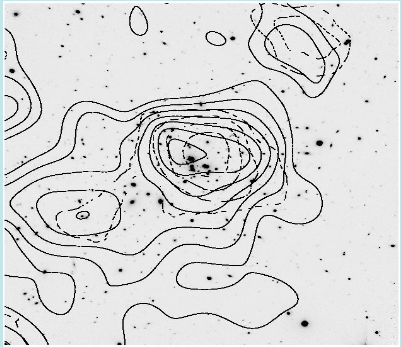
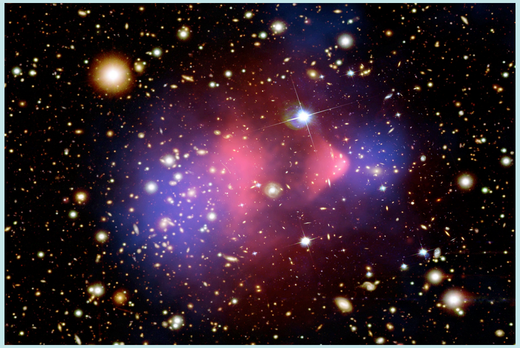




Cluster mass estimation from lensing

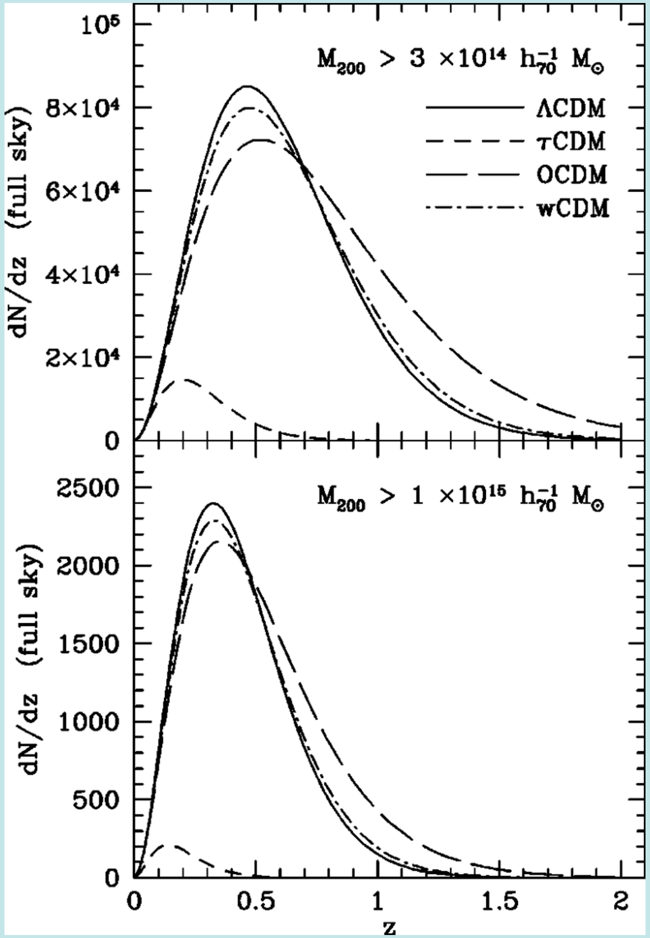
Lindsay King

IoA, Cambridge

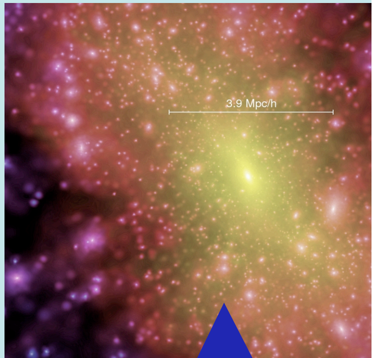
Some motivation

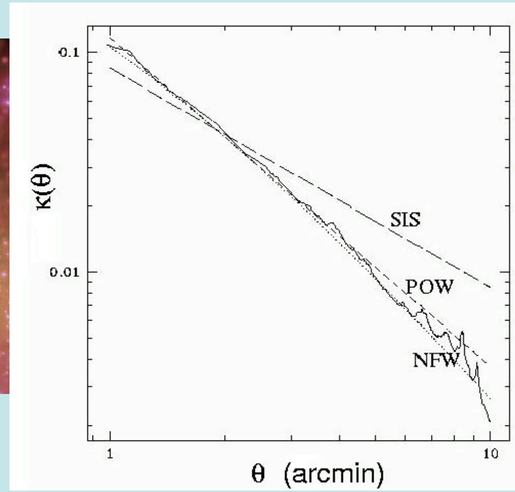
- (Halo) mass function evolution very sensitive to cosmology

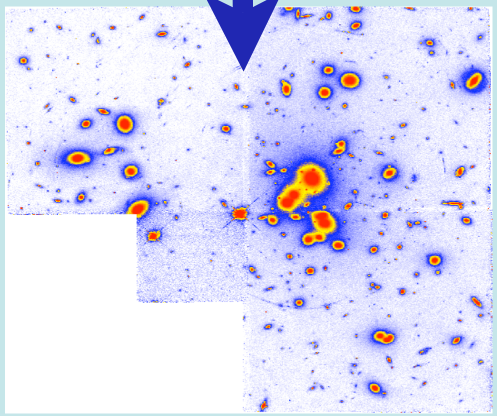


Voit 2005

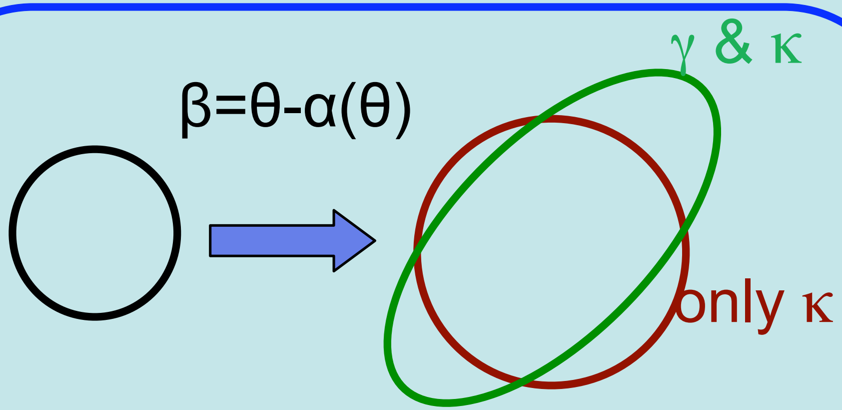
- Distribution of mass tests structure formation paradigm and nature of dark matter







Lensing basics



$$A = \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix}$$

$$\mu = 1/\det A$$

$$\kappa = \frac{1}{2}\nabla^2\Psi$$

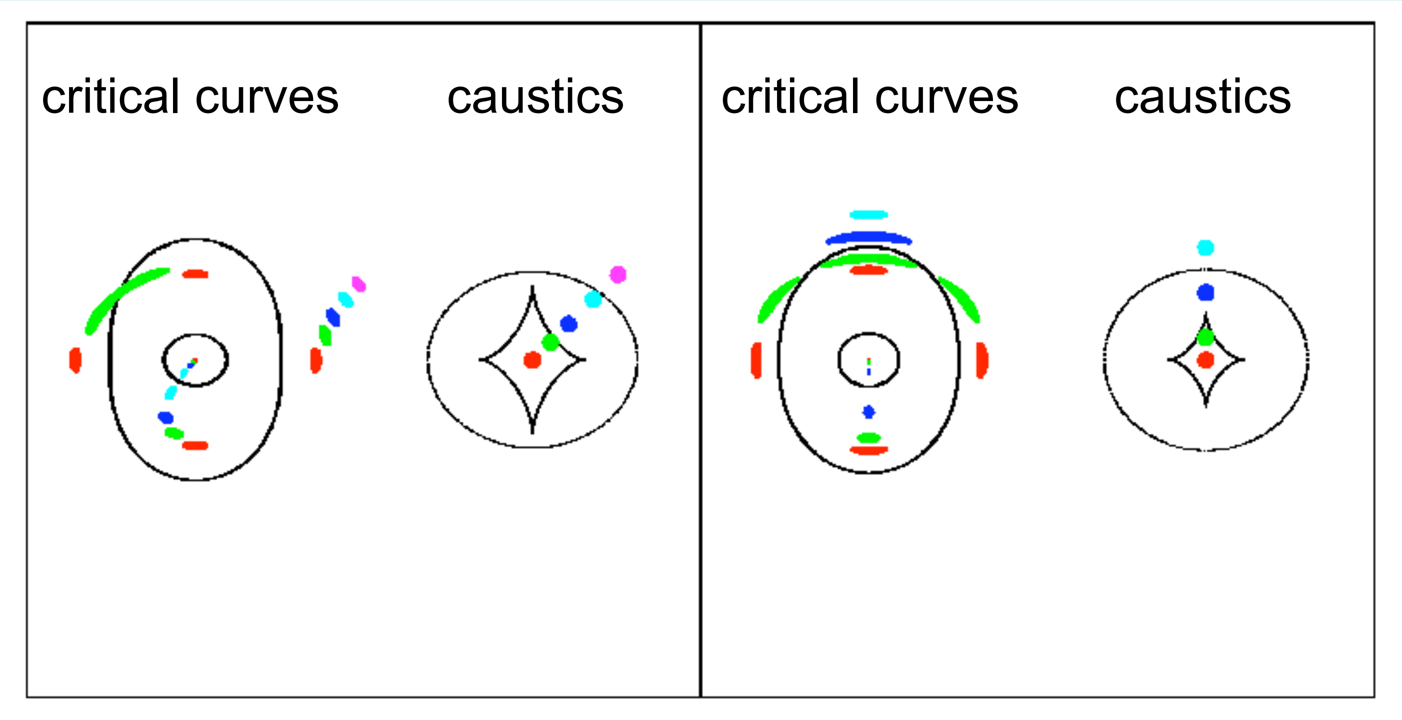
$$\gamma \equiv \gamma_1 + i\gamma_2 = |\gamma| e^{i2\phi}$$

$$\gamma_1 = \frac{1}{2}(\Psi 11 - \Psi 22)$$

$$\gamma_2 = \Psi 12$$

Strong lensing $\gamma , \kappa \sim 1$

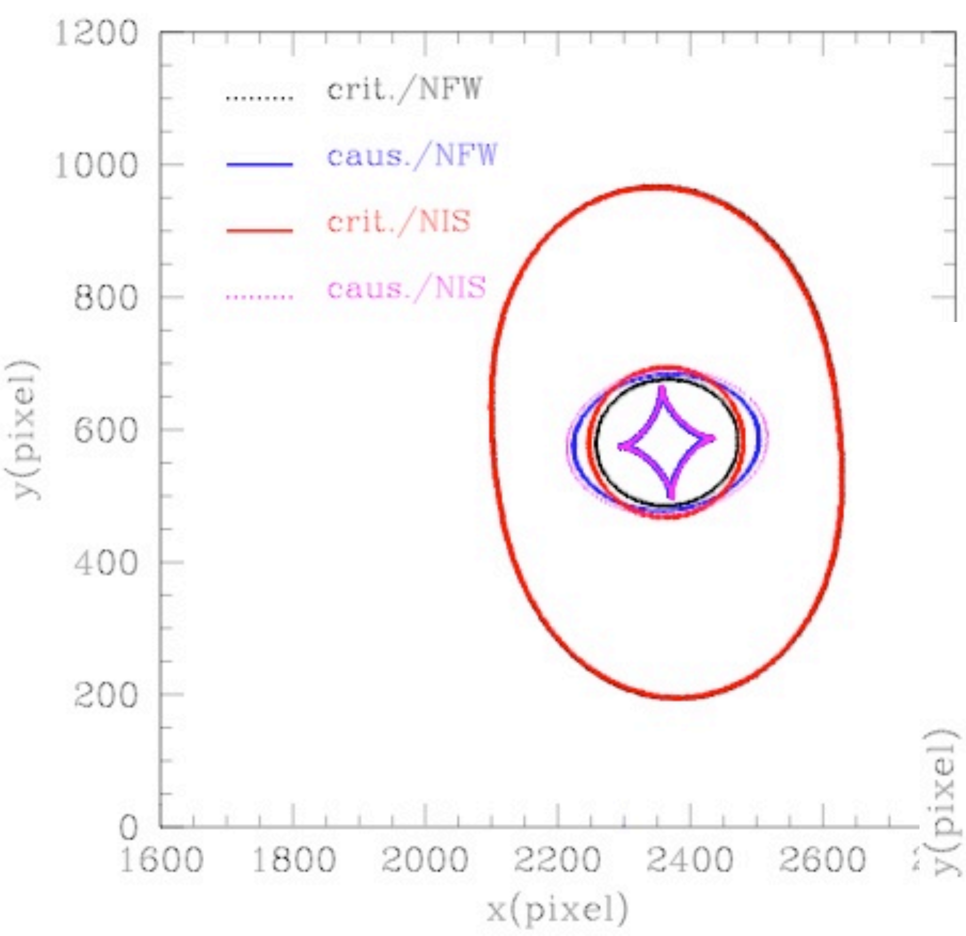
Caustics & critical curves for a typical galaxy lens



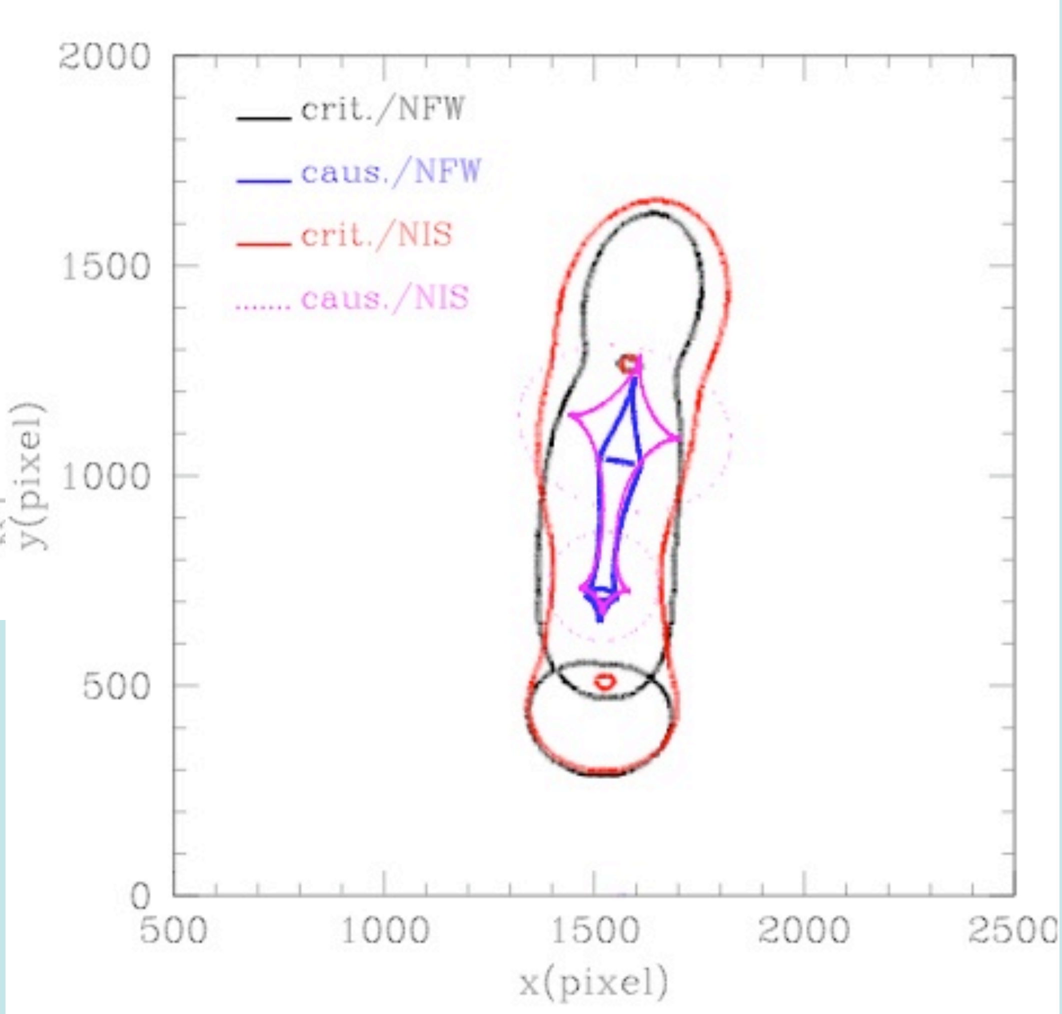
Left panel: source moving towards fold caustic
Right panel: source moving towards cusp caustic

from Narayan & Bartelmann lectures

More complicated for galaxy clusters!



A370



MS2137

Shu et al. 2008

Strong lensing mass estimates

Multiple image positions, fluxes and shapes constrain
mass model of lens inside ~100 - 200 kpc/h

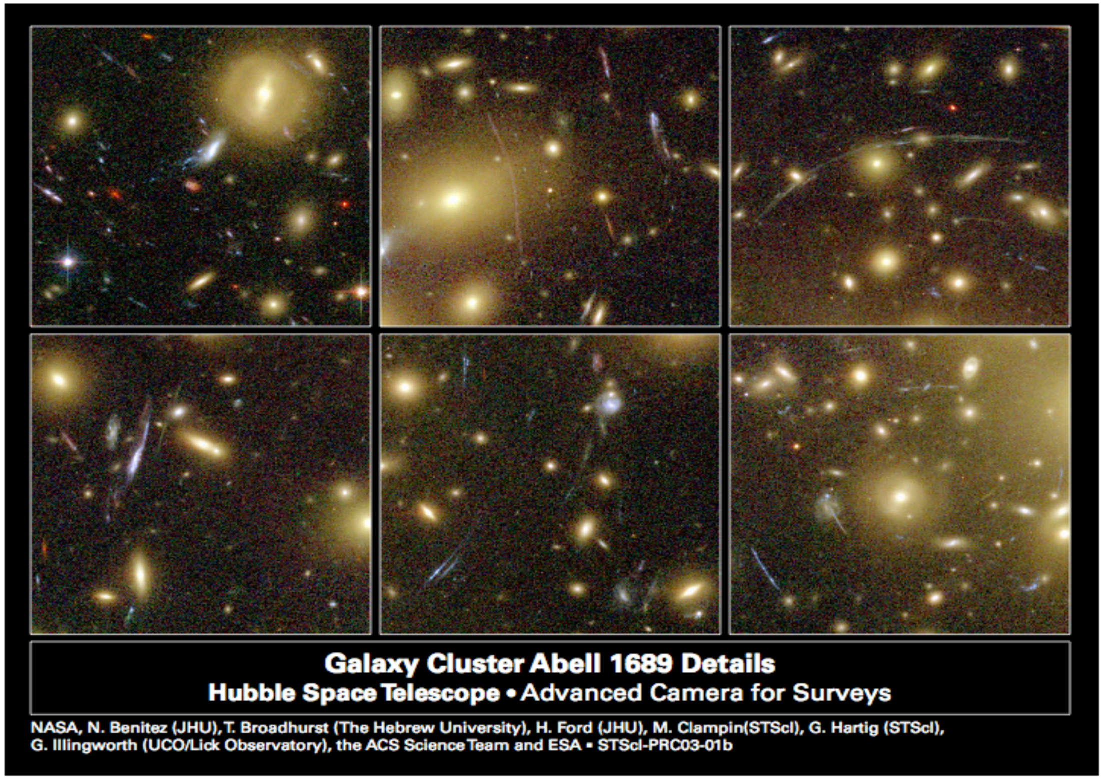
First-order estimate of mass... Axial symmetry....

$M(\theta_{arc}) \approx \pi\theta^2_{arc}\Sigma_{cr}$

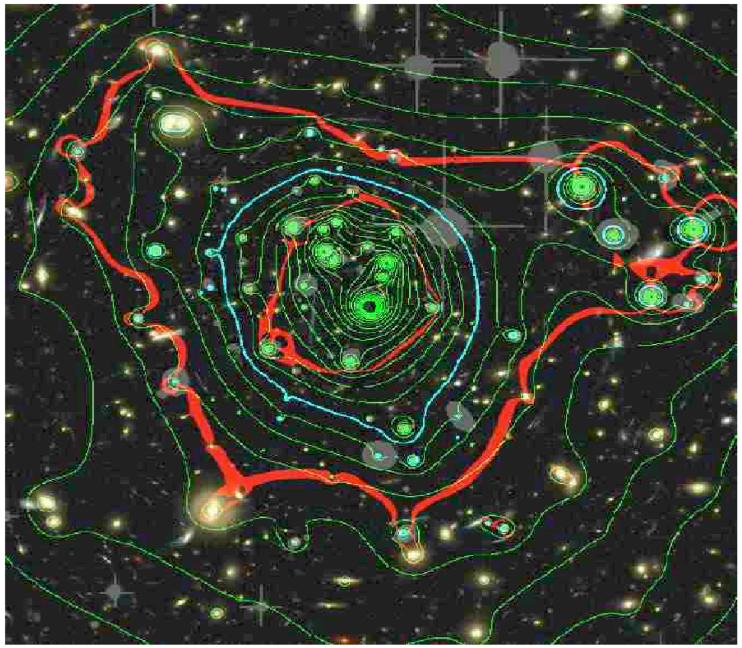
$\Sigma_{cr} = c^2/4\pi G\ (D_s/D_dD_{ds})$

Need source (and lens) redshifts

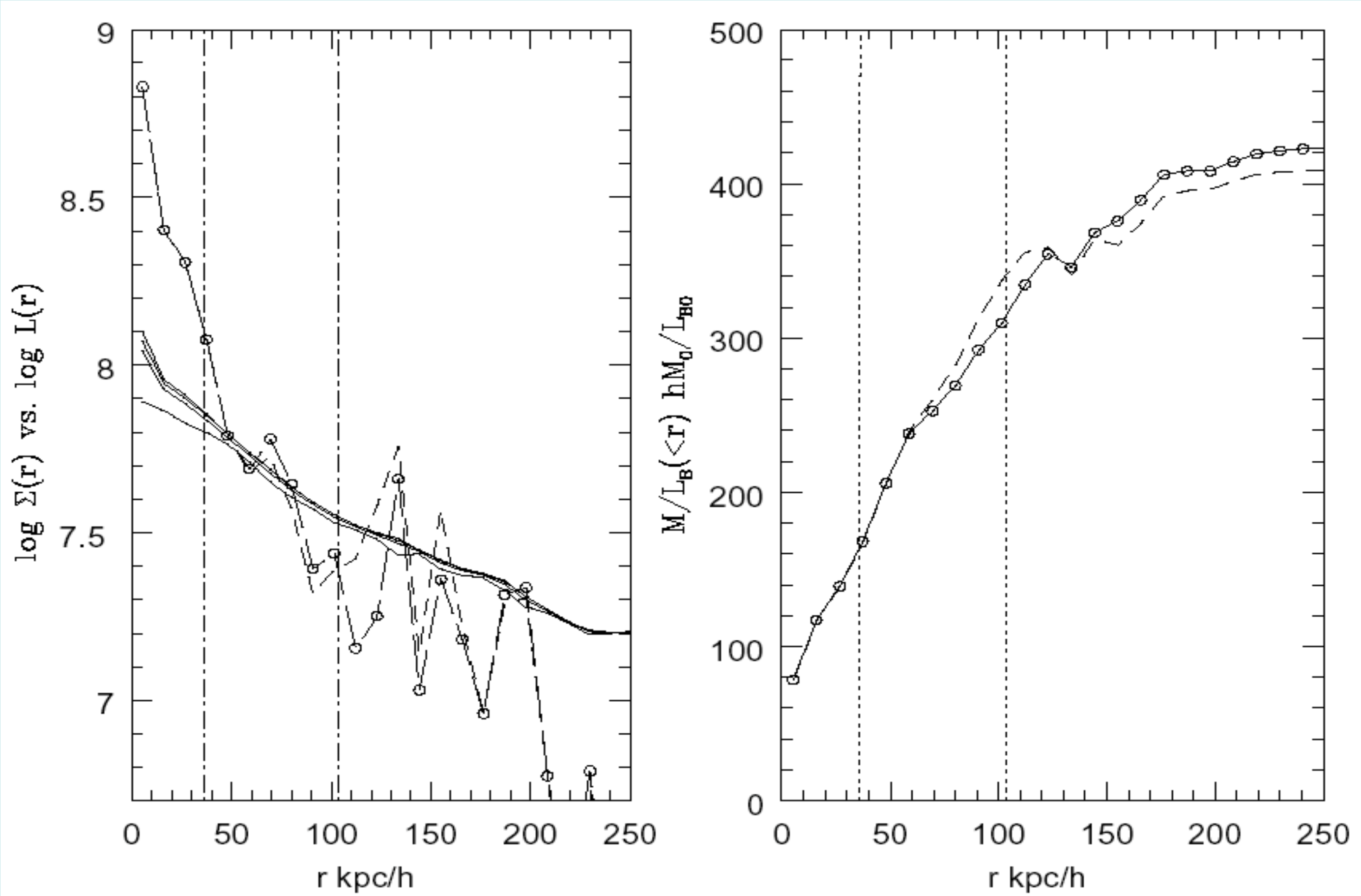
Most likely over-estimate masses; for more realistic models, to have critical curves at given distance from cluster centre need lower mass density (Bartelmann 2003)...



- Use (many!) multiple image positions
- Find model giving best fit to image positions

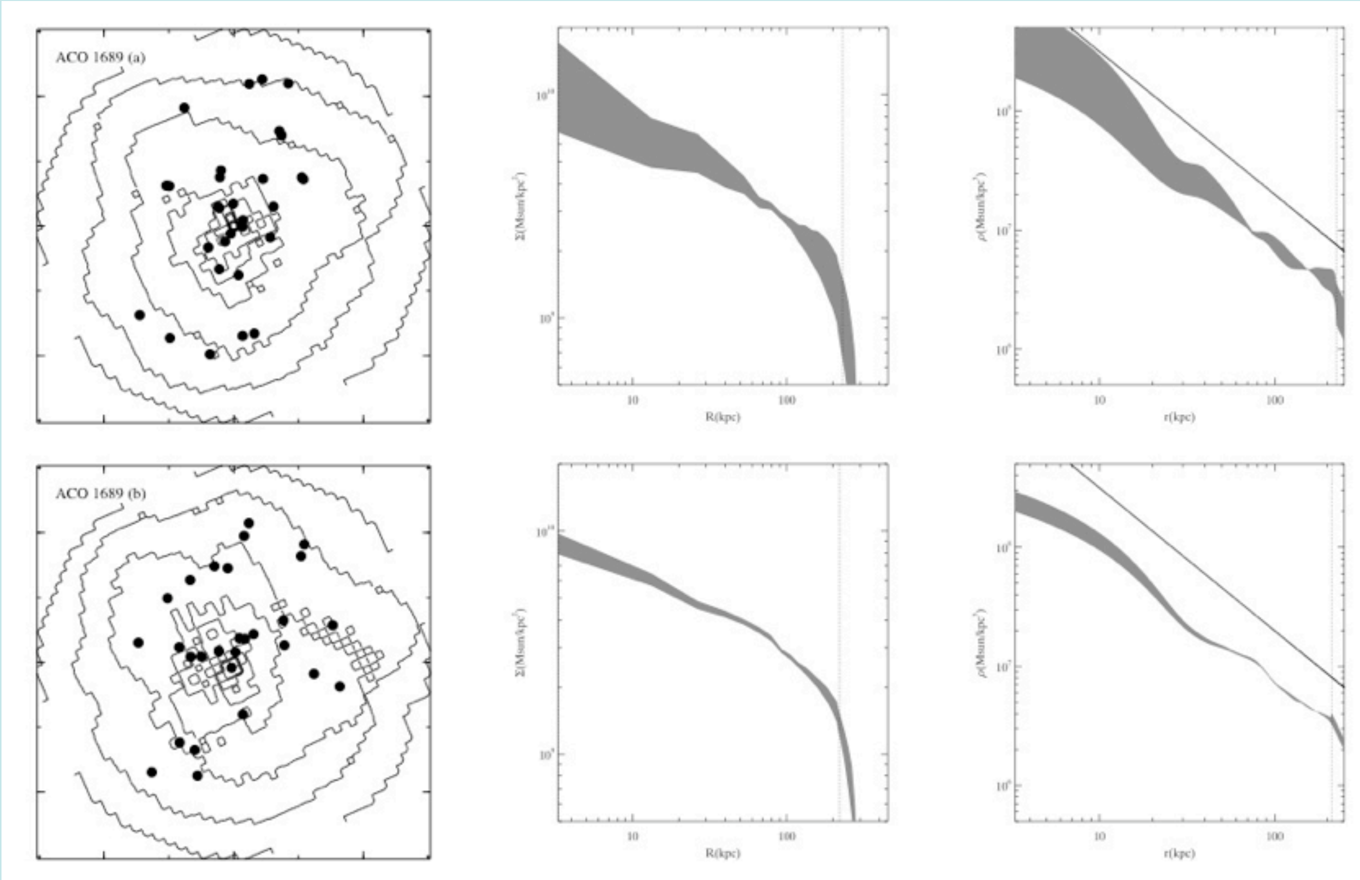


Broadhurst et al. 2004



- The mass profile is flatter than the light profile
- M/L increases away from the cluster centre
- Concentration parameter >8

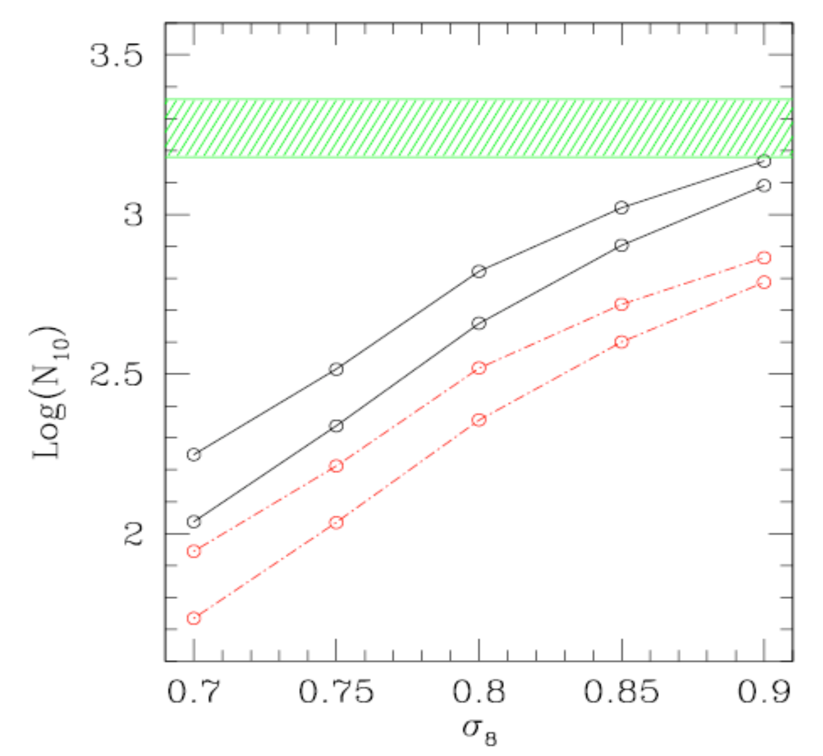
Saha et al. 2006 (PixeLens)



➢ Slopes indistinguishable from (dark matter) simulations even on small scales!...

➢ (Surprisingly small?) impact of baryons ~10%

Evidence that our understanding of clusters is limited?



Fedeli, Bartelmann et al. 2008

Similar result from Li et al. (2007) from incidence of lensed QSOs in SDSS.

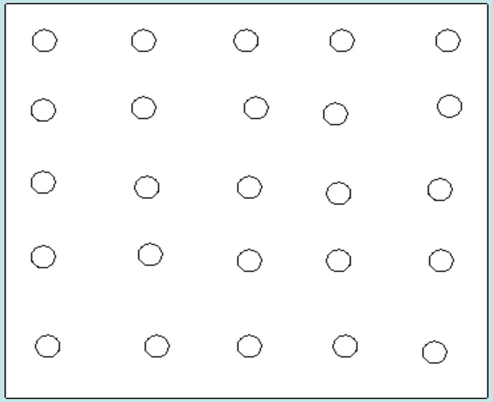
Also, unexpectedly high number of arcs in high z clusters (Gladders et al, Zaritsky & Gonzalez)

Cosmologies with early dark energy? (Bartelmann et al 2006)

Non-Gaussian initial density fluctuations? (Mathis et al 2004)

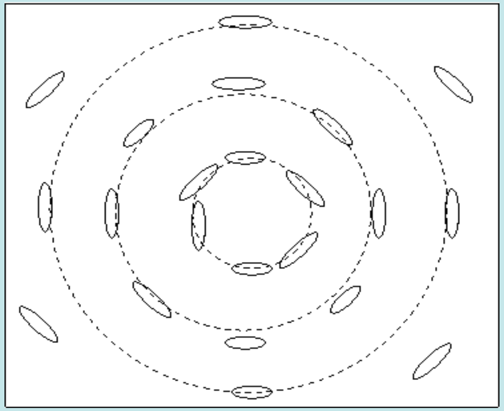
Need updated well-defined arc sample?

Weak lensing $\gamma, \kappa \ll 1$



background galaxies

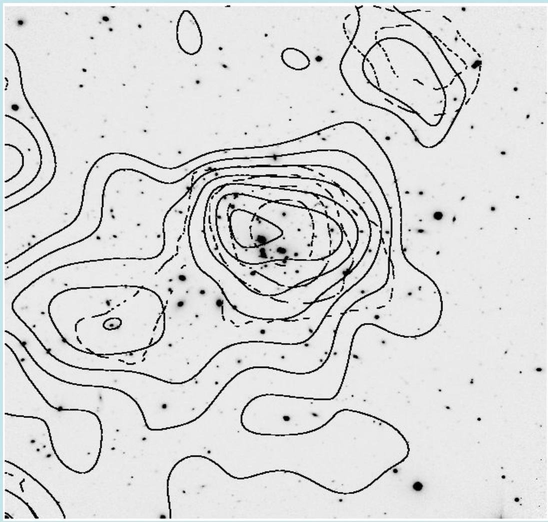
LENS



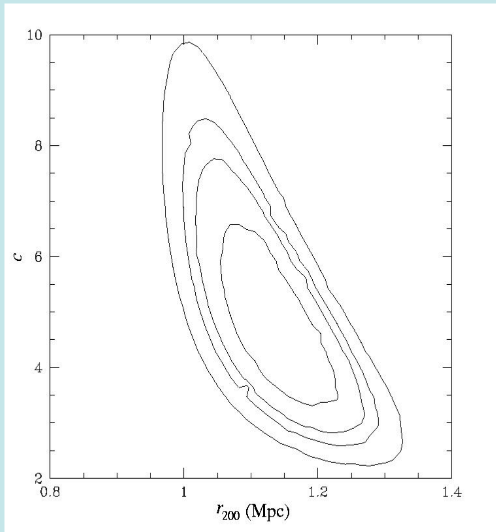
$$\varepsilon \approx \varepsilon^{s} + \gamma$$

$$\langle \varepsilon \rangle \approx \gamma$$

MASS MAP



MASS PROFILE



Relate γ, κ e.g. in Fourier space as in Kaiser & Squires (1993)

Parametric model fit to WL data

King et al. 2002a, b

Using galaxy shapes to determine mass profile

Unlensed, lensed ellipticities & parameter dependent reduced shear $g(\theta)$ for particular family

$$\varepsilon^s = \frac{\varepsilon - g(\theta)}{1 - g^*(\theta)\varepsilon}$$

$$\ell_\gamma = -\sum_{i=1}^{N_\gamma} \ln(p_\varepsilon(\varepsilon_i \mid g(\theta_i)))$$

Minimise the log-likelihood function

$$p_\varepsilon = \frac{\exp(-|\varepsilon^s|^2/\sigma^2)}{\pi\sigma^2\left[1 - \exp(-1/\sigma^2)\right]}\left|\frac{d^2\varepsilon^s}{d^2\varepsilon}\right|$$

Best-fit parameters p_{max}

Schneider, King & Erben

* Require good seeing (<1 arcsec) for accurate measurement of galaxy shapes

* Need sufficient background galaxies to probe potential and to overcome noise from galaxy shapes (distribution in ellipticity)

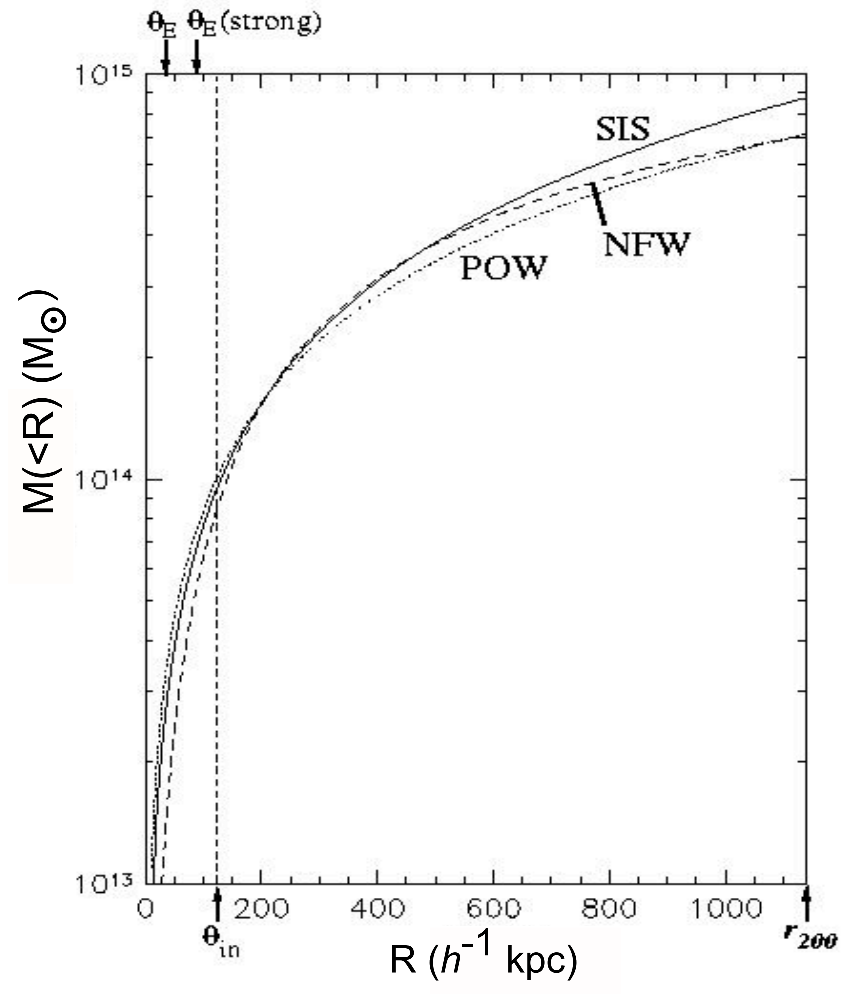
Typically have ~25/arcminsq ground-based, ~50/arcminsq space-based useful for weak lensing analysis

* Important to be able to identify background galaxies, and also have knowledge of their redshifts...

Parametric models require adopting a particular model family (e.g. NFW, SIS); but easy to determine parameter errors

Usually proceed by
- finding the best fit to the (azimuthally averaged) cluster shear profile
- using a maximum likelihood fit.

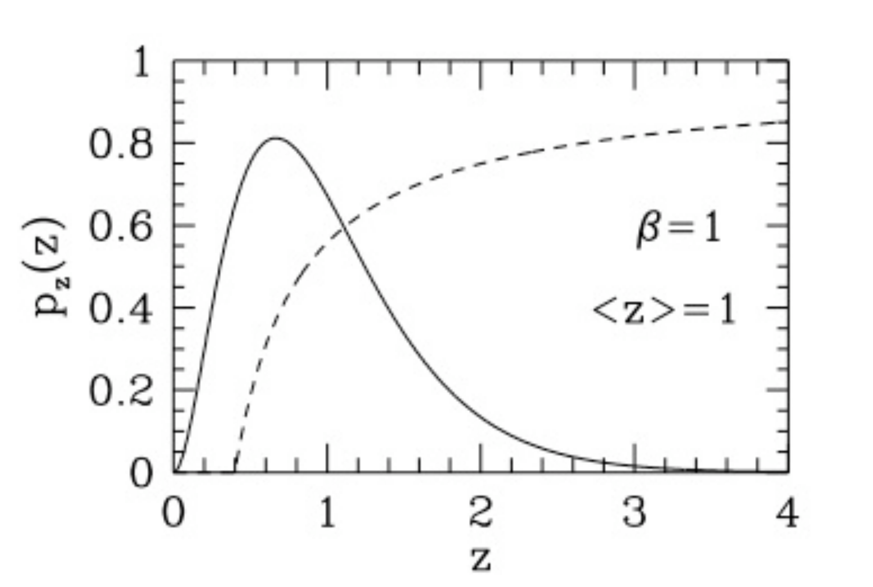
Distinguishing model families is not easy - but.....



Redshift information

$$w(z;z_d) = \frac{\lim_{z\to\infty}\Sigma_{crit}(z)}{\Sigma_{crit}(z)} = \frac{\Sigma_{crit_\infty}}{\Sigma_{crit}(z)}$$

$$\kappa(z) = w(z)\kappa_\infty \text{ and } \gamma(z) = w(z)\gamma_\infty$$



Seitz & Schneider 1997

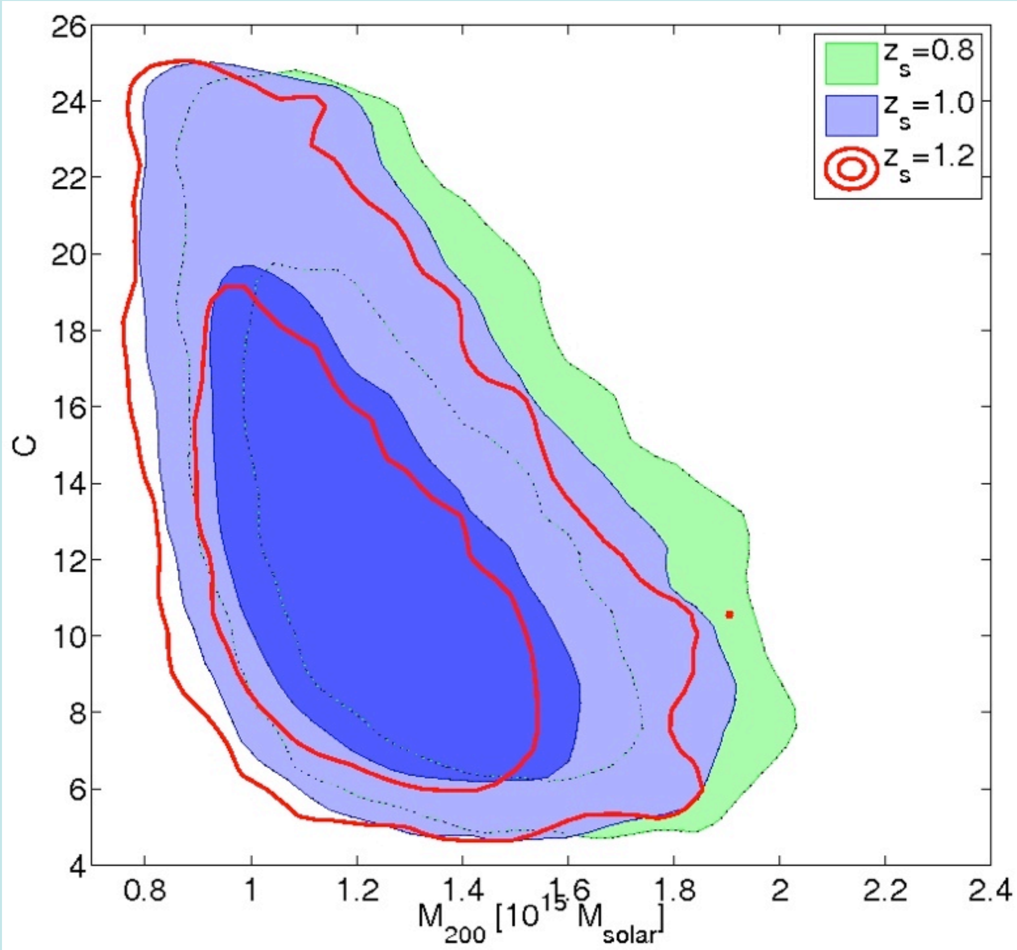
Often assume that sources "on a sheet" at $z_s \equiv \langle 1/\Sigma crit \rangle$ for population....

Fine for lower z clusters, or if we accurately knew the distribution...

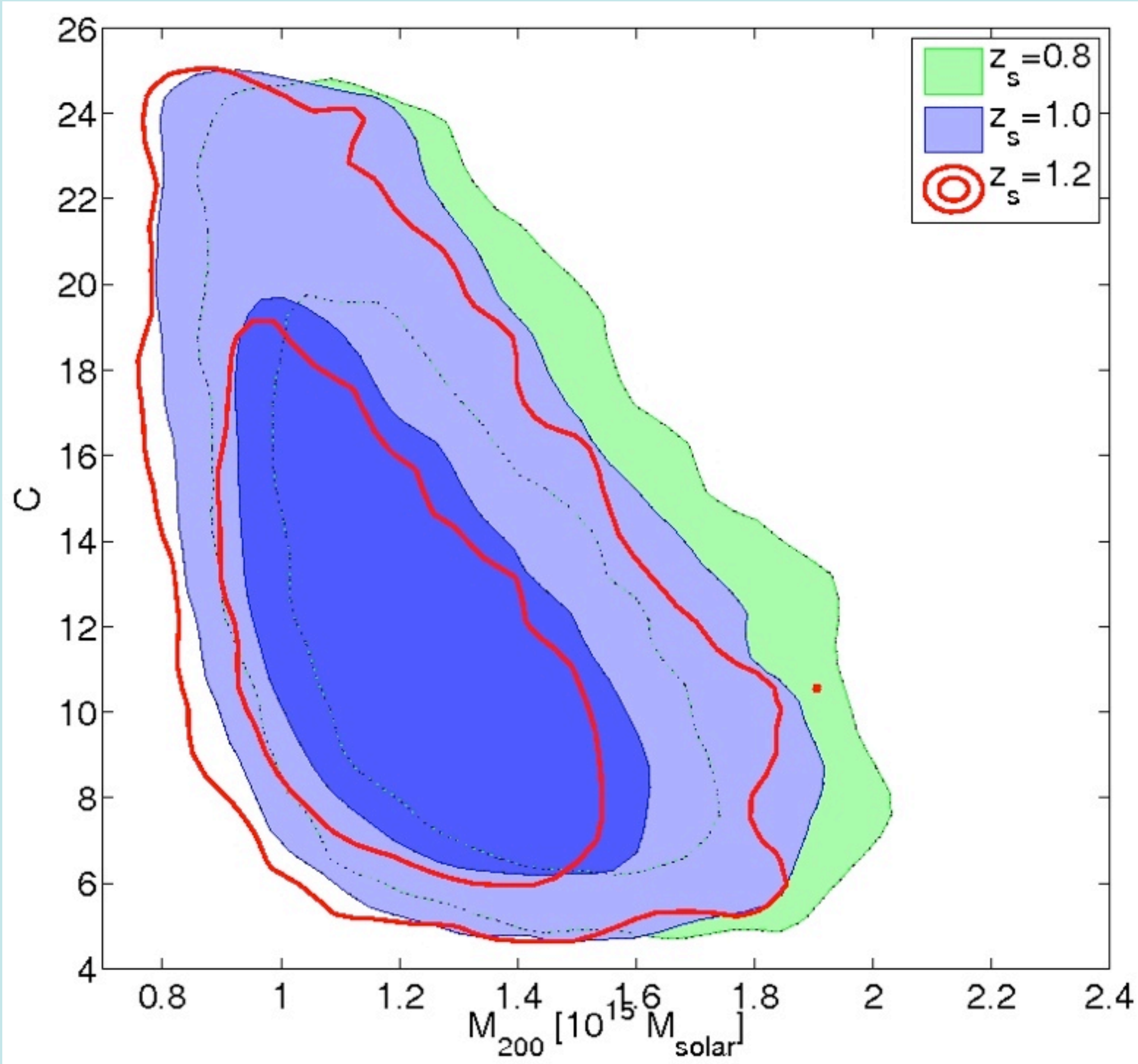
e.g. for A1689
(Corless et al 2008 in prep)

z_s	0.8	1.0	1.2
M_{200}	1.34	1.26	1.21x10^15 M_{sol}

Knowledge of redshifts of sources important particularly for clusters at z>0.25



26
24
22
20
18
16
14
12
10
8
6
4
C
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
M200 [10^15 Msolar]
zs=0.8
zs=1.0
zs=1.2

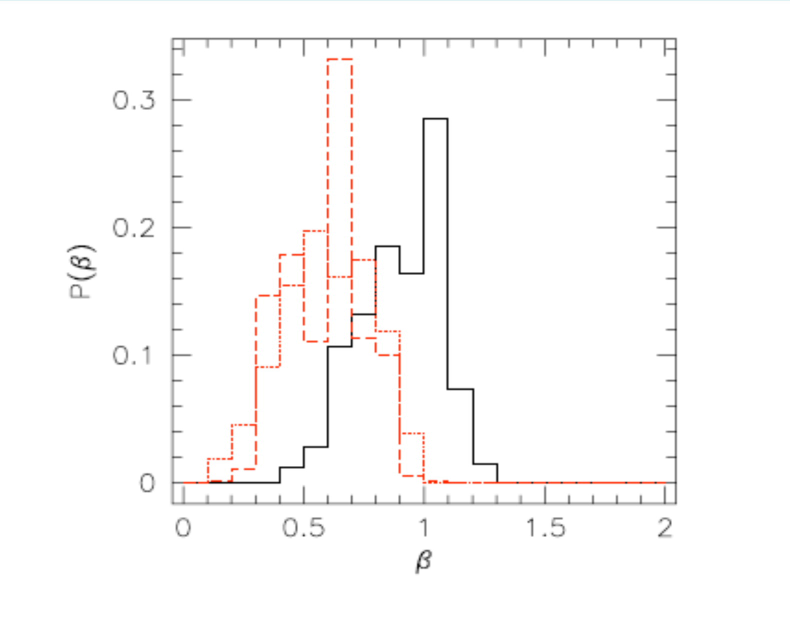


Corless et al. 2008 in prep

Most fits to lensing data are broadly consistent with NFW (e.g. samples from Clowe et al. 2006 (EDisCS), Dahle et al.).

Suggestions that some cluster profiles conflict with CDM paradigm (e.g. Broadhurst et al., Sand, Treu & Ellis).

Problem with CDM? What can go wrong in analyses?



Meneghetti et al. 2007

Looking first at the combination of SL and dynamics, Meneghetti et al. (2007) show that fitting circularly symmetric mass models doesn't give the correct inner profile slope...

Need to add ellipticity to the mass models used for SL /dynamics

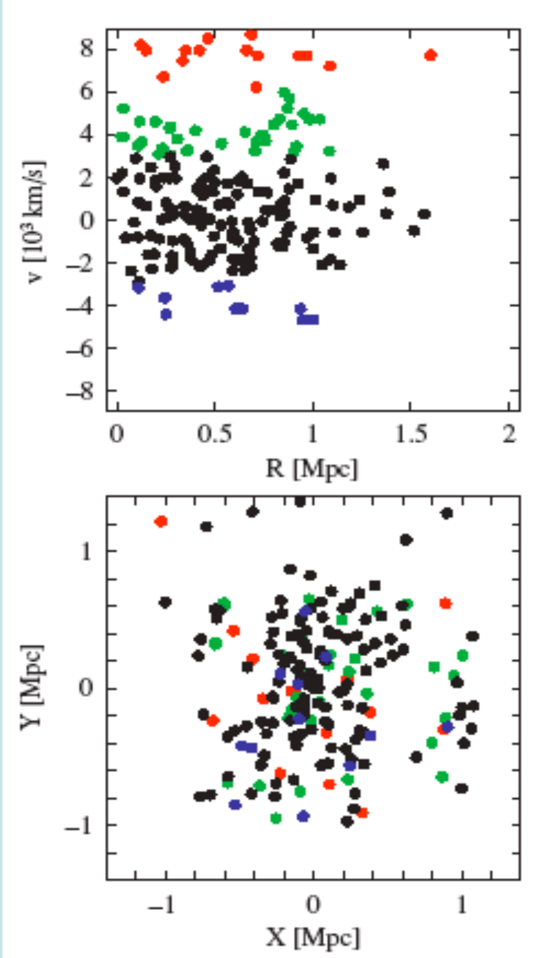
In the weak lensing regime we are less “contaminated” by baryons

But many complications!!

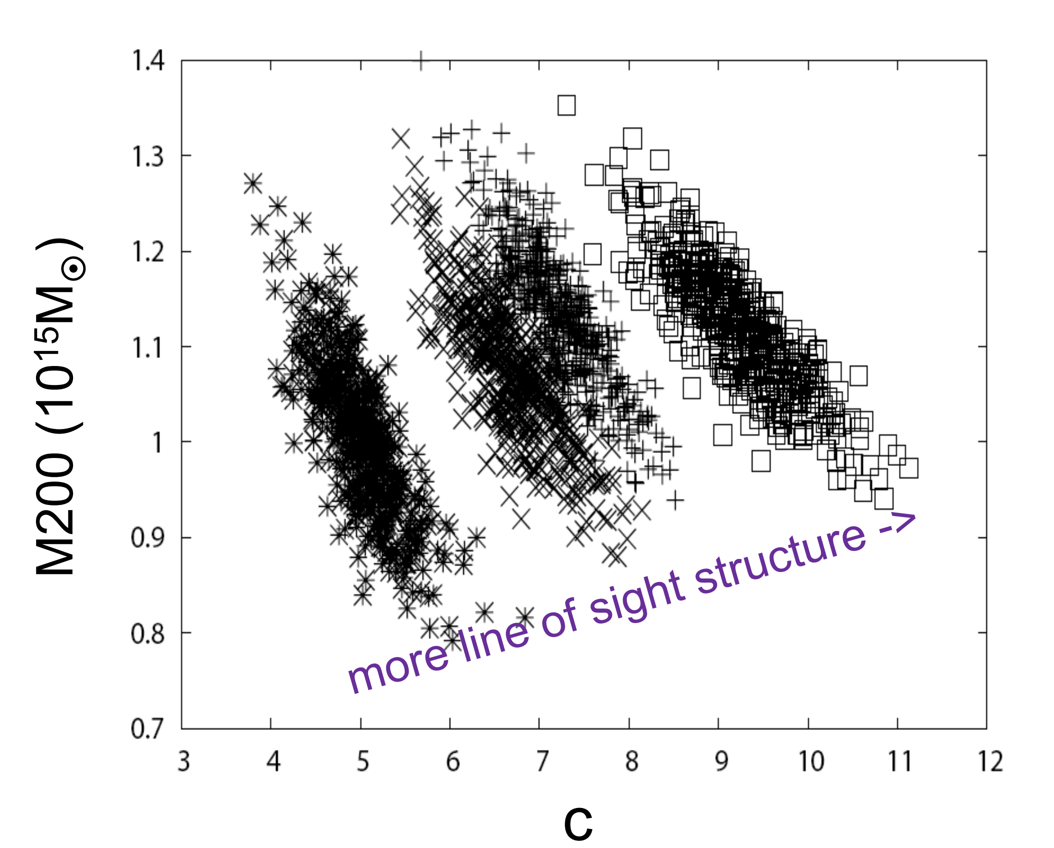
1: Important to identify line-of-sight structures.

Distant non-dynamically bound haloes can cause complex multi-peak velocity distributions (Lokas et al. 2006)....

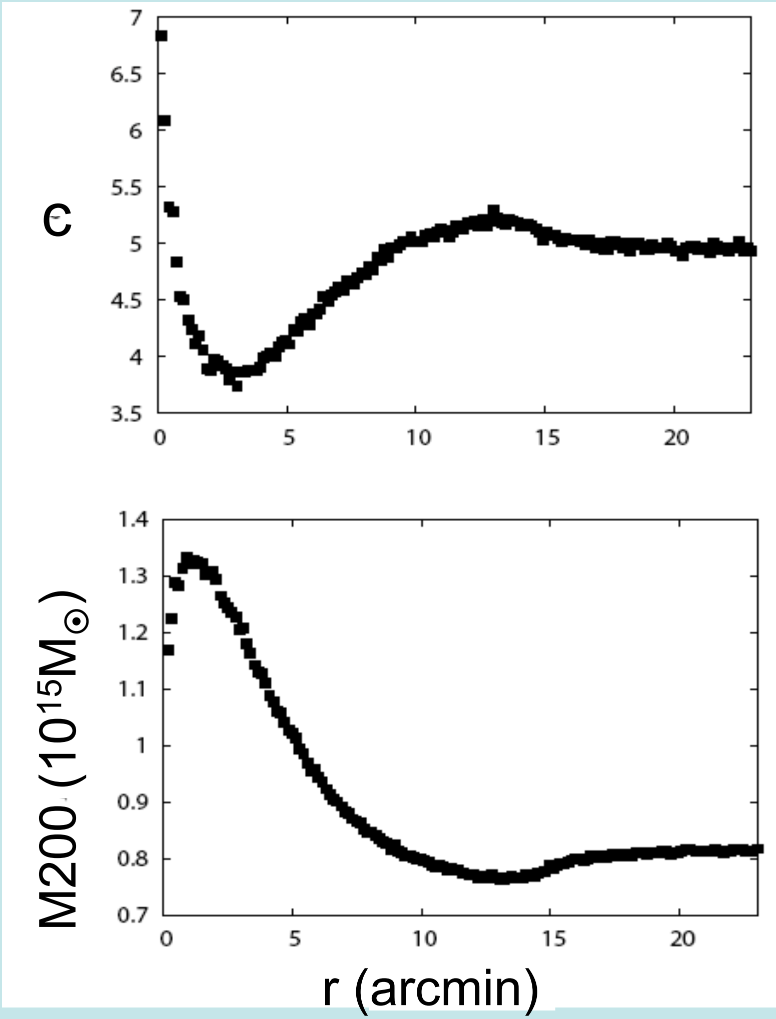
How does this impact on the mass and other cluster parameters from a WL analysis?



Lokas et al. 2006
(A1689 field)

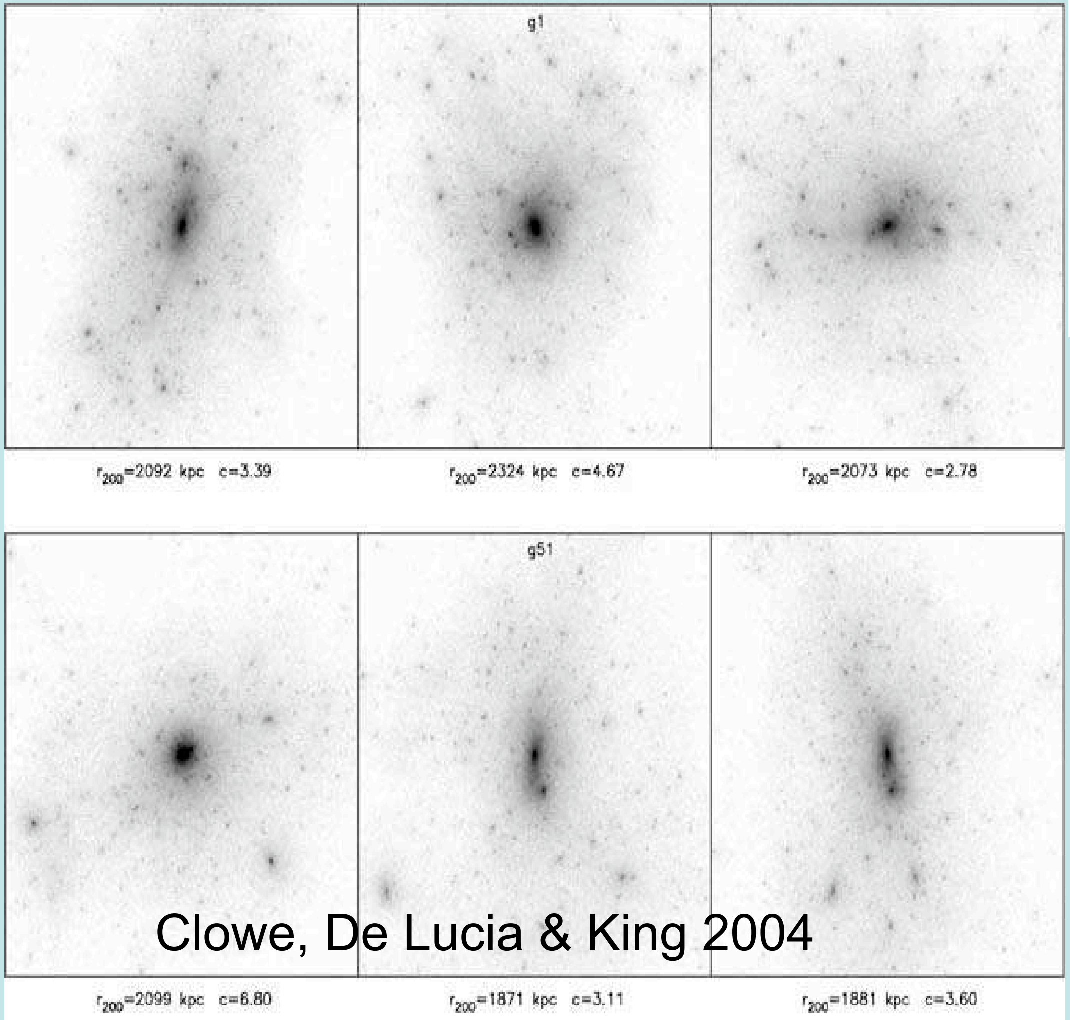


Ignoring structures close to l.o.s. can lead to erroneous parameter estimates

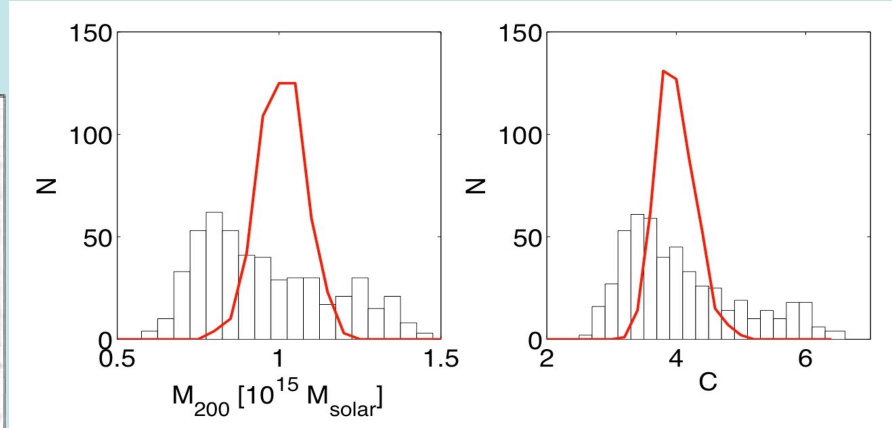


King & Corless 2007

2: Clusters have 3-D structure...
We sample this in projection



Clowe, De Lucia & King 2004

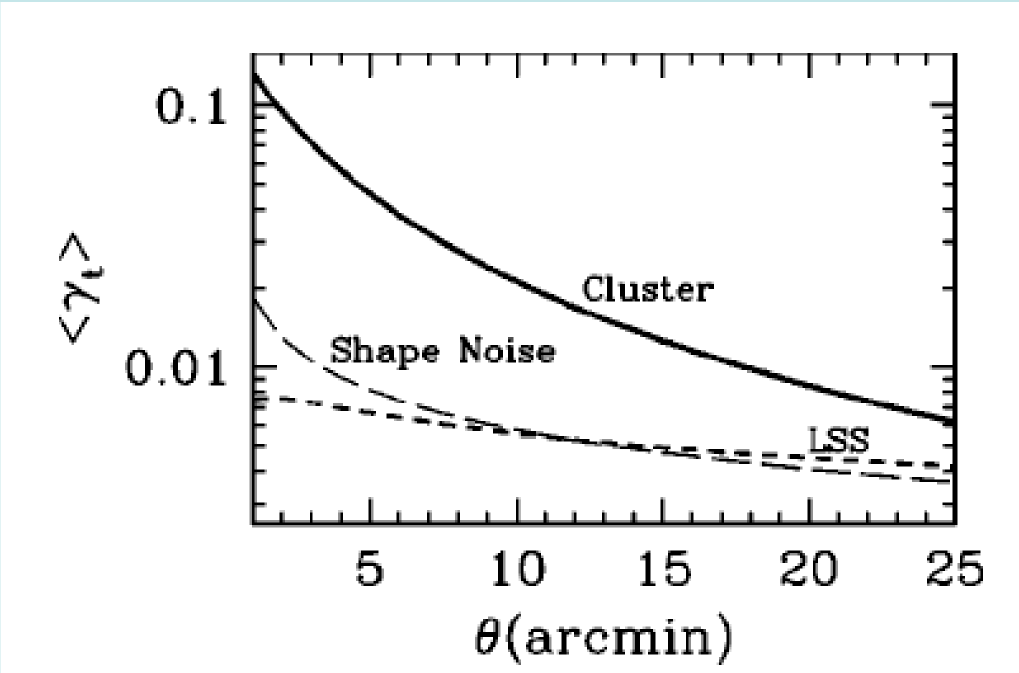


Corless & King 2007

Important to account for triaxiality in error budget... biases mass estimates

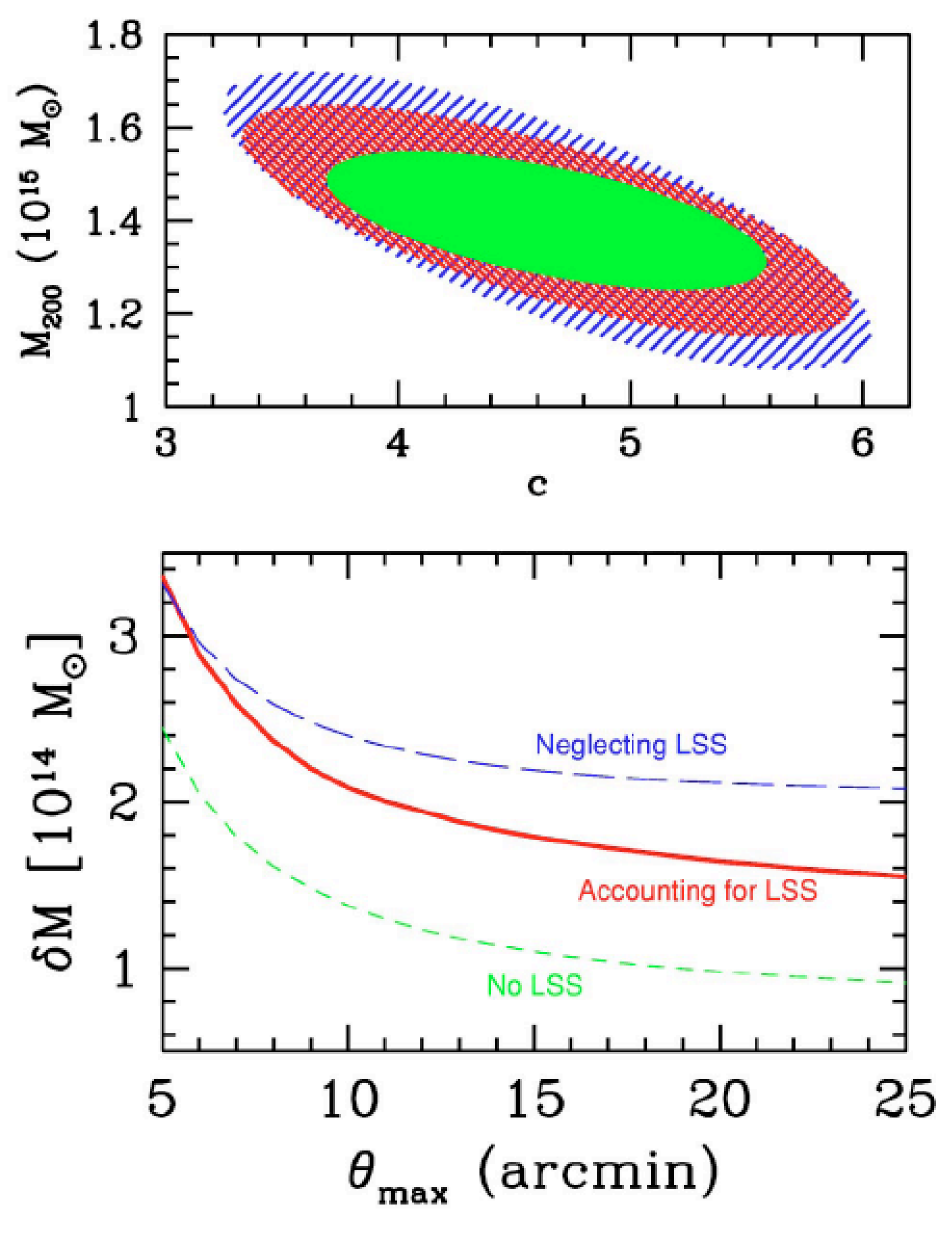
SEE VIRGINIA CORLESS TALK!

3: Large Scale Structure



Dodelson 2004

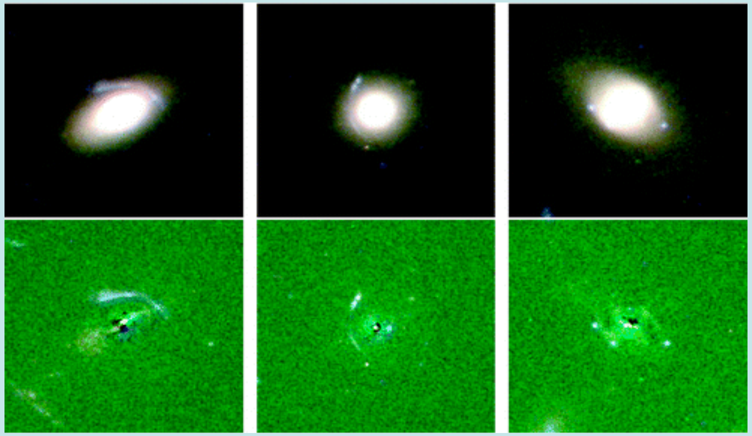
Increases errors on parameters



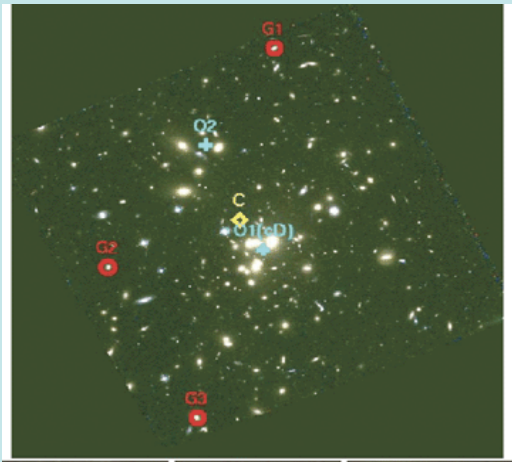
Should be incorporated in lensing analysis!

Help on understanding cluster mass distributions from outside the conventional weak and strong lensing regimes....

Strong lensing dominated by cluster members



Limousin et al. 2007



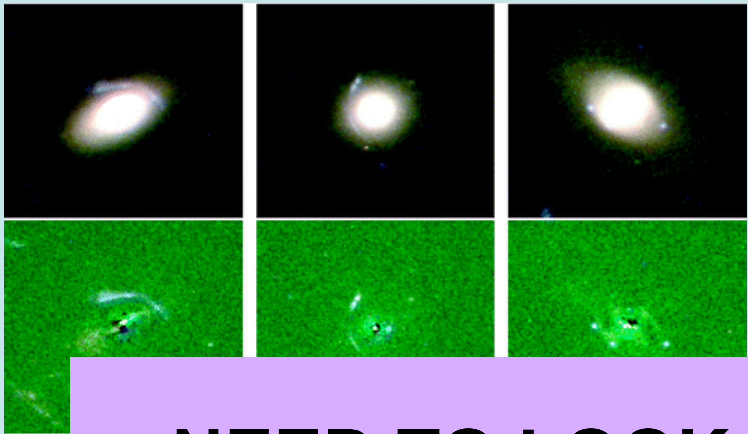
Tu et al. 2008

Abell 1689: several strong lensing events dominated by cluster members outside critical region (Limousin et al. 2007).

Lensing is assisted by the underlying (sub-critical) cluster convergence and shear. These events cover scales intermediate between weak and strong lensing, yielding improved mass models (Tu et al. 2008).

Multiple imaging cross-section is enhanced by ~3 in this region. Image separation is also boosted by the underlying cluster, so we can probe haloes of mass ~5 times smaller cp. the field (King 2007).

Strong lensing dominated by cluster members



Lim

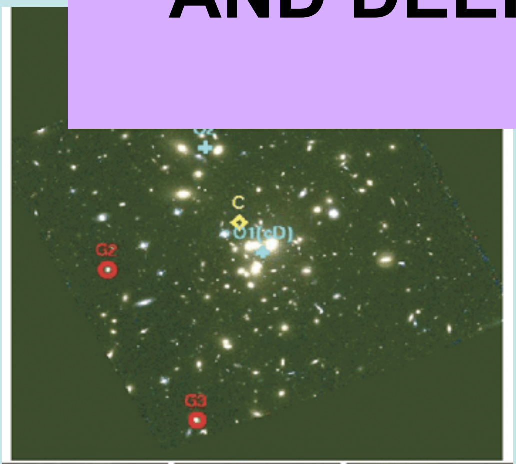
In Abell 1689, there are several strong lensing events dominated by cluster members just outside the critical region (Limousin et al. 2007).

Lensing is assisted by the underlying

NEED TO LOOK AT ARCHIVAL HST AND DEEP GROUND-BASED DATA

g

els



Tu et al. 2008

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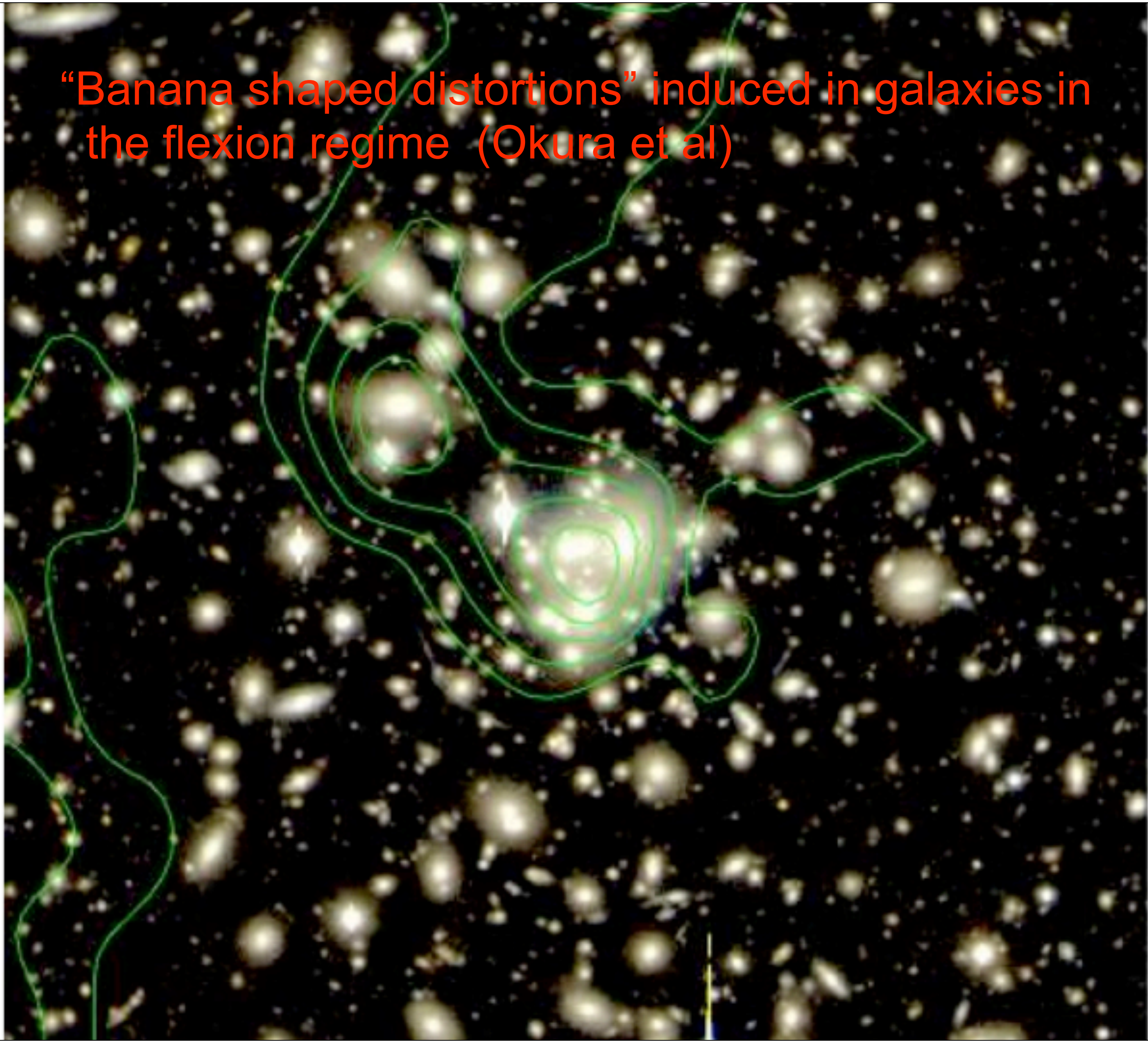
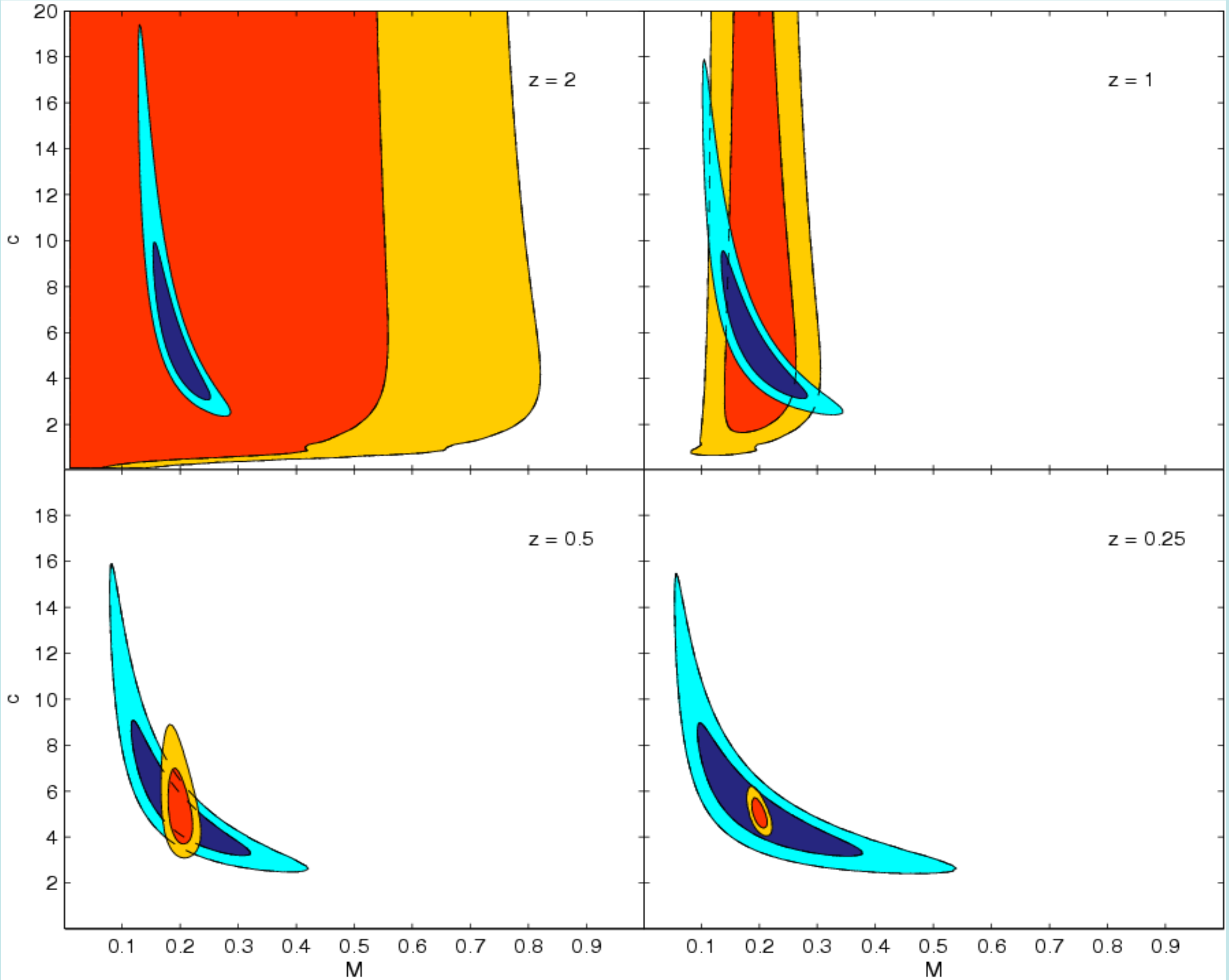

"Banana shaped distortions" induced in galaxies in
the flexion regime (Okura et al)

Cluster mass profiles from CMB and galaxy weak lensing

Lewis & King 2006



For z>1 clusters future CMB data will provide more accurate profiles than using galaxy lensing

NFW profile
M = 2 x 10^{14} h^{-1} $M_{\odot}$
c=5

CMB polarization only (0.02 μK arcmin noise)

Galaxies (500 gal/arcmin^2)

Pressing issues....

Awareness of impact of over-simplified mass models in both weak and strong lensing (e.g. needing triaxiality etc)

Comparison of observational results with “projected” mass functions from simulations, incorporating LSS and correlated structures

Detailed studies of impact of cluster physics; resolution of arc/wide sep qso statistics

Understanding what is going on in results reported for some clusters (e.g. latest 1689 results with c>25)