Triaxial Galaxy Clusters

Importance for Weak Gravitational Lensing Mass Measurements

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Cluster Weighing Workshop, MPE
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Dark Matter Halos

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- Universal density profile (NFW)

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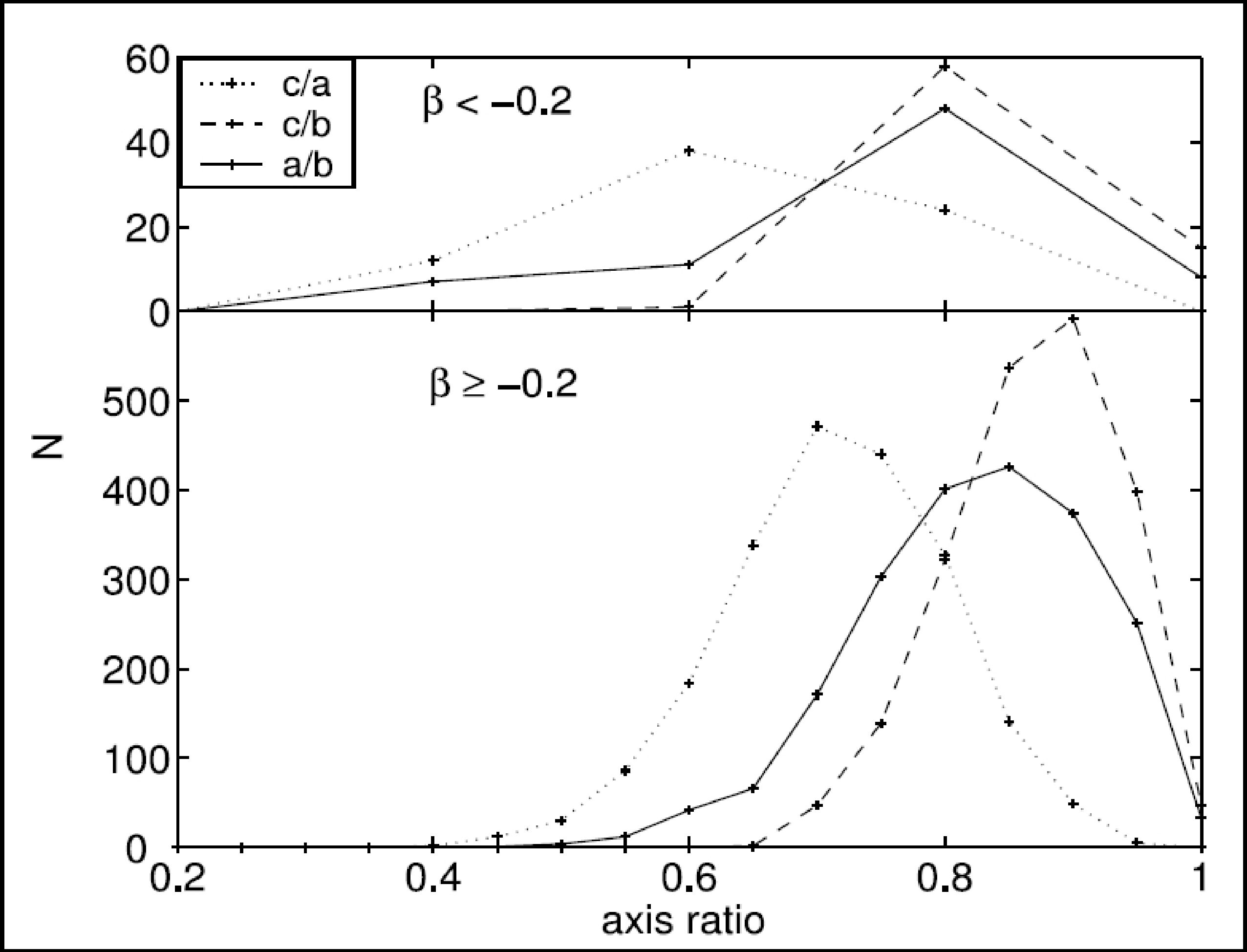
- Defined by 2 parameters: “virial” mass (M_{200}) and concentration (C)
- Significant triaxiality

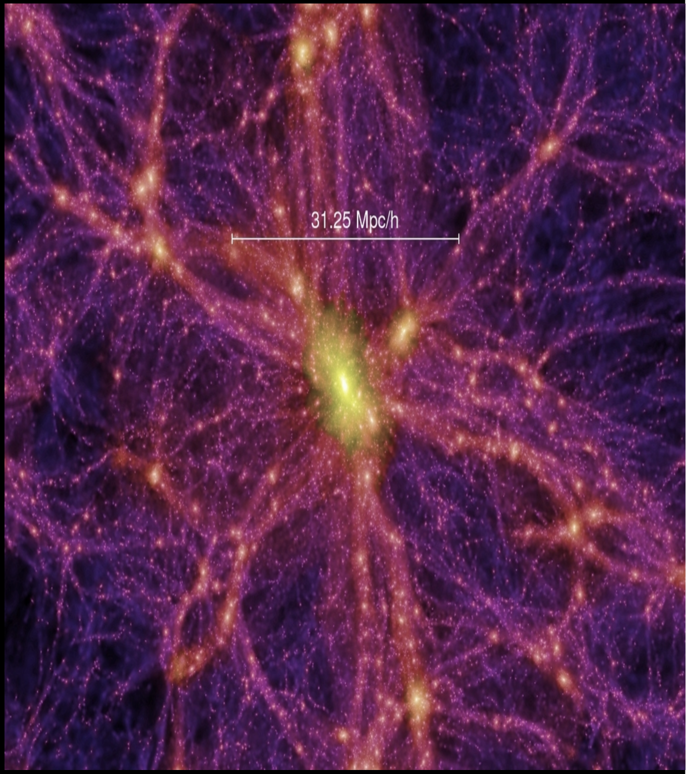
Triaxial Dark Matter Halos



Shaw et al., 2006

Triaxial Dark Matter Halos

- In LCDM we fully expect halos to exhibit significant triaxiality



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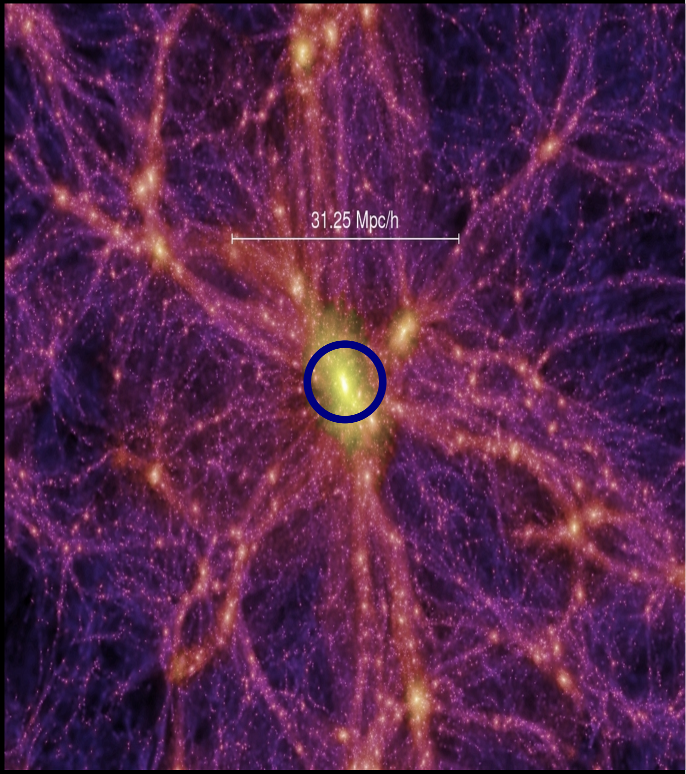

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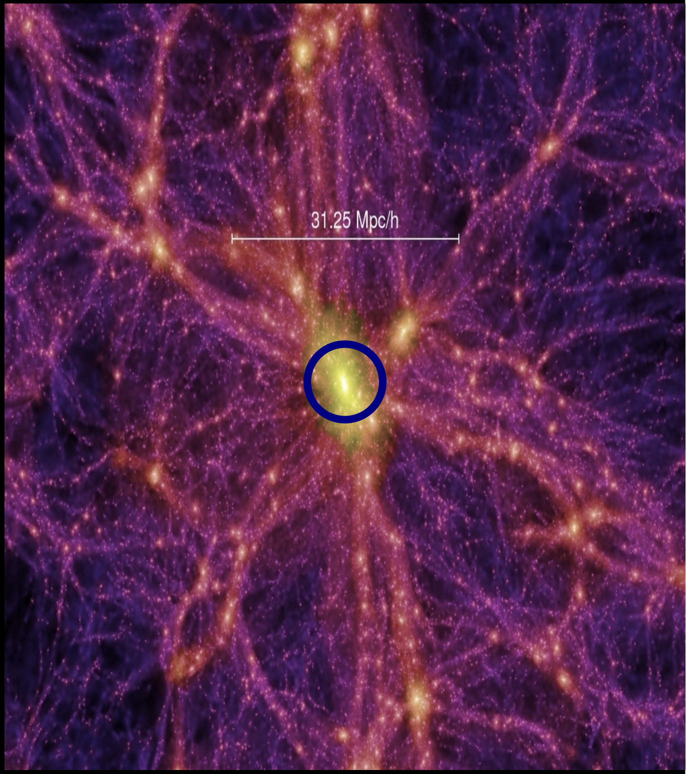

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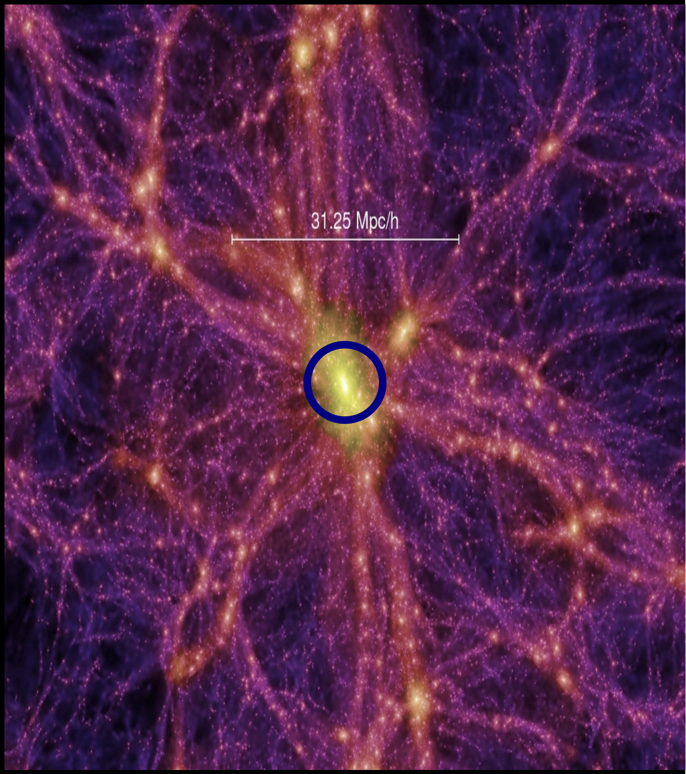
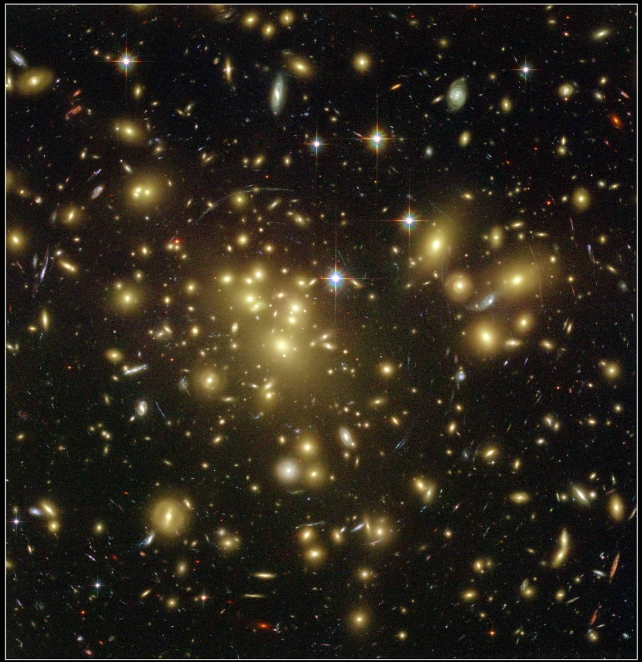
- In particular, in lensing we measure a 3D structure with 2D information!
- Is this a good assumption?



Why triaxiality?

- LCDM simulations predict a C-M_{200} relation: very massive clusters have low concentrations (M = 10^{15} $M_{solar,}$ C~4)



Galaxy Cluster Abell 1689
Hubble Space Telescope • Advanced Camera for Surveys

NASA, N. Benitez (JHU), T. Broadhurst (The Hebrew University), H. Ford (JHU), M. Clampin (STScI), G. Hartig (STScI), G. Illingworth (UCO/Lick Observatory), the ACS Science Team and ESA
STScI-PRC03-01a

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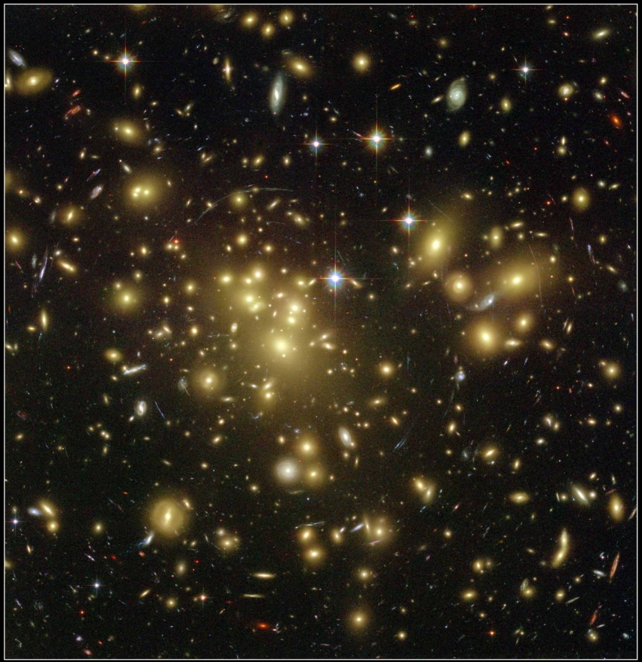

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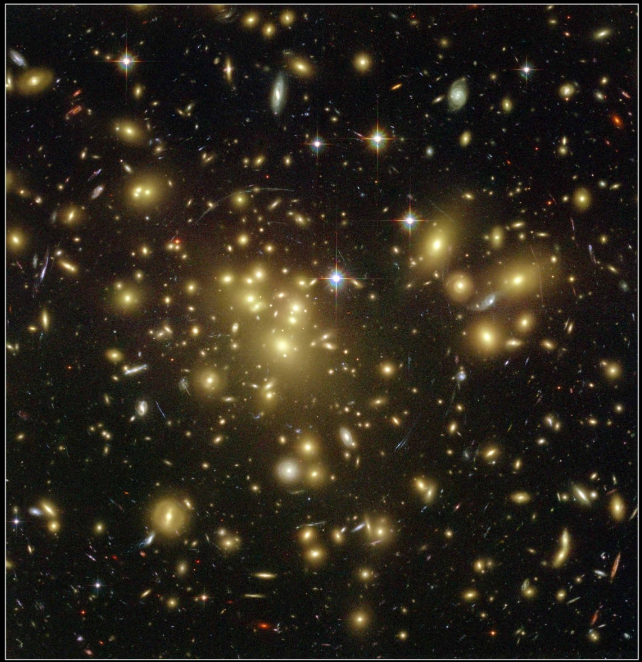
- Problems with CDM? Systematics?



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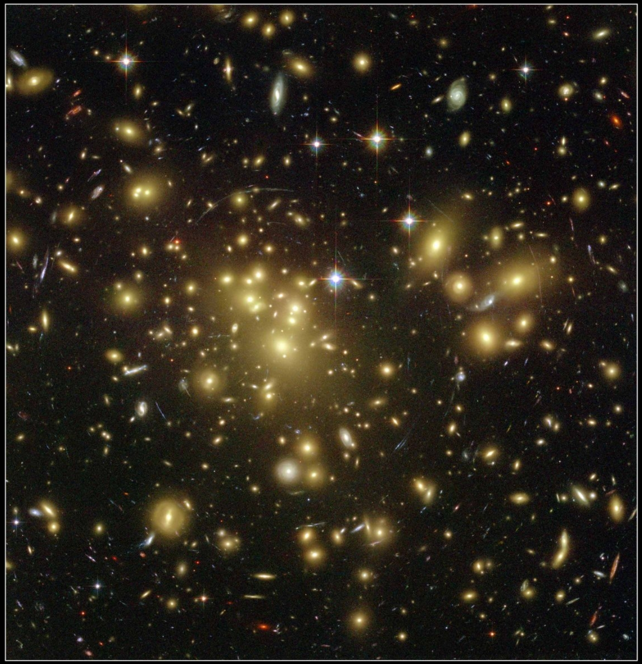
- Some groups have examined the impact of this in specific cases (e.g. Oguri et al. 2005, Gavazzi 2005)



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Triaxial Dark Matter Halos

$$\rho(R) = \frac{\delta_c \rho_c(z)}{R/R_s(1 + R/R_s)^2}$$

$$R^2 = \frac{X^2}{a^2} + \frac{Y^2}{b^2} + \frac{Z^2}{c^2} \; (a \leqslant b \leqslant c = 1)$$

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$$M_{200} = \frac{800\pi}{3} a b R_{200}^3 \rho_c$$

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Effective spherical

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$$m_{200} = (800\pi/3) r_{200}^3 \rho_c$$

$$r_s = R_s (abc)^{1/3}$$

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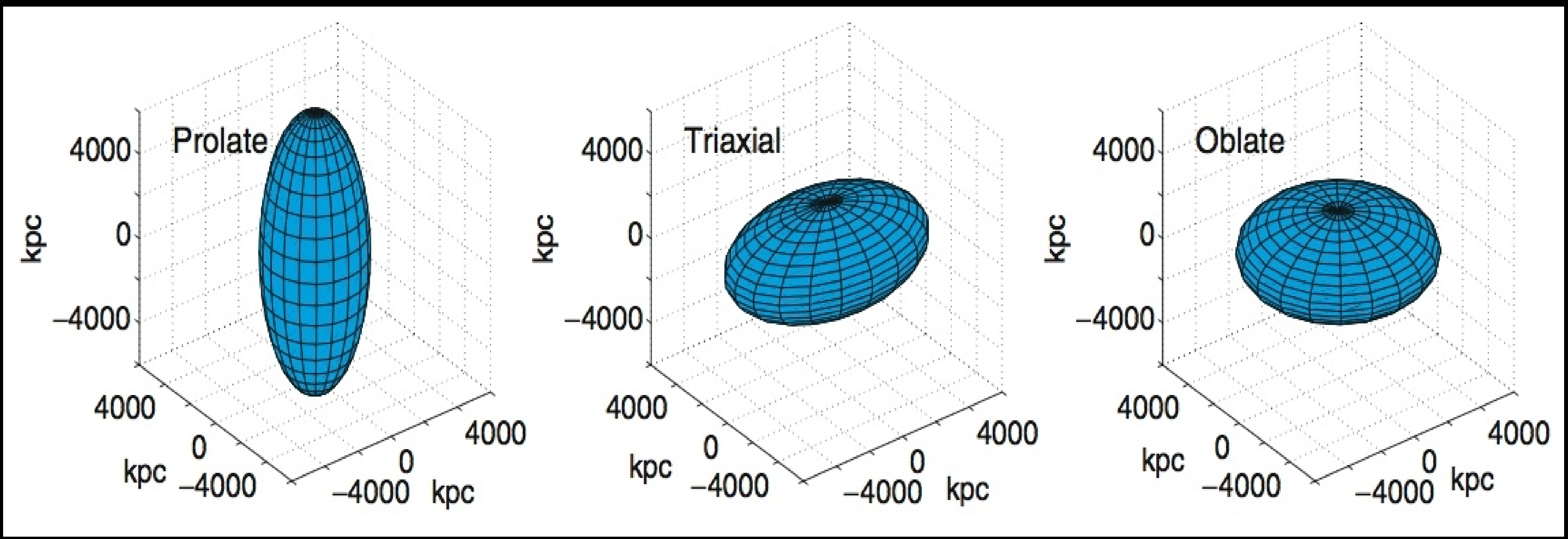

a = b = 0.4
"Cigar"

a = 0.4, b = 1.0
"Pancake"

Triaxiality: what impact in weak lensing?

- Simulate weak lensing through symmetric prolate and oblate halos
  - (this is the computationally tricky bit – see Keeton 2001; Jing & Suto 2002; Oguri, Lee & Suto 2003; Corless & King 2007)

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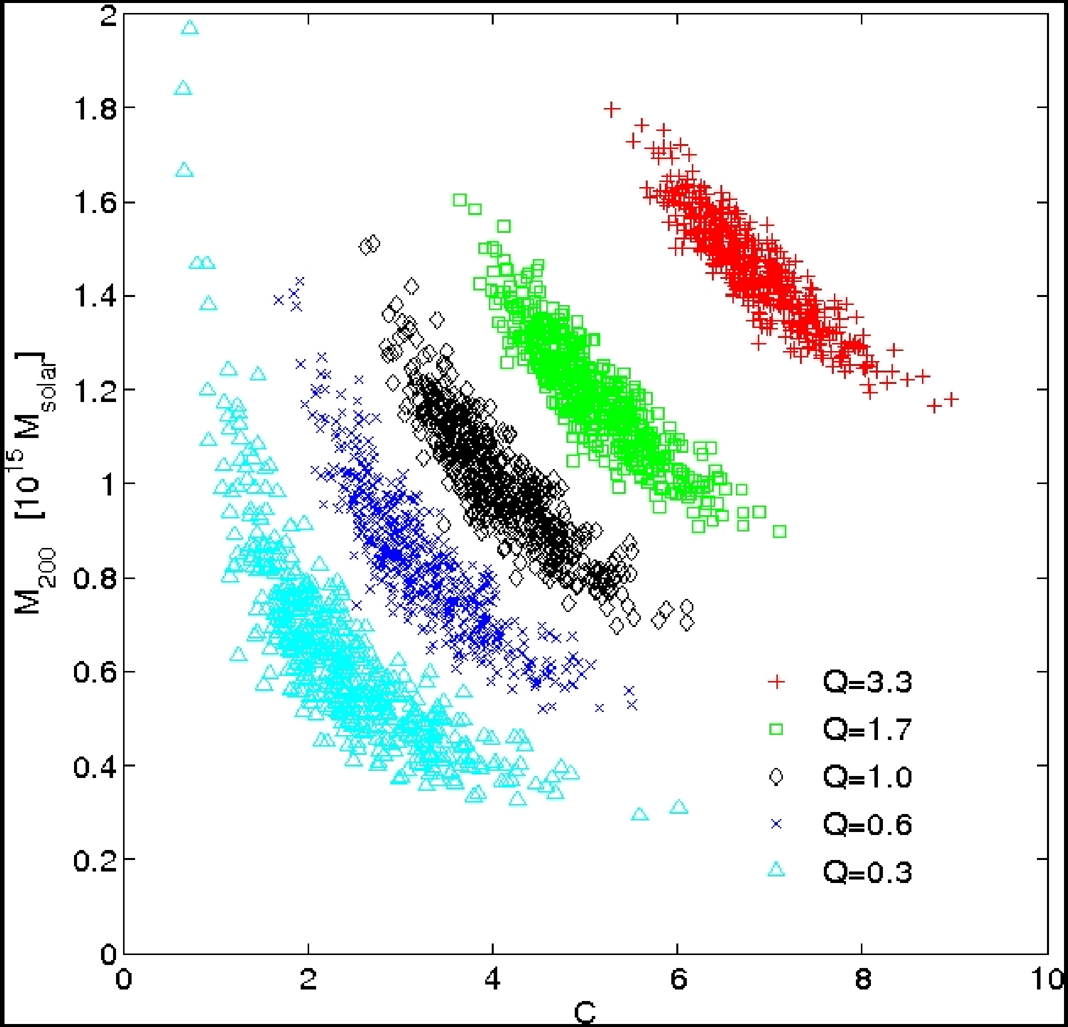
- Simulate weak lensing through symmetric prolate and oblate halos
  - (this is the computationally tricky bit – see Keeton 2001; Jing & Suto 2002; Oguri, Lee & Suto 2003; Corless & King 2007)
- Fit spherical NFW models using a standard maximum likelihood technique to the resulting catalogues of lensed objects to obtain estimates of mass and concentration

A Significant Impact!

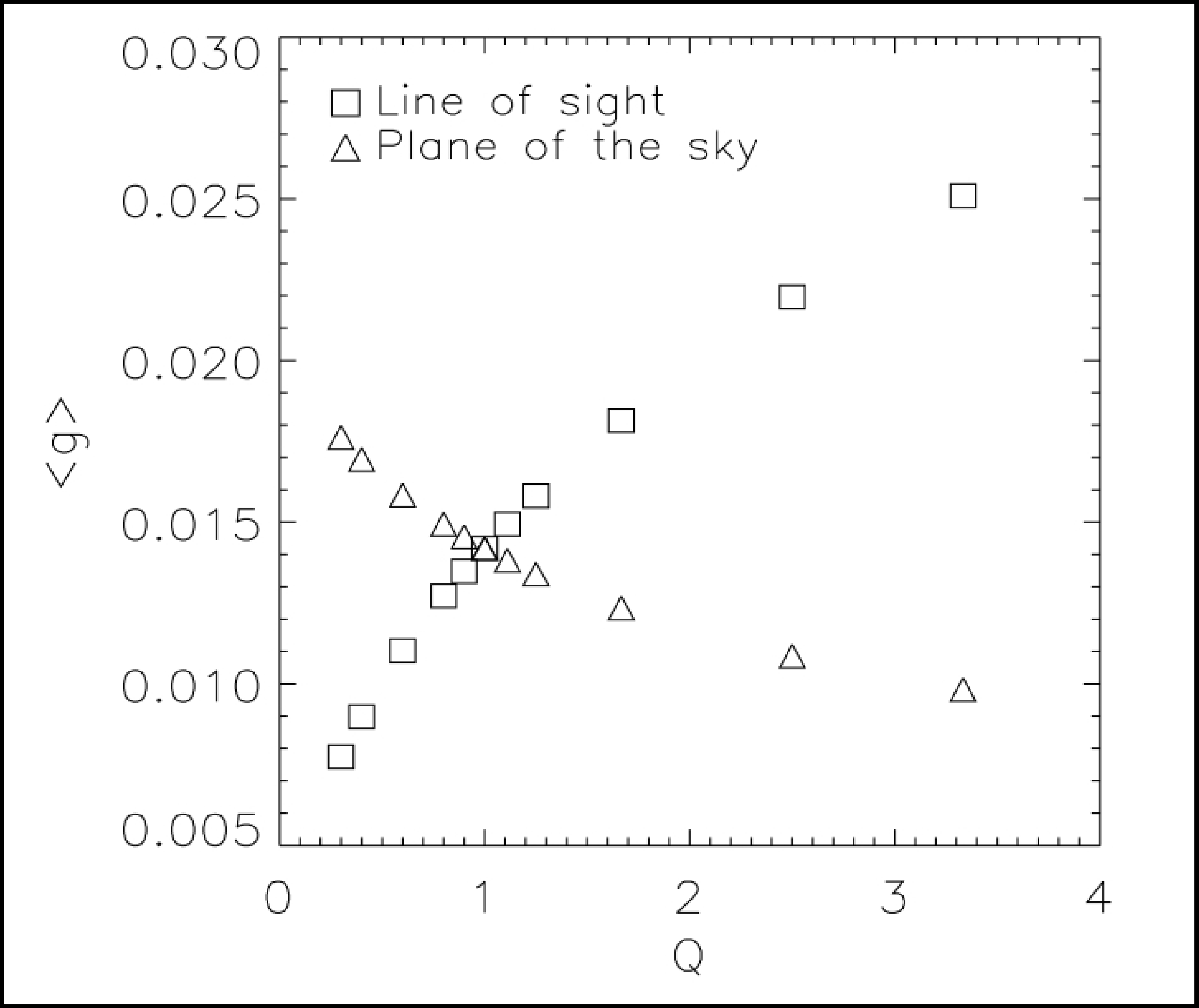
$M_{200} = 10^{15}\ M_{solar}$, C=4, Line of Sight



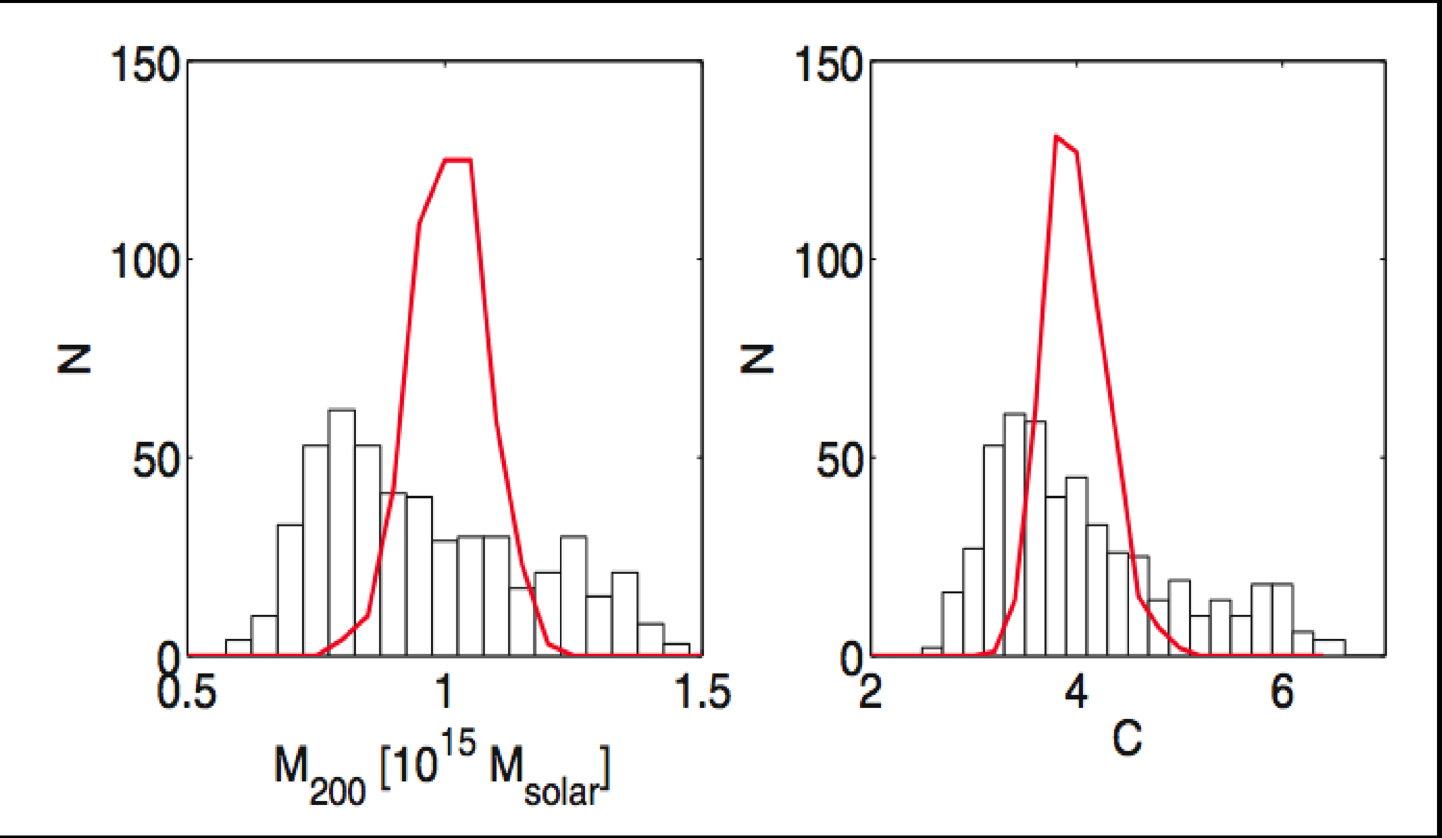
Corless & King, 2007

- Errors in mass of up to ~40%
- Errors in concentration of up to a factor of 2

Lensing efficiency of triaxial halos



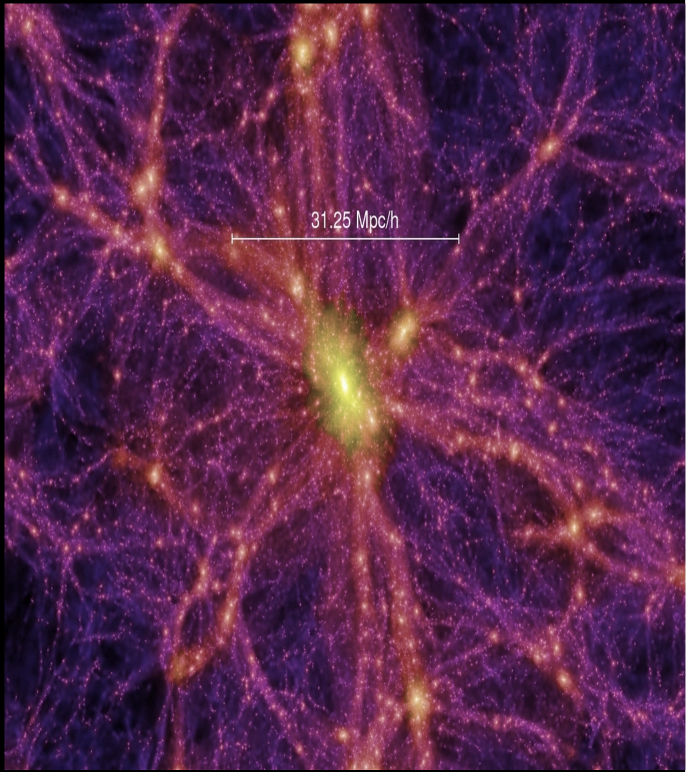
Populations of triaxial halos



$M_{200} = 10^{15}\ M_{solar}$, C=4, Prolate a = b = 0.4

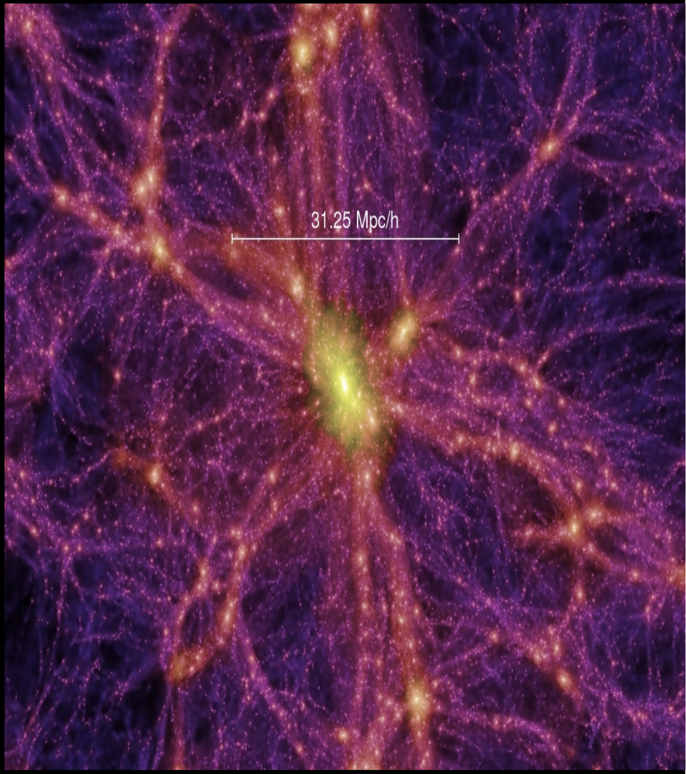
So…

- Triaxiality is important – can cause significant errors in some cases, small errors in all cases
- Some very triaxial structures are the most efficient lenses



So...

- Triaxiality is important – can cause significant errors in some cases, small errors in all cases
- Some very triaxial structures are the most efficient lenses
- Can we fit triaxial models to lensing data?
- An intrinsically underconstrained problem: 3 axes to constrain in the model with 2 axes of observed data



Fitting triaxial mass models

Markov Chain Monte Carlo

A "guided" random walk that maps complex posterior probability distributions by preferentially sampling regions of high probability, but is free to move downhill to lower probabilities to move between peaks

likelihood prior

$$p(\pi|\theta) = \frac{p(\theta|\pi)p(\pi)}{p(\theta)}$$

evidence

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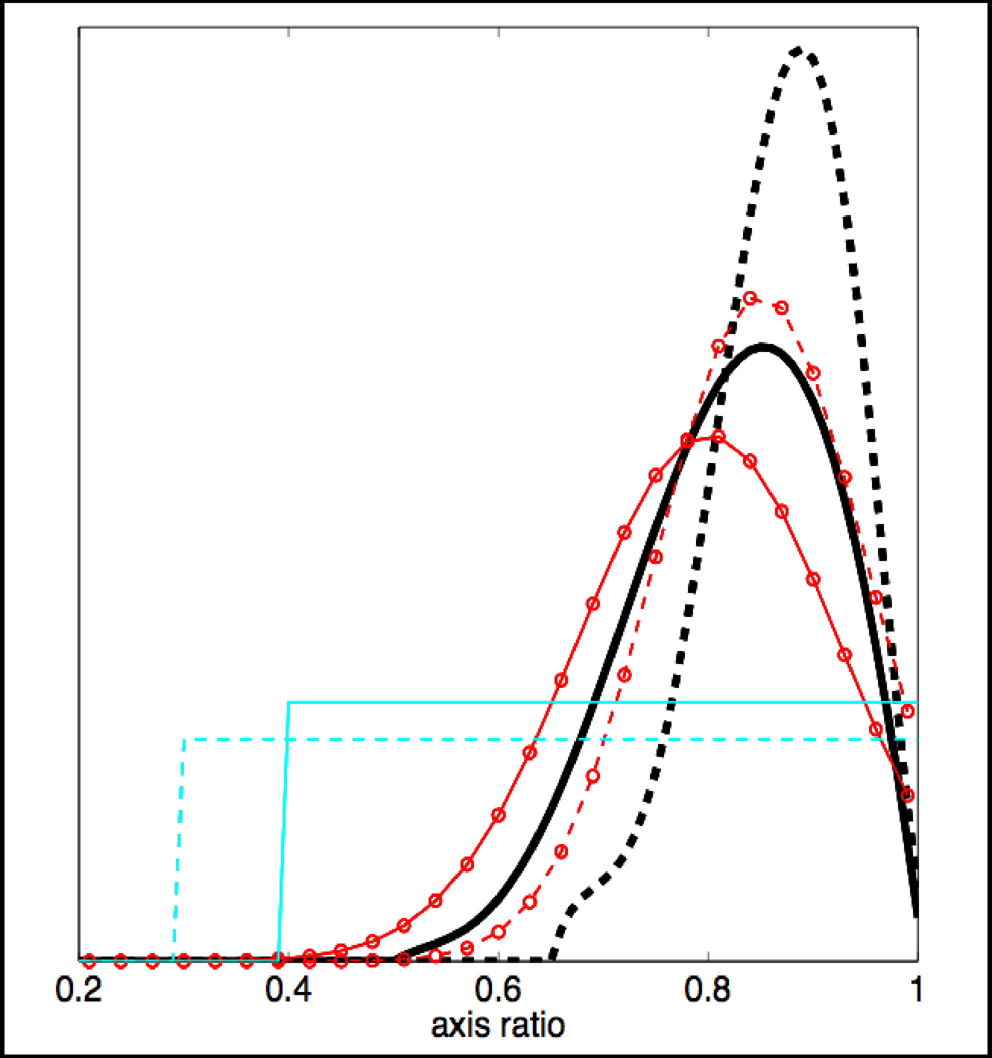
Choice of Prior

A fundamentally underconstrained problem!

- Flat
- Simulations
- Spherical



Choice of Prior

A fundamentally underconstrained problem!

- Flat
- Simulations
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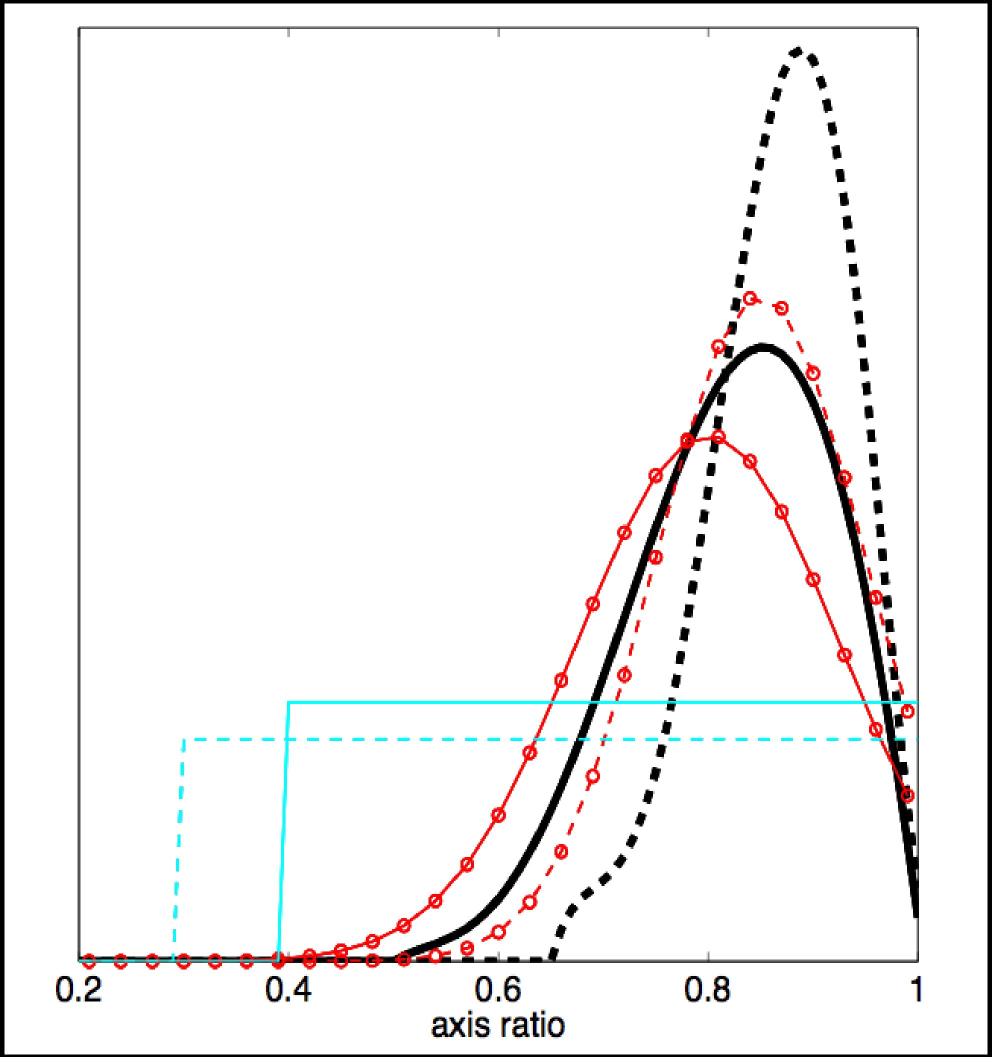
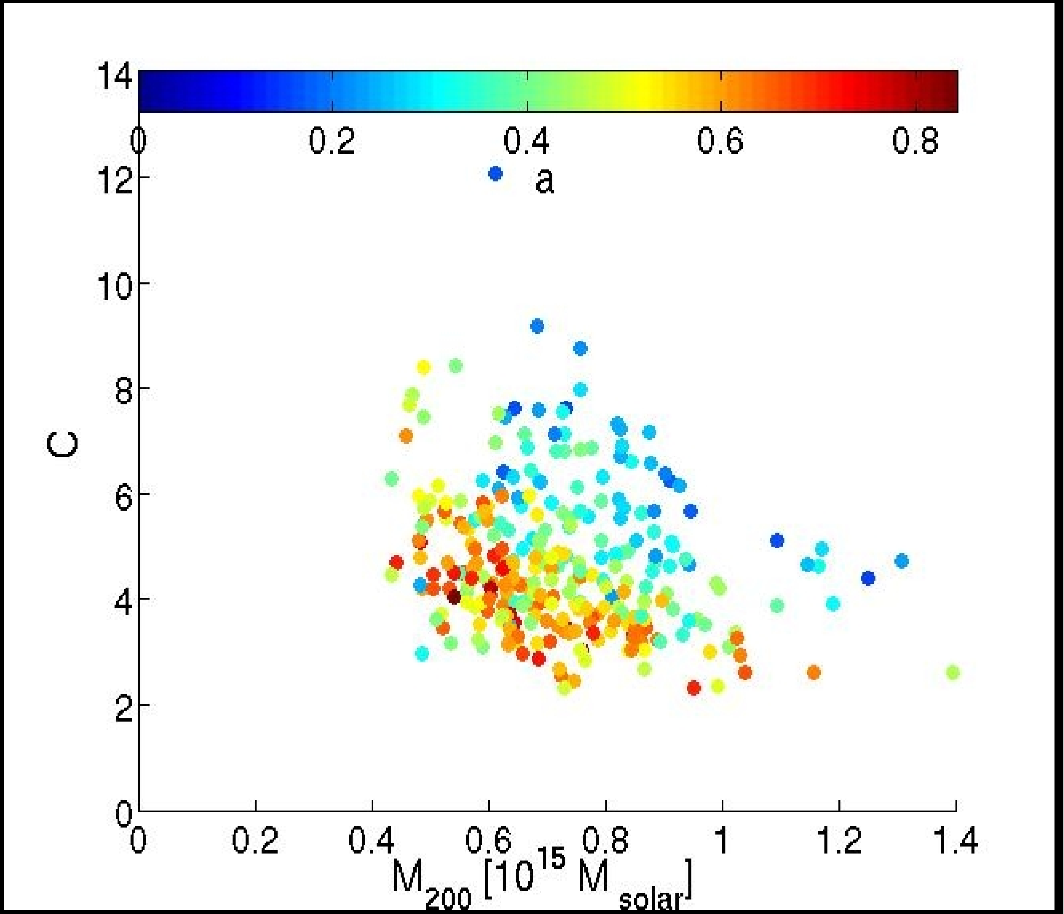
- Mass
- Lens efficiency



MCMC

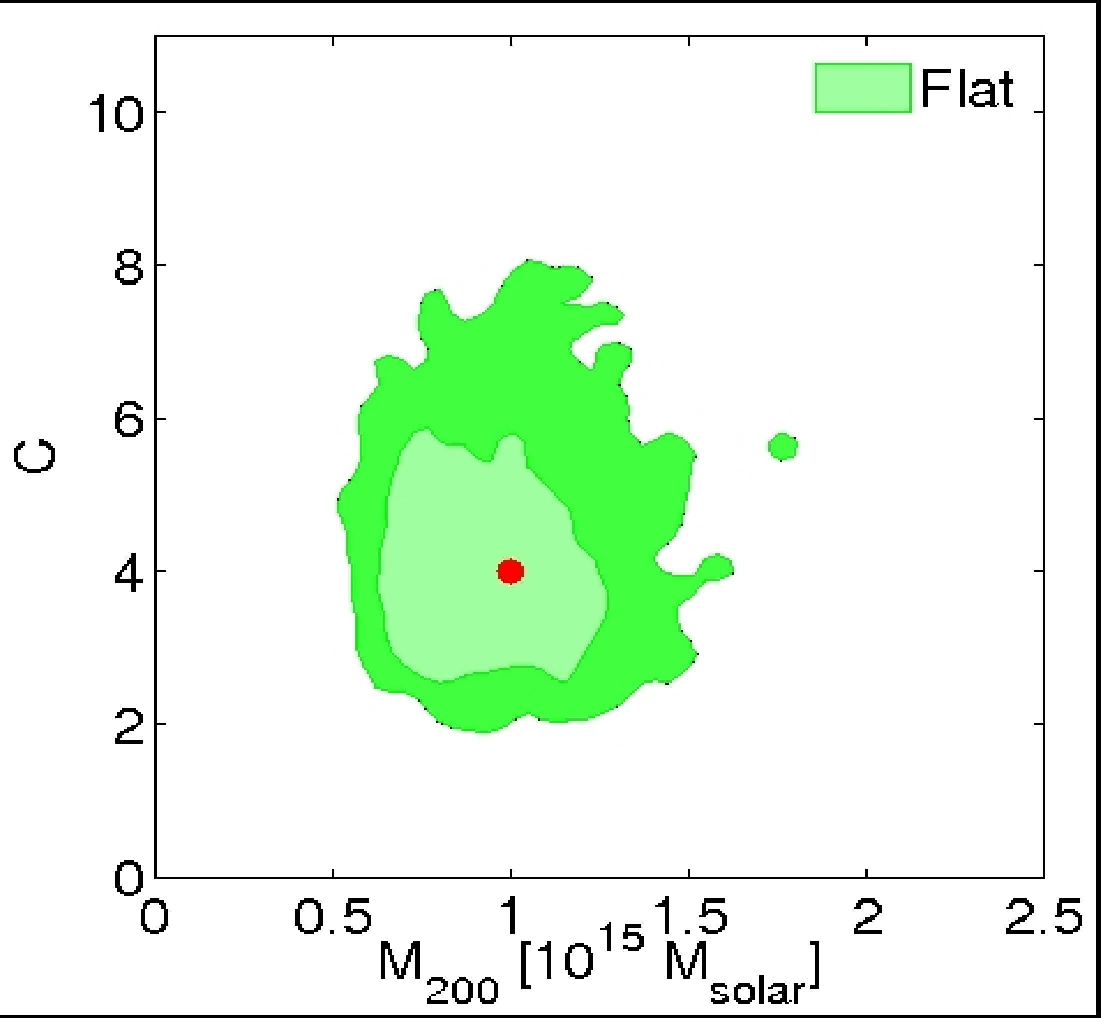
Can define the full posterior probability distribution of triaxial models, giving us true(r) error contours!

Probability proportional to density of points



MCMC: C=4, $M=10^{15} M_{solar}$, a=.44, b=.63

Flat Prior on Axes



Corless & King 2008, accepted in MNRAS

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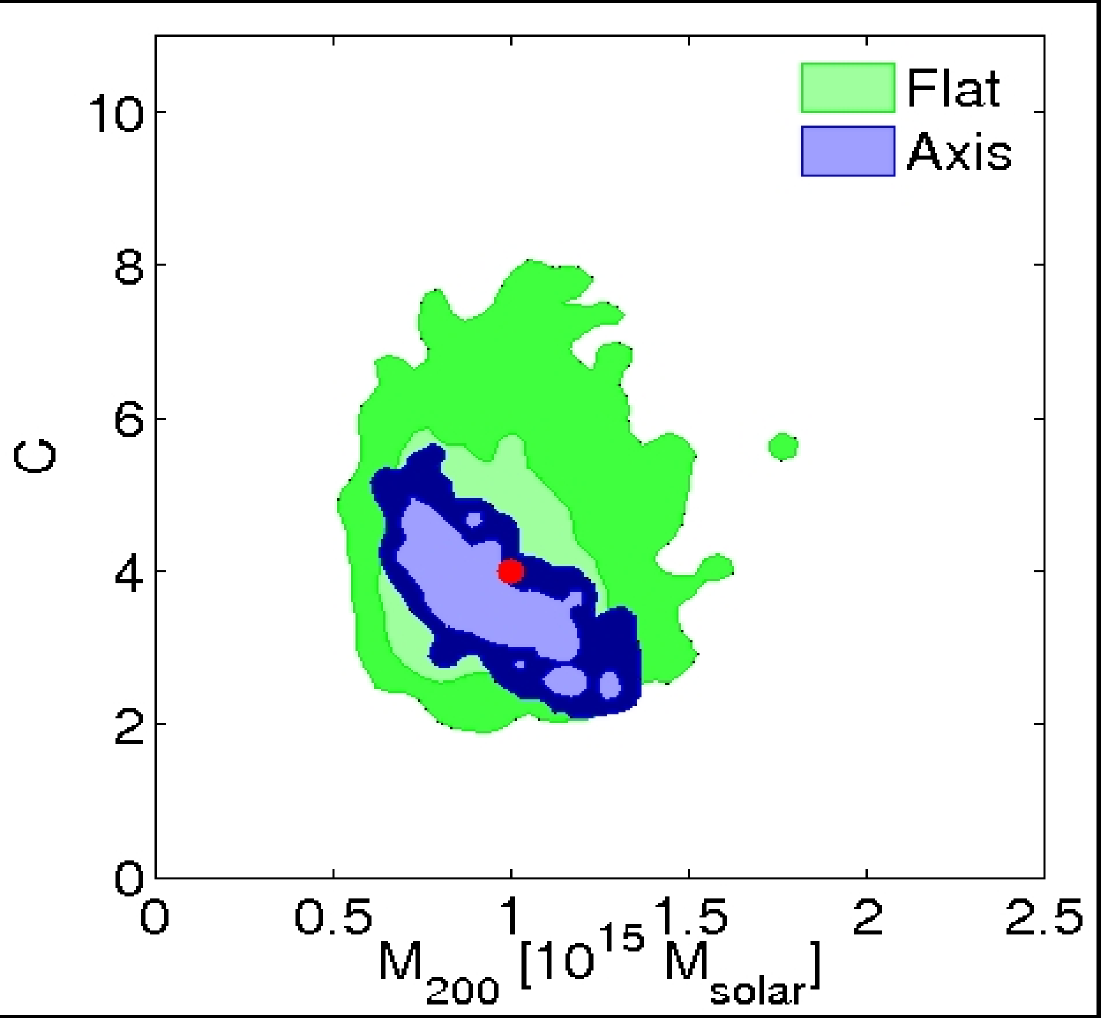
Shaw Prior on Axes



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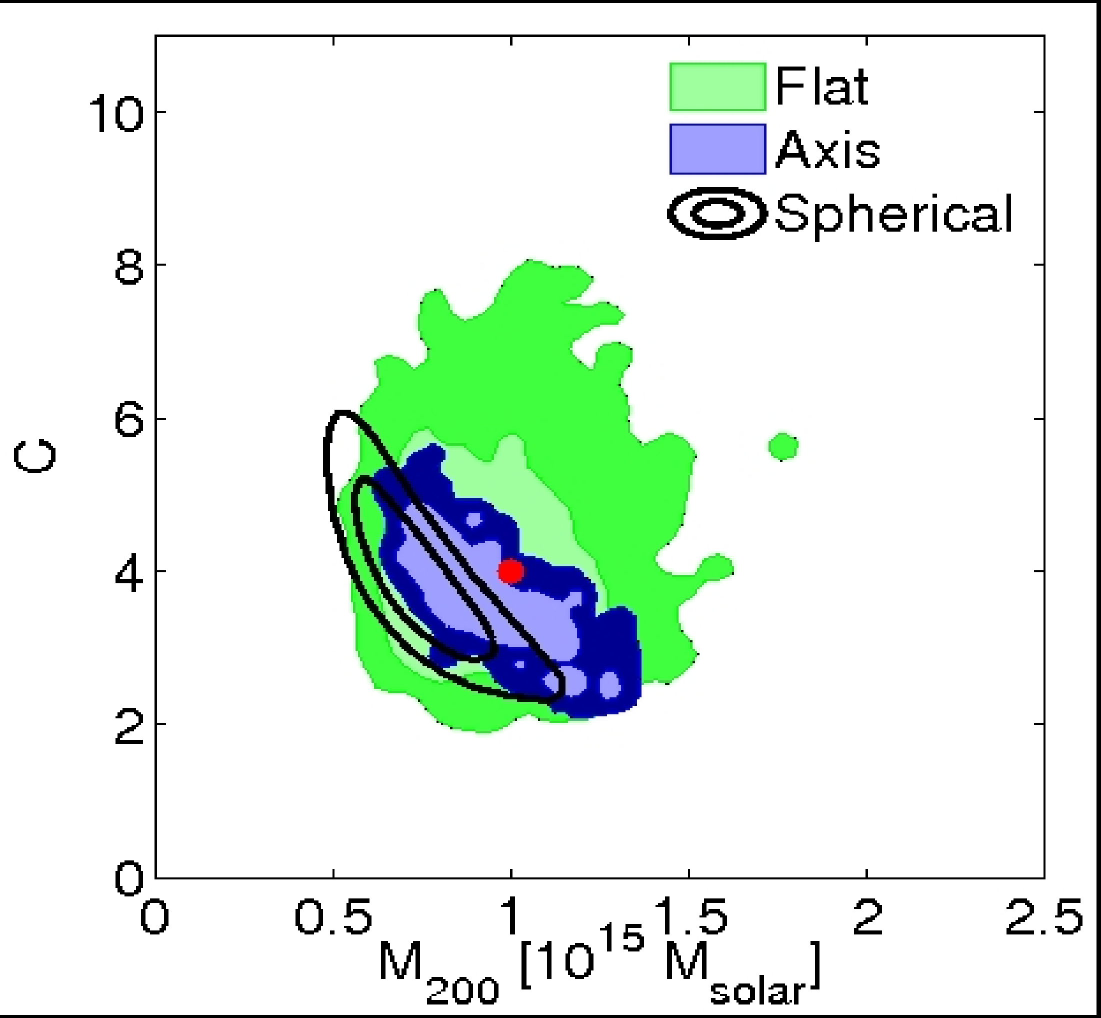
Spherical Prior on Axes



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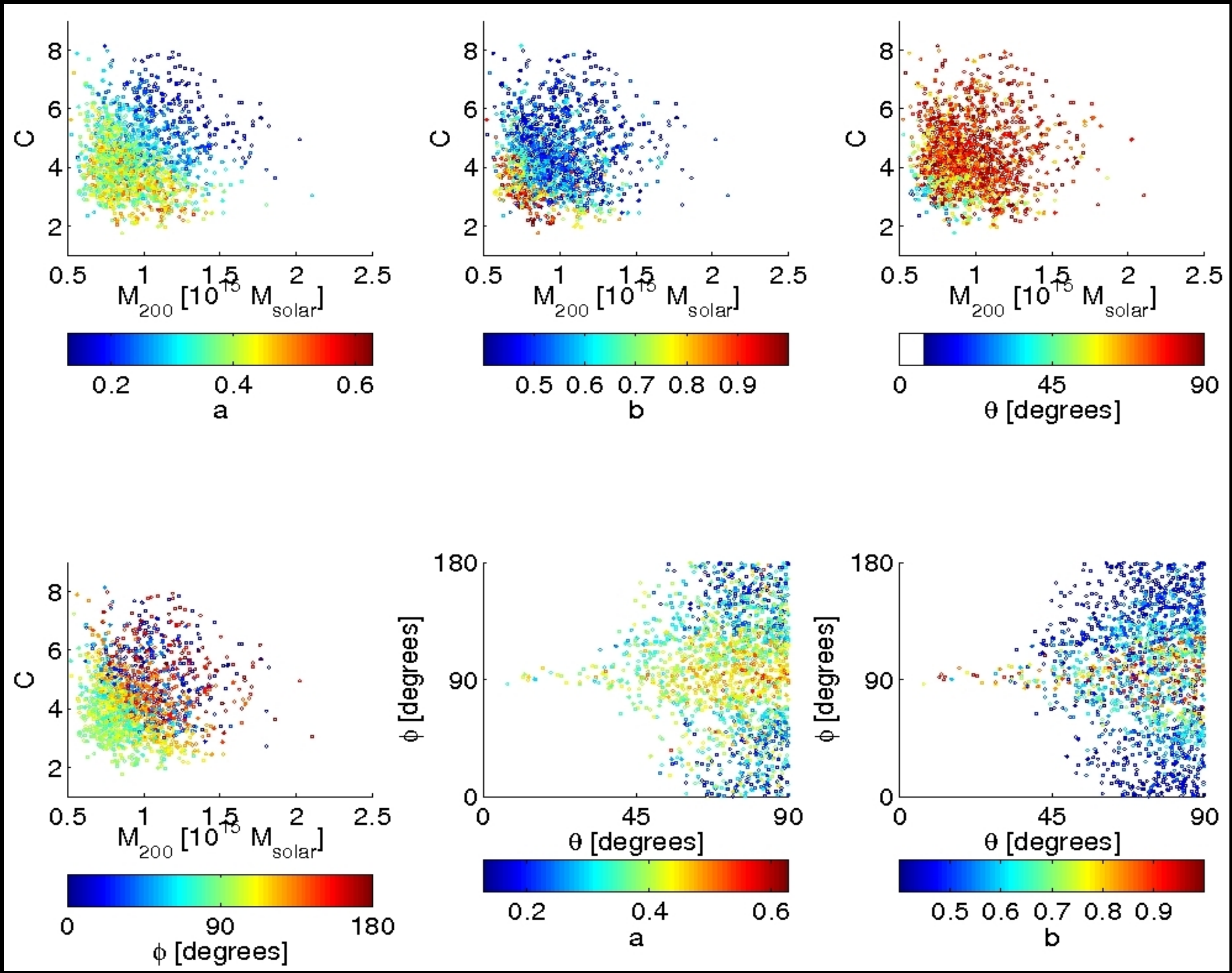

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Statistical Performance

Confidence Contours under various priors

Prior	68%	95%
Flat	86	99
Shaw	**66**	**94**
Axis	70	96
Mass	86	99
Spherical	53	81
Effective Spherical Parameterisation		
Flat	84	99
Shaw	61	89
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Corless & King 2008, accepted in MNRAS

Statistical Performance

Mean population values under various priors

Prior	$M_{200}[10^{15} M_\odot]$	C
Original Population	1.00	4.0
Flat	1.12	4.7
Shaw	1.04	4.2
Axis	1.04	4.3
Mass	1.07	4.7
Spherical	1.02	4.1
Effective Spherical Parameterisation	m_{200}	C_{sph}
Original Population	0.986	3.98
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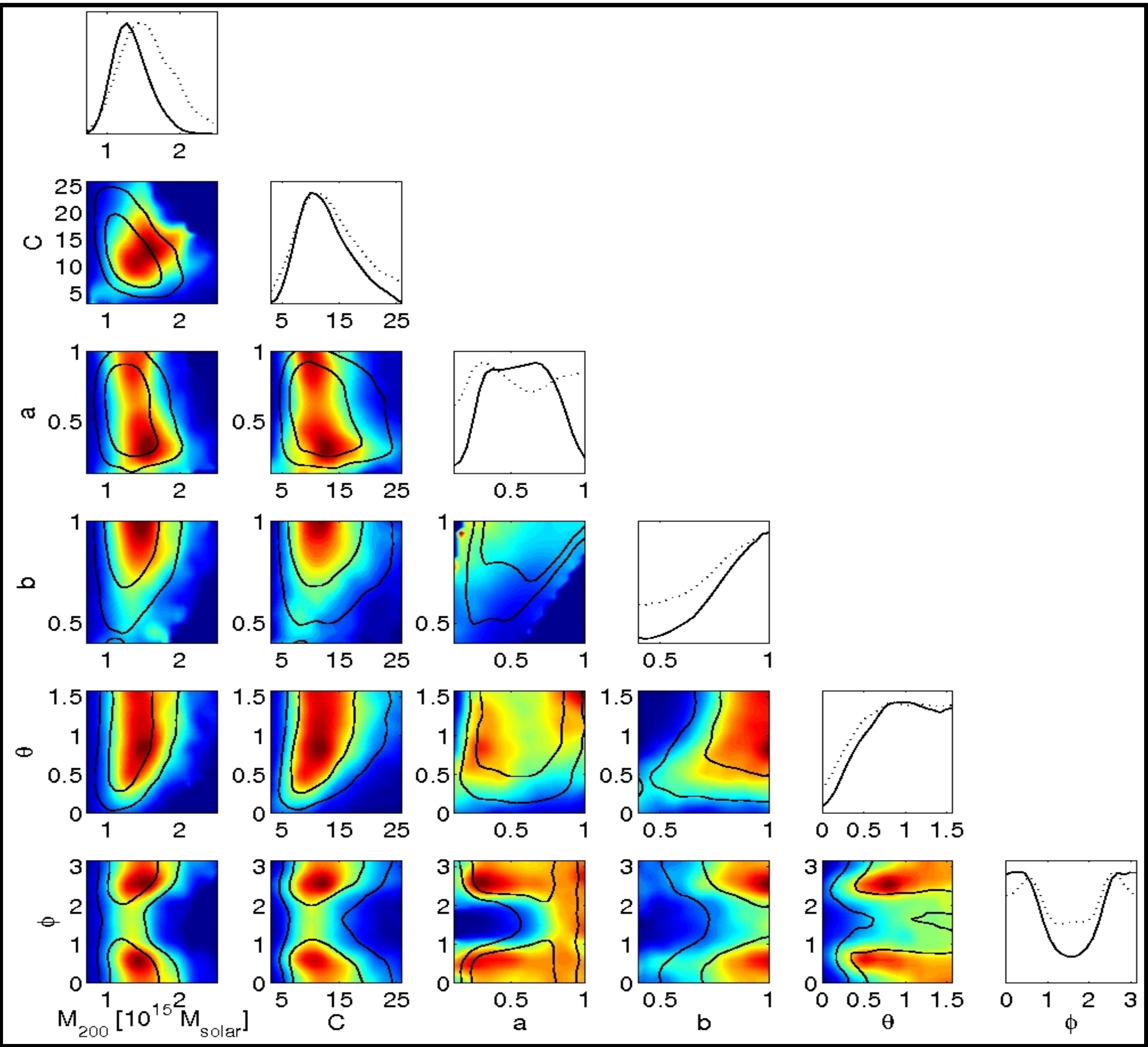
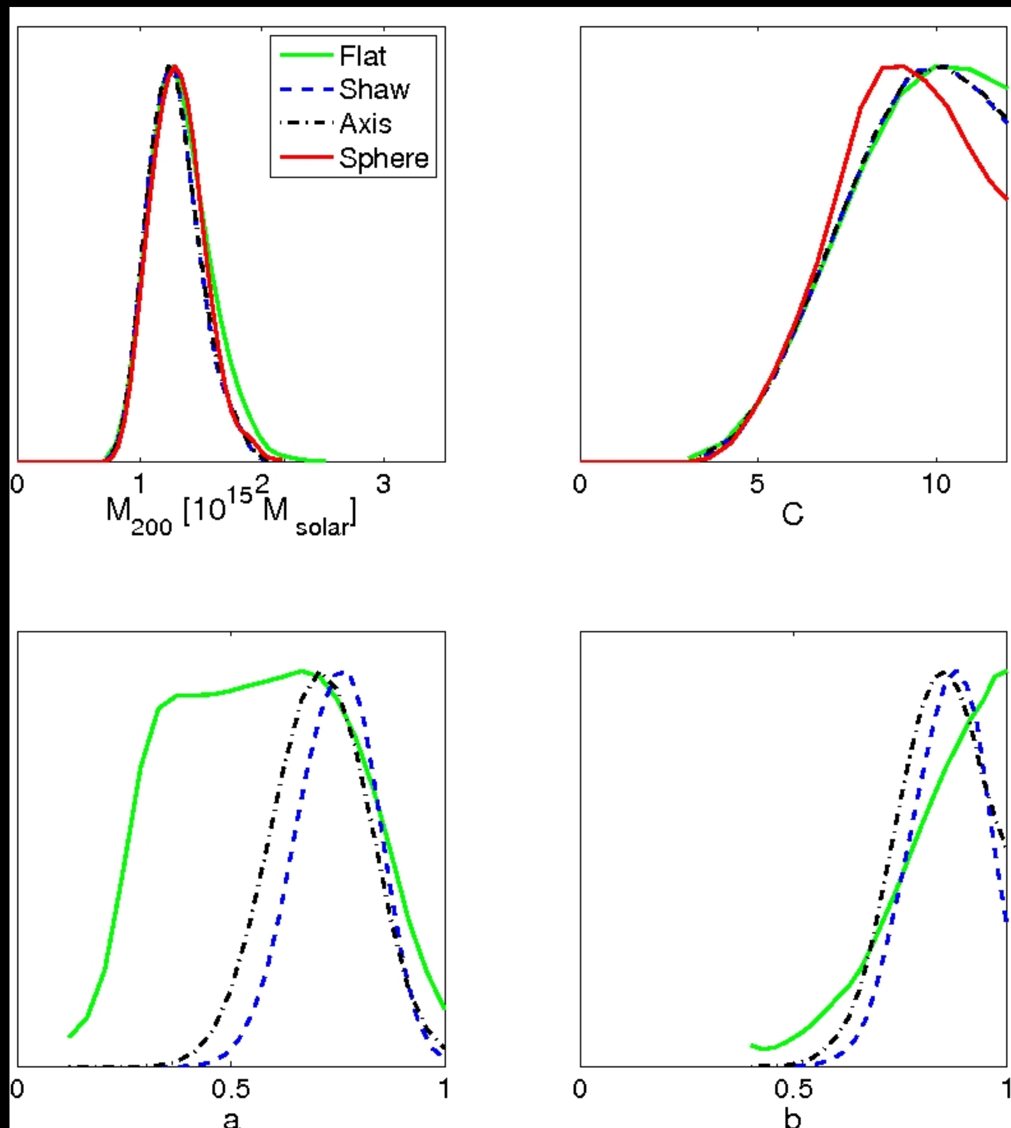
But, spherical model may be ok for averages (better for masses than concentrations)

Abell 1689: Flat Axis Prior



Corless, King, & Clowe, in prep

Parameter distributions: Abell 1689



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b &= 0.83^{+0.17}_{-0.04}
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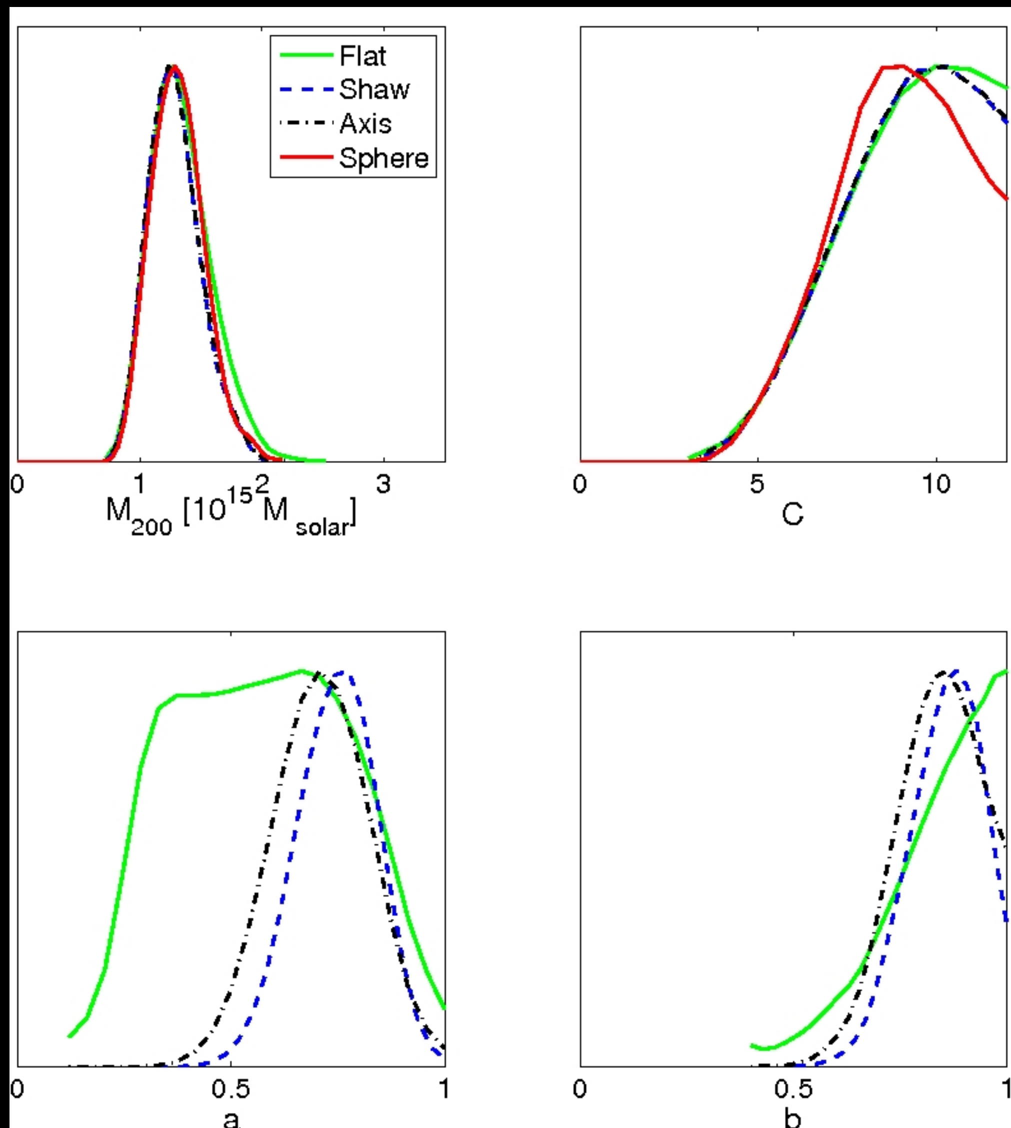

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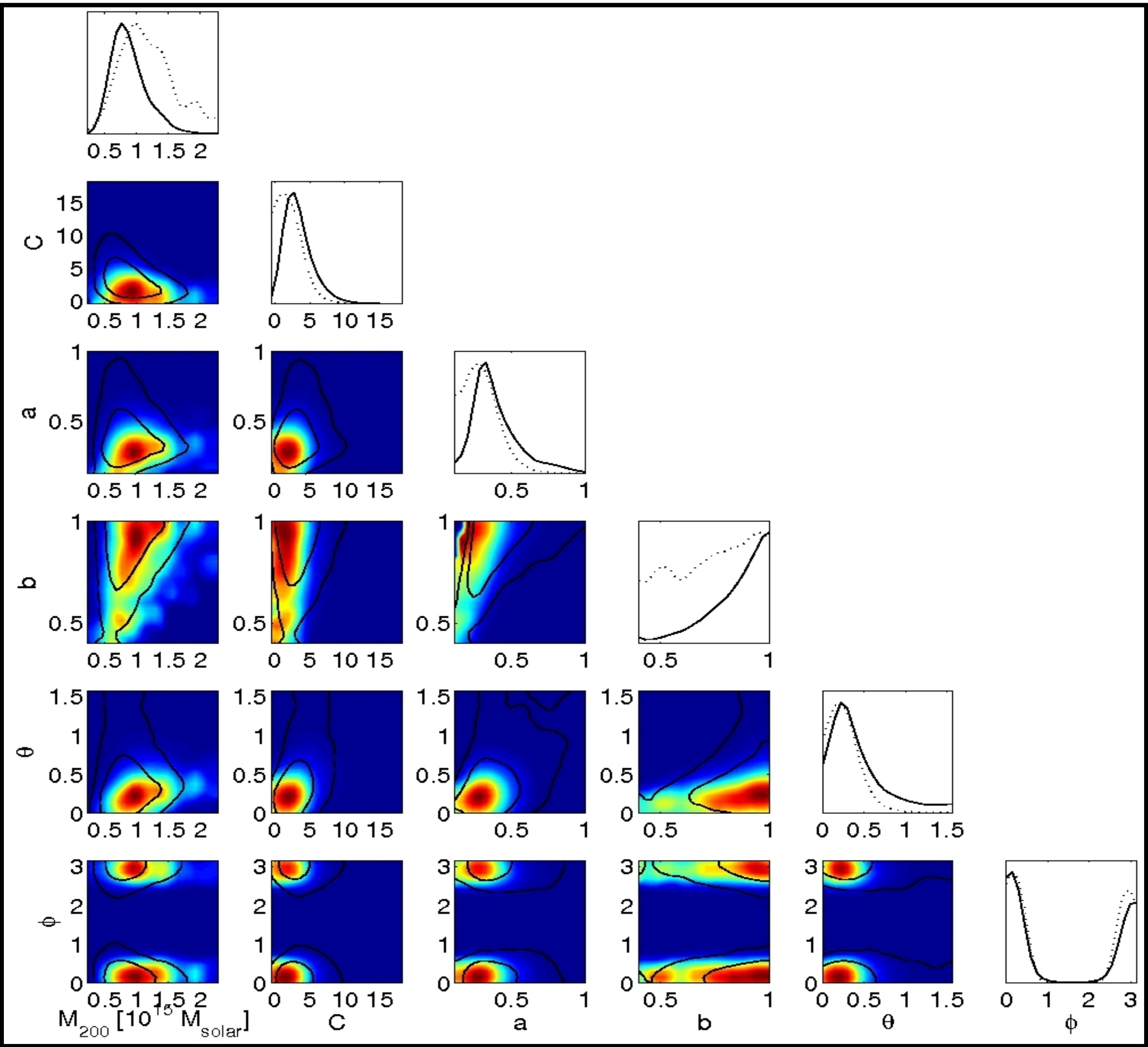
Better Prior?

Abell 2204: Flat Prior



Corless, King, & Clowe, in prep

Conclusions

- MCMC method gives mass estimates and errors that reflect (more) **realistic** triaxial dark matter structures
- No more quoting spherical lensing results with small errors – though on average, spherical masses may be ok
- Combined methods (X-ray, SZ, dynamical, SL) are necessary to improve error constraints
- *Ongoing work*
    - *Better choice of priors*
    - *Mass functions*
    - *Combination methods*