# Lensing Twins: probing galaxy formation with SLACS & OWLS.


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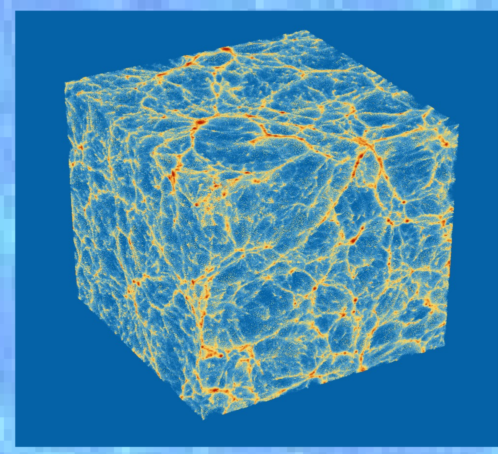


Purpose: Obtain insight on galaxy formation by comparing gravitational lensing data with cosmological simulations

We focus on the matter distribution and the influence of feedback.
Strong and weak lensing data give information on different scales.
OWLS simulations (Schaye et al. 10) cover different galaxy formation scenarios.

## Sloan Lens ACS Survey DATA (www.slacs.org)

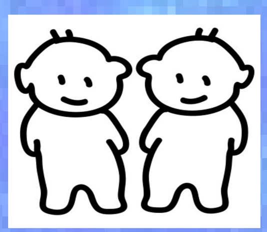
- SLACS strong lenses are selected from the SDSS database for the presence of two galaxies along the line of sight, the lens galaxy being a massive early-type galaxy.
- The sample of lenses consist of 22 early-type galaxies, and have weak and strong lensing data and stellar velocity dispersions (Gavazzi et al. 07).
- Stellar masses are also available from Auger et al. 10.

Mean values of the sample:

$z \approx 0.22$

$\sigma_{ap} \approx 248\ \mathrm{km\ s^{-1}}$

$M_{ein} \approx 2.2\times10^{11}\ M_{sun}$

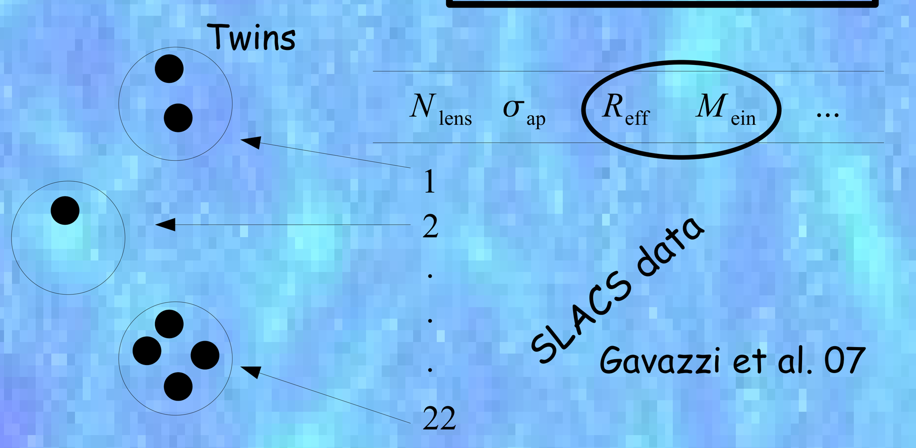


**Twin: main halo from OWLS with the mass inside the einstein's radius (Mein) and effective radius (Reff) inside the error range of a strong lens galaxy.**

### COMPARISON DATA/SIMULATIONS

We randomly pick 100 twins (repeats are possible) to have 100 samples of sets of twins, and we plot the 100 average excess surface density profiles.

Note that some lenses may not have twins.




## OWLS SIMULATIONS

Schaye et al. 10

Up to 50 simulations, from which we select 16
Dark matter & gas
2xN³ particles. N 512 max.

$m_{dm} = 4.1\times10^{8}\ h^{-1} M_{\odot}$

$m_{g} = 8.7\times10^{7}\ h^{-1} M_{\odot}$

$L = 100\,h^{-1}\,\mathrm{Mpc}$ max

Different physical processes included in each simulation.

### REF model

WMAP3 set cosmological parameters
Z cooling el.-by-el. calculation
ISM polytropic e.o.s. Index 4/3
Chabrier IMF
SNe feedback
Exponential time delay mass injection

### Variations

NOZCOOL: primordial
**NOSNNOZCOOL**: primordial+no feedback
**EOS**: Index 1
**DBLIMFCONT**: Top-Heavy
**AGN**: Sne + AGN feedback
WDENS: density dependent feedback.
**WPOT**, WVCIRC: momentum driven winds
**MILL**: millenium simulation set cosmological parameters
**SNIaGauss**: gaussian time delay
**NOSN**: no feedback
**REFL50**: boxsize of 50 Mpc h^(-1)
**WML4,WML1V848**: more SNe feedback.

### SIMULATIONS OUTPUTS

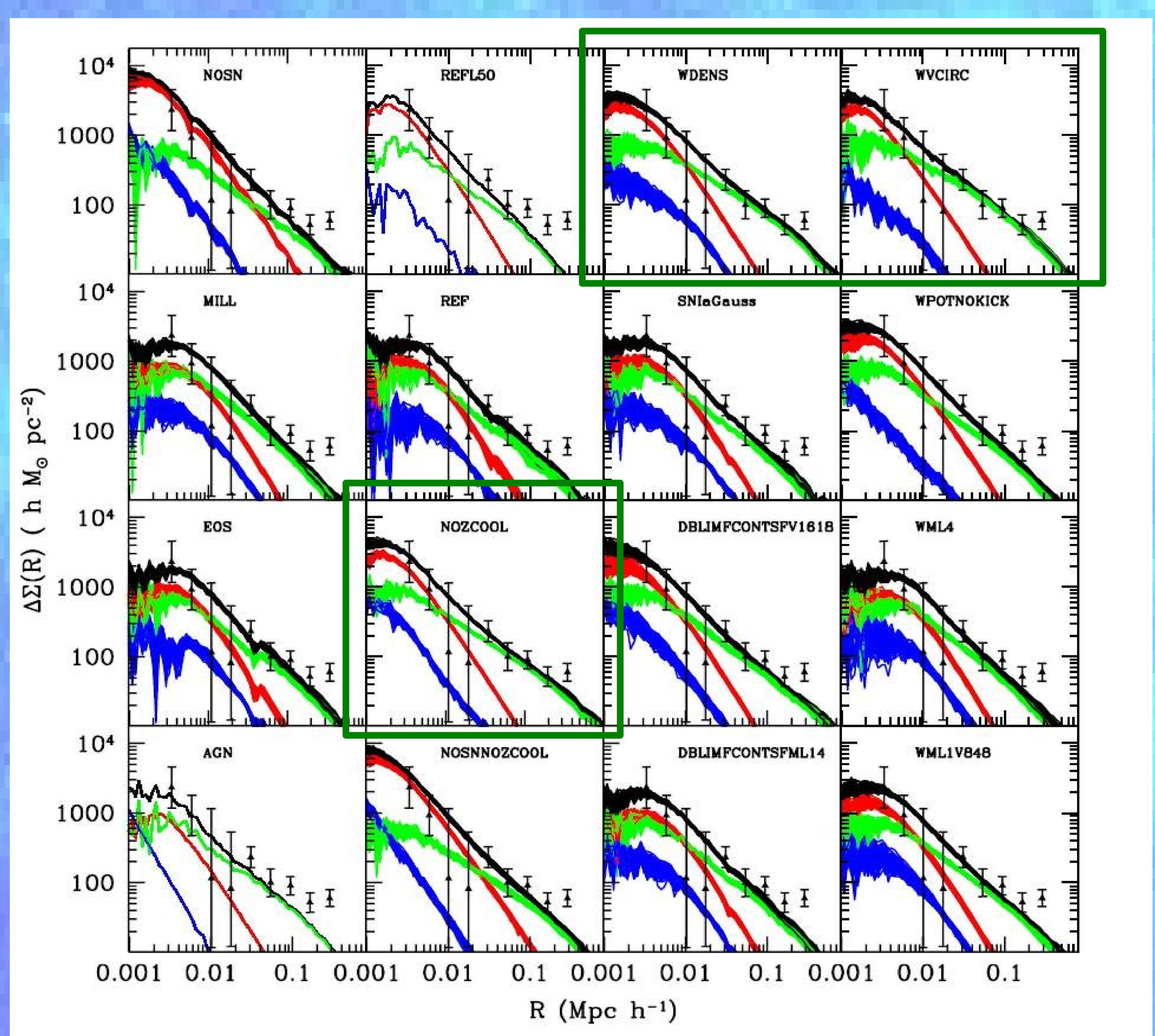
We use both snapshots and subfind catalogues.

For the weak lensing signal we use the snapshots and for the scaling relations the subfind catalogues..

Average excess surface density profiles of the 100 samples of twins and datapoints from Gavazzi et al. 07. Stars are in red, dark matter in green, gas in blue and the total is in black.

The simulations inside the green boxes fit better to the datapoints. The simulation called NOZCOOL does not implement metal-line cooling computed element by element, and in WDENS and WVCIRC feedback depends on the halo.

$$\Delta\Sigma(R) = \overline{\Sigma(<R)} - \Sigma(R)$$



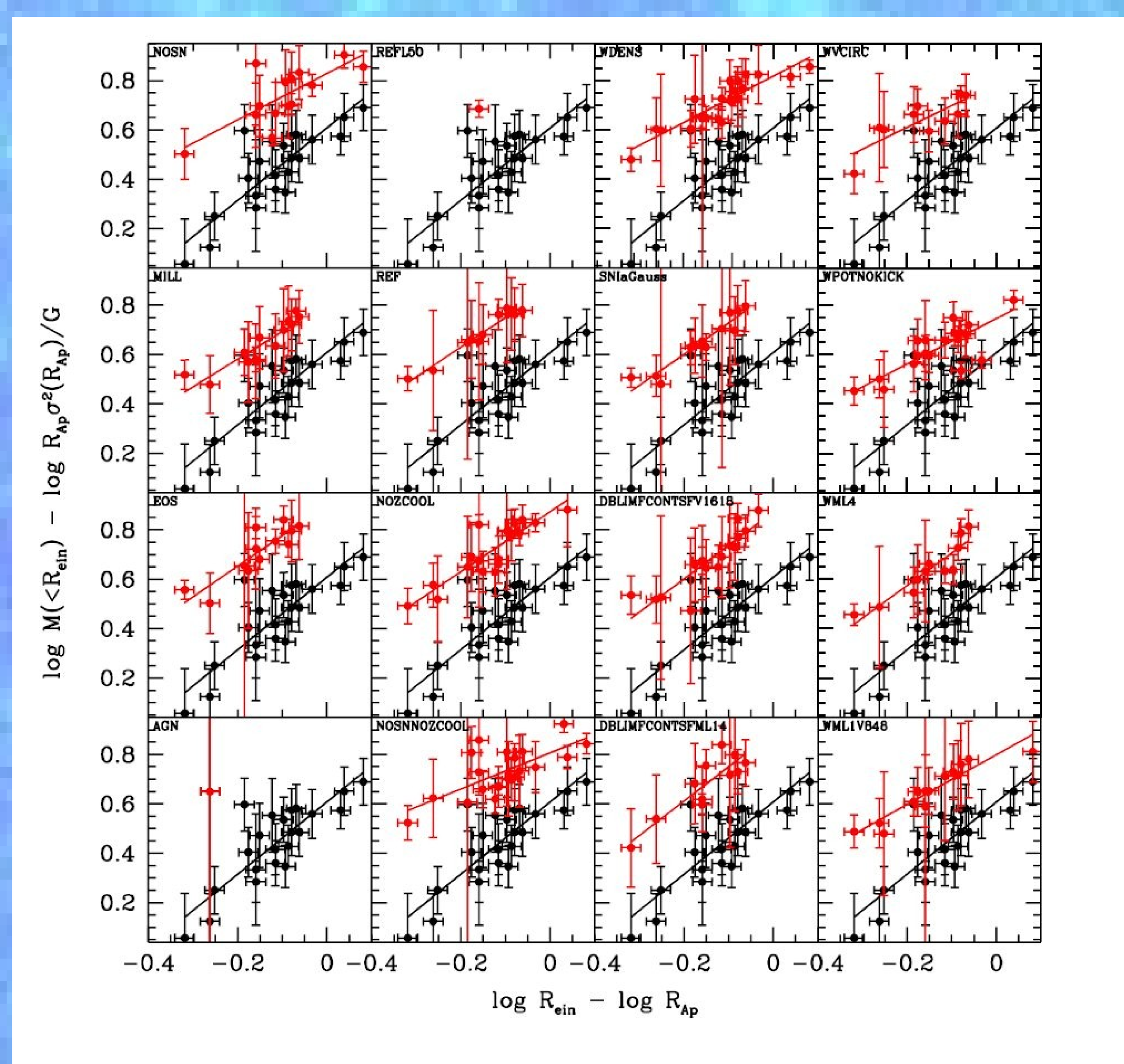

$$M_{dyn} = \frac{\sigma^2(R_{ap})R_{ap}}{G}$$

Red: twins

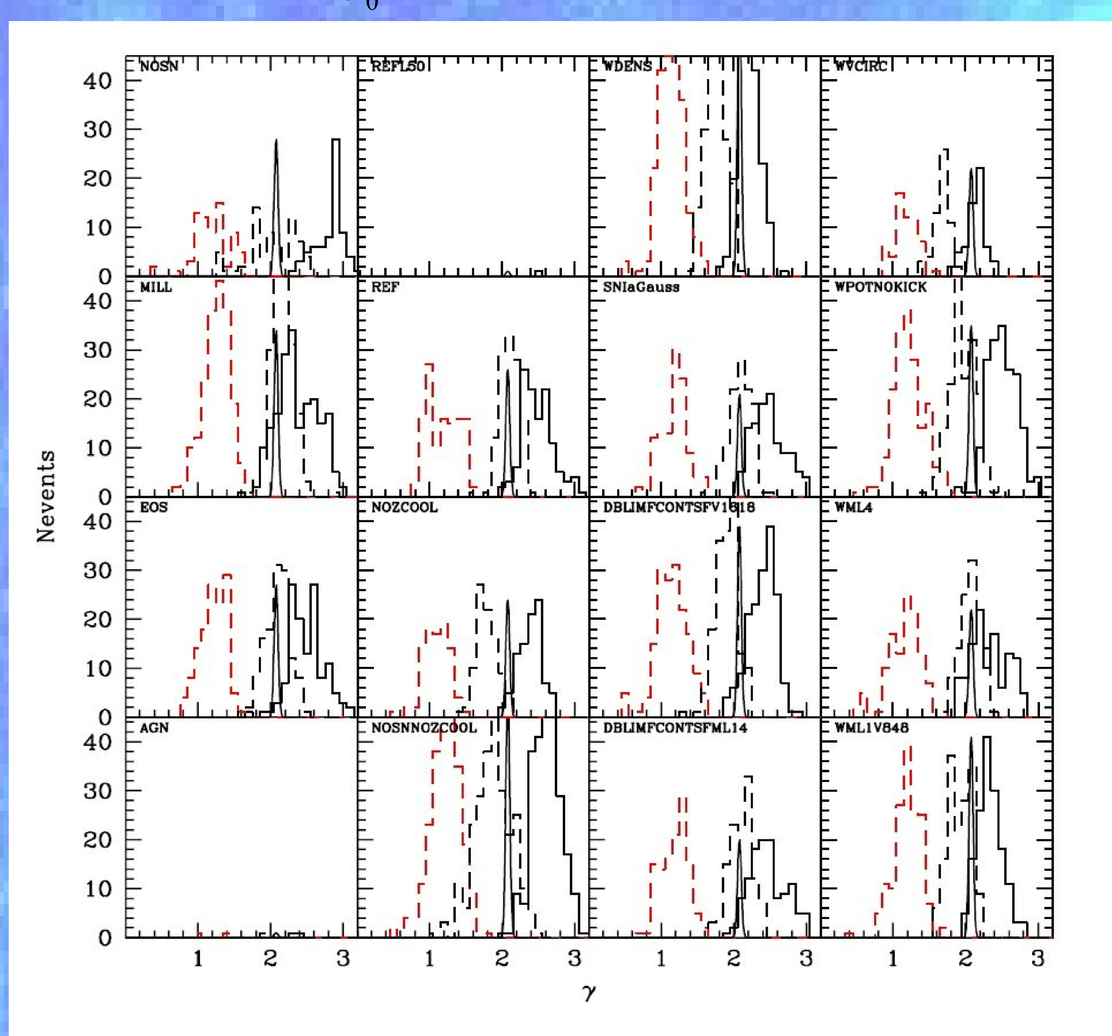
Black: lenses

Red dots are computed with the average values of the set of twins of their respective lens, represented by black dots.

By construction, the quantity we are probing here is the stellar velocity dispersion.




$$\rho = \rho_0\left(\frac{r}{r_0}\right)^{-\alpha},\ 3.3\ \mathrm{Kpc} < r < 20.0\ \mathrm{Kpc}$$




Histograms of inner slopes a of the twins for the DM (black dashed line) and for the sum of DM and stars (solid line). We plot also a solid gaussian with mean and intrinsic spread of SLACS lenses (Koopmans et al. 09, Auger et al. 10) for comparison.

We select DM halos from an OWLS n-body simulation (100 Mpc boxsize also) with the closest virial mass to the twins and we plot the histogram of inner slopes a of these halos (red dashed line) to see the effect of baryons on dark matter.

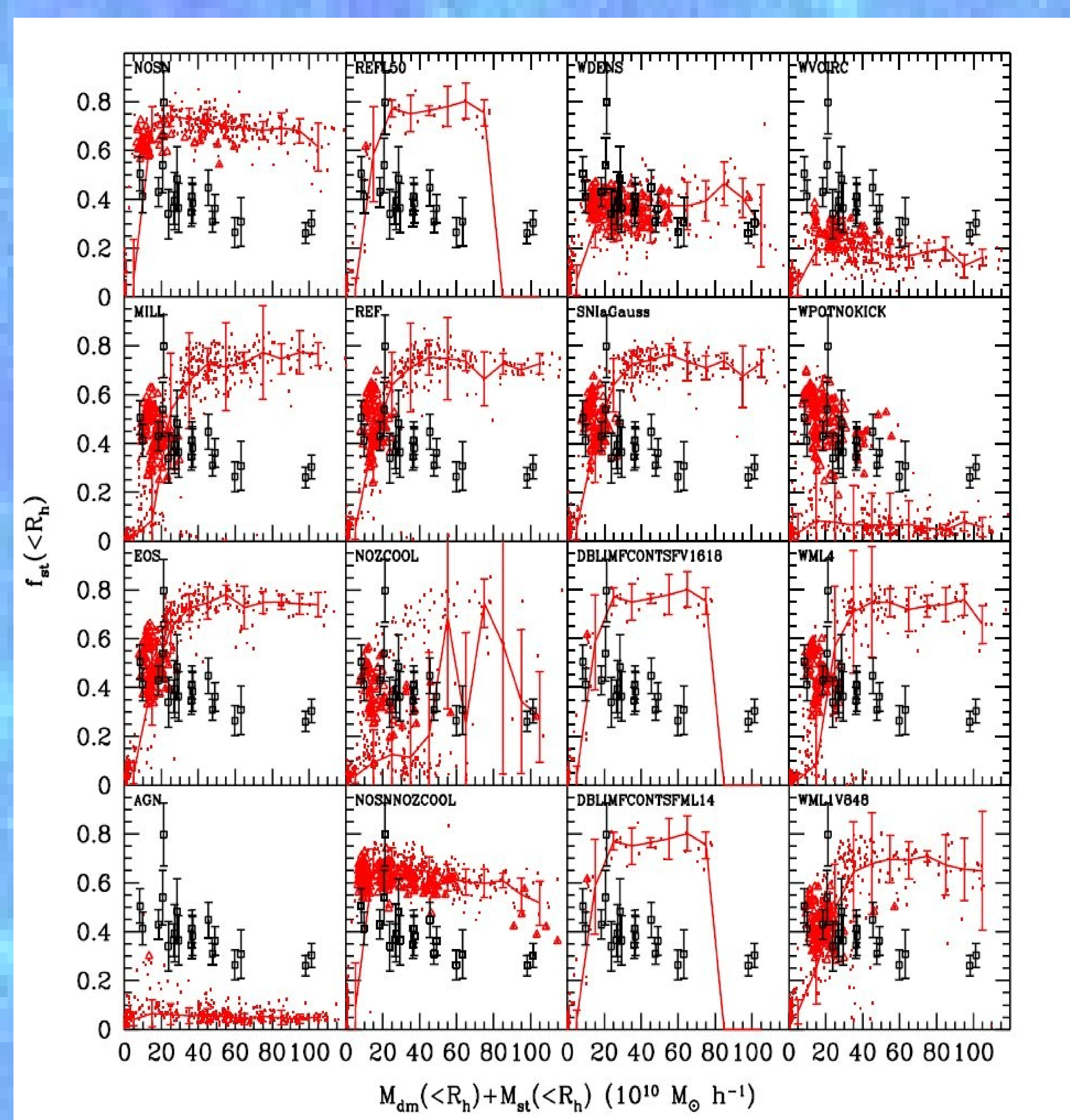
$$f^{st}(<R_{eff}) = \frac{M_{st}/2}{M_{ein}\frac{R_{eff}}{R_{ein}}}$$

Red: twins & halos

Black: lenses

Red dots are the stellar mass fractions of a representative sample of the main-halos in the simulations. The red line goes through the median values for visual aid. The twins are differentiated with a red triangle.

Note here that the observed stellar mass fraction for a lens is not compared with the mean value of their twins.




## FINAL REMARKS

Weak lensing and stellar fractions of strong lenses can constrain galaxy formation scenarios.
Simulations with density dependent feedback and halo dependent feedback do better.
Scaling relations do not match the observed ones. Halos and the 22 lenses are not the same objects.
Resolution effects can influence the results.
Baryons make the dark matter profiles steeper. The effect is clear, although difficult to model.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