The masses and shapes of dark matter halos from galaxy-galaxy lensing in the CFHTLS

Laura Parker

Henk Hoekstra

Ludo van Waerbeke

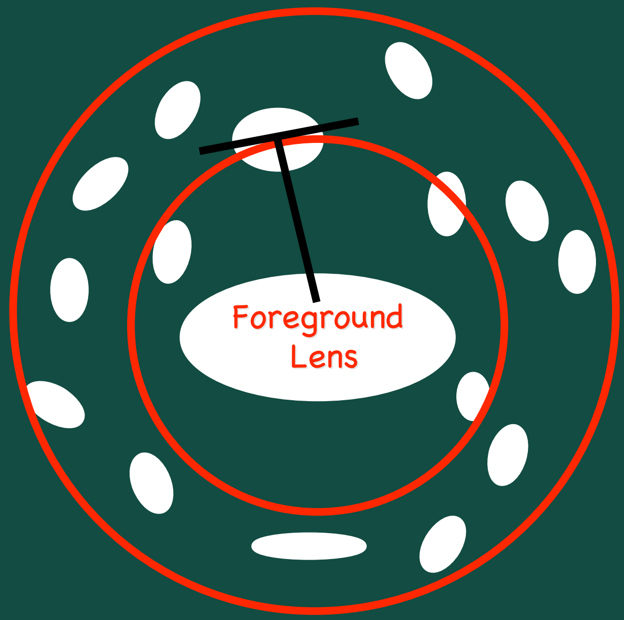
Mike Hudson

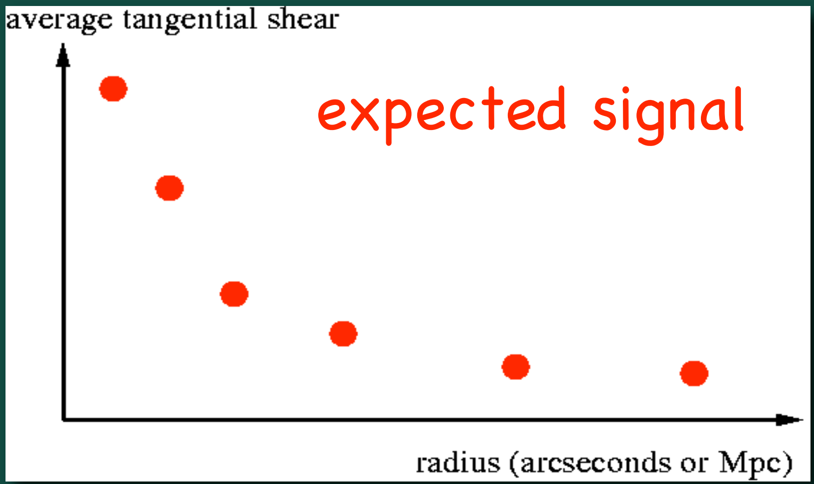
Yannick Mellier

Weak Lensing

- Small coherent distortion of background galaxy shapes, caused by:
  - Galaxy clusters
  - Galaxy groups
  - Individual galaxies
  - Large scale structure (aka cosmic shear)
- Need to measure the shapes of thousands – millions of background galaxies in order to build up a statistical signal
- S/N proportional to velocity dispersion squared

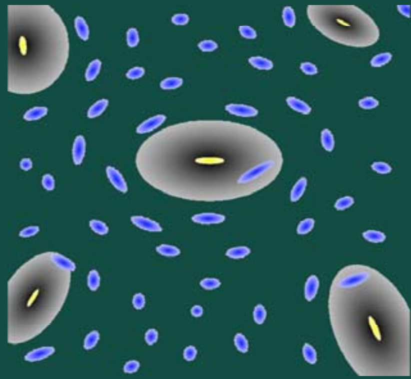
'basic' weak lensing





- Measure tangential component of shear in bins
- For galaxies, S/N << 1 so need to stack signal around MANY foreground lenses
- Signal much smaller than intrinsic variation in galaxy shapes (~30%)
- Lensing is not the only thing that changes galaxies shapes--must correct for atmosphere and optics
    - Use stars for calibration

CFHTLS Galaxy-Galaxy Lensing



- 5 year, 3 component imaging survey
  - Deep – SN, dark energy
  - Wide – weak lensing
  - Very wide – KBOs

- Galaxy masses
- Halo profiles
- Galaxy extents (field vs. cluster)
- Halo shapes (flattening)
- Link dark matter halos to their host galaxies
  - divide lens sample by redshift, morphology, luminosity, environment

Why study G-G Lensing?

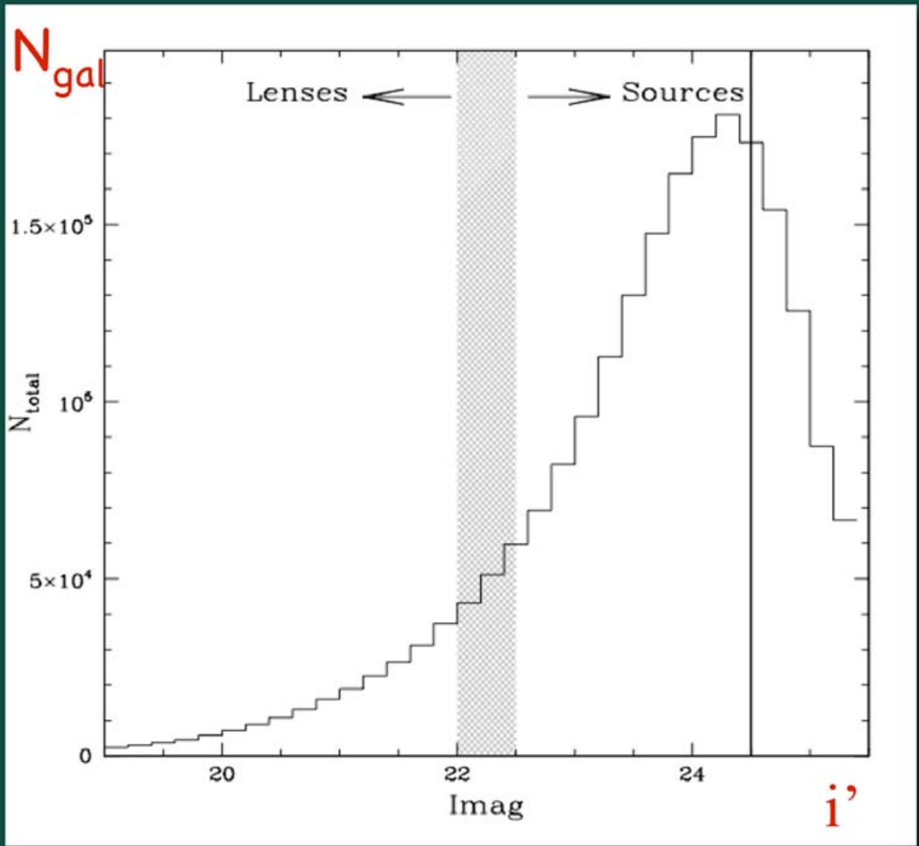
Link with galaxy formation studies:

- The relation between galaxies and the underlying mass distribution can provide important information about the way galaxies form (constraints on cooling & feedback).

- Weak lensing provides a unique way to study the biasing relations as a function of scale

- G-G lensing probes dark matter halos to large radii, beyond rotation curves, strong lensing

Data

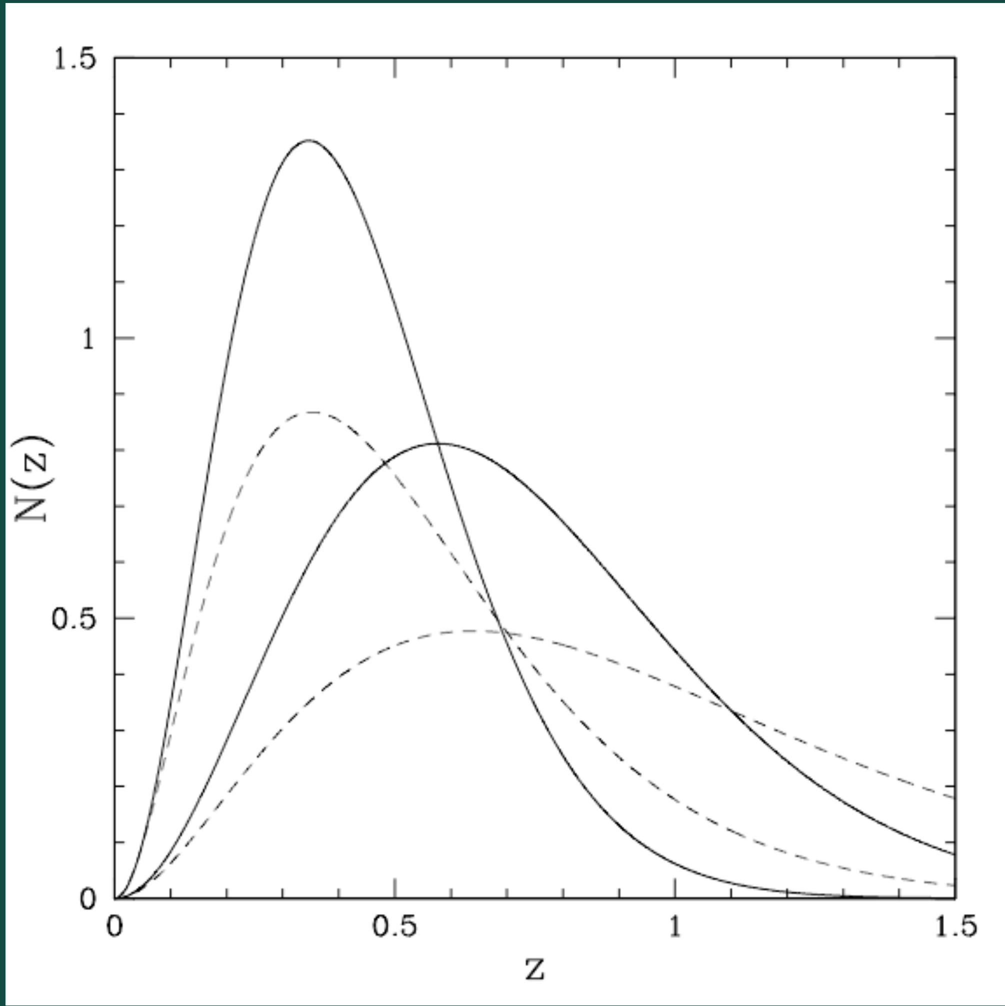


Magnitude distribution – used to estimate redshifts, and hence β

- Early CFHTLS wide data
  - ~22 sq degrees
  - no colours / redshifts
- Lenses and sources must be divided based on their observed magnitudes
  - i' band
- Eventually there will be photometric redshifts for every lens and source

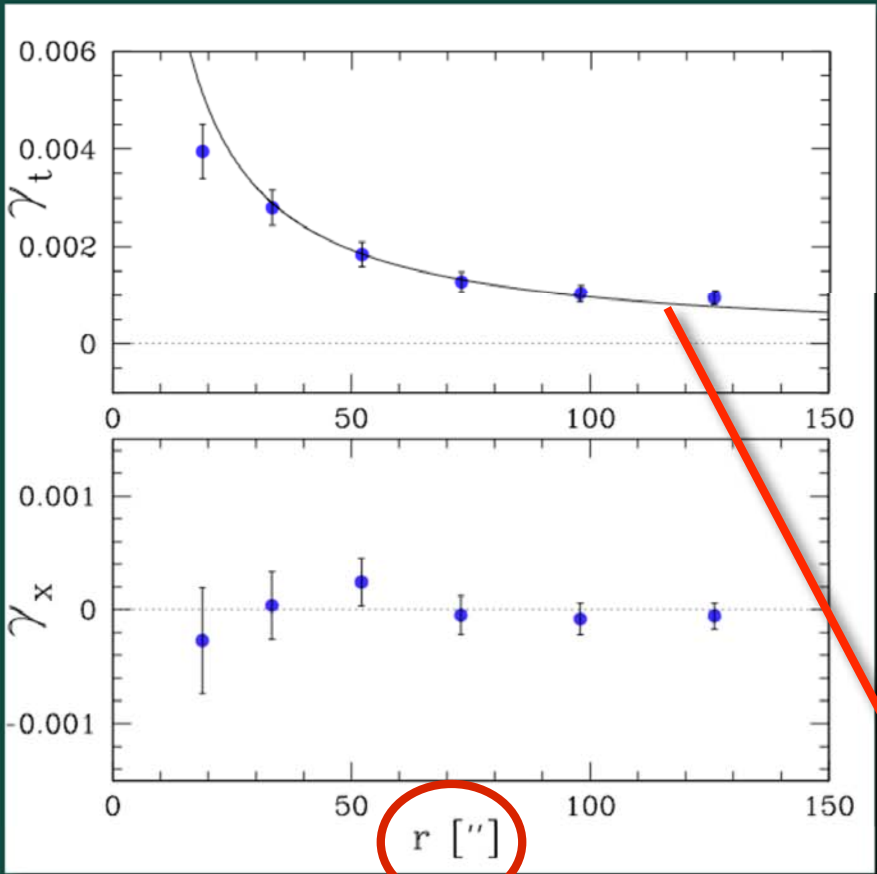
$$\beta = D_{LS}/D_S$$

Redshift Distribution



- Solid - based on HDF, biased low (Van Waerbeke et al 2006)
- Dashed - based on Ilbert et al. photo-zs
- Same β

Shear Results

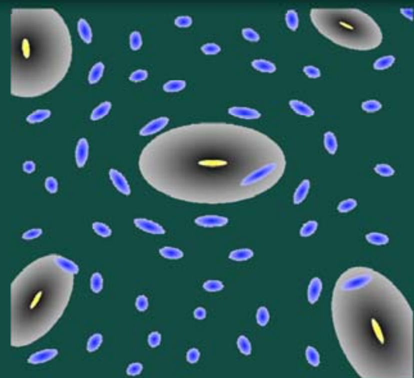


- Velocity dispersion depends on the lens sample.
- Must scale to some typical L* galaxy, based on an assumed relation between L and velocity
  - σ prop.to $L^{0.25}$, for example
- Use σ* to estimate the total mass of the halo assuming a cut-off radius

<σ> km/s	<σ>* km/s	Mass total	Mass at r_{200}	<M/L> R-band
121+/-9	137+/-10	2.5e12	1.7e12	130+/-26

- well-fit with a singular isothermal sphere with a velocity dispersion of 121 +/- 9 km/s
- no evidence of systematics (cross-shear is consistent with 0)

start to see "two-halo" term unless galaxies are truly isolated



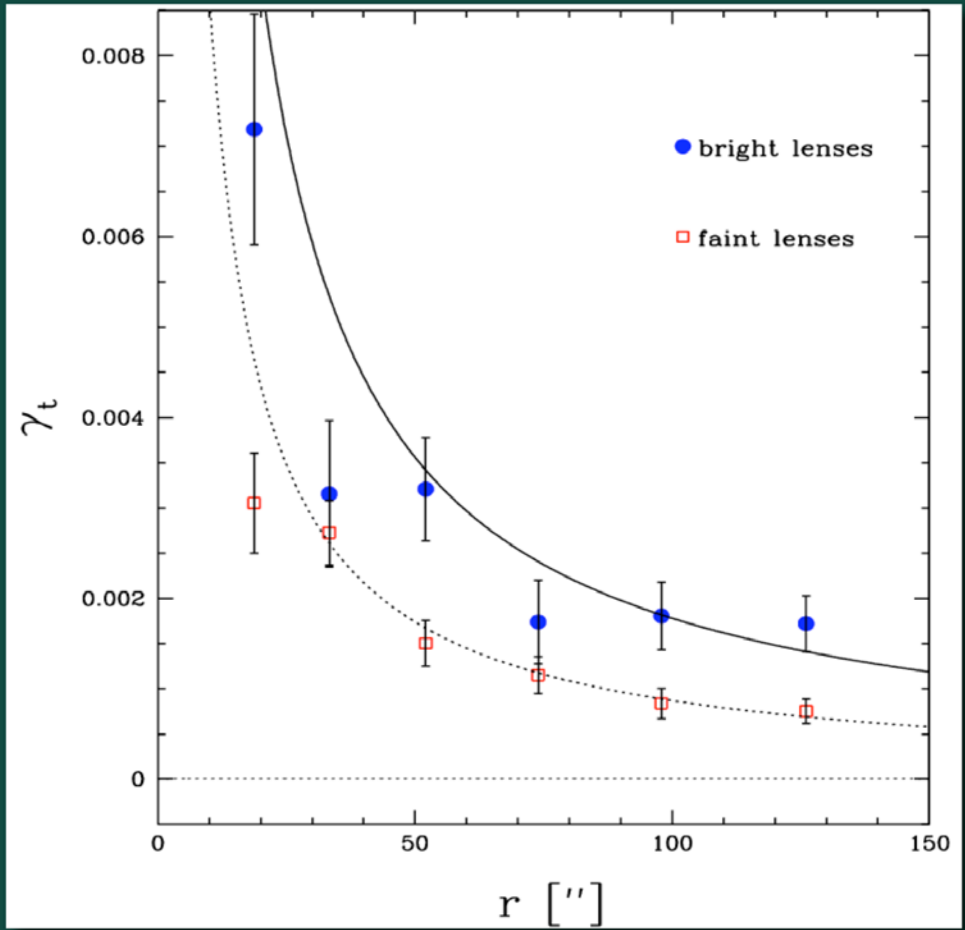
Evolution?

- Generate two lens catalogues divided by observed magnitude
    - different average redshifts
- Shear profiles vary, but so do the lens redshifts (and thus β)
- This measurement will be greatly improved by having photometric redshifts for all lenses and sources

Result:

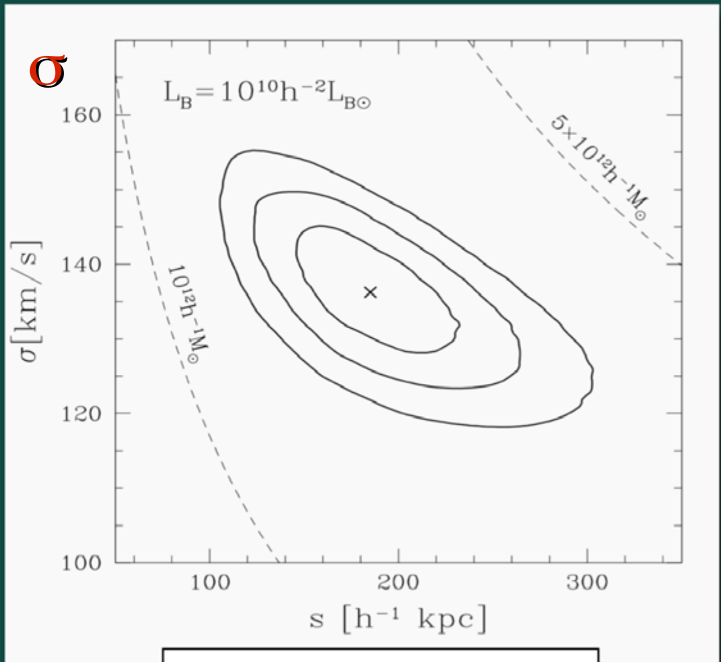
Faint lenses: $\langle\sigma\rangle$= 134+/-17 km/s
(high z)

Bright lenses: $\langle\sigma\rangle$= 117 +/- 10 km/s
(low z)



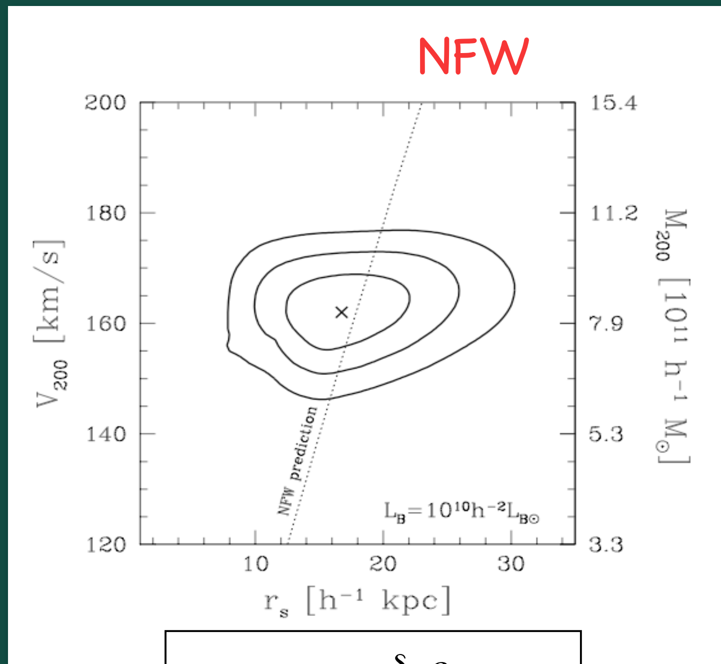
Extent of Halos

- Maximum likelihood technique to fit for halo model
- For each source you determine the influence from all nearby foreground lenses with a parameterised lens model
- Need redshifts (see Kleinheinrich et al. 2005)



$$\rho(r) = \frac{\sigma^2 s^2}{2\pi G r^2 (r^2 + s^2)}$$

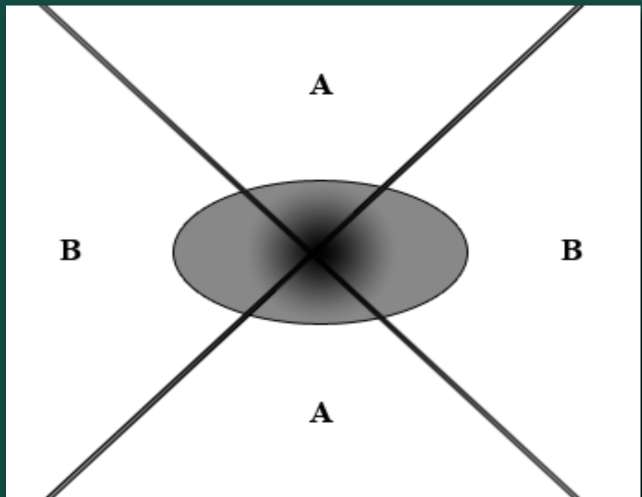
Hoekstra et al., 2004

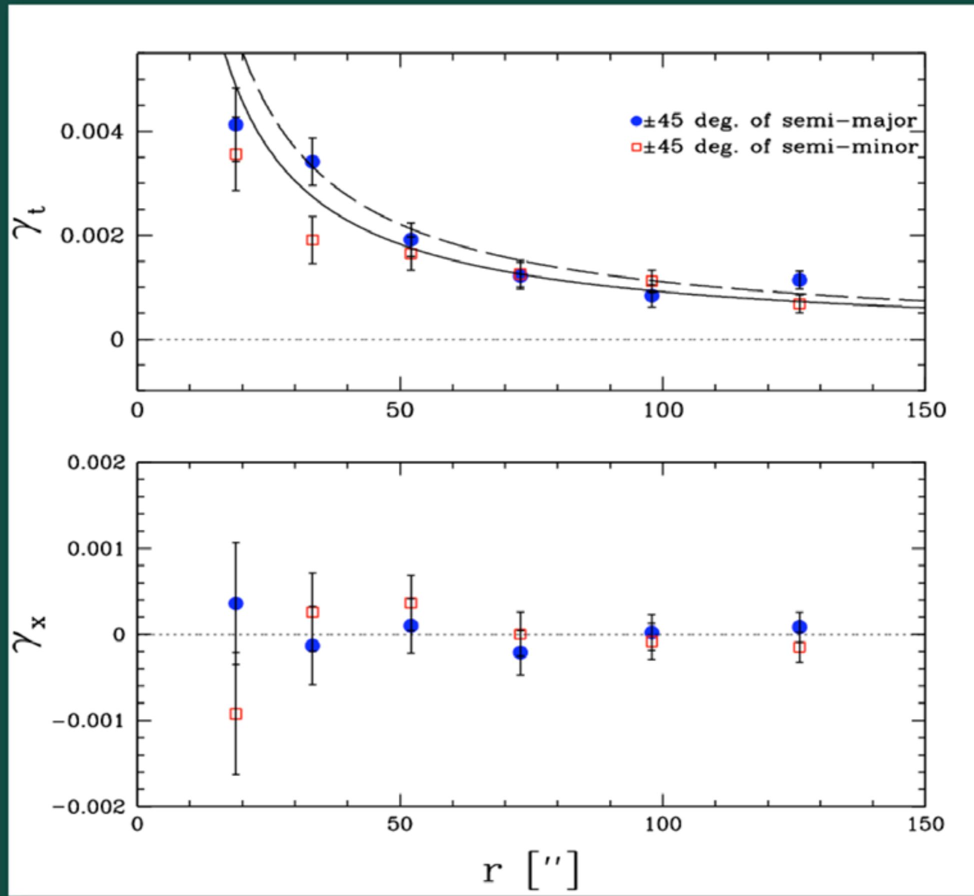


$$p(r) = \frac{\delta_c \rho_c}{(r/r_s)(1 + r/r_s)^2}$$

Halo Shapes

- Halo shapes can constrain alternative gravity theories.
- Look for non-spherical halo shapes by comparing the tangential shear along the semi-major axes to that along the semi-minor

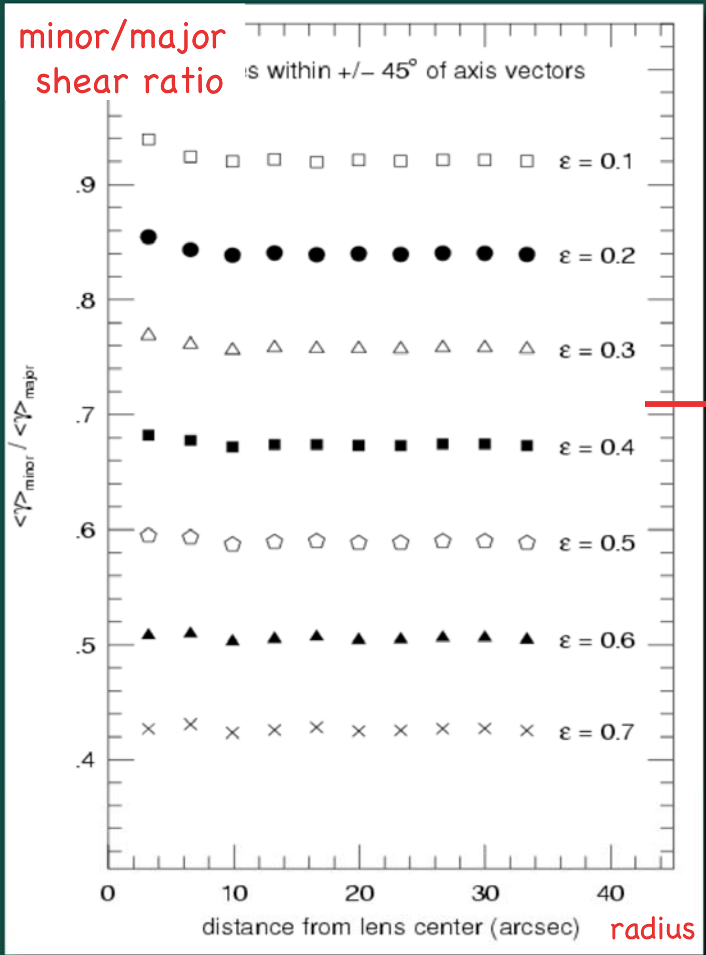




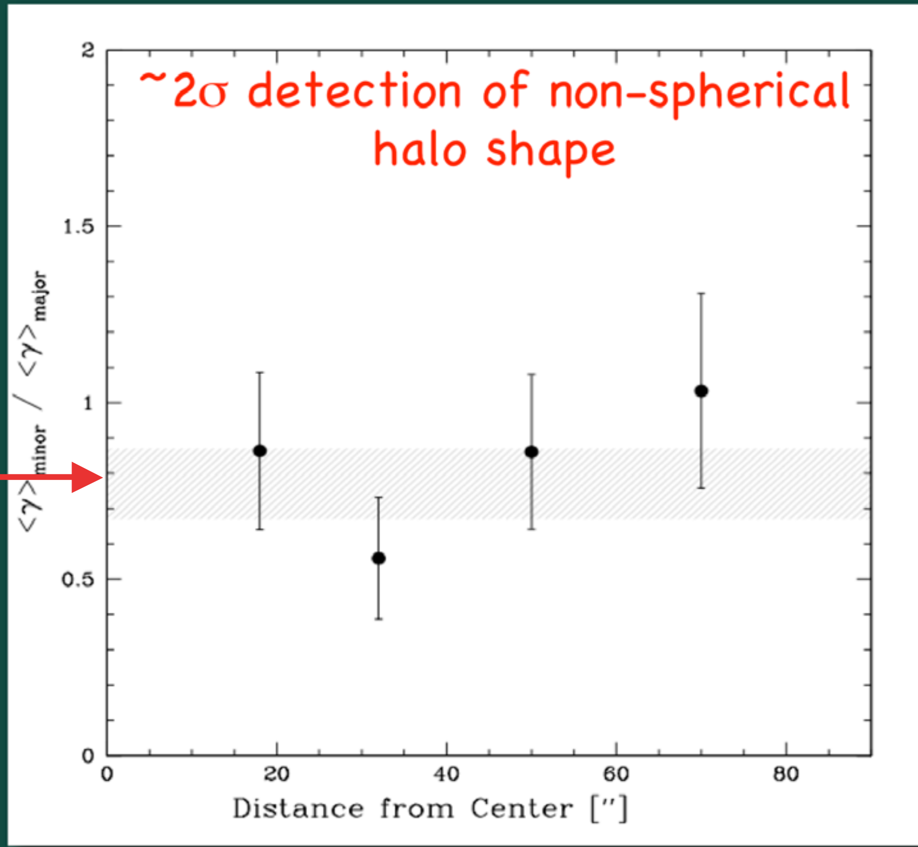
Halo flattening was observed in a weak lensing analysis of RCS data (Hoekstra et al., 2004), but not in a recent analysis of SDSS by Mandelbaum et al. (2005) →

Results not totally inconsistent -- low significance measurement of flattening in SDSS for gals with same luminosities as the RCS

Halo Shapes

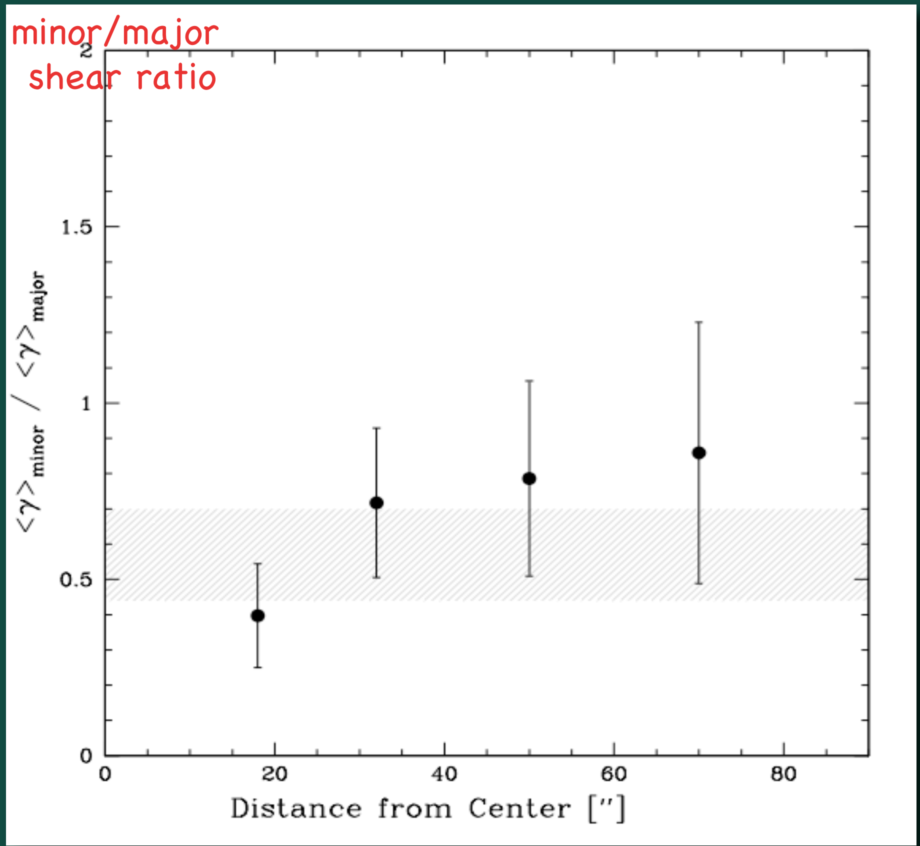


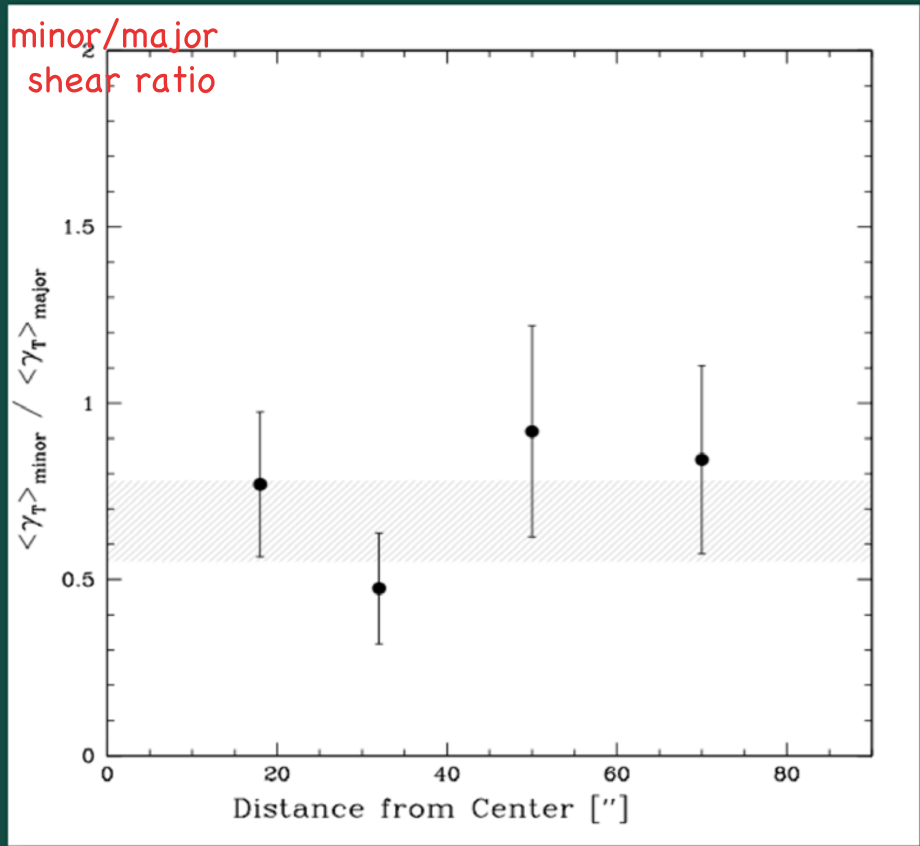
Brainerd & Wright, 2000



Our results favour a halo ellipticity of ~0.3. This is roughly in agreement with simulations of CDM halos (eg Dunbinski & Carlberg, 1991)

Without any redshift information there may be contamination from satellites





Targeting galaxies with with e>0.15
(throw out roundest gals.)

Targeting early types
by looking at 0.5<b/a<0.8

Flattening of dark matter halos from RCS

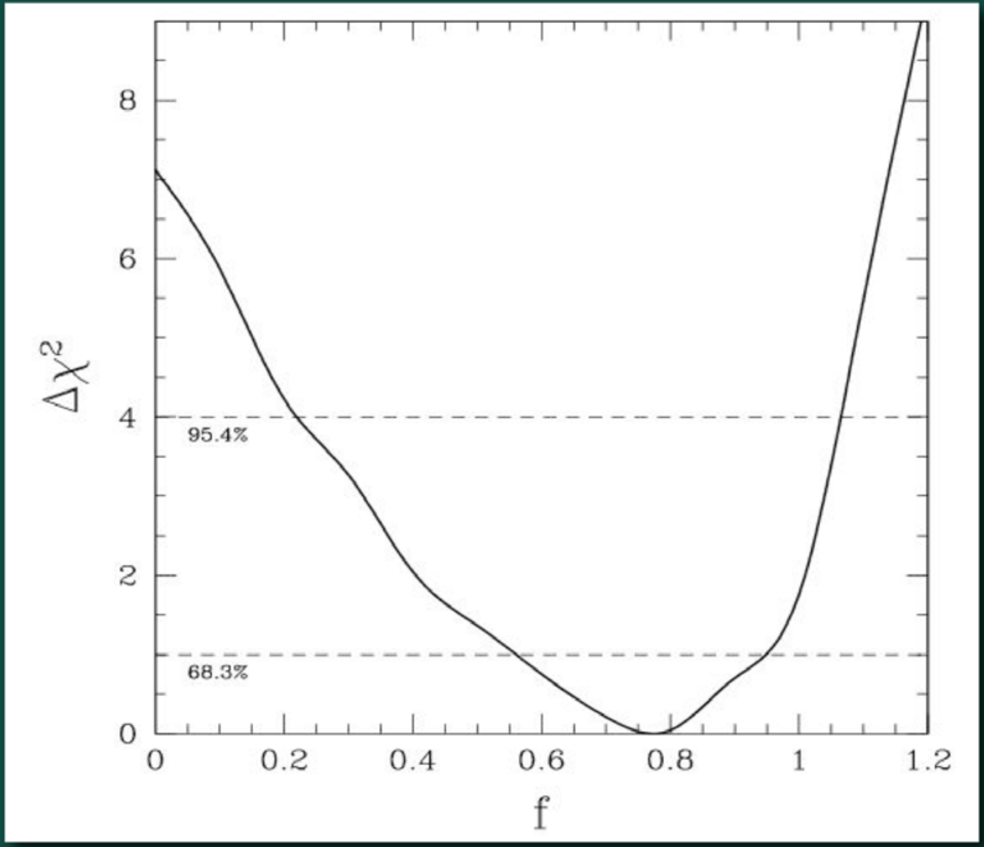
Simple model:

$$e_{halo} = f\, e_{lens}$$

and determine f

Found $f = 0.77 \pm 0.20$

- Spherical halos excluded with 99.5% confidence
- Good agreement with CDM predictions
- If halos are not aligned with galaxy then the flattening is underestimated



Hoekstra et al., 2004

Alternative Theories of gravity?

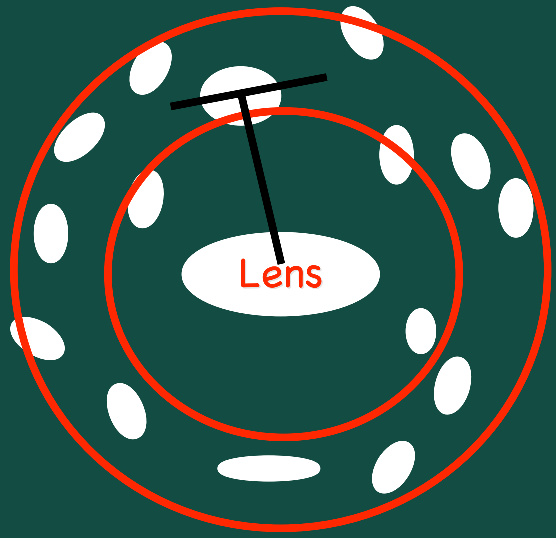
In alternative theories of gravity (without dark matter) the lensing signal is coming from the observed luminous material

- The lensing signal is measured at large radii
- Quadrupole term from flattened baryon distribution decays rapidly

Hence, all such theories *predict* an *isotropic* lensing signal!

Dark matter halo shapes places constraints on any alternative gravity theory

Systematics G-G lensing



- √ Rotate source images by 45 degrees
- √ Measure signal around random centres
- N(z) distribution?
- Intrinsic alignments
  - without redshift information some sources will be physically associated with the lens
  - if associated sources, such as satellites, are preferentially aligned this will either increase or reduce the lensing signal

Summary

- Using early data in only one band we were able to measure a galaxy-galaxy lensing signal at very high significance
- Estimated the mass, M/L and shape of dark matter halos for an L* galaxy
- Stay tuned - g-g lensing with CFHTLS data will be greatly improved with the determination of photometric redshifts
- Goal: g-g lensing for galaxies segregated by luminosity, morphology, redshift etc

The End

Why study G-G Lensing?

Measuring the clustering of galaxies is an indirect probe of mass distribution (subject to bias parameter)

Can see galaxies very well. Can simulate DM very well.
Do galaxies trace DM?

$$b^2 = \xi_{gg}/\xi_{mm}$$

$$r = \xi_{gm}/(\xi_{mm}\xi_{gg})^{1/2}$$

$\xi_{gg}/\xi_{gm} = b/r$ → Depends on gal colour & L

Use lensing to estimate b – important input for galaxy formation models

SDSS (Sheldon et al.) and RCS (Hoekstra et al.) show b/r (from lensing) is scale invariant out to ~10 Mpc (low-z)

Halo Shapes Simulations

- Allgood et al., 2005, Flores et al., 2005, Bullock 2001, Jing & Suto 2002
  - Mean and scatter of halo shape parameters (axis ratios) as a function of mass and epoch
  - More massive halos are more triaxial
  - Halos of a given mass are more triaxial at earlier times
  - Halos are increasingly round at large radii
  - Halos in lower sigma8 cosmologies are more triaxial
  - Ratio of smallest to largest axis, s, = 0.54 (Mvir/M*) ^(-0.05)