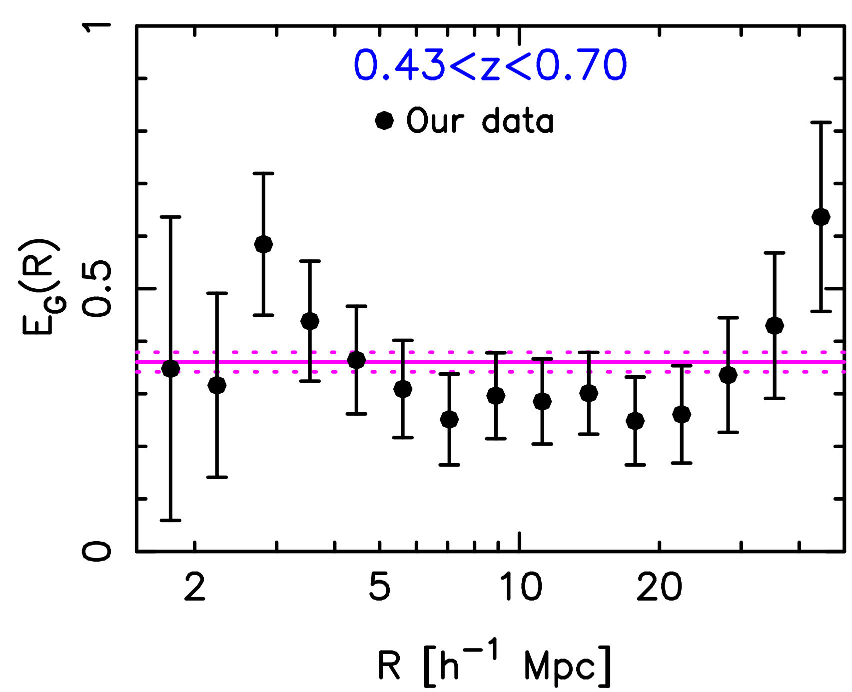
Reyes et al. (2010; Nature), SDSS



angular scale

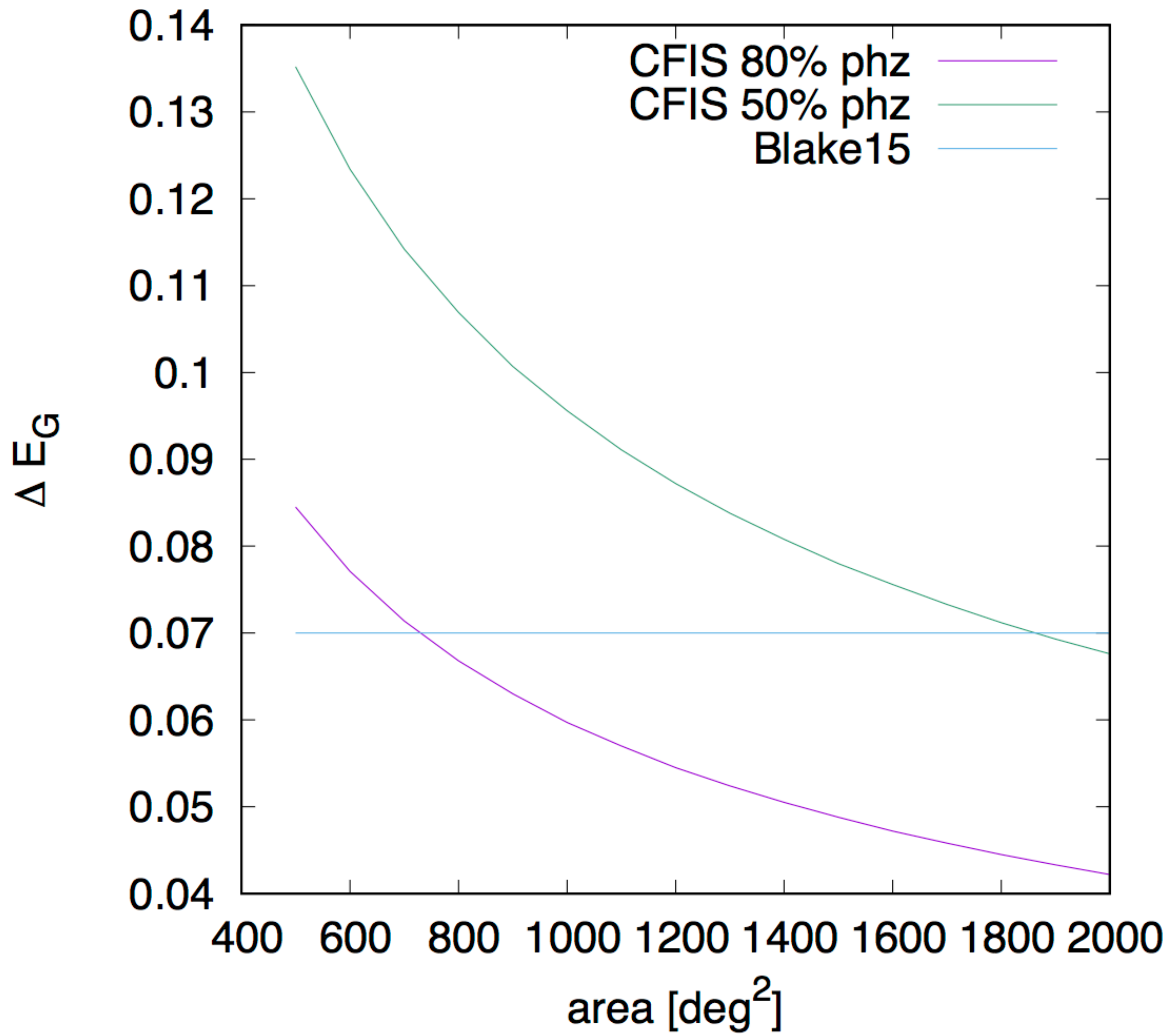
Blake et al. (2015), CFHTLenS+RCSLens, WiggleZ+BOSS



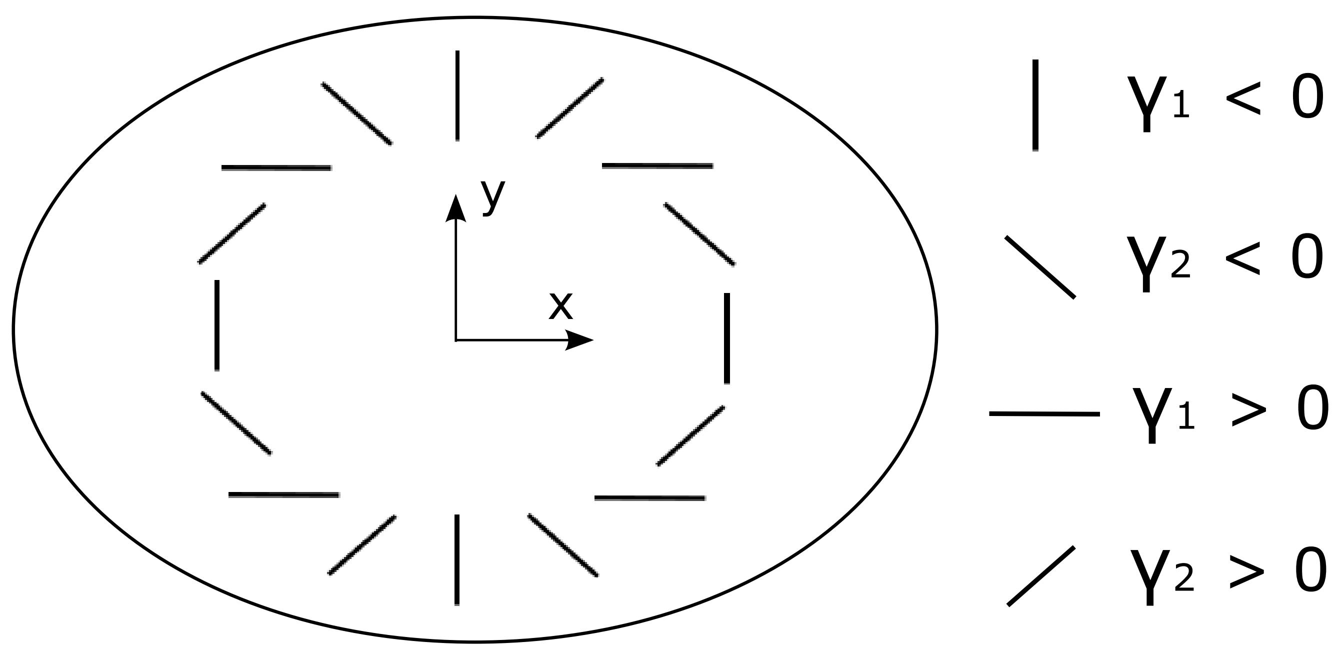


- RCS2, Gilbank et al. (2011), 800 deg^2 in g’, r’, z’, and i’ (2/3 of the area).
- RCSLenS, Hildebrandt et al. (2016), lensing with r’=24.3.

Simple CFIS prediction

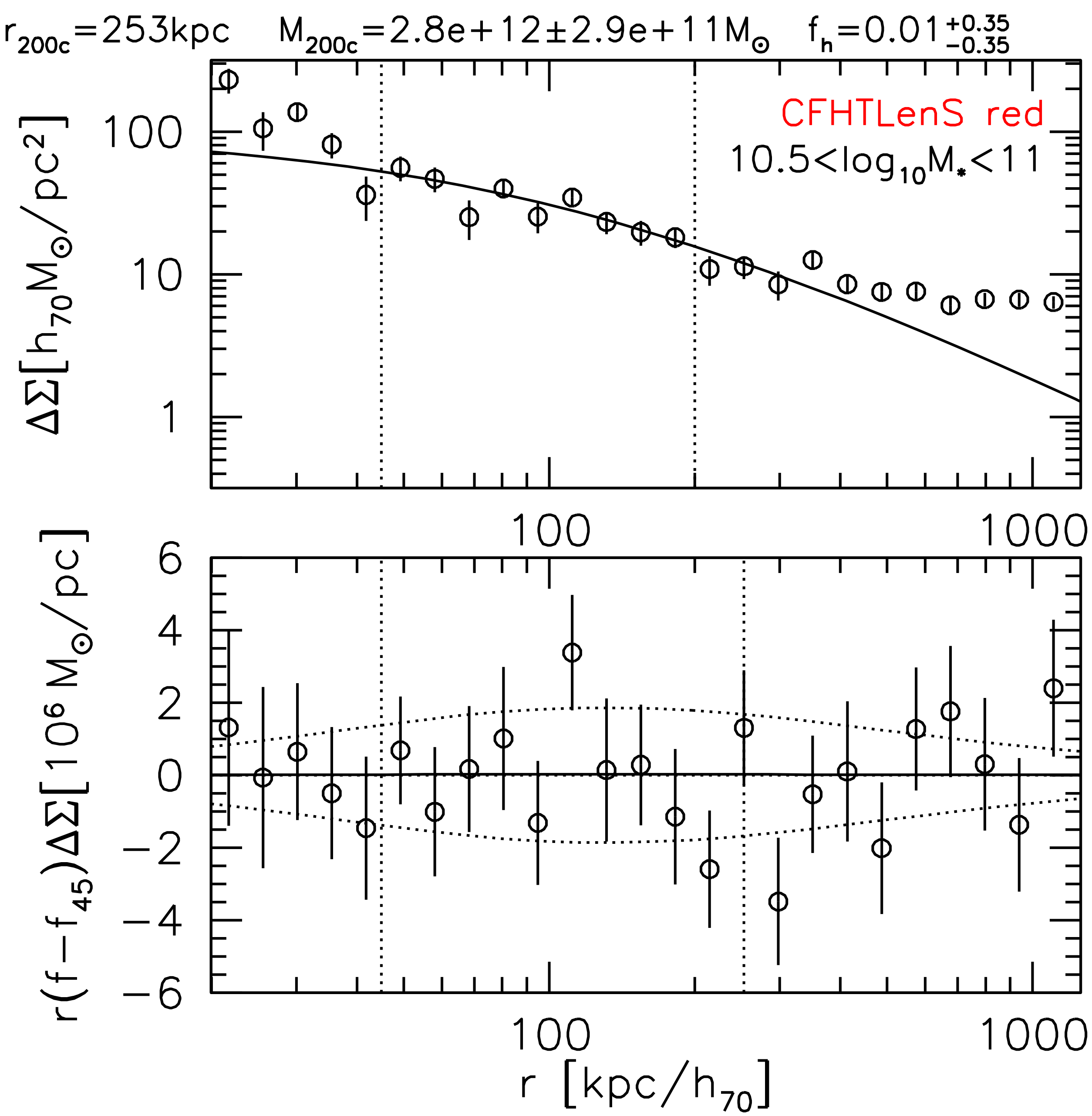


DM halo shapes



Clampitt & Jain (2016)

DM halo shapes

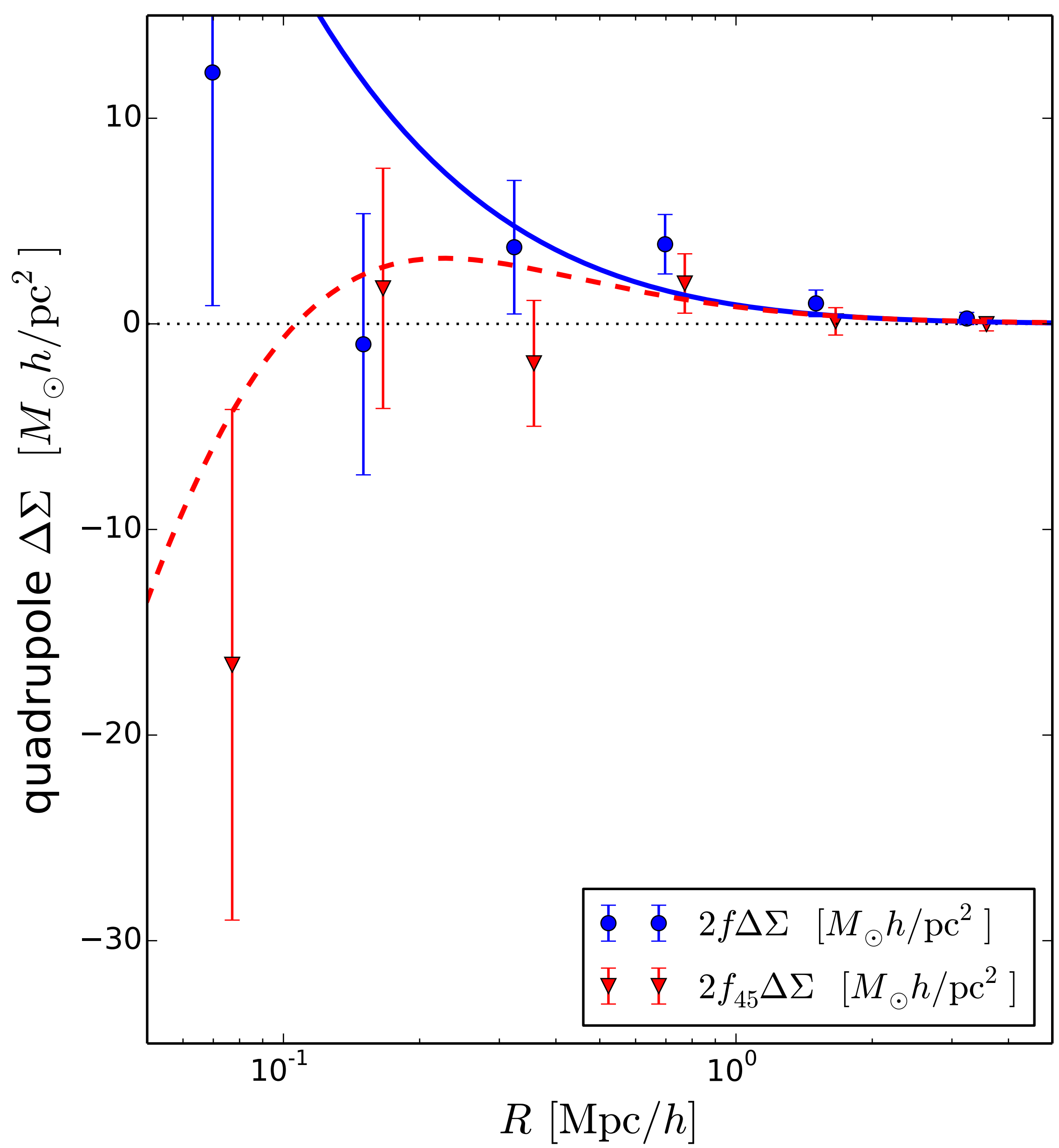


$$\Delta\Sigma_{\rm model}(r,\,\Delta\theta) = \Delta\Sigma_{\rm iso}(r)\left[1 + 4f(r)|e_{\rm g}|\cos(2\Delta\theta)\right]$$

CFHTLenS, Schrabback et al. (2015)

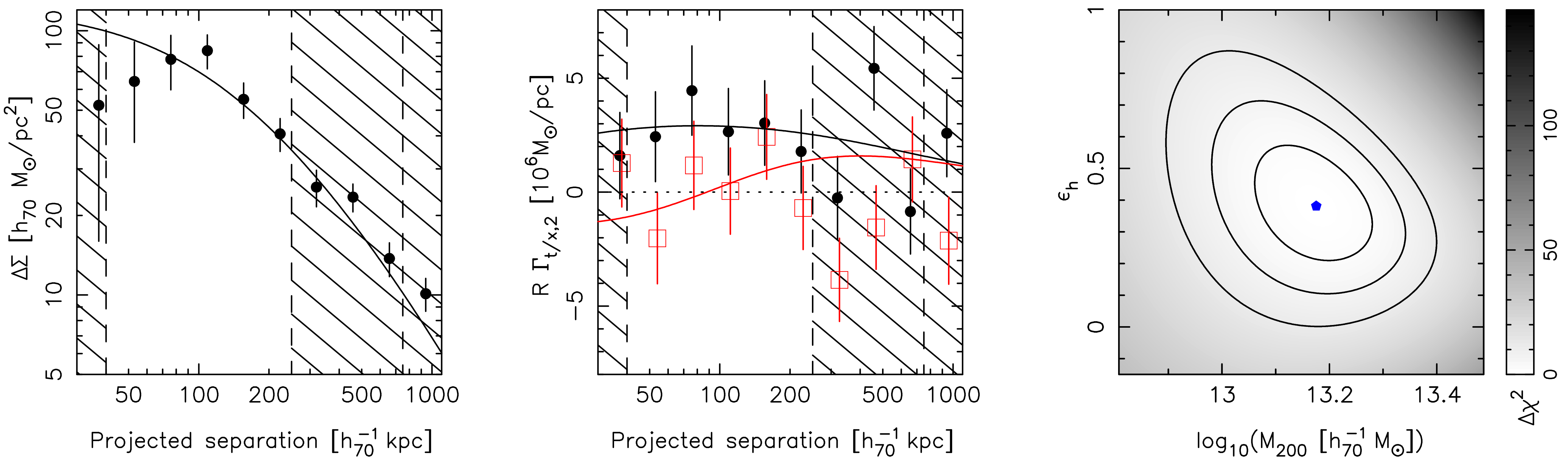
93,000 bright galaxies i<23.5, 0.2<z<0.6, 150 deg².

DM halo shapes



SDSS, Clampitt & Jain (2016)
70,000 LRGs, DR-7

DM halo shapes



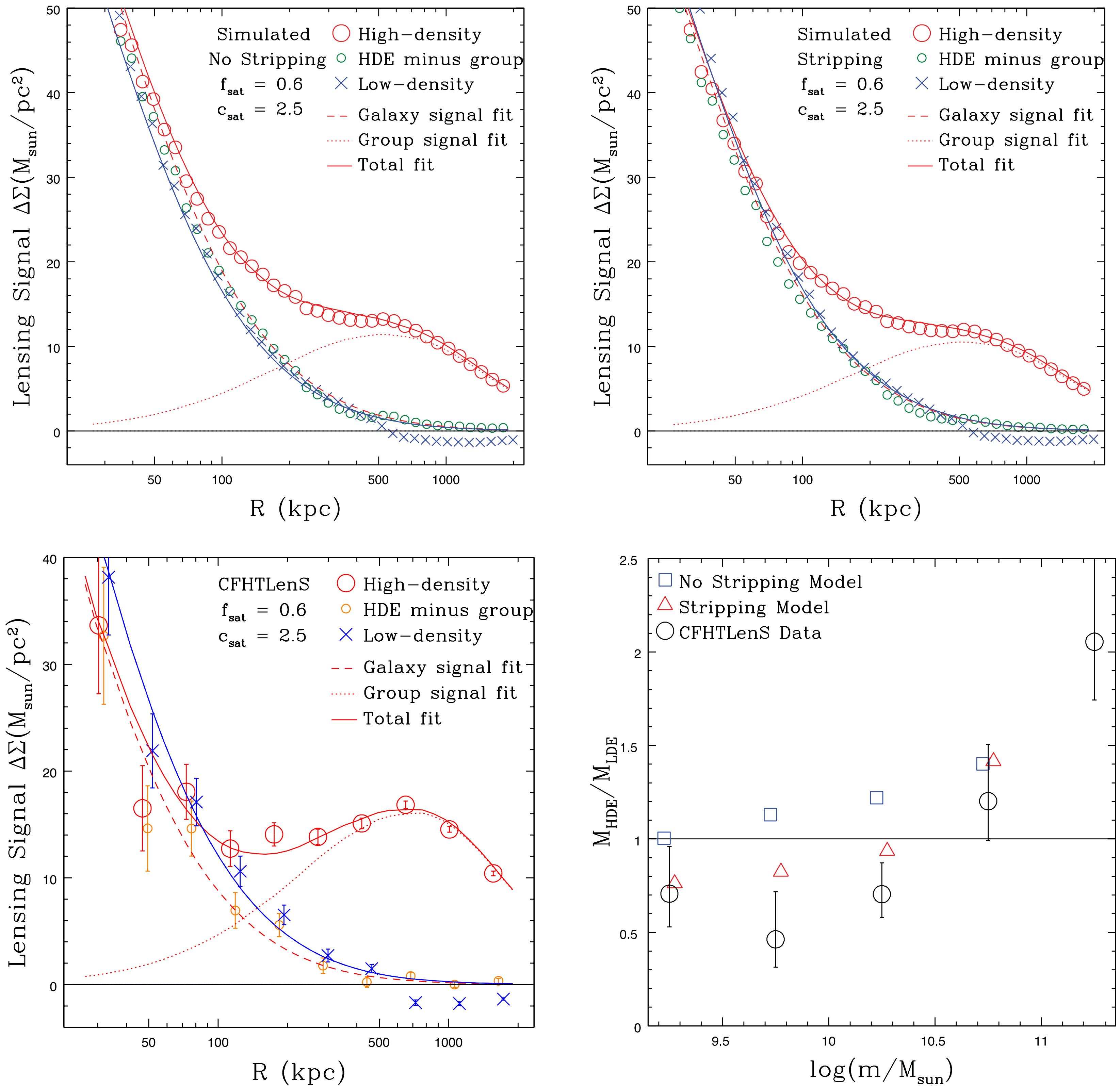
KiDS-450 + GAMA, van Uitert et al. (2016)

2600 groups in 60 deg^2

GAMA r<19.8

Tidal stripping of satellite galaxies

Gillis et al. 2015



Spectroscopic data

Survey	Period	n_{gal} [deg²]	Galaxies	Redshift	A_{joint}
BOSS	DR12 released in 2016	147	LOWZ, CMASS	0.15 < z < 0.7	2 800
eBOSS	2014 - 2018	50	LRG, ELG	$0.6 < z < 1$	3 000
DESI-2y	2019 - 2021	~285	LRG low-z	$0.4 < z < 1$	4 000
		~700	BGS	$0.04 < z < 0.4$	4 000

Shear calibration

Additive and multiplicative shear bias:

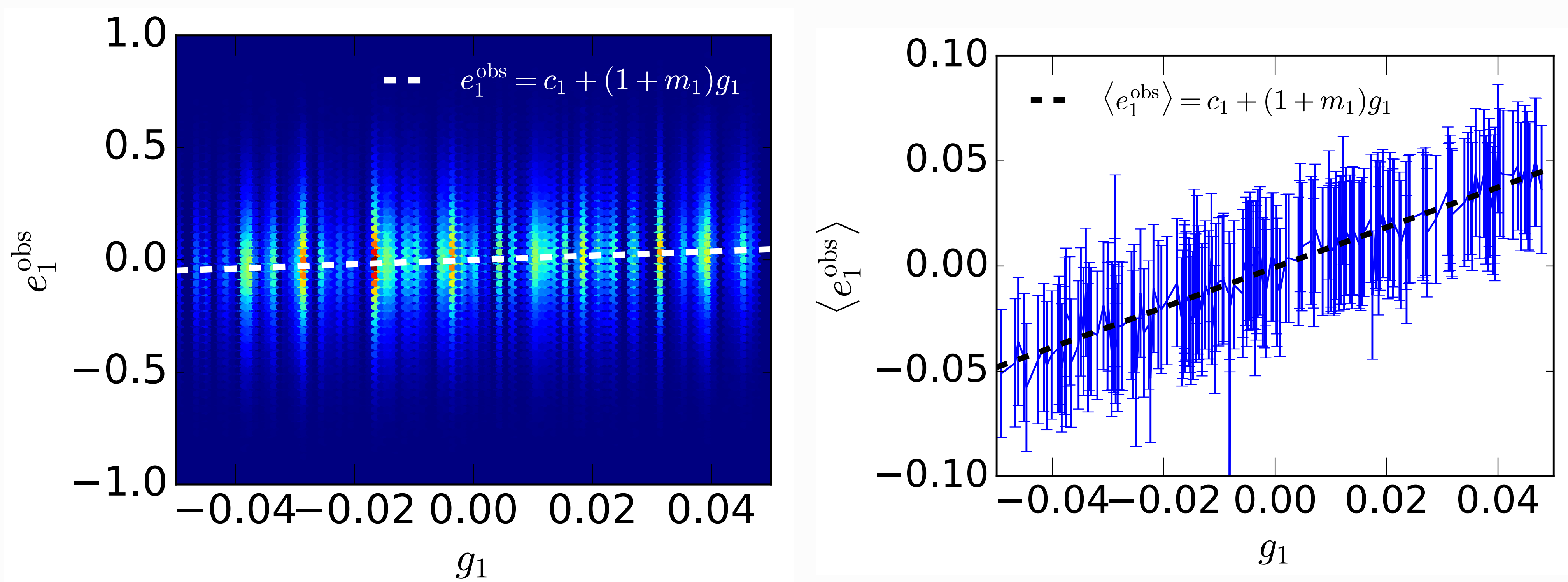
$$\langle \varepsilon_\alpha^{\mathrm{obs}} \rangle = g_\alpha^{\mathrm{obs}} = (1 + m_\alpha) g_\alpha^{\mathrm{true}} + c_\alpha; \quad \alpha = 1, 2.$$

for sample of galaxies with vanishing intrinsic ellipticity $\langle \varepsilon_\alpha^{\mathrm{I}} \rangle = 0$.

How can we determine the multiplicative bias?

Simple method

From linear fit of many simulated pairs $(\varepsilon_\alpha^{\mathrm{obs}}, g_\alpha^{\mathrm{true}})$.

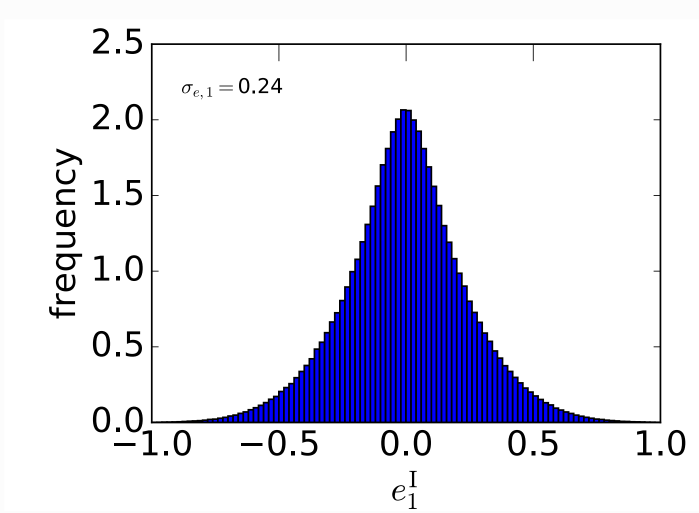


Shear bias uncertainty

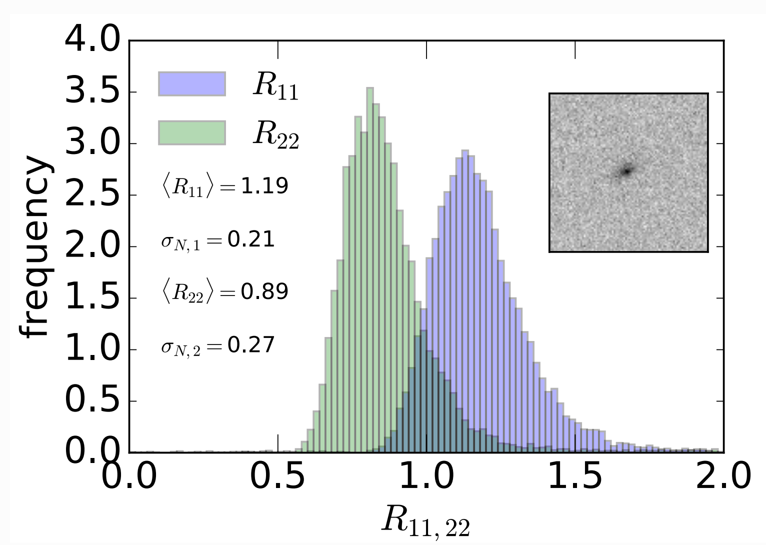
Error on best-fit m_α given by width in $\varepsilon^{\mathrm{obs}}$ (including measurement errors), g^{true}, and stochasticity of galaxy images (from pixel noise),

$$\sigma_{m,\alpha} = \frac{1}{\sqrt{N}} \sqrt{\sigma_{R,\alpha}^2 + \frac{\sigma_{S,\alpha}^2}{\sigma_{g,\alpha}^2}}$$

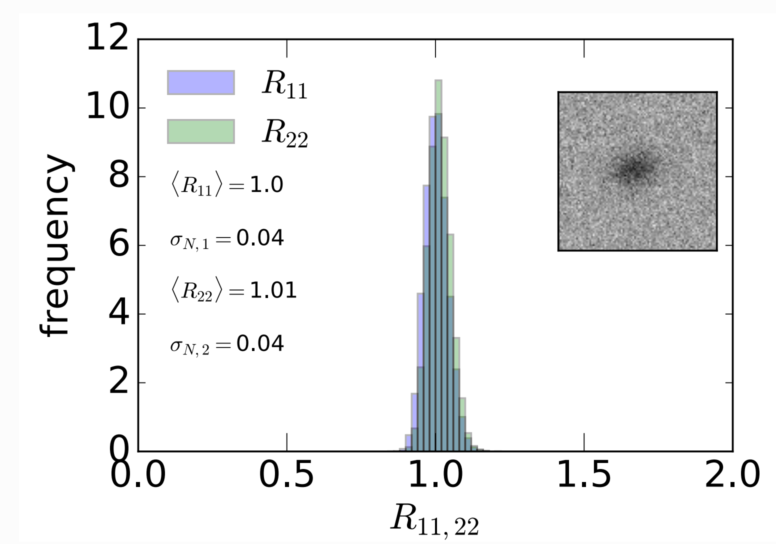
Second terms is dominant in most cases.



Ell. distribution.



Stochasticity for low SNR.



Stochasticity for high SNR.

Noise suppression

Simulate pairs of galaxies with same shear and orthogonal intrinsic ellipticity (rotated by 90 degrees),

$$\varepsilon^{\mathrm{I}}_{A} + \varepsilon^{\mathrm{I}}_{B} = 0.$$

This however does not mean that the *observed* ellipticity vanishes, due to:

- Measurement stochasticicy
- Ellipticity bias, if depends on galaxy orientation wrt PSF, shear, (pixelization)
- Selection effects, one pair member might drop out of sample

Derivative method

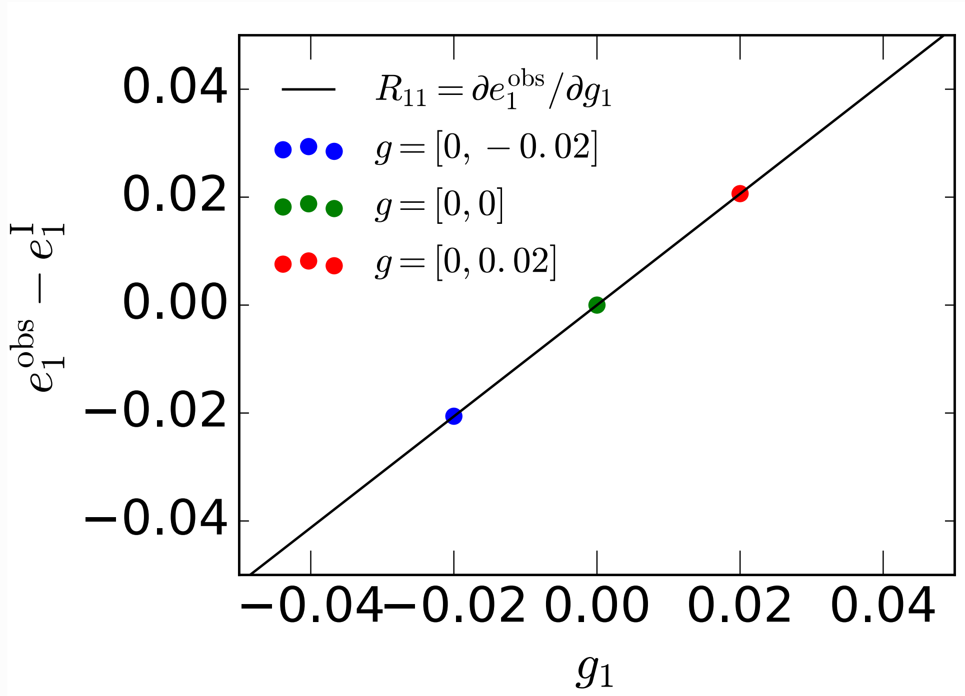
Write shear bias for individual galaxies, and as matrix equation (Huff & Mandelbaum 2017):

$$\boldsymbol{\varepsilon}_\alpha^{\mathrm{obs}} = \mathbf{R}\boldsymbol{g}^{\mathrm{true}} + \boldsymbol{c}$$

The shear response tensor $\mathbf{R}$ generalizes m: $1 + m_\alpha = R_{\alpha\alpha}$.
To get population bias, average over measured shear responses $\langle R \rangle$, and correct measured ellipticities by $\langle R \rangle^{-1}$.
Measure individual $\mathbf{R}$ as numerical derivatives

$$R_{\alpha\beta} = \frac{\partial \varepsilon_\alpha^{\mathrm{obs}}}{\partial g_\beta}$$

by simulating the same galaxy several times with small added shear $\pm\Delta g_\alpha \sim 0.02$. With same noise realisation this measurement is extremely precise!

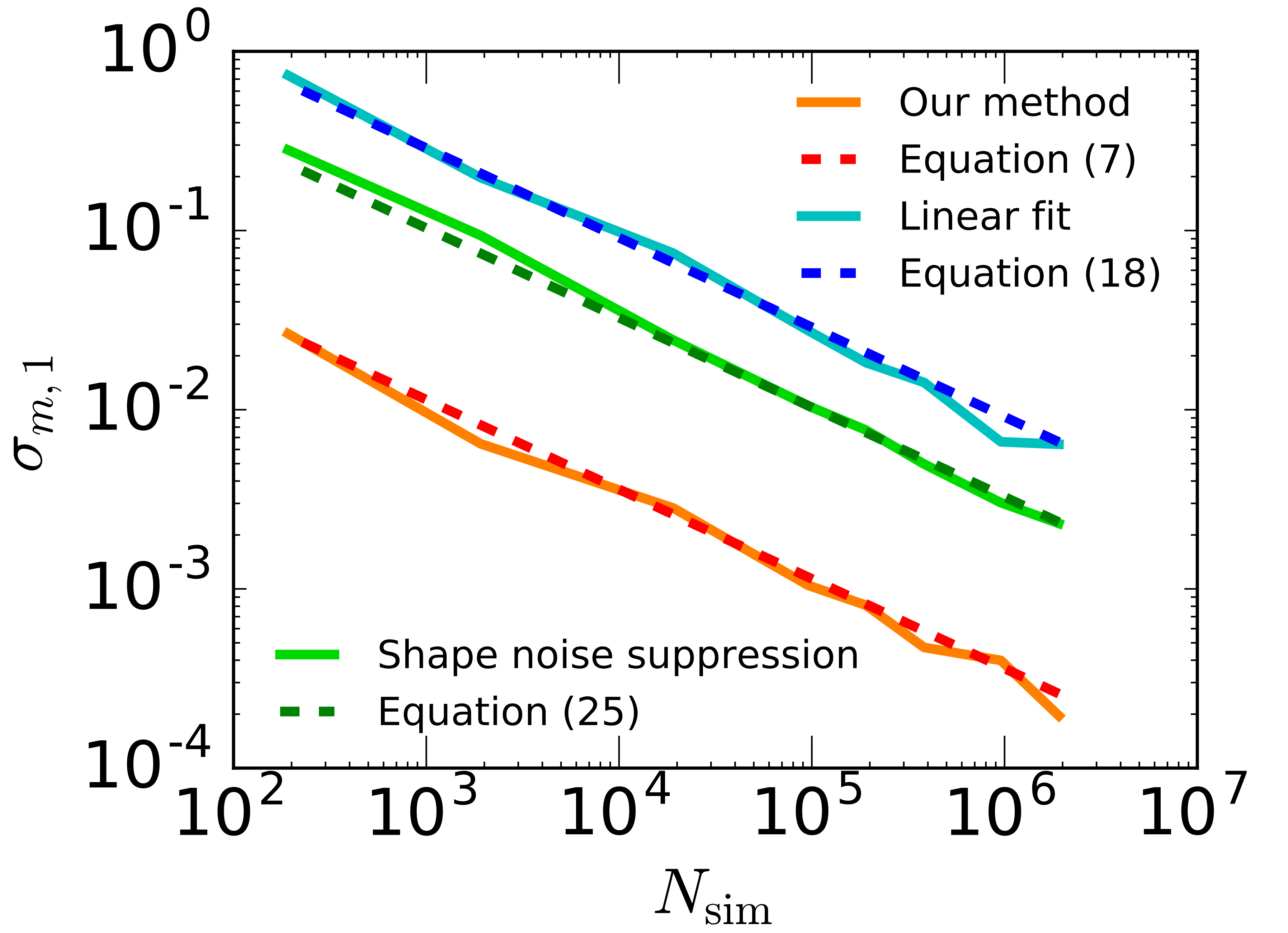


This measurement is independent of ellipticity (observed and intrinsic) and thus removes the main uncertainty of error!
Note: For a different noise realisation, the obtained $\mathbf{R}$ can be quite different. But the use of many simulated galaxy images assures the sampling of the distribution of R, no additional error is introduced on the population bias.
Error on bias estimate:

$$\sigma_{m,\alpha} = \frac{\sigma_{R,\alpha}}{\sqrt{N}}$$

This method requires a factor of several hundred fewer image simulations.

Shear bias uncertainty



Pujol, Kilbinger, Sureau & Bobin (2018), arXiv:180610537

Work in progress

- CFIS image simulations (Isaac Spitzer), shear calibration tests, validation of metacalibration
- Machine learning calibration (Arnau Pujol)
- Higher-order terms in shear-ellipticity relation, spatially varying shear bias (Axel Guinot, Olivier Kauffmann)

$$e = \frac{e^I + g}{1 + g^* e^I} = e^I + g - g^*(e^I)^2 + O(g^2)$$

$$\vec{e} = \vec{e}^I + \begin{pmatrix} 1 - (e_1^I)^2 + (e_2^I)^2 & -2e_1^I e_2^I \\ -2e_1^I e_2^I & 1 + (e_1^I)^2 - (e_2^I)^2 \end{pmatrix} \vec{g} = \vec{e}^I + A(\vec{e}^I)\vec{g}$$

$$\vec{e}^{obs} = R(\vec{P})A(\vec{e}^I)\vec{g} + \vec{a}(\vec{P}) + f(\vec{e}^I)$$

$$\frac{\partial e_\alpha^{obs}}{\partial g_\beta} = \left[R(\vec{P})A(\vec{e}^I)\right]_{\alpha\beta} = \widetilde{R}(\vec{P}, \vec{e}^I)_{\alpha\beta}$$