Lens Galaxy Environments

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1. Who cares?
2. What to do
3. Results
4. Problems!
5. The future

Does environment matter?

- Yes! Environment can generate shear at lenses, which affects image morphology, multiplicity...

- Also, projected mass at lenses leads to mass-sheet degeneracy, impeding H_0 determination.

The need for external shear

Single-galaxy models fail. PG1115+080:

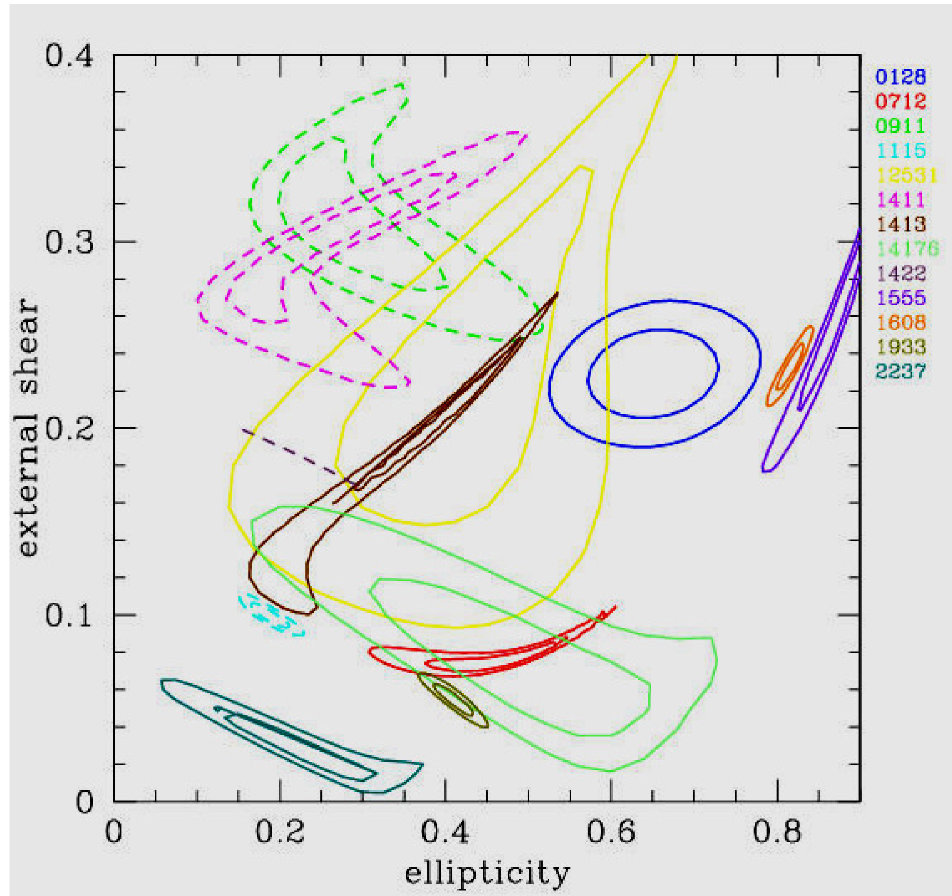
- data: $\sigma_x = 2$ mas
- models: $\delta x \sim 40$ mas

Changing the model doesn't help.

Need an external tidal shear.

- models: $\delta x \sim 0.2$ mas

Quads:



(from Chuck Keeton)

Input from theory

In CDM model, halo mass and environment are closely related : more massive halos cluster more strongly, and we know quantitatively how halo clustering depends upon mass (e.g. Mo & White, Seljak & Warren 2004)

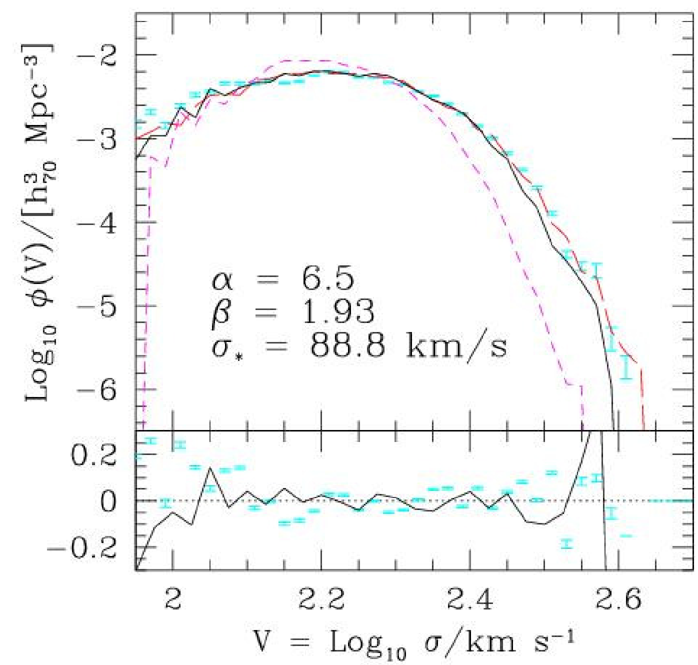
So assessing importance of lens environments means determining: where (in which halos) do lenses live?

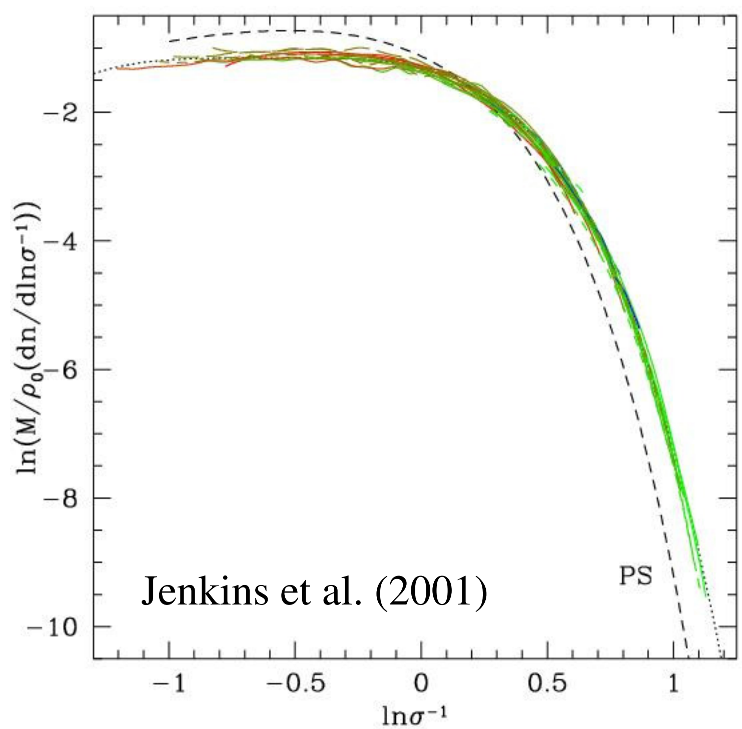
Fortunately, we can begin to answer this question with recent results from SDSS

1. number counts (Sheth et al. 2003)
2. tangential shear profiles (Sheldon et al. 2004)

Number counts of massive ellipticals

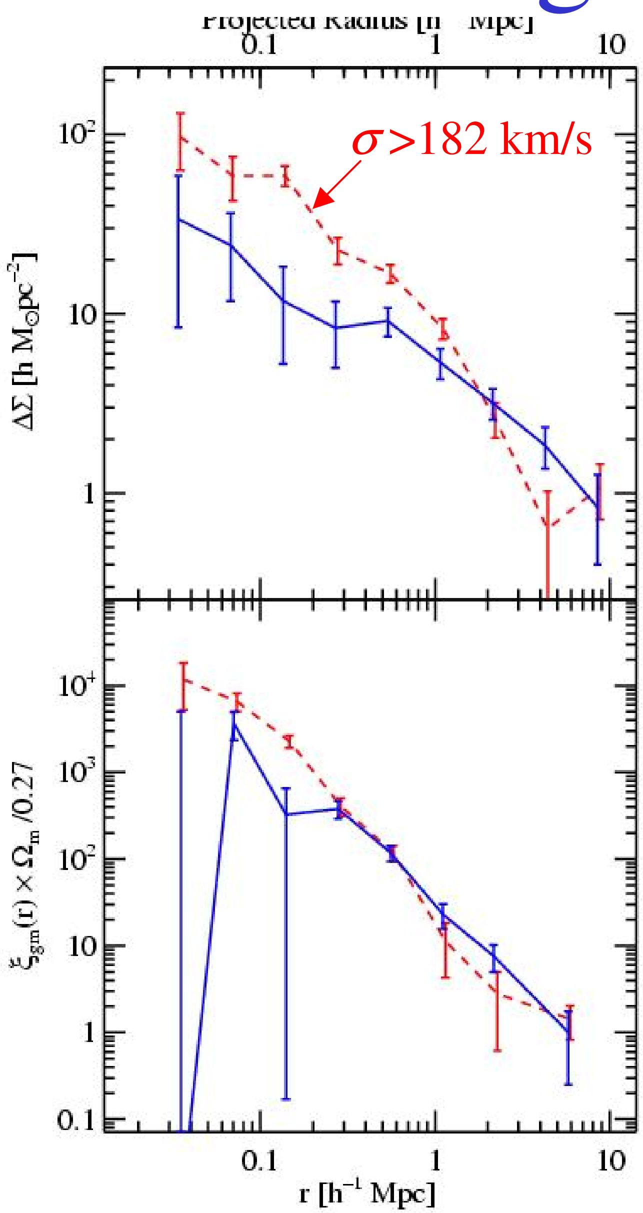
Most lenses are massive ellipticals, and Sheth et al. (2003) have measured their number density in SDSS as a function of velocity dispersion.





Since we know the theoretical mass function of DM halos, this constrains the halo occupation distribution of massive elliptical galaxies.

Tangential shear profiles



Sheldon et al. (2004) have measured the average tangential shear profile around massive SDSS elliptical galaxies. This constrains the galaxy-mass correlation function and power spectrum

$$\langle \gamma_{\tan} \rangle(\theta) = \int \frac{l\,dl}{2\pi} C_l^{g\kappa} \mathrm{J}_2(l\theta)$$

$$C_l^{g\kappa} \sim \int dz\, P_{gm}\left(k = {l}/{r(z)}\right)$$

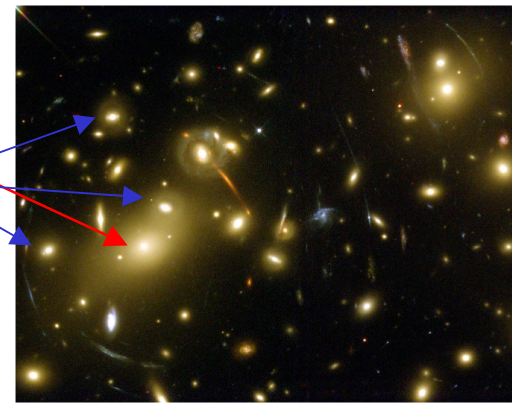
In the halo model, P_{gm} contains several pieces

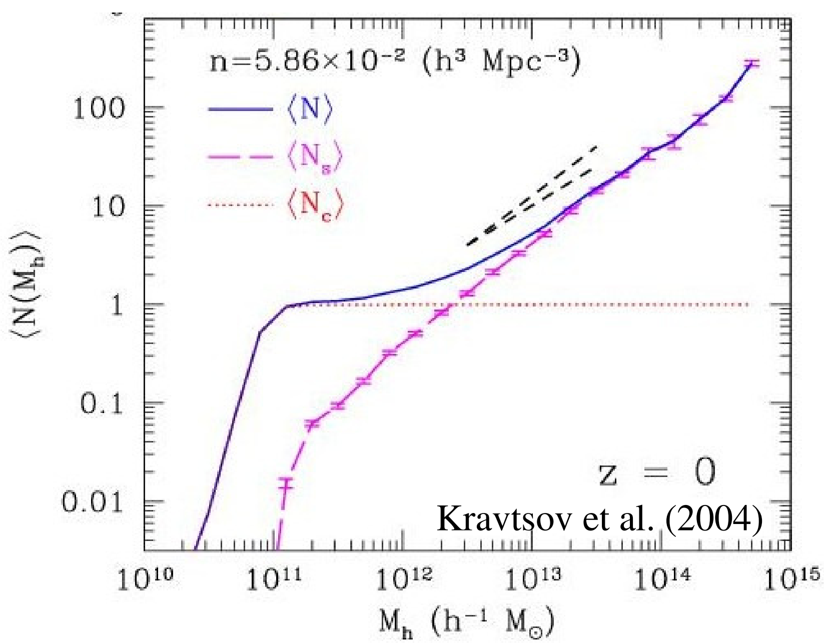
1. density profiles of galaxies' own halos
2. profiles of parent halos for satellites
3. nearby correlated halos (2-halo term)

Halo occupation distribution

To fit SDSS data, we need a model for the HOD. Simulations (N-body, SPH, semi-analytic) find that the HOD has two distinct pieces:

1. Central galaxies sitting at potential minimum (e.g. field galaxies, cluster cD galaxies)
2. Satellites: (other galaxies in groups or clusters)





Each piece has simple behavior:

1. Central galaxies, either present or not, with

$$\langle N_{\rm cen}\rangle(M) = \Theta(M - M_{th})$$

2. Satellites: Poisson random # with mean

$$\langle N_{\rm sat}\rangle(M) = \left(\frac{M}{A\cdot M_{th}}\right)^m$$

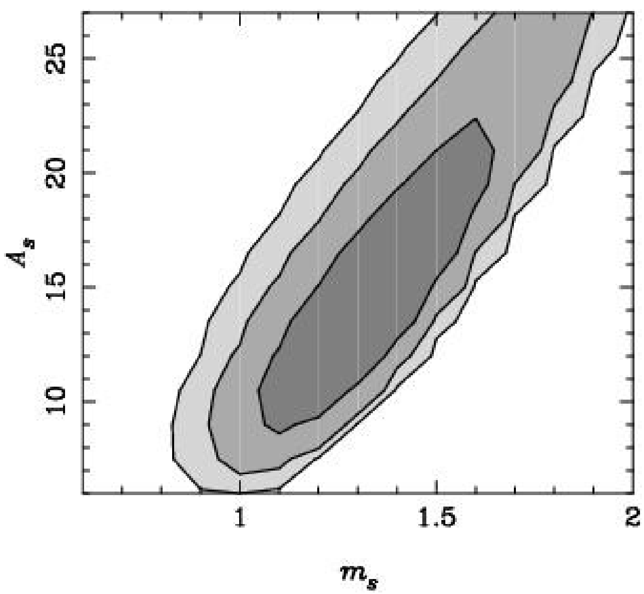
so total number is $\langle N\rangle = \langle N_{\rm cen}\rangle + \langle N_{\rm sat}\rangle$

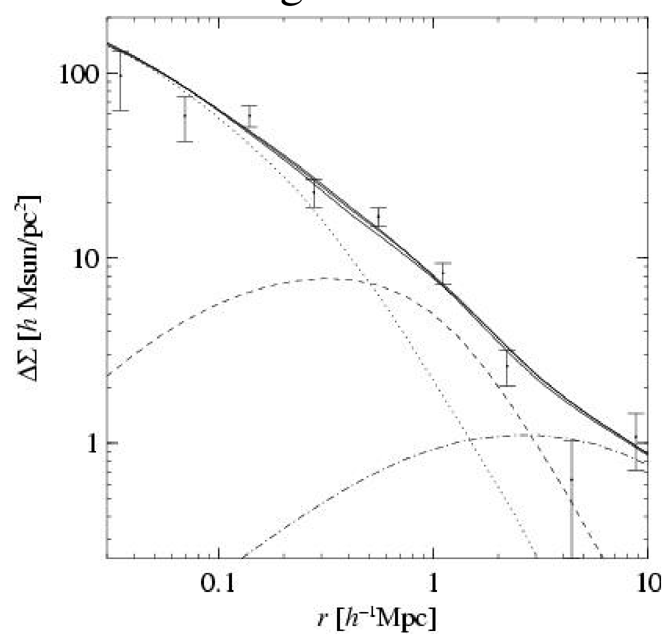
Fit to SDSS data

Our HOD has 3 free parameters : (note halo parameters are not free!)

1. M_{th}: lowest mass halo which can host a lens galaxy
2. A: controls the fraction of lenses that are satellites
3. m: controls whether satellite lenses are placed mostly in low mass halos (e.g. poor groups) or high mass halos (e.g. clusters)

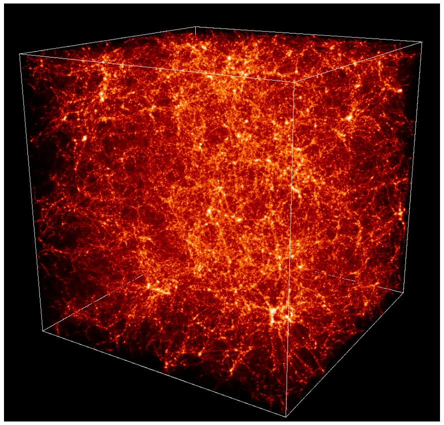
Found $M_{th} \sim 10^{12.5}\,M_{sun}$ tightly constrained, but A and m are degenerate





Can improve constraints with measurements of multiplicity function from SDSS or DEEP2

N-body simulation

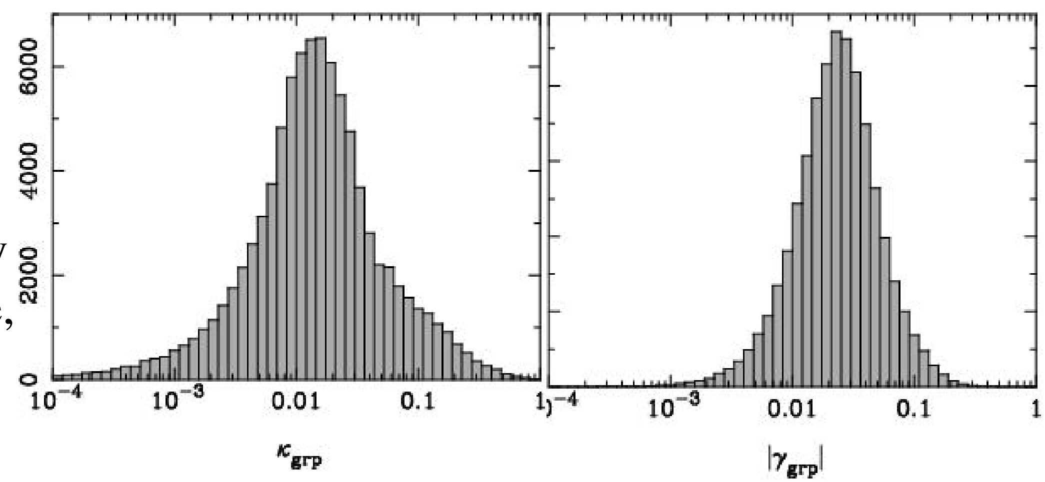


Next we used this HOD to populate a 256^3 particle ΛCDM simulation with WMAP parameters in 256 h^{-1}Mpc box.
We ran FOF to find halos, and populated the halos with lens galaxies using our best-fitting HOD.
Then we projected the box and computed convergence and shear at the galaxy positions.

Results:

1. typical $\kappa_{\rm env} \approx |\gamma_{\rm env}| \approx 0.03$

2. stronger events occur more rarely
   e.g. κ>0.1 occurs 6% of the time,
   $|\gamma|$>0.1 occurs 3% of the time.

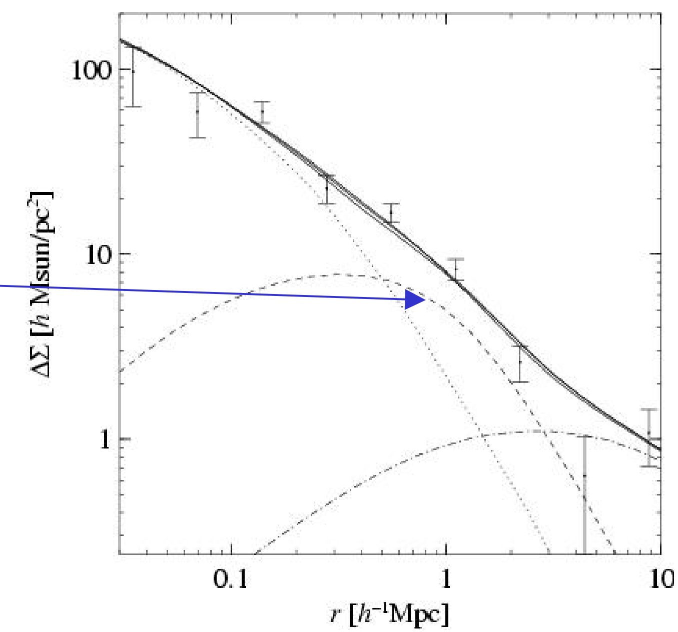


So environment shouldn't significantly bias H_0. But note that there remains one puzzling discrepancy: our shear values are far below the γ~15% external shear found in models of strong lenses!

Too much shear?

There was a broad degenerate region in parameter space – are there models which match strong lensing results?

No – the group contribution to γ_{tan} is dominant on Mpc scales, so we can't increase it by factor of ~5 without grossly violating g-g lensing constraints.

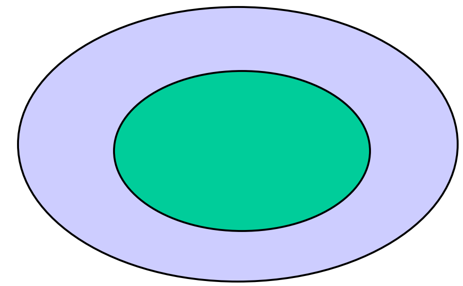


Are there other sources of shear to explain strong lensing?

- projected LSS in line-of-sight? Doesn't work because cosmic shear measurements limit this to γ~1-2%.

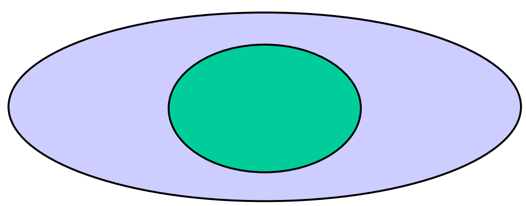
- lens halos? External shear in strong lenses could originate in the lenses' own halos (Keeton et al. 1997), but this also has difficulties…

How to make shear

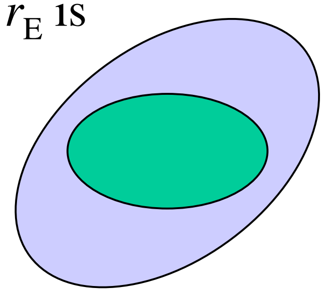


Newton: if density is stratified on concentric ellipses of constant ellipticity, then material on ellipses exterior to a point have no effect at that point.

To produce shear, the halo material must either have a different ellipticity, or be twisted relative to galaxy. For isothermal profile with Einstein radius r_E, if we distort shape at radius r_0, then induced shear at r_E is



$$\Delta\gamma \sim \frac{r_E}{r_0}\frac{\Delta\varepsilon}{2\pi}$$



$$\Delta\gamma \sim \frac{r_E}{r_0}\frac{\varepsilon}{\pi}\sin^2\Delta\theta$$

Problem: Hoekstra et al. (2004) find that galaxies align with their extended halos, with

$$\langle\varepsilon_{\rm halo}\rangle \geq 0.7\langle\varepsilon_{\rm gal}\rangle \quad\Rightarrow\quad \Delta\gamma \leq 0.3\frac{\varepsilon}{2\pi}\frac{r_E}{r_0}$$

so for lens halos to produce the excess shear, there must be drastic changes in density structure at $r \sim r_E$ (another way of saying that the model has problems).

Conclusions

1. Current SDSS data indicate that environment should be unimportant for typical strong lensing systems; typically ~3% errors in H_0.

2. However there may be a discrepancy between g-g lensing, which indicates ~3% shear at lens galaxies, and strong lensing, which requires ~15% shear.

3. There appear to be no good alternative candidates for the source of the discrepant shear; perhaps massive substructure in halo?

4. Upcoming data on multiplicity function for groups & clusters should help refine the HOD massive elliptical galaxies.