Weak-lensing stacking techniques

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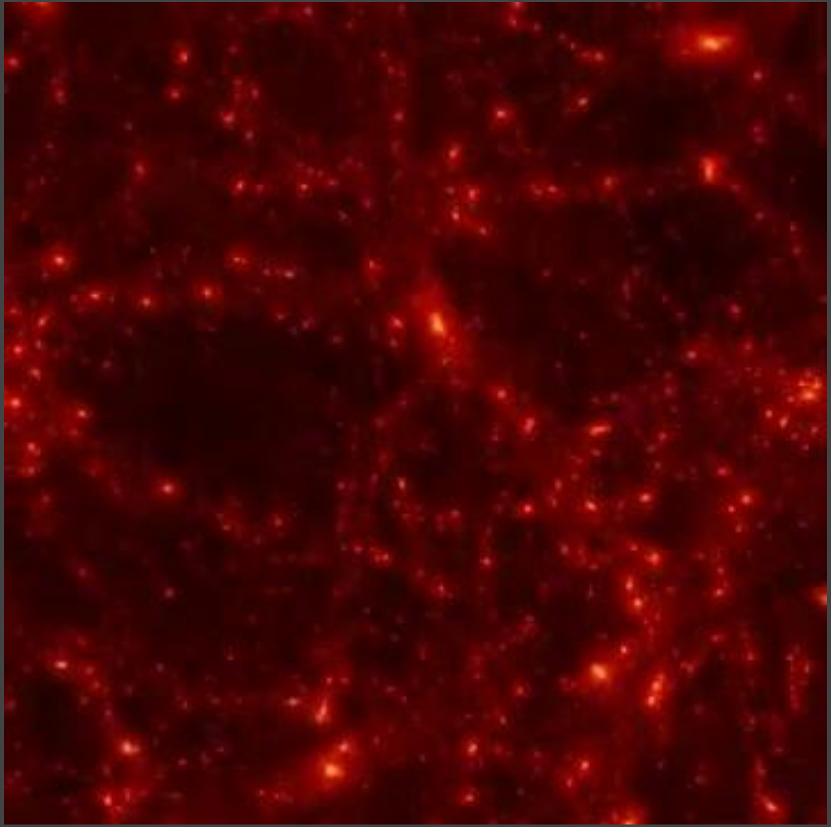
I A T E

The LSS of the Universe

Navigating in a dark-matter only Universe

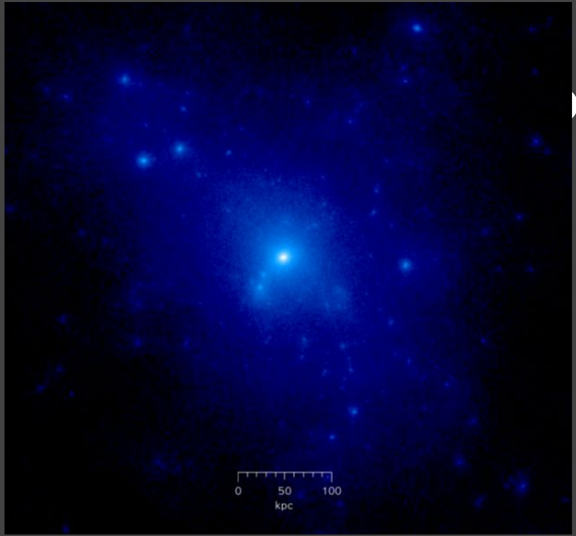
Ruiz et al. (2011)

60 Mpc/h, 8.93×10^8 Msun/h



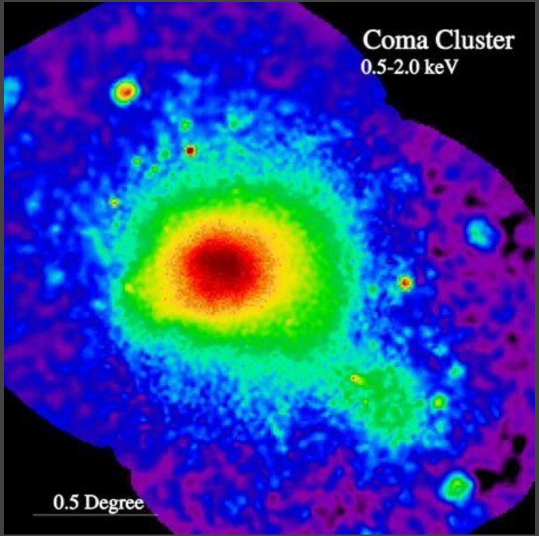
Galaxy systems

Galaxies tend to group together and form galaxy systems ranging from galaxy pairs to rich clusters.



~80%

Matéria escura



~15%

Gás

~5%

Estrelas

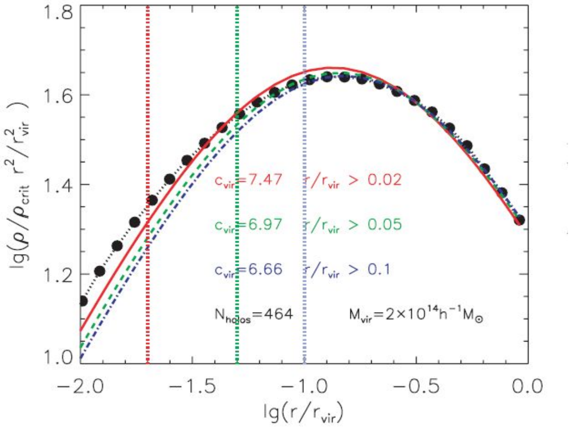
Dark matter halos

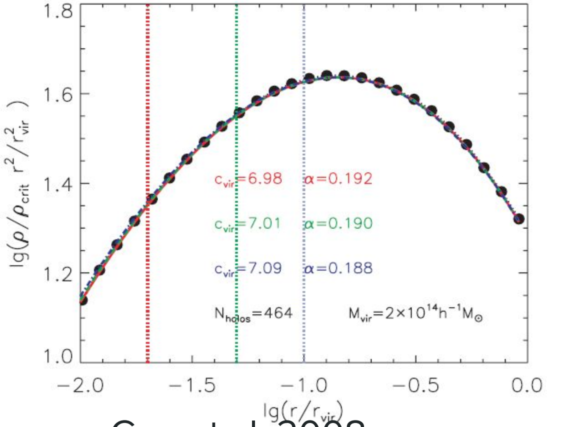
NFW model (Navarro et al. 1997):

$$\rho(r) = \frac{\rho_{\text{crit}}\delta_c}{(r/r_s)(1+r/r_s)^2}, \quad \delta_c = \frac{\Delta}{3}\frac{c_\Delta^3}{\ln(1+c_\Delta) - c_\Delta/(1+c_\Delta)}$$

Einasto model (Einasto & Haud 1989;
Retana-Montenegro et al. 2012):

$$\rho(r) = \rho_{-2}\exp\left(-\frac{2}{\alpha}\left[\left(\frac{r}{r_{-2}}\right)^{\alpha} - 1\right]\right)$$

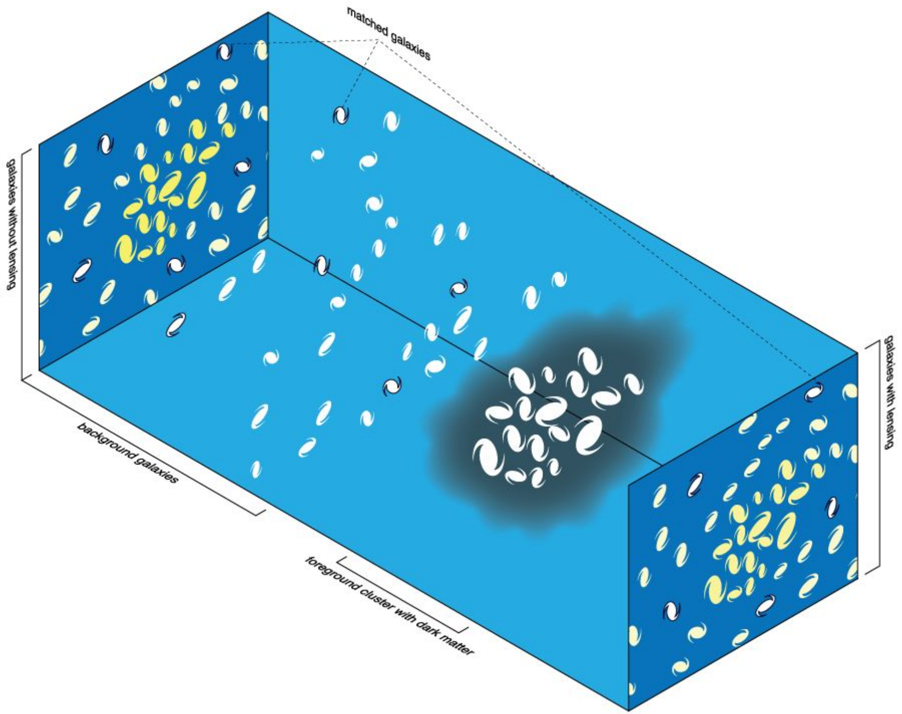




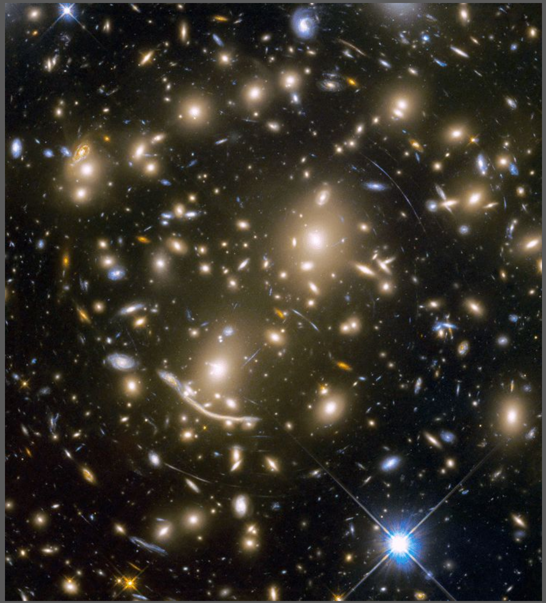
Gao et al. 2008

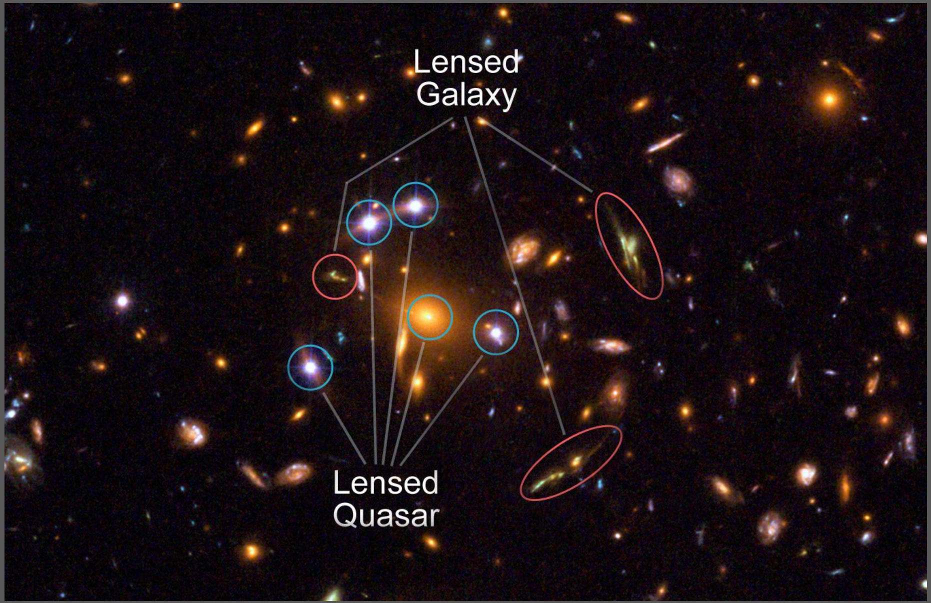
Lensing effect by galaxy clusters

The gravitational lensing effect introduces a distortion in the luminous sources that are behind a gravitational potential considered as the lens. Galaxy systems in particular are powerful lenses that distort the shape of the galaxies that are behind.



Strong lensing effect





Weak lensing effect

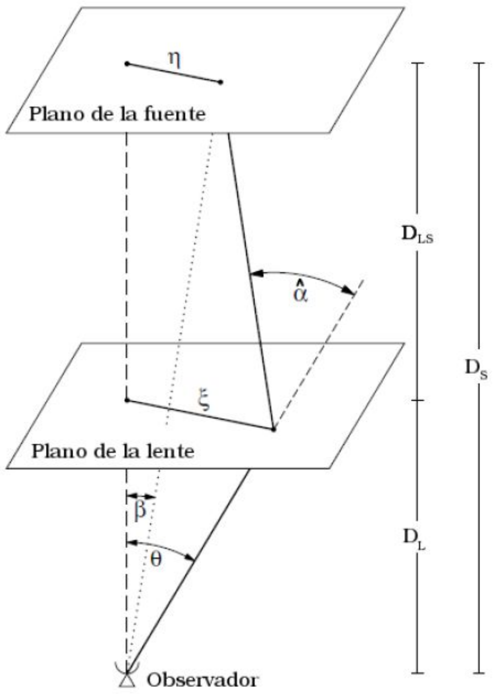
At the weak lensing regime the effect can be quantified through the shear

$$e = \frac{a-b}{a+b} = \frac{|\gamma|}{1-\kappa} \approx |\gamma|$$

$$\gamma_{\mathrm{t}}(r) \times \Sigma_{\mathrm{crit}} = \bar{\Sigma}(< r) - \bar{\Sigma}(r) \equiv \Delta\Sigma(r)$$

$$\Sigma_{\mathrm{crit}} = \frac{c^2}{4\pi G} \frac{D_{\mathrm{OS}}}{D_{\mathrm{OL}} D_{\mathrm{LS}}}$$

"You have a mass distribution about which you don't know anything, and then you observe sources which you don't know either, and then you claim to learn something about the mass distribution?"



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Surface density distribution

$$\gamma_t(r) \times \Sigma_{crit} = \bar{\Sigma}(< r) - \bar{\Sigma}(r) \equiv \Delta\Sigma(r)$$

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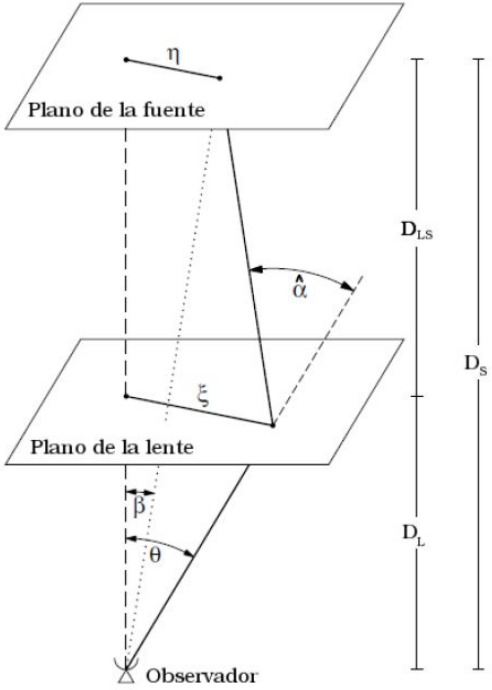

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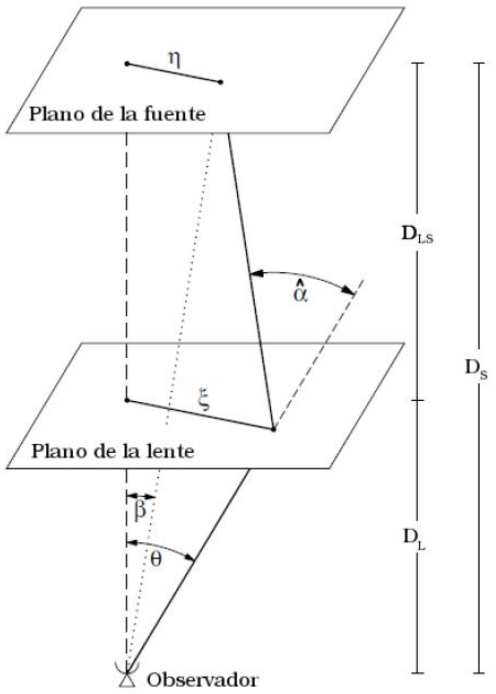
Density contrast

$$\Sigma_{\rm crit} = \frac{c^2}{4\pi G} \frac{D_{\rm OS}}{D_{\rm OL} D_{\rm LS}}$$

"You have a mass distribution about which you don't know anything, and then you observe sources which you don't know either, and then you claim to learn something about the mass distribution?"

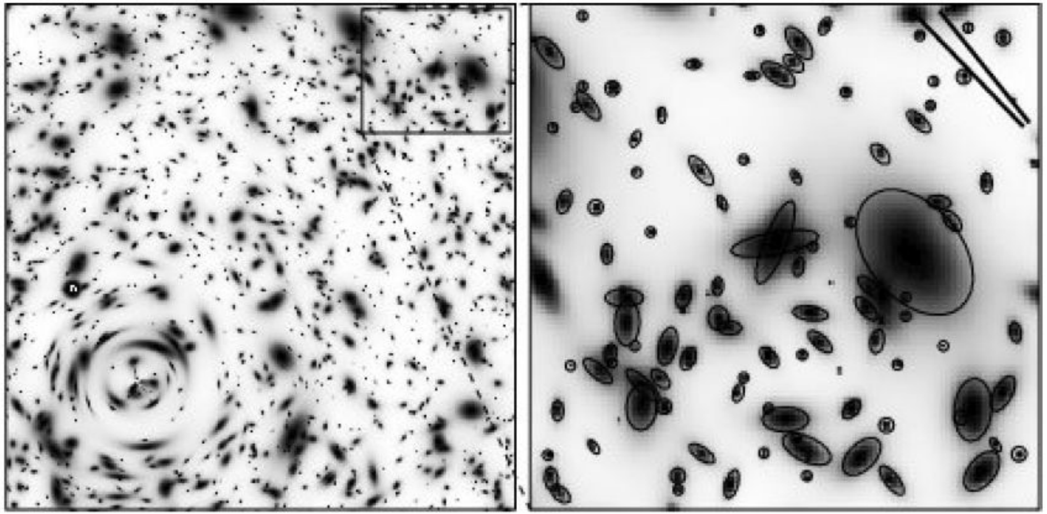


Weak lensing effect

$$\boldsymbol{e} = \boldsymbol{e}_{\mathrm{s}} + \gamma$$

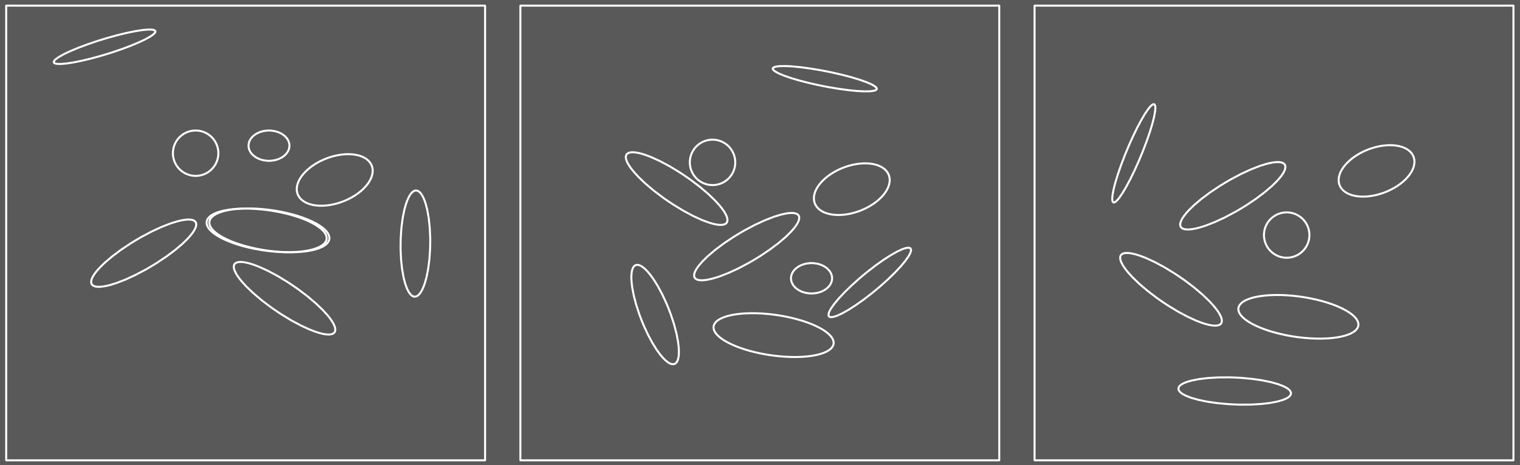
$$\langle \boldsymbol{e} \rangle = \langle \gamma \rangle$$

$$\sigma_\gamma \approx \frac{\sigma_\epsilon}{\sqrt{N}}$$



Stacking techniques

Enables to obtain the mean mass distribution at large radial ranges of a combined sample of clusters, by artificially increasing the lensing signal



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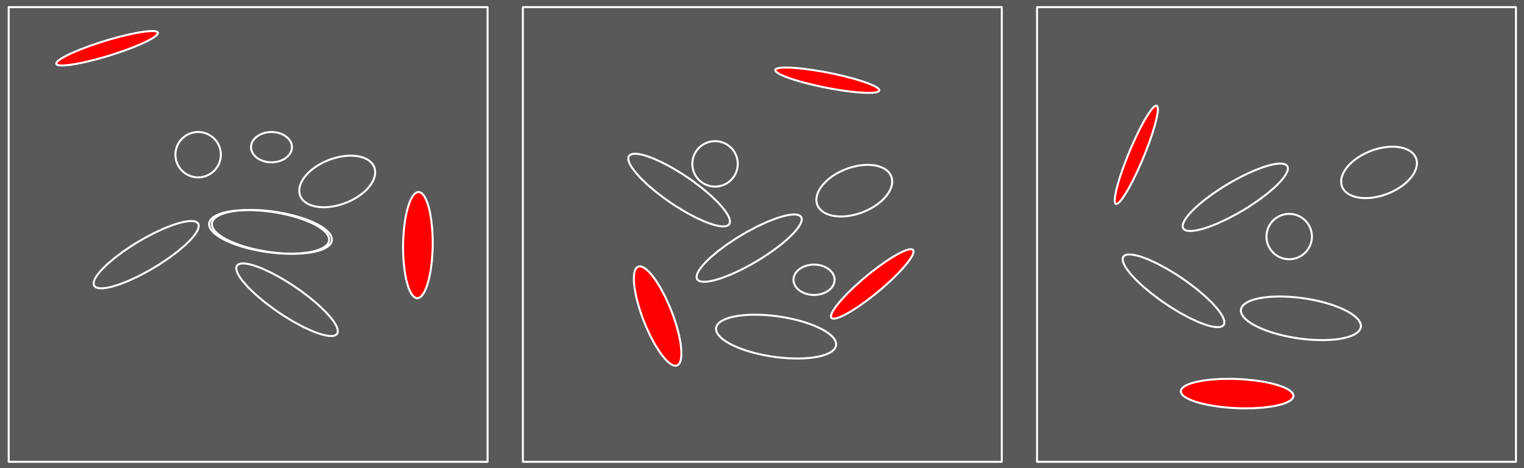

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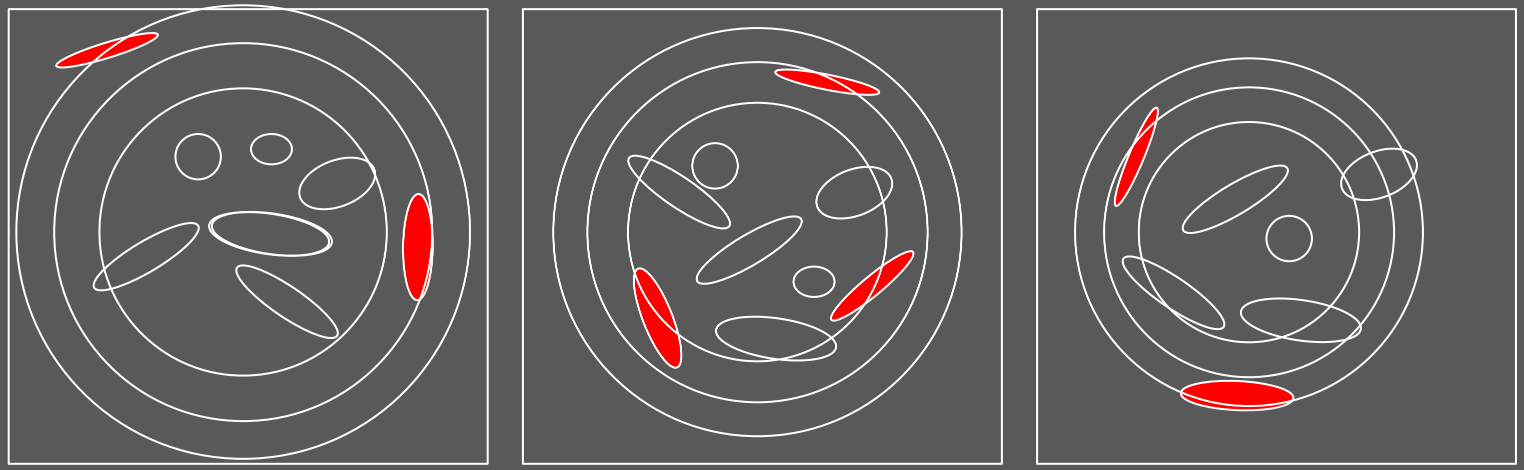
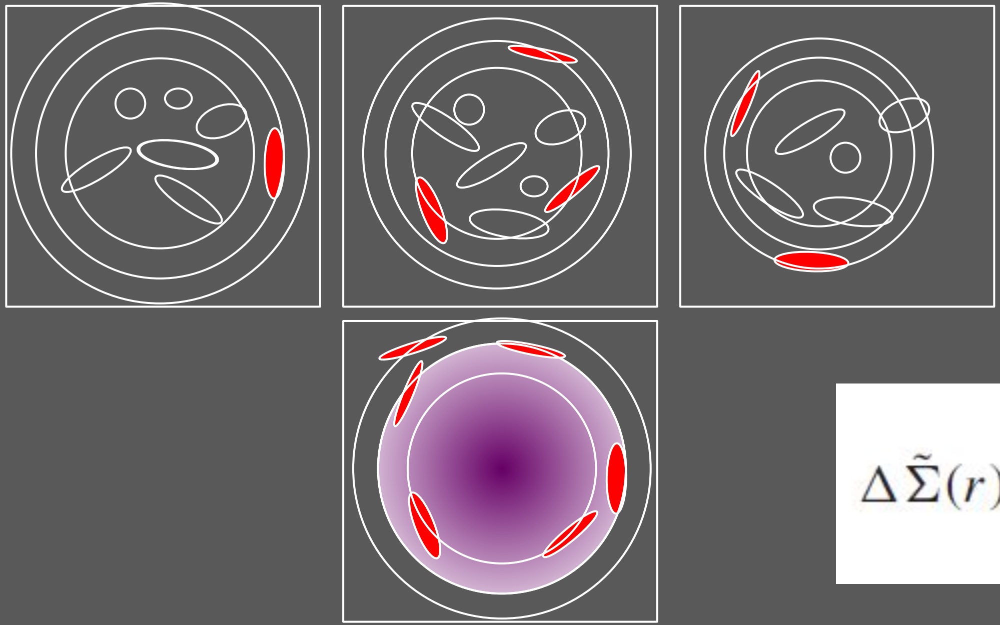
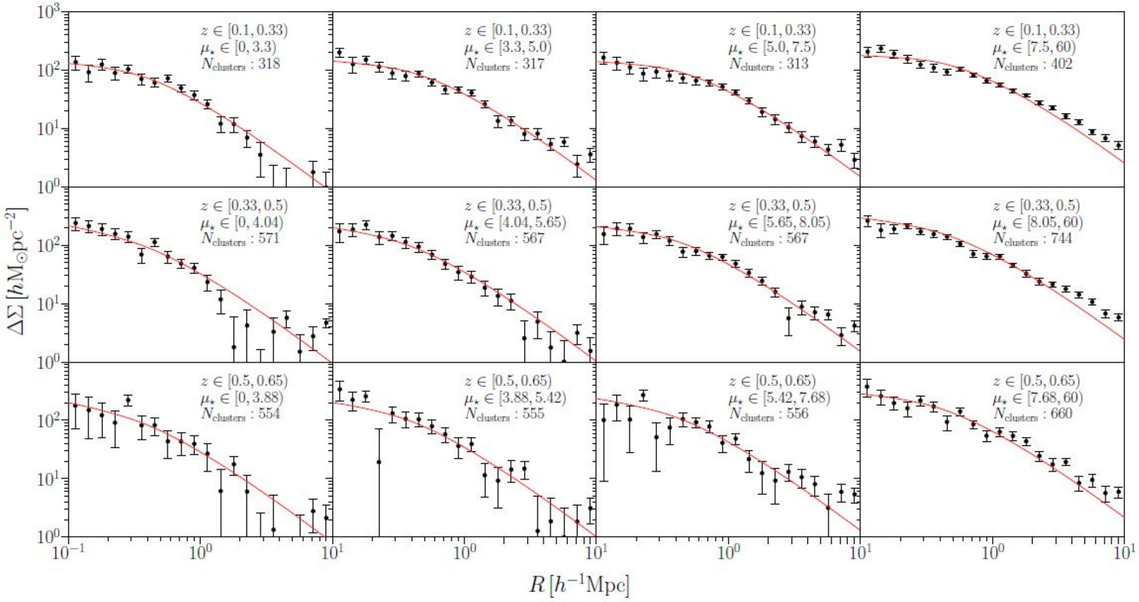


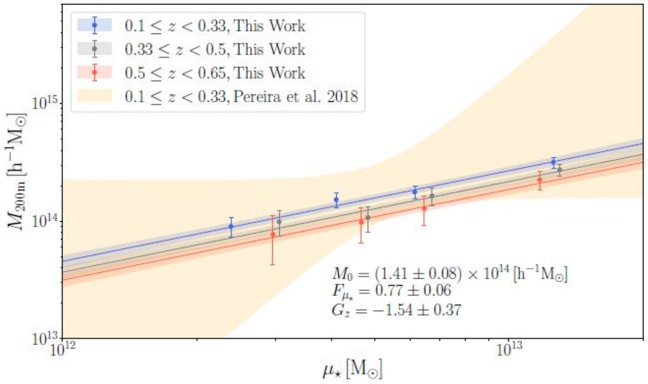
Stacking techniques



$$\Delta\tilde{\Sigma}(r) = \frac{\sum_{j=1}^{N_{\rm L}} \sum_{i=1}^{N_{{\rm S},j}} \omega_{{\rm LS},ij}\, \Sigma_{{\rm crit},ij}\, e_{{\rm t},ij}}{\sum_{j=1}^{N_{\rm L}} \sum_{i=1}^{N_{{\rm S},j}} \omega_{{\rm LS},ij}}$$

Stacking techniques





Pereira et al. (2020)

Let's lens!

Lenses -> redMaPPer Galaxy Clusters (v6.3; Rykoff et al. 2016, http://risa.stanford.edu/redmapper/)

Sources -> CFHTLens shear catalogue

You can access to the data through the COSMOHub platform (https://cosmohub.pic.es/home)

Combining the shapes of the sources tangentially to the cluster centres we obtain

$$\Delta\tilde{\Sigma}(r) = \frac{\sum_{j=1}^{N_{\mathrm{L}}} \sum_{i=1}^{N_{\mathrm{S},j}} \omega_{\mathrm{LS},ij} \Sigma_{\mathrm{crit},ij} e_{\mathrm{t},ij}}{\sum_{j=1}^{N_{\mathrm{L}}} \sum_{i=1}^{N_{\mathrm{S},j}} \omega_{\mathrm{LS},ij}}$$

Let's model!

Go to https://github.com/elizabethjg/example_fit and follow the instructions :)

Main halo component (NFW):

$$\rho(r) = \frac{\rho_{\mathrm{crit}}\delta_c}{(r/r_s)(1+r/r_s)^2}, \quad \delta_c = \frac{\Delta}{3}\frac{c_\Delta^3}{\ln(1+c_\Delta) - c_\Delta/(1+c_\Delta)}$$

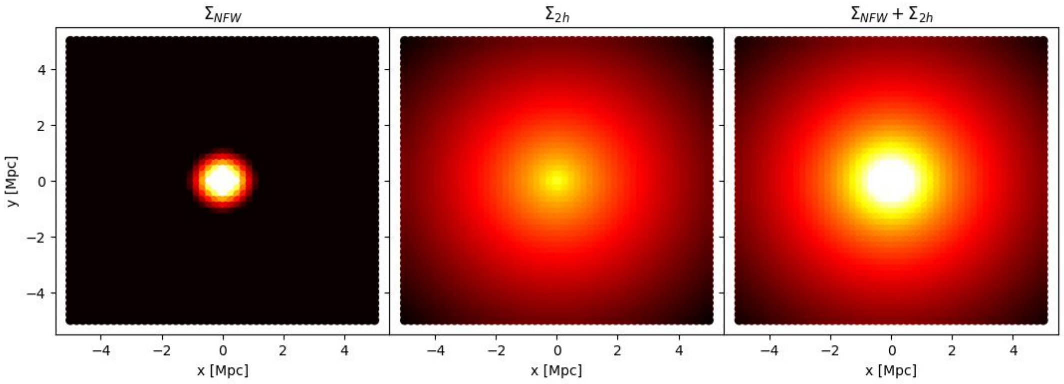
Neighbouring mass component:

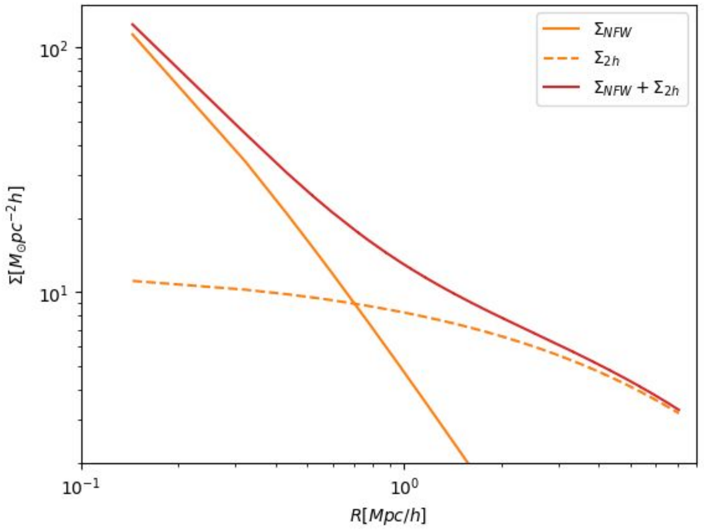
$$\rho_{2h}(r) = \rho_m \xi_{hm} = \rho_{\mathrm{crit}}\Omega_m(1+z)^3 b(M_{200}, \langle z \rangle)\xi_{mm}$$

Let's model!

$\rho \rightarrow \Sigma$

$$\Sigma(\vec{\xi}) \equiv \int \rho(\xi_1, \xi_2, r_3)\, dr_3$$





Let's model!

$\rho \longrightarrow \Sigma \longrightarrow \Delta\Sigma$

$$\Delta\Sigma(R) = \frac{1}{\pi R^2}\int_0^R 2\pi r \Sigma(r) dr - \Sigma(R)$$