A lensing study of the matter environment of galaxy pairs in CFHTLenS and its comparison to a galaxy model

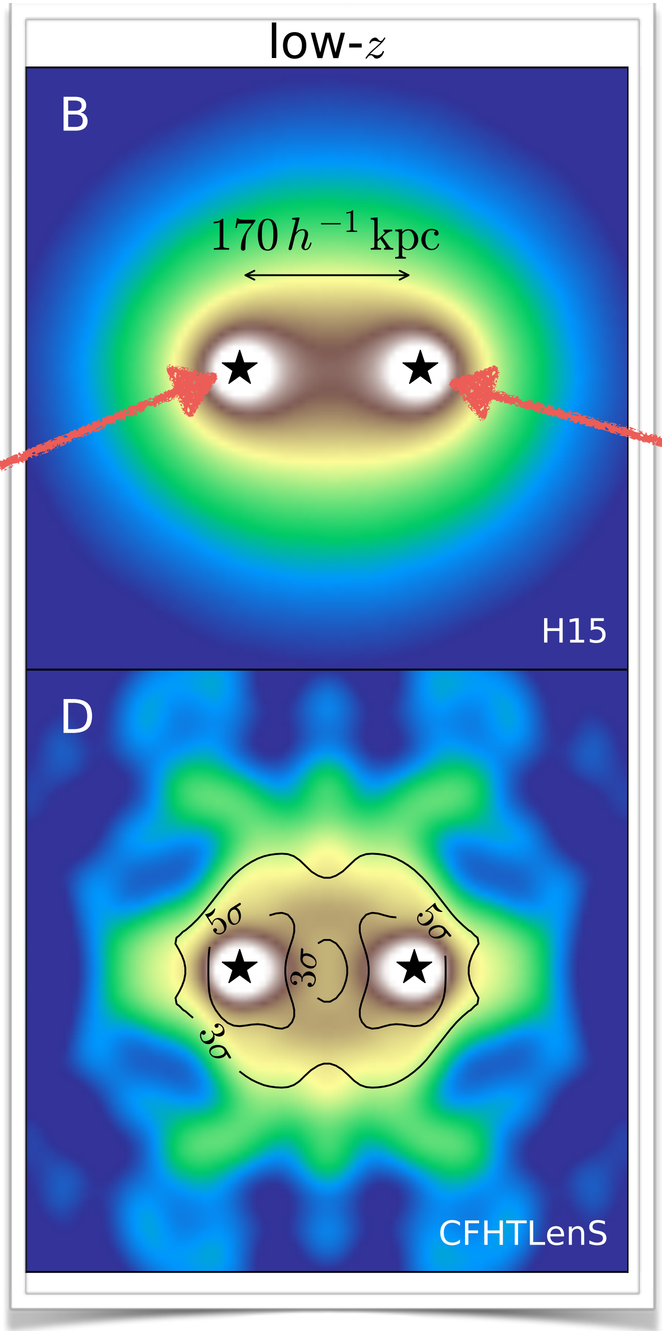
Patrick Simon

Cosmology/lens seminar 07/03/19

https://arxiv.org/abs/1710.09902
Simon et al., 2019, A&A, 622, 104

Collaborators: H. Saghiha,
S. Hilbert, P. Schneider, C. Boever, A.H. Wright

Teaser: excess mass around average galaxy pairs



Forecast (SAM)

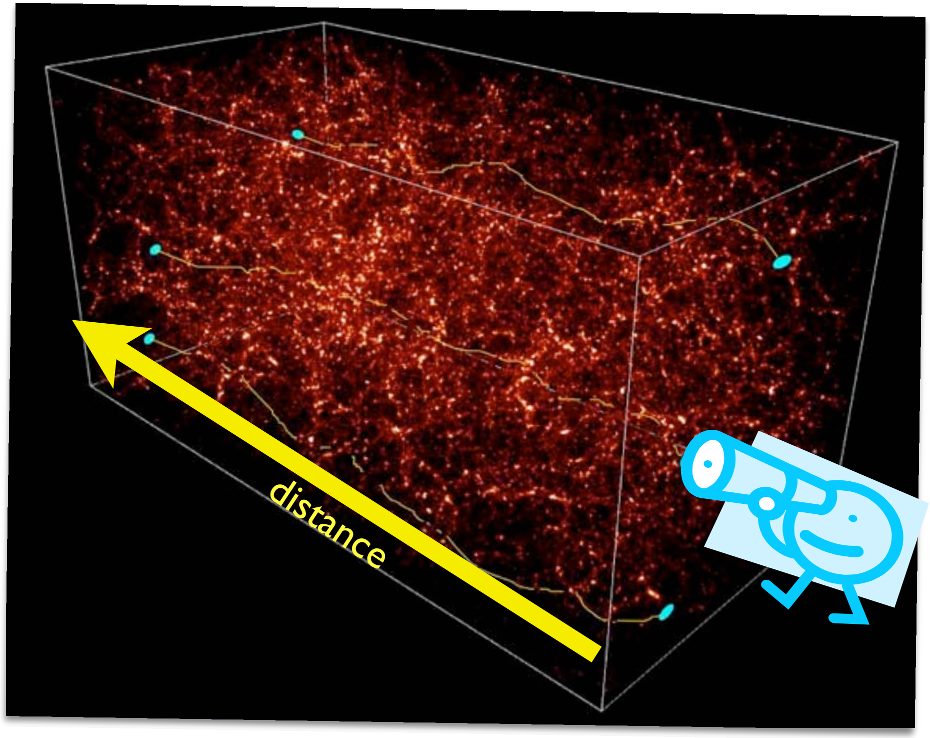
lens 2

lens 1

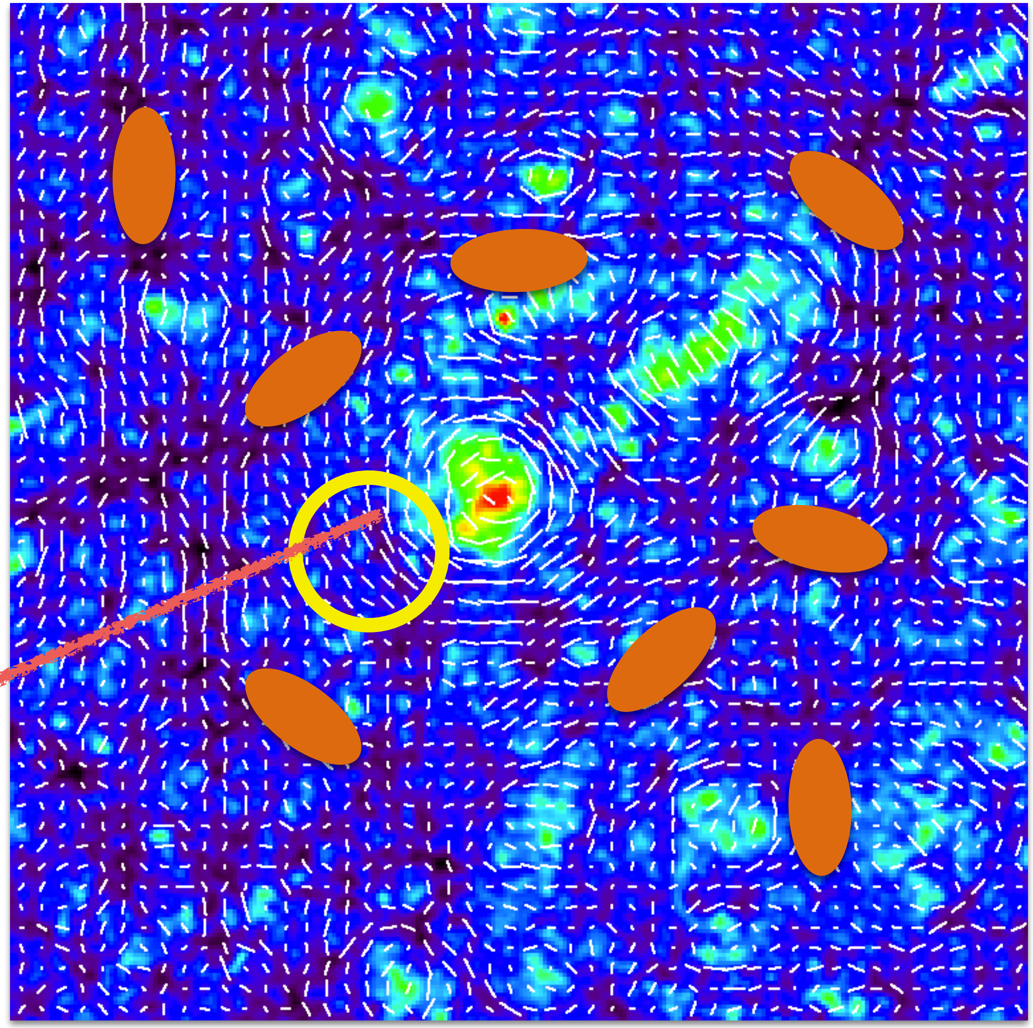
Real data

Primer on weak gravitational lensing

Credit: S. Colombi

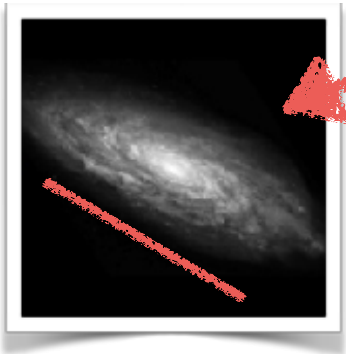


Credit: T. Hamana



Gravitational shear pattern on the sky

$$\gamma_1 + i\gamma_2 = \gamma$$



Shapes of galaxy images are correlated with shear

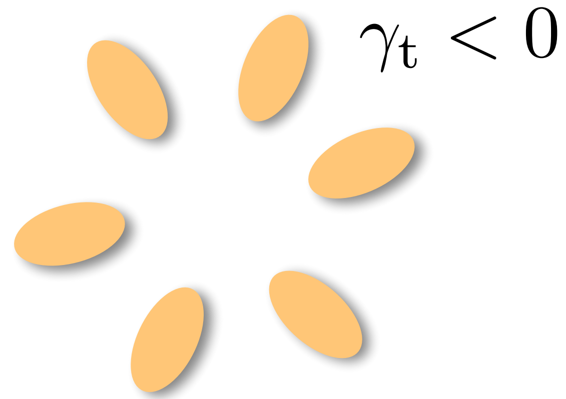
Primer on weak gravitational lensing

- lensing convergence

$$\kappa(\theta;\chi_\mathrm{s}) = \frac{3H_0^2\,\Omega_\mathrm{m}}{2\,c^2}\int_0^{\chi_\mathrm{s}} \mathrm{d}\chi\,\frac{\chi\,(\chi_\mathrm{s}-\chi)}{a(\chi)\,\chi_\mathrm{s}}\,\delta_\mathrm{m}(\chi\,\theta,\chi)$$

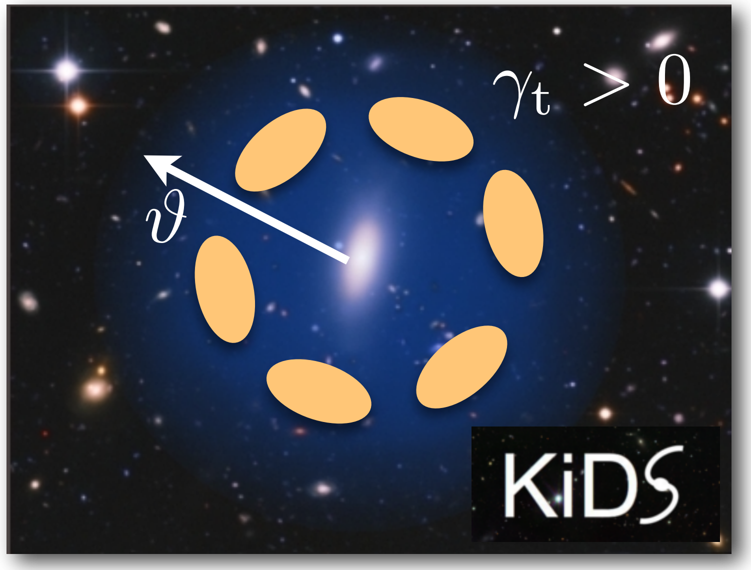
- relation convergence to shear

$$\nabla_\theta\kappa(\theta) = \begin{pmatrix} \partial_{\theta_1}\gamma_1(\theta) + \partial_{\theta_2}\gamma_2(\theta) \\ \partial_{\theta_1}\gamma_2(\theta) - \partial_{\theta_2}\gamma_1(\theta) \end{pmatrix}$$



- low S/N of galaxy lenses demands stacking

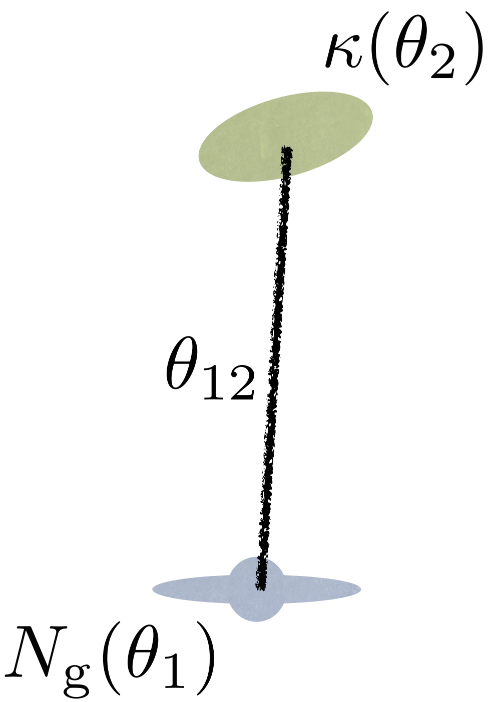
$$|\kappa| \sim |\gamma| \sim 1\%$$



- Stacking of single lenses is a correlation function:

$$\langle \kappa(\theta_2) | \text{lens at } \theta_1 \rangle = \frac{\langle N_{\rm g}(\theta_1)\kappa(\theta_2)\rangle}{\langle N_{\rm g}(\theta_1)\rangle} = \underline{\langle \kappa_{\rm g}(\theta_1)\kappa(\theta_2)\rangle} = \overline{\kappa}(\theta_{12})$$

two-point correlator



lens number density

$$N_{\rm g}(\theta) := \overline{N}_{\rm g}\left[1 + \underline{\kappa_{\rm g}(\theta)}\right]$$

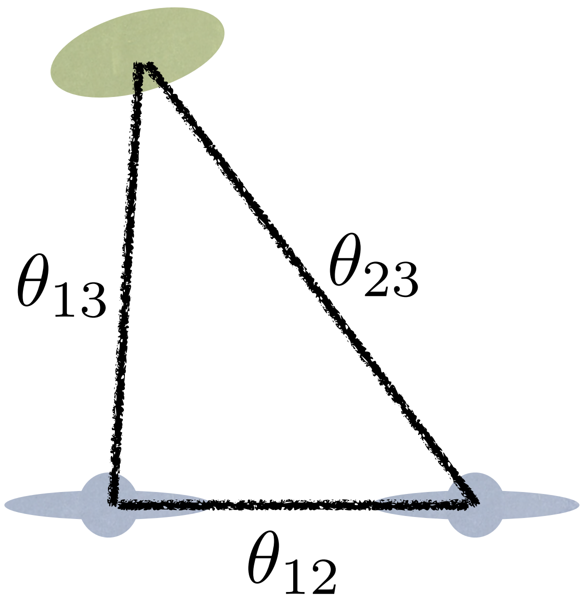
density contrast

- Stacking of lens pairs is a 3pt-correlation function:

$$\langle \kappa(\theta_3) | \text{lenses at } \theta_1 \wedge \theta_2 \rangle = \frac{\langle N_{\rm g}(\theta_1) N_{\rm g}(\theta_2) \kappa(\theta_3) \rangle}{\langle N_{\rm g}(\theta_1) N_{\rm g}(\theta_2) \rangle} =: \underline{\overline{\kappa}_{\rm pair}(\theta_{13}, \theta_{23}; \theta_{12})}$$

$$= \frac{\langle N_{\rm g}(\theta_1) N_{\rm g}(\theta_2) \kappa(\theta_3) \rangle}{\overline{N}_{\rm g}^2 [1 + \omega(\theta_{12})]}$$

$$= \frac{\langle [1 + \kappa_{\rm g}(\theta_1)][1 + \kappa_{\rm g}(\theta_2)] \kappa(\theta_3) \rangle}{1 + \omega(\theta_{12})} = \frac{\langle \kappa_{\rm g}(\theta_1) \kappa_{\rm g}(\theta_2) \kappa(\theta_3) \rangle \boxed{+ \overline{\kappa}(\theta_{13}) + \overline{\kappa}(\theta_{23})}}{1 + \omega(\theta_{12})}$$



$$\omega(\theta_{12}) = \langle \kappa_{\rm g}(\theta_1) \kappa_{\rm g}(\theta_2) \rangle$$

clustering of lenses

A connected 3pt-correlation function of galaxy pairs

$$\langle \kappa_{\mathrm{g}}(\theta_1)\, \kappa_{\mathrm{g}}(\theta_2)\, \kappa(\theta_3) \rangle =$$

$$= \frac{1}{\overline{N}_{\mathrm{g}}^2} \langle [N_{\mathrm{g}}(\theta_1) - \overline{N}_{\mathrm{g}}][N_{\mathrm{g}}(\theta_2) - \overline{N}_{\mathrm{g}}] \kappa(\theta_3) \rangle$$

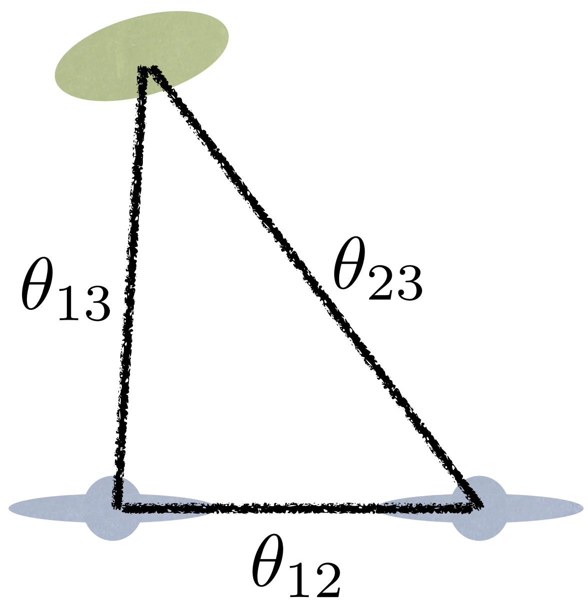
$$= \frac{1}{\overline{N}_{\mathrm{g}}^2} \langle N_{\mathrm{g}}(\theta_1) N_{\mathrm{g}}(\theta_2) \kappa(\theta_3) \rangle - \frac{1}{\overline{N}_{\mathrm{g}}} \langle N_{\mathrm{g}}(\theta_1) \kappa(\theta_3) \rangle - \frac{1}{\overline{N}_{\mathrm{g}}} \langle N_{\mathrm{g}}(\theta_2) \kappa(\theta_3) \rangle$$

$$= [1 + \omega(\theta_{12})]\, \overline{\kappa}_{\mathrm{pair}}(\theta_{13}, \theta_{23}; \theta_{12}) - \overline{\kappa}(\theta_{13}) - \overline{\kappa}(\theta_{23})$$

$$=: \overline{\Delta\kappa}_{\mathrm{emm}}(\theta_{13}, \theta_{23}, \theta_{12})$$

"Excess mass"

- vanishes for Gaussian fields



Galaxy-galaxy lensing…

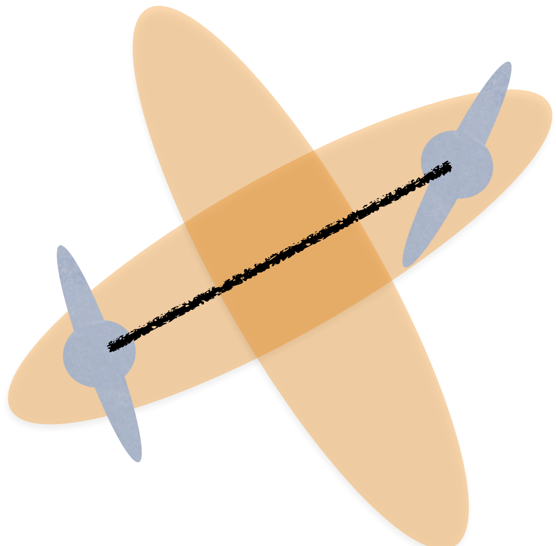
- probes the average matter-density profile around individual galaxies (in projection);

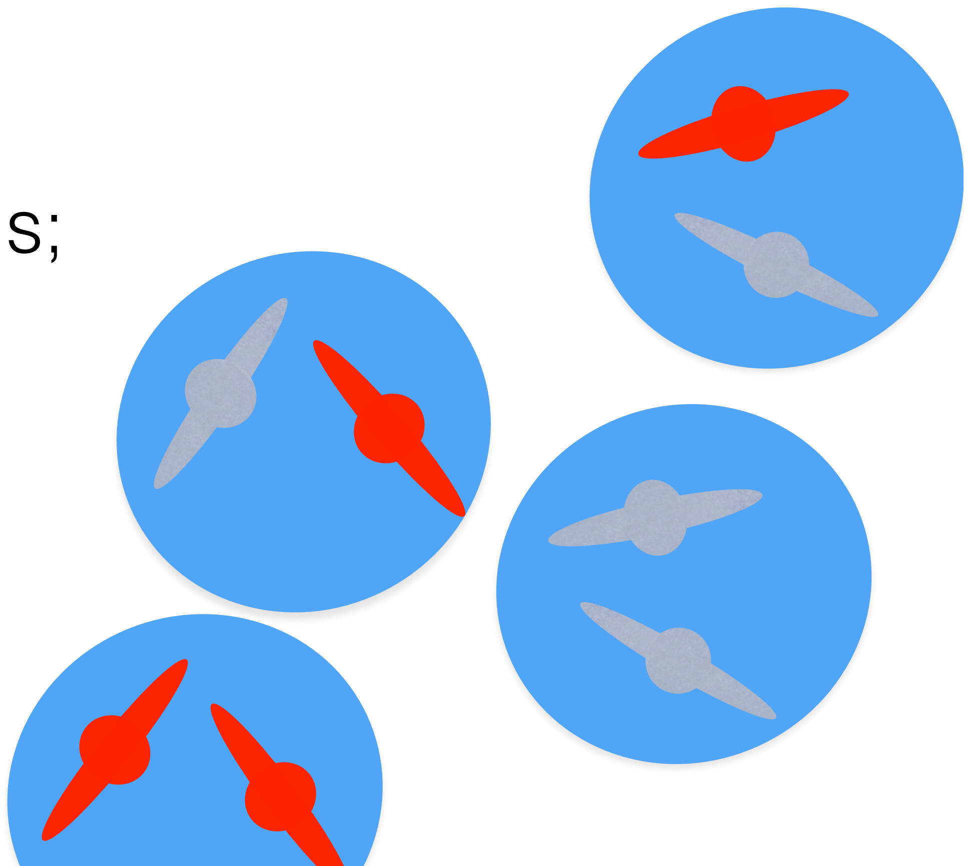
- inferes, e.g., the average number of galaxies in matter haloes, stellar mass per halo mass;

- stacks randomly oriented lenses and thus erases all directional dependence;

- is blind towards changes in the density profile due to close-by galaxies (or any other factor);

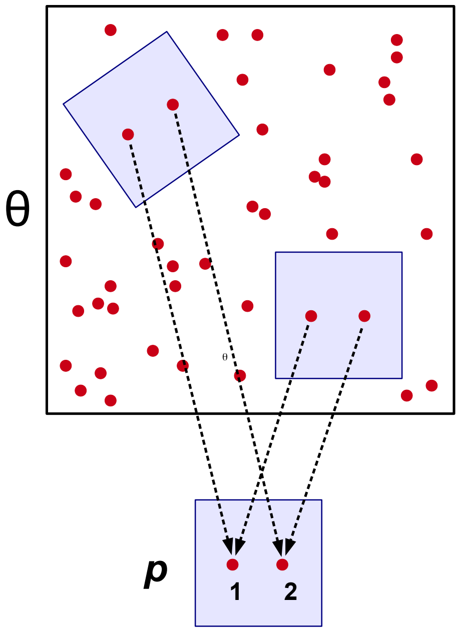
- Lensing by galaxy pairs or "galaxy-galaxy-galaxy lensing"…
  - defines a reference direction;
  - measures the change in the density profile as function of separation from another lens;
  - probes the population statistics of galaxy pairs inside haloes;
  - sensitive test of galaxy models;

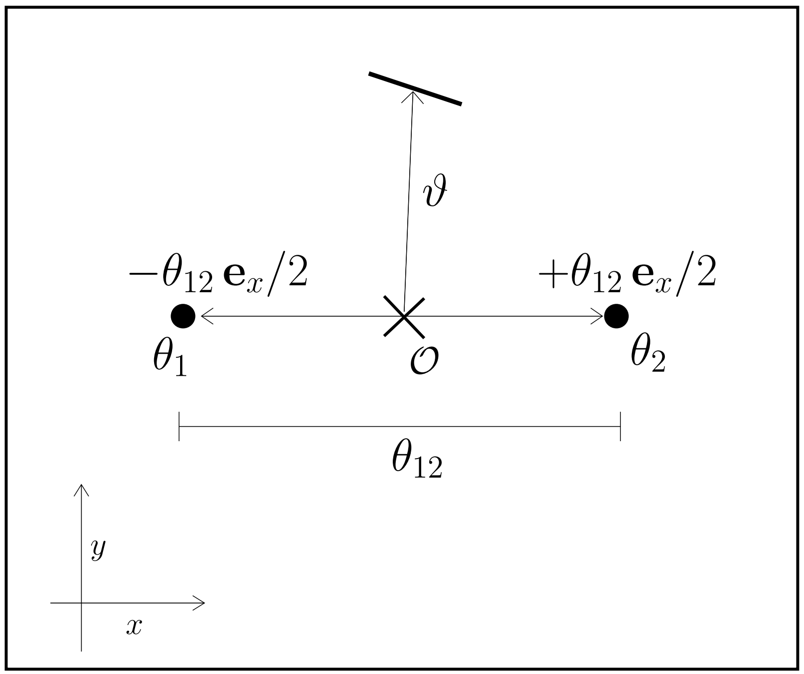




Practical estimator of the excess mass

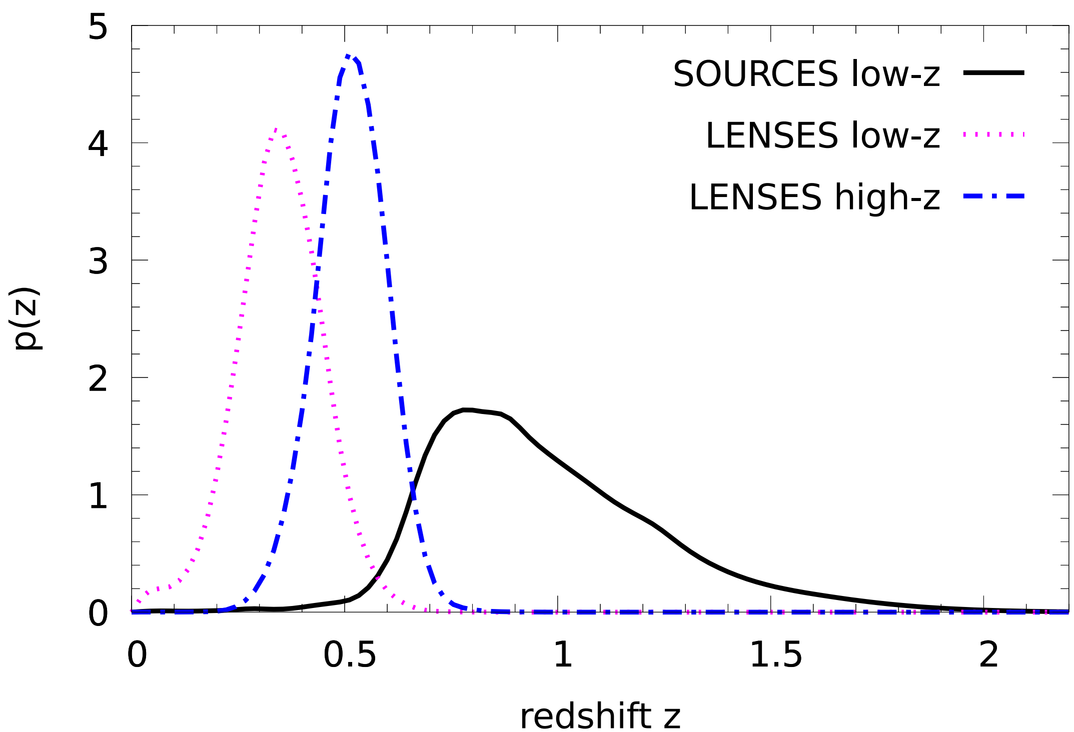
1. measure the angular clustering correlation-function of lenses;
2. measure the mean tangential shear around single lenses;
3. stack the shear around lens pairs;
4. compute the excess shear, and apply Kaiser & Squire (1993);





$$[1+\omega(\theta_{12})]\,\overline{\kappa}_{\rm pair}(\theta_{13},\theta_{23};\theta_{12})-\overline{\kappa}(\theta_{13})-\overline{\kappa}(\theta_{23})$$

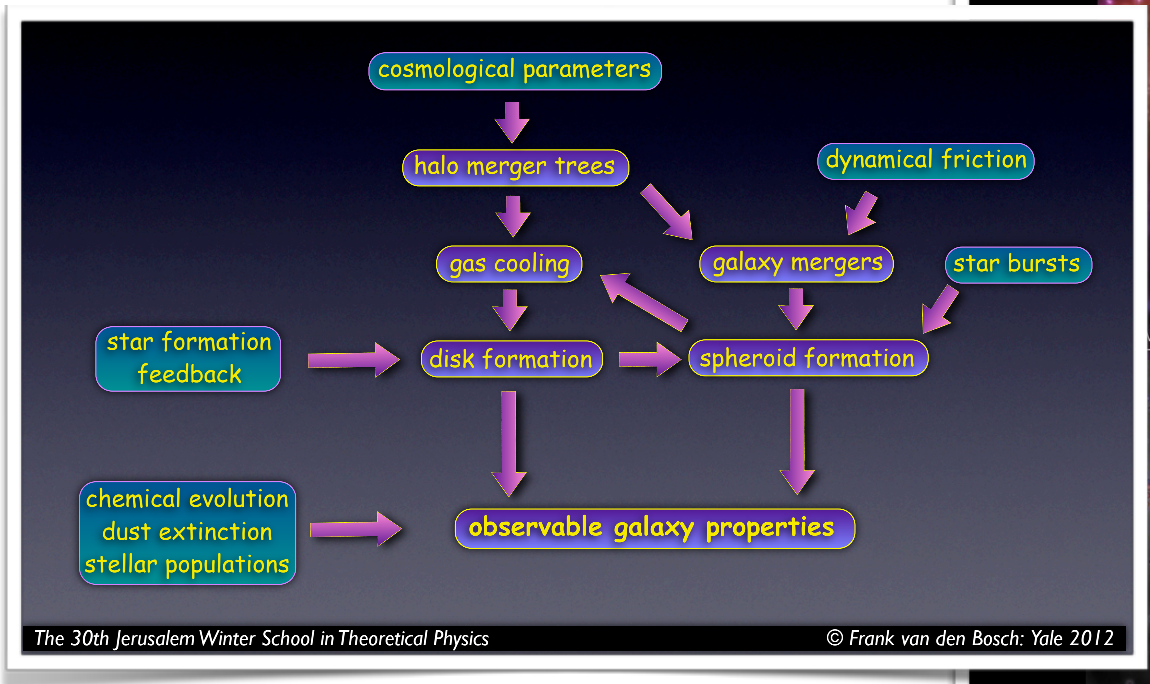
- Data: Canada-France-Hawaii Telescope Lensing Survey
  - photometric ugriz survey, ~95 sdeg used (Heymans et al. 2012)
  - lenses: i<22.5 in two photo-z bins; stellar masses from 5x10^9 to 3x10^11 Msol; 0.5 and 0.7 per arcmin^2;
  - sources: i<24.7; 5.5 per arcmin^2; r-band PSF 0.66-0.82 arcsec;

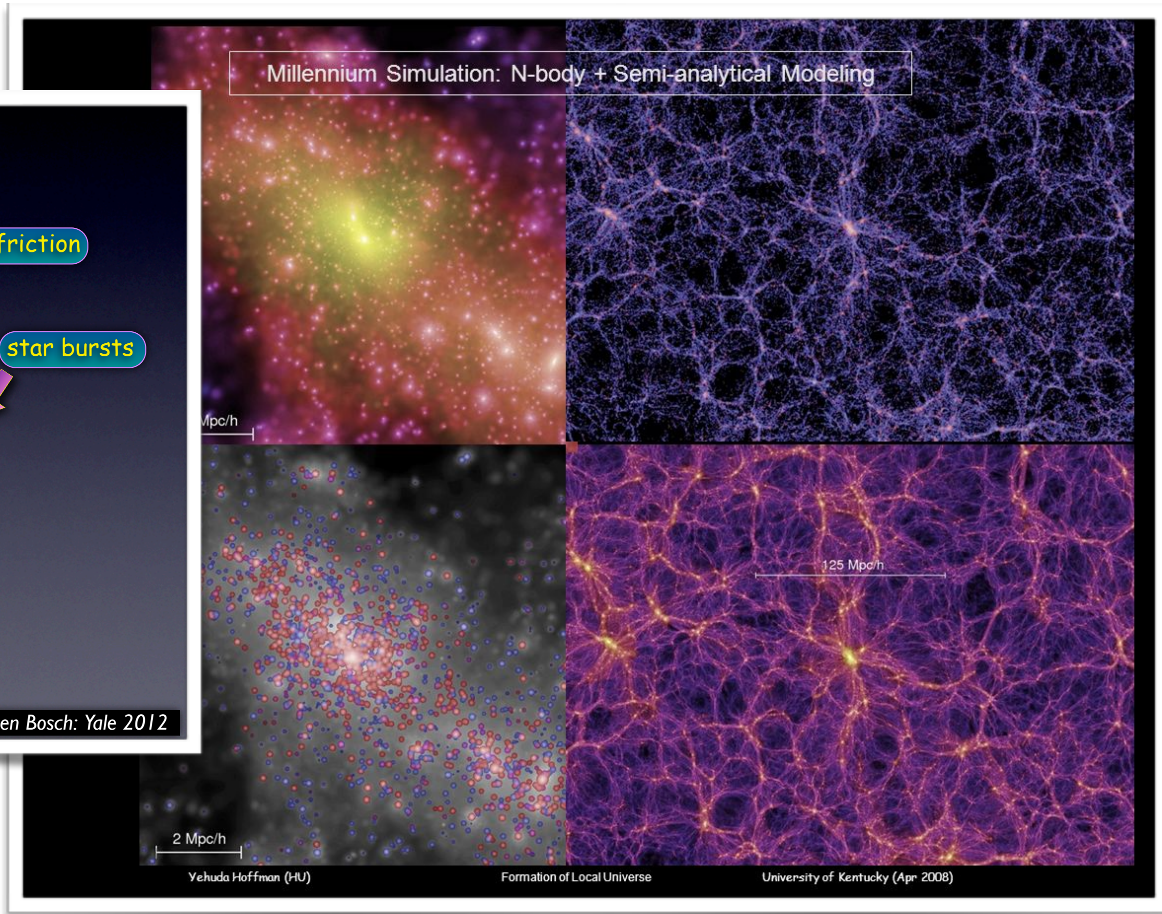


Mock shear and galaxy catalogues

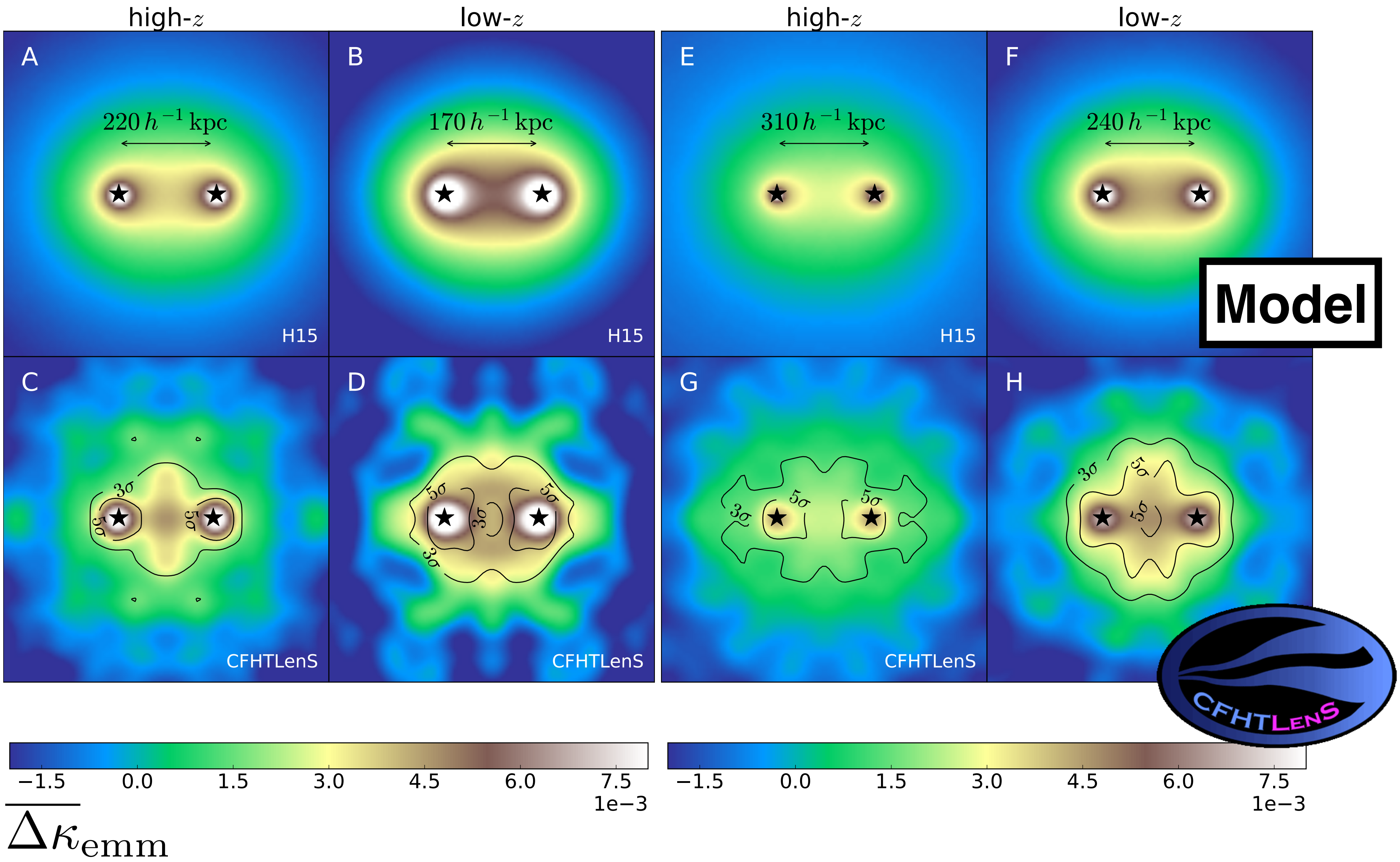
- dark matter: Millennium Simulation; 1024 sdeg; (Springel et al. 2005; Hilbert et al. 2009);

- galaxies: semi-analytical “Garching” model; (Saghiha et al. 2017; Henriques et al. 2015; Guo et al. 2011)

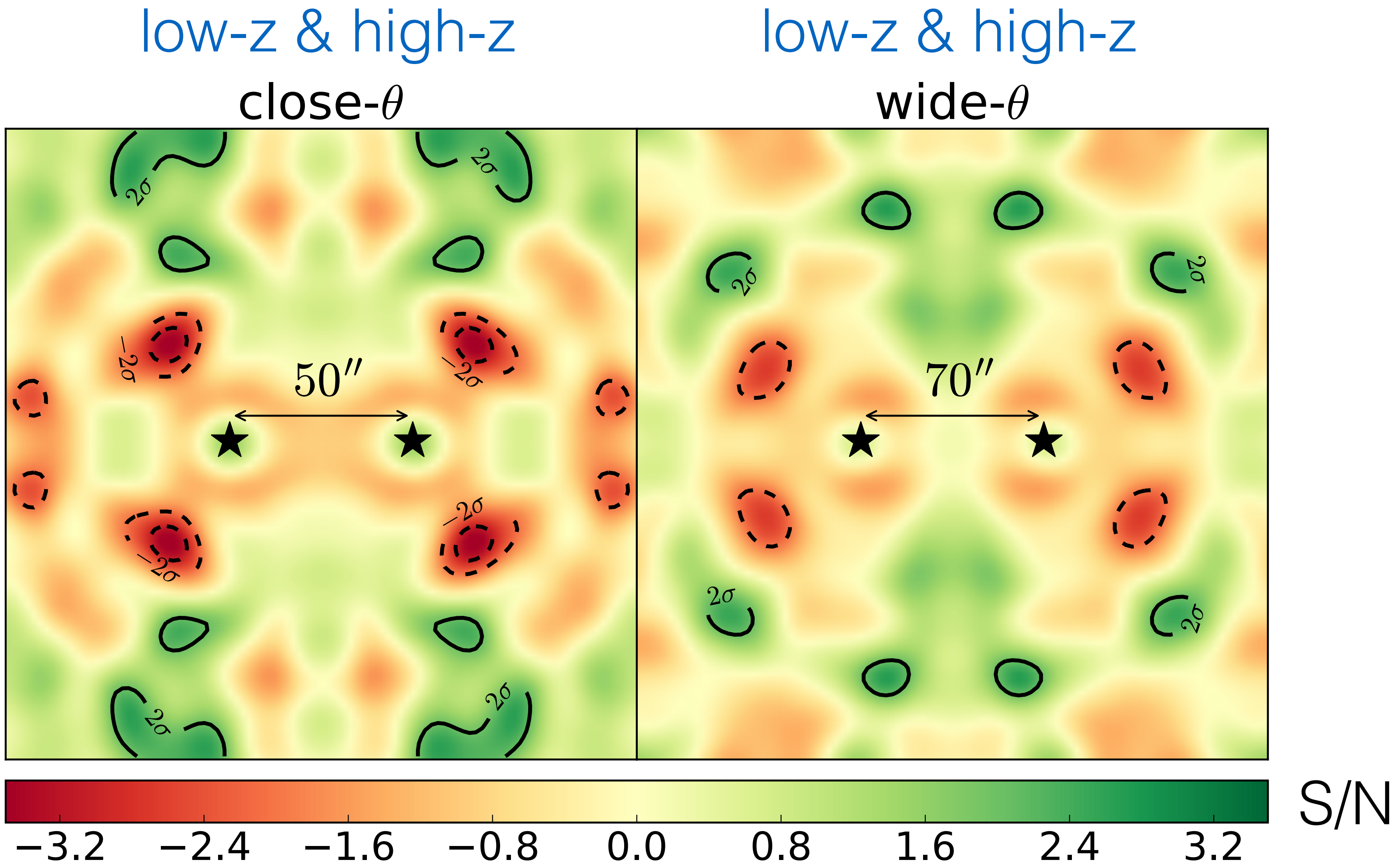




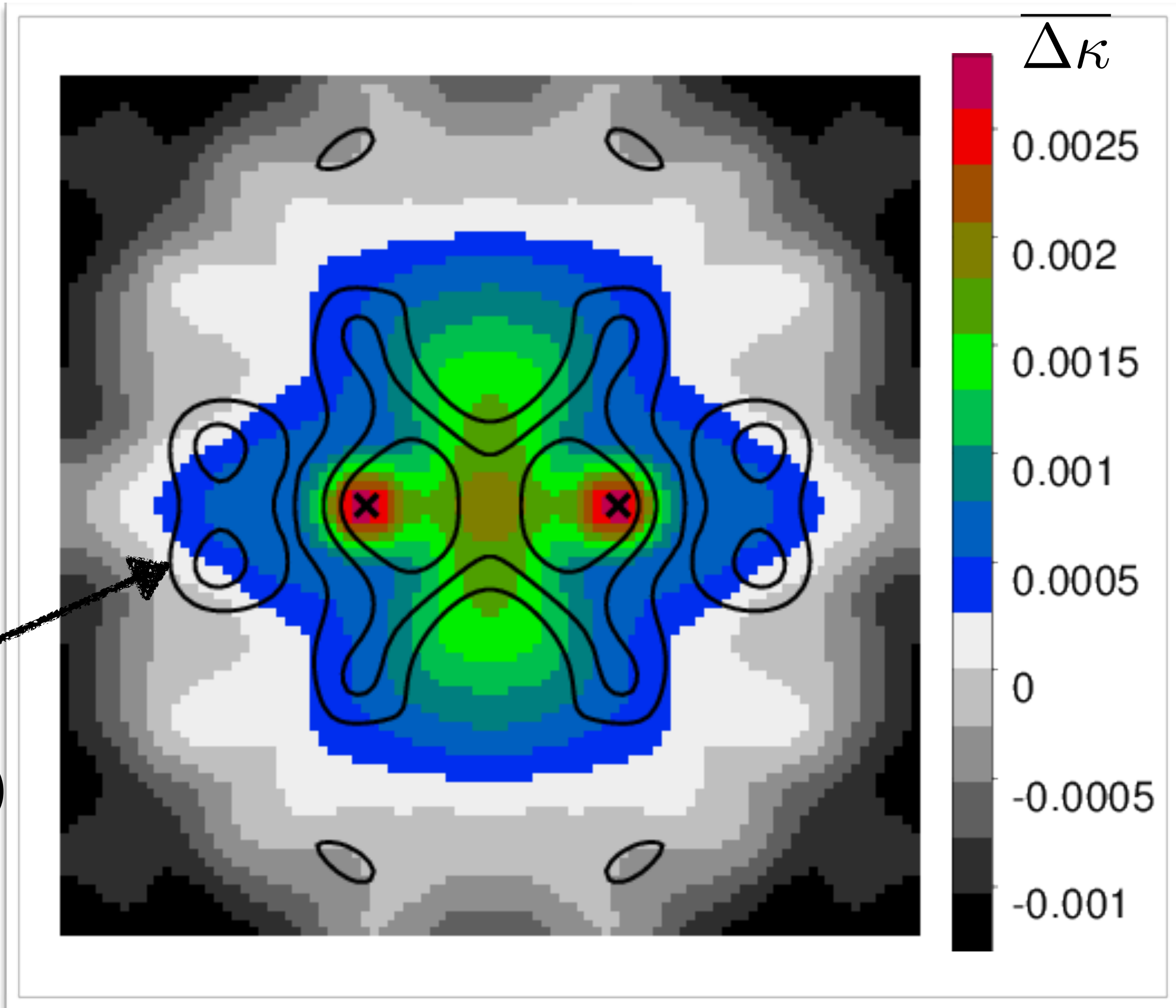
Results for the excess mass from our paper



- Mass map of (shear) residuals between forecast and CFHTLenS: some mismatch S/N~3.5



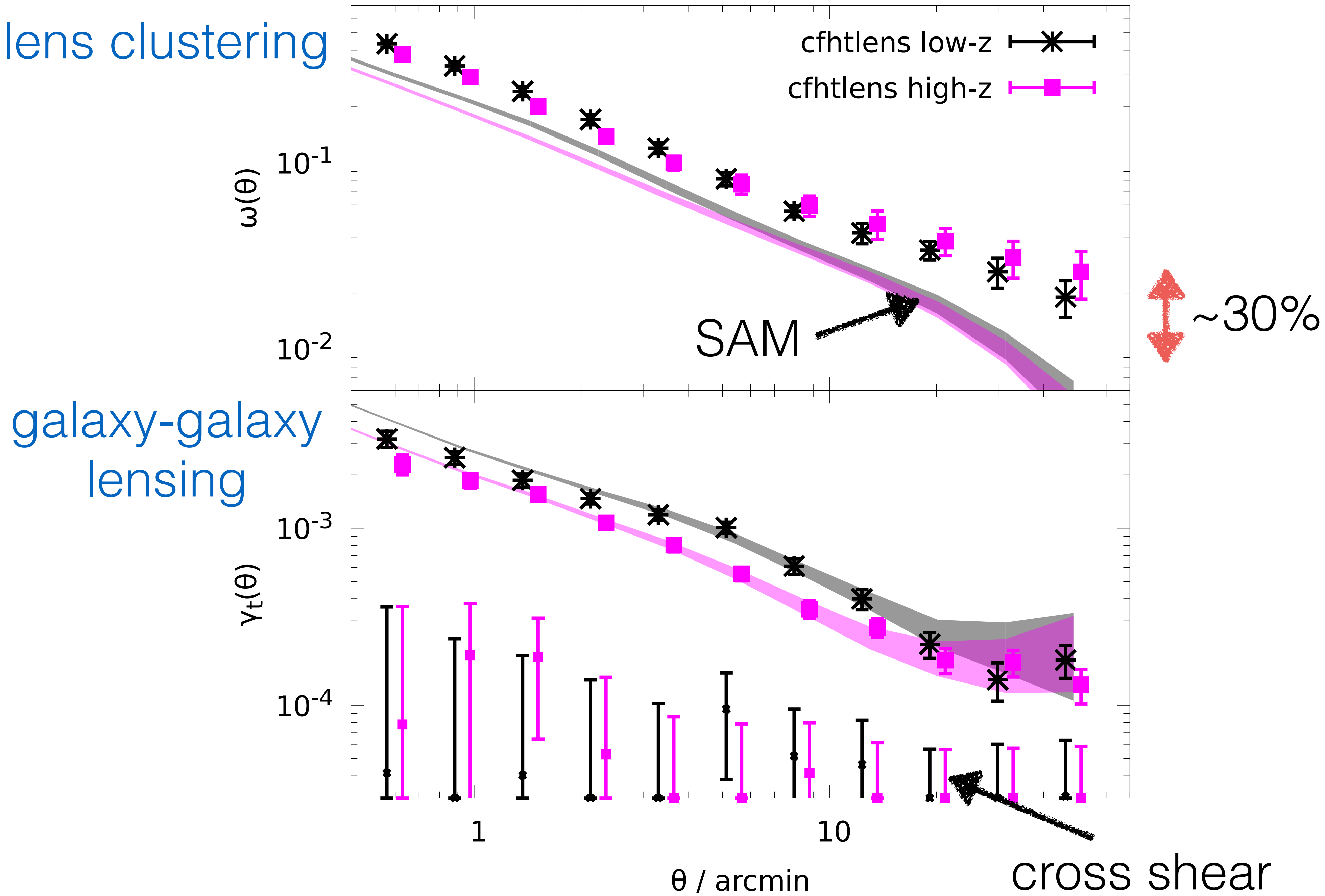
- [ ] Is the vertical bulge of excess mass real?



B-modes
(2-6x10^-4)

Combined maps for all z-bins and separation bins
(pair convergence)

More differences: second-order statistics



Conclusions

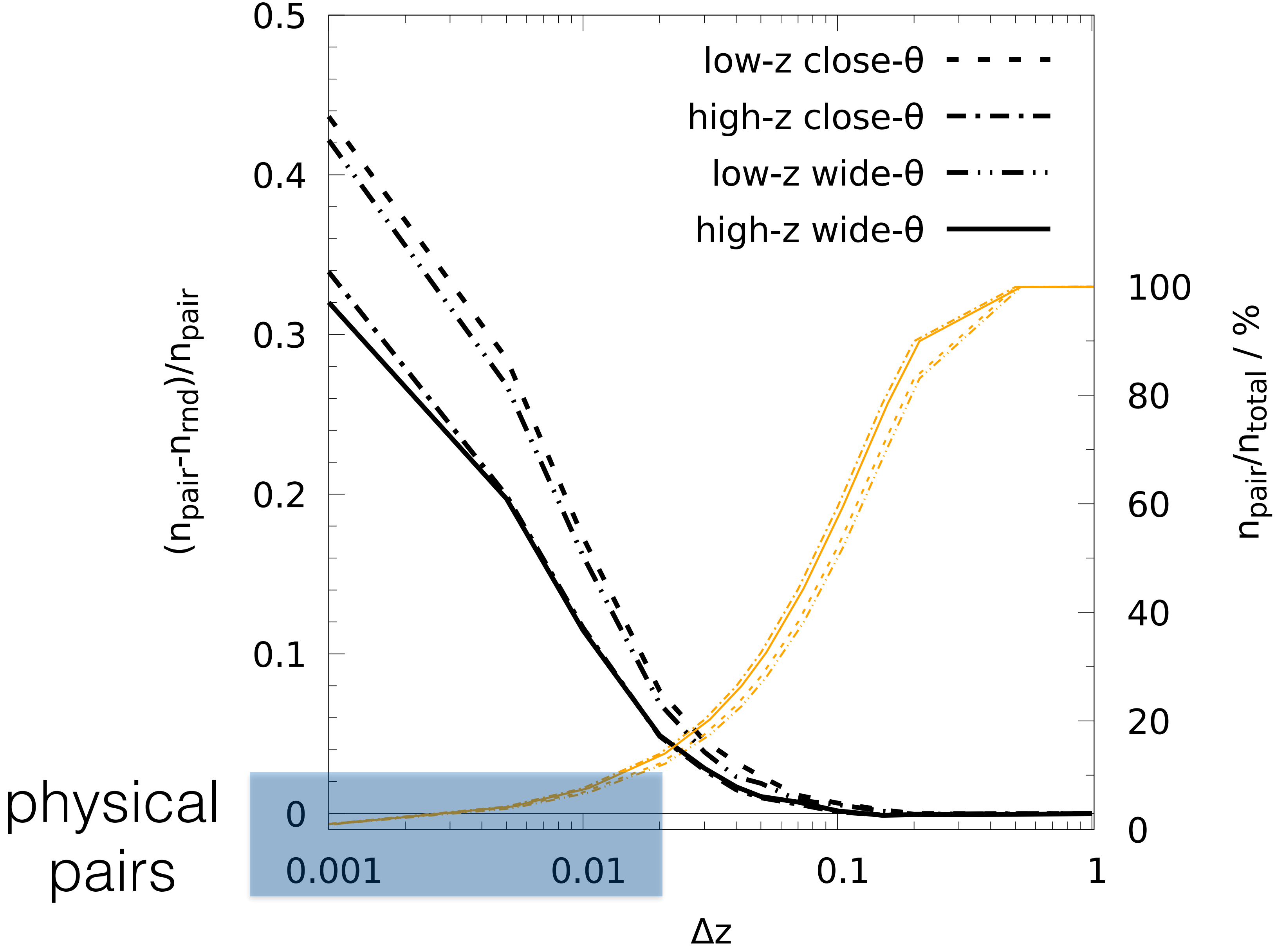
- reasonable good match between SAM and CFHTLenS for the excess mass around (physical) galaxy pairs with 150-300 kpc/h separation and z<0.6 (Mstar>10^9 Msol);

- weak evidence for unexpected vertical bulge of excess mass; needs to be confirmed (KiDS e.g.);

- tension for clustering of lenses but very good agreement for mean matter-density profile around single lenses;

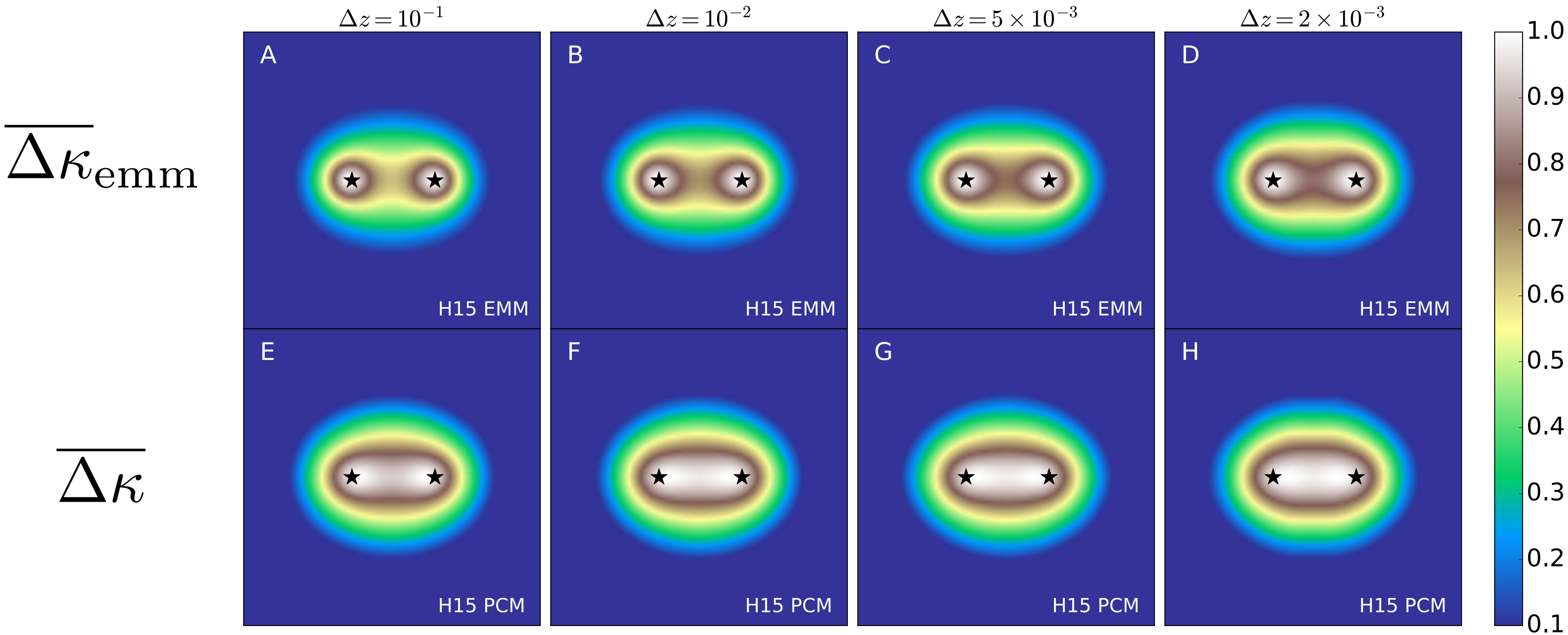
- might be related to residual B-modes in the shear data — or possible misaligned distribution of halo dark-matter or the IGM;

- most lens pairs are non-physical (r>>5 Mpc/h)



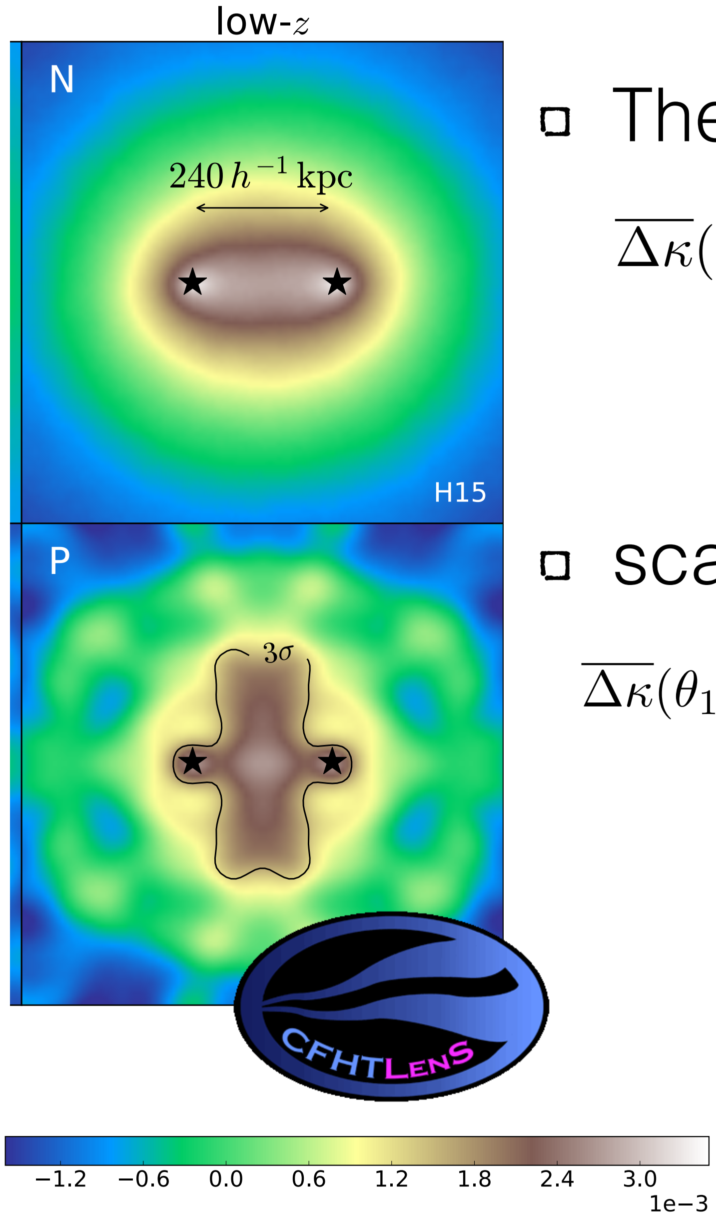
Statistics of pair distances in mock data

▢ …but mostly affects only the mean amplitude in the map



Split lens pairs into physical "true" pairs (tp) and non-physical pairs:

$$\overline{\Delta\kappa}_{\rm emm}(\theta_{13},\theta_{23};\theta_{12}) = \frac{p_{\rm tp}(1+p_{\rm tp}\omega_{\rm tp})}{1+\omega_{\rm tp}} \times \quad \overline{\Delta\kappa}_{\rm emm}(\theta_{13},\theta_{23};\theta_{12})|_{\rm tp}$$
$$+\frac{p_{\rm tp}(1-p_{\rm tp})\omega_{\rm tp}^2}{1+\omega_{\rm tp}} \times \quad \left(\overline{\kappa}_{\rm ind}(\theta_{13}) + \overline{\kappa}_{\rm ind}(\theta_{23})\right)$$



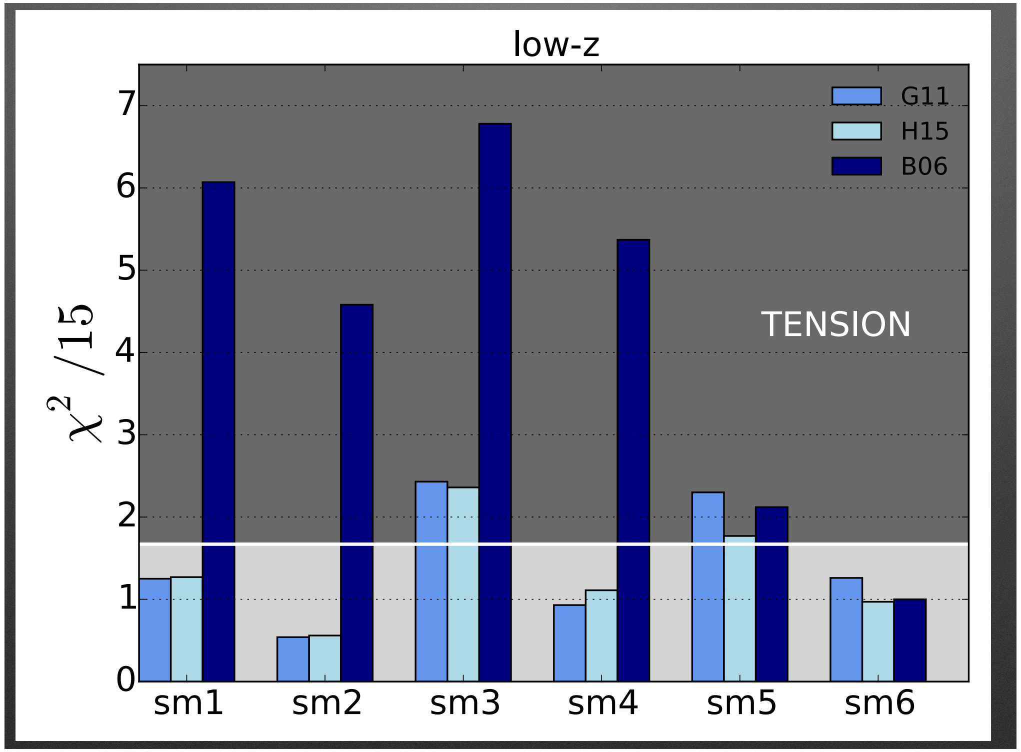
- The pair convergence is defined as

$$\overline{\Delta\kappa}(\theta_{13},\theta_{23};\theta_{12}) := \overline{\kappa}_{\rm pair}(\theta_{13},\theta_{23};\theta_{12}) - \overline{\kappa}(\theta_{12}) - \overline{\kappa}(\theta_{13})$$

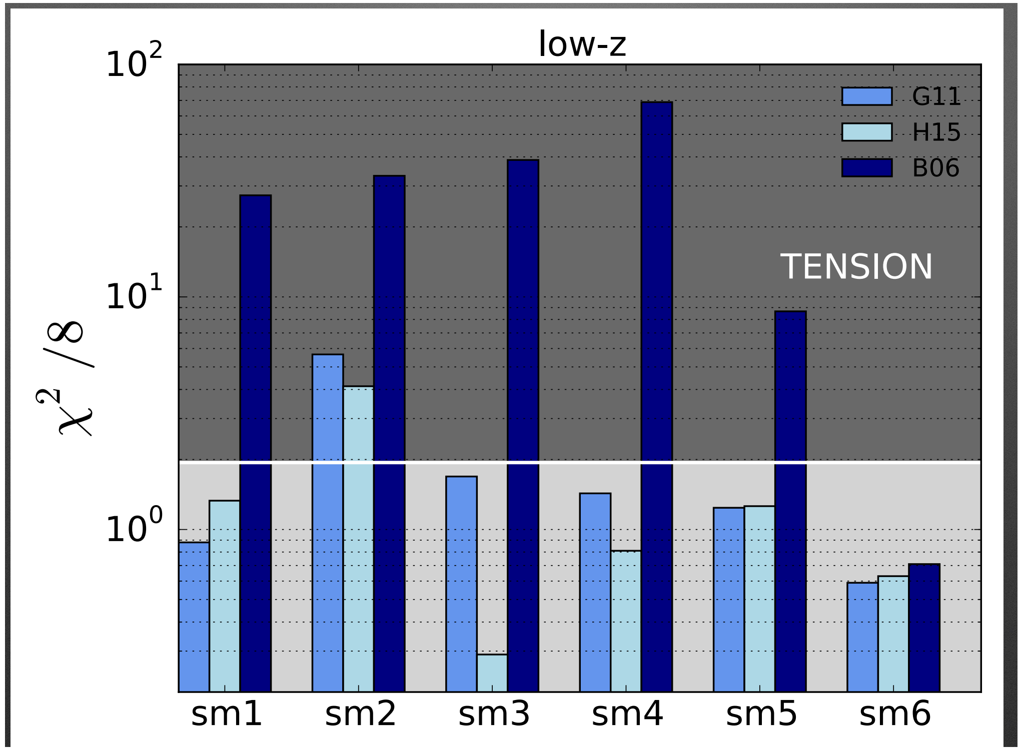
- scaling with true-pair fraction

$$\overline{\Delta\kappa}(\theta_{13},\theta_{23};\theta_{12}) = p_{\rm tp}\left(\overline{\kappa}_{\rm pair}(\theta_{13},\theta_{23};\theta_{12})|_{\rm tp} - \overline{\kappa}(\theta_{12}) - \overline{\kappa}(\theta_{13})\right)$$

- sensitivity for galaxy-model testing
(from talk slides by Hananeh Saghiha, 2016)



GGL



G3L