Measuring the 3D shape of galaxy clusters

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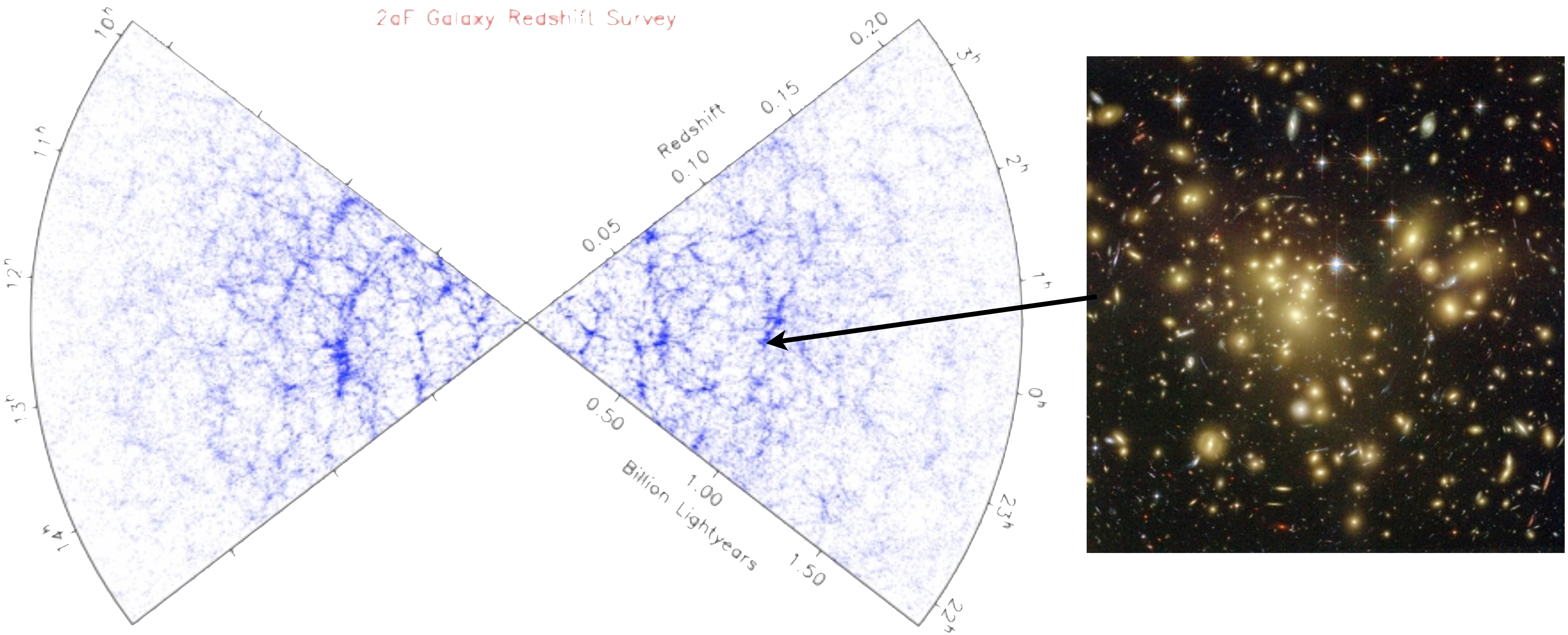
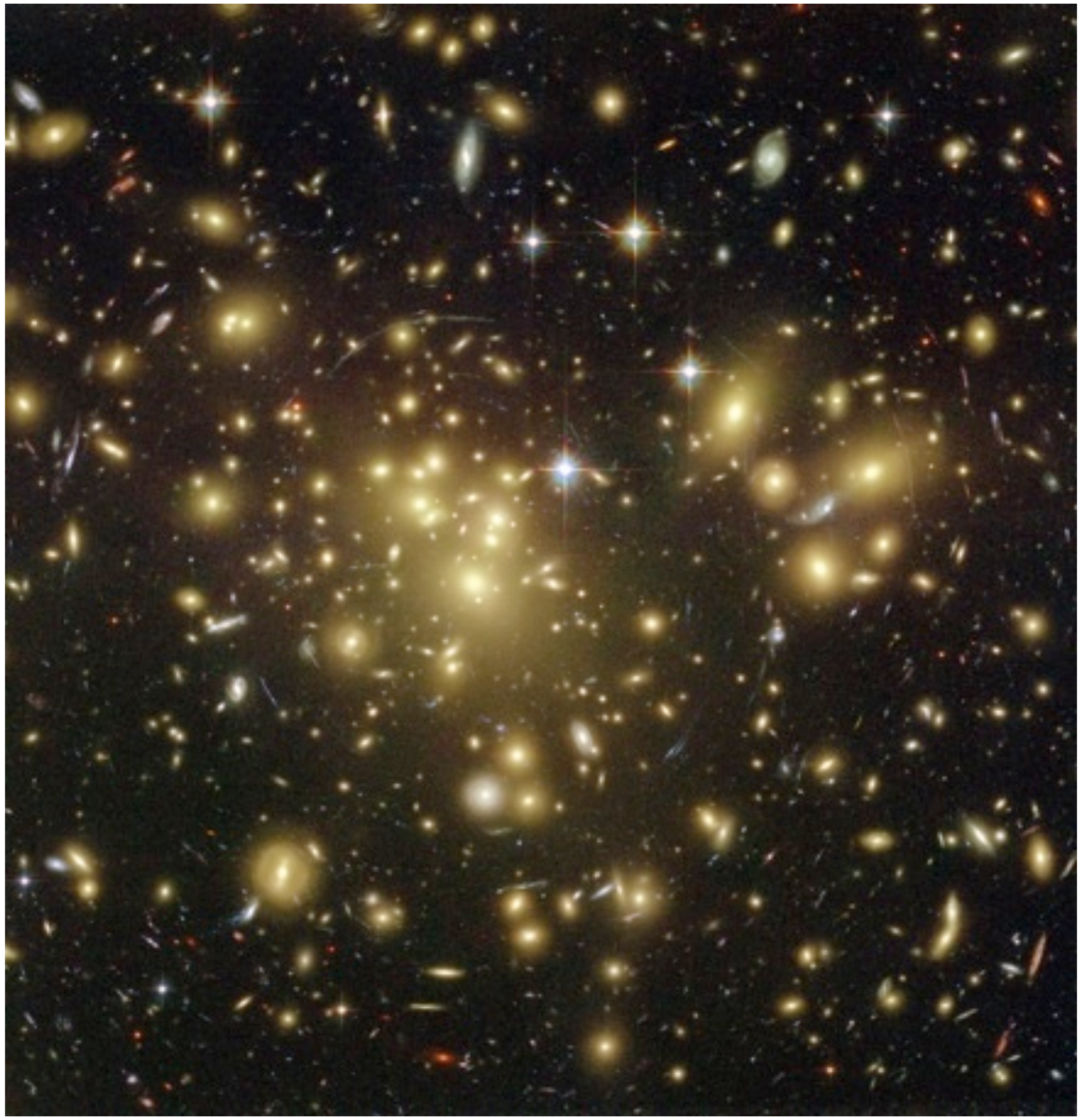
Large scale structure



Clusters of galaxies

Largest gravitationally bound structures

Galaxies	~ 5 %	
Hot gas	~ 10 %	
Dark matter	~ 85 %	



Abell 1689, Hubble Space Telescope

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Clusters of galaxies

Largest gravitationally bound structures

	Galaxies	~ 5 %
	Hot gas	~ 10 %
	Dark matter	~ 85 %

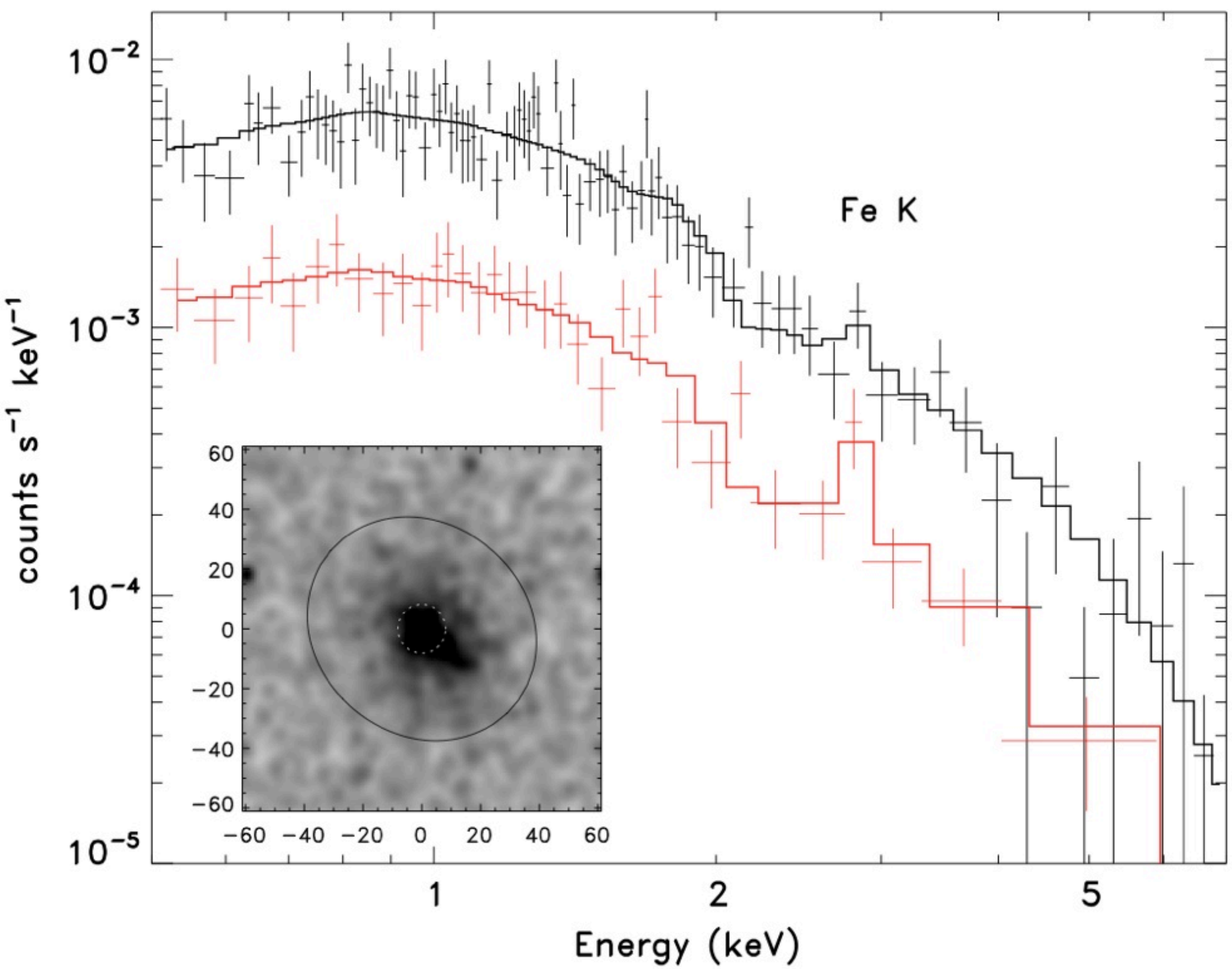
Extended X-ray emission

Luminosity: $L \approx 10^{43-45}$ erg/s

Abell 1689, HST + Chandra

Extended X-ray emission

Rosati et al. (2009)



Thermal bremsstrahlung: $\epsilon_{\rm ff} = 1.4 \times 10^{-27} T^{1/2} n_e n_i Z^2 g_B \propto T^{1/2} n_H^2$

Temperature: $T \sim 10^8$ K

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Gas in equilibrium

Hydrostatic equilibrium and spherical symmetry:

$$M(r) = -\frac{kT(r)r}{G\mu m_p}\left(\frac{d\ln\rho_g(r)}{d\ln r} + \frac{d\ln T(r)}{d\ln r}\right)$$

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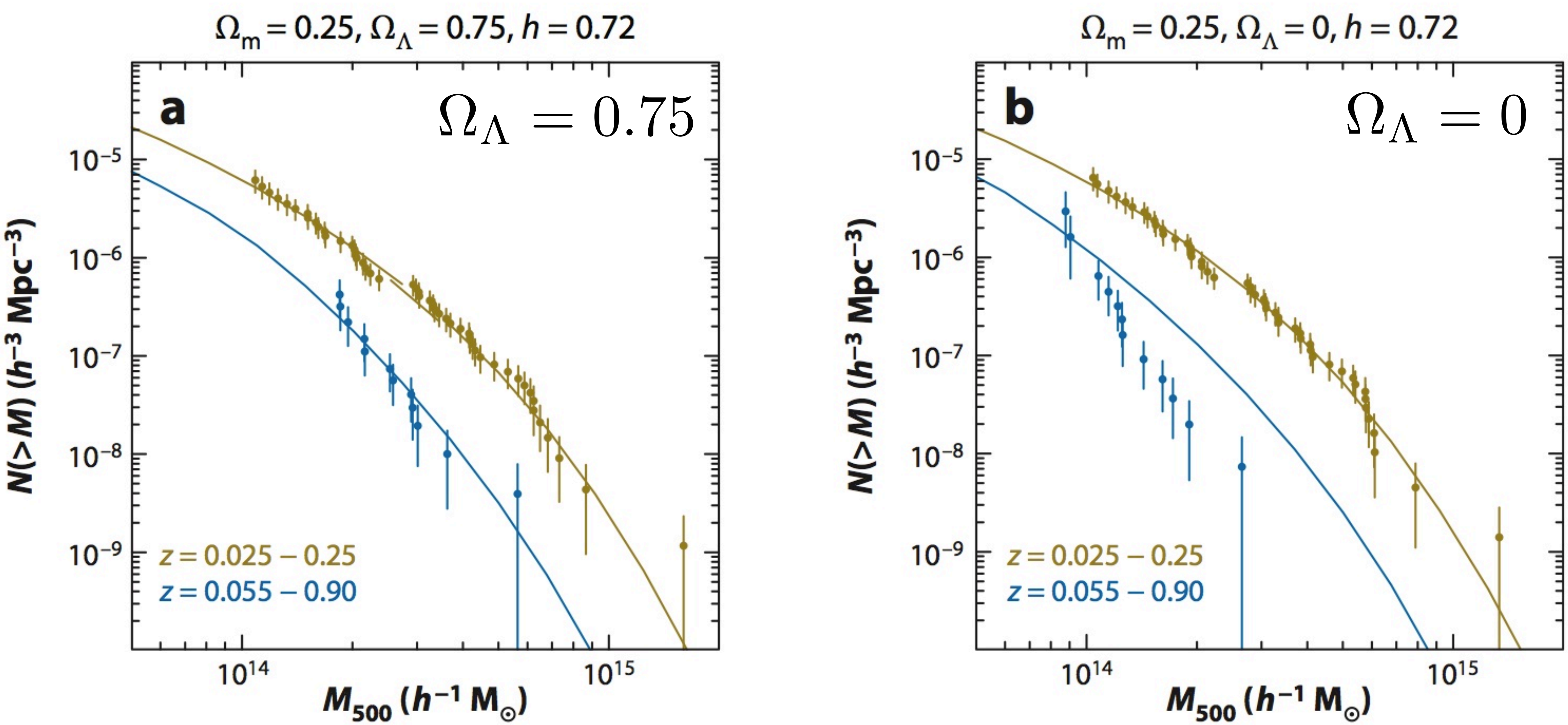
Cluster mass determination

Testing cosmological models using cluster mass functions



Vikhlinin et al. (2009)

HE: $M(\rho, T)$

Bremsstralung: $\epsilon(\rho, T)$

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X-ray emission luminosity

Surface brightness

$$S = \int_{\rm LOS} \epsilon(T, \rho) dr$$

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X-ray emission luminosity

Surface brightness

$$S = \int_{\text{LOS}} \epsilon(T, \rho) dr$$

Total luminosity from each shell

$$L_n = \int_{V_n} \epsilon_n(T, \rho) dV \quad [\text{erg/s}]$$

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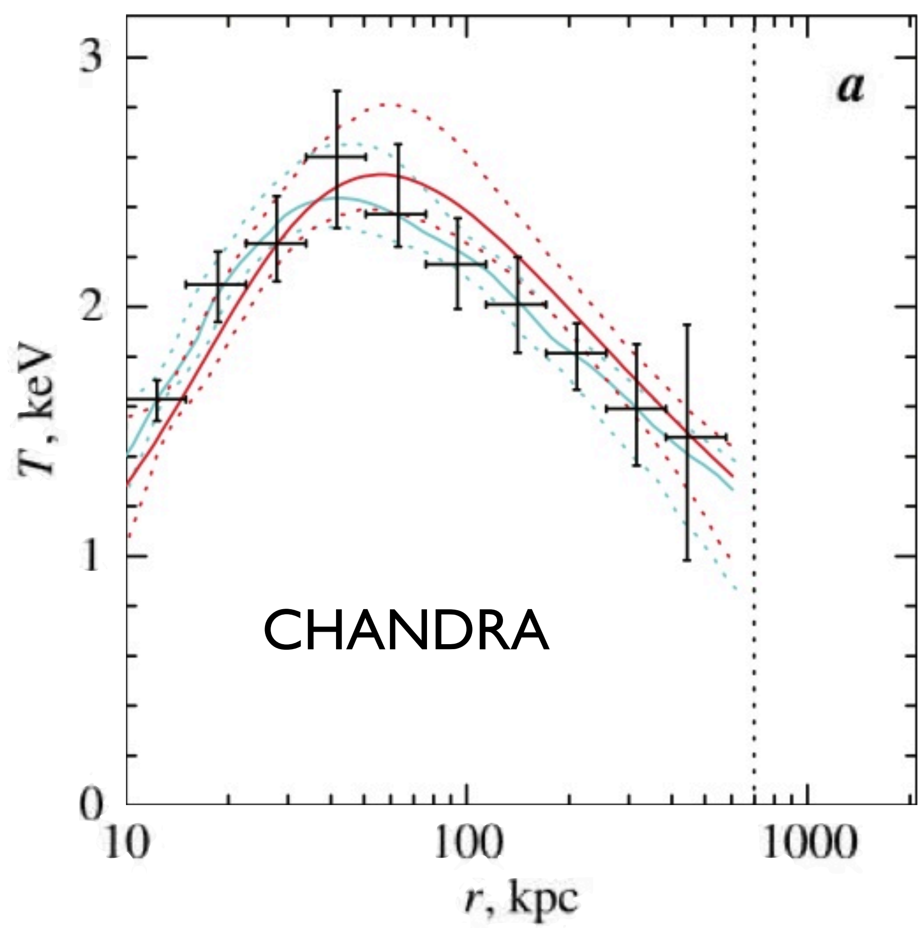
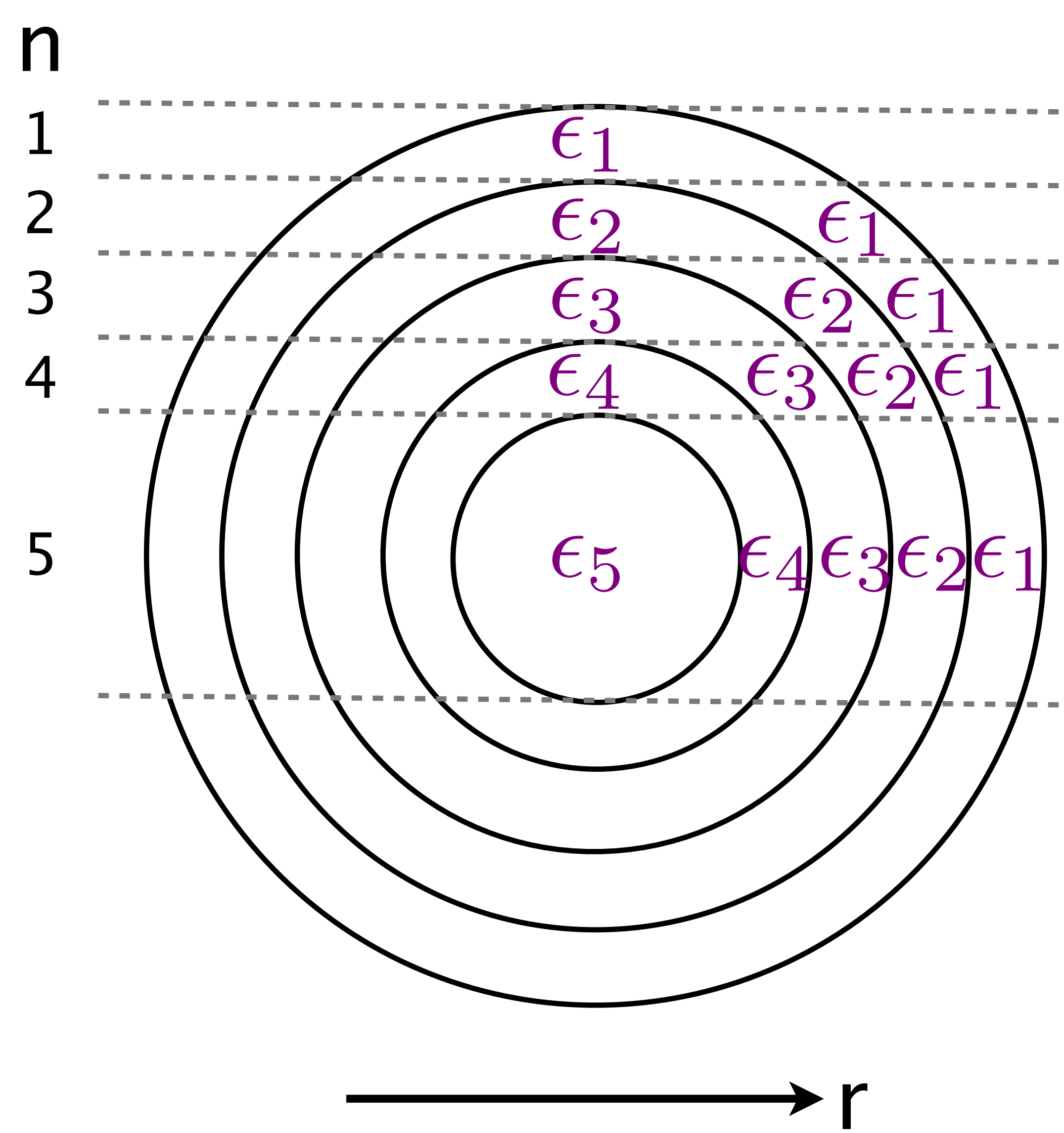
Cluster binning

Assume isothermality and isodensity

$$L_n = \sum_{i=1}^{n} \epsilon_i(T_i, \rho_i) V_{i,n}$$

Vikhlinin et al. (2006)





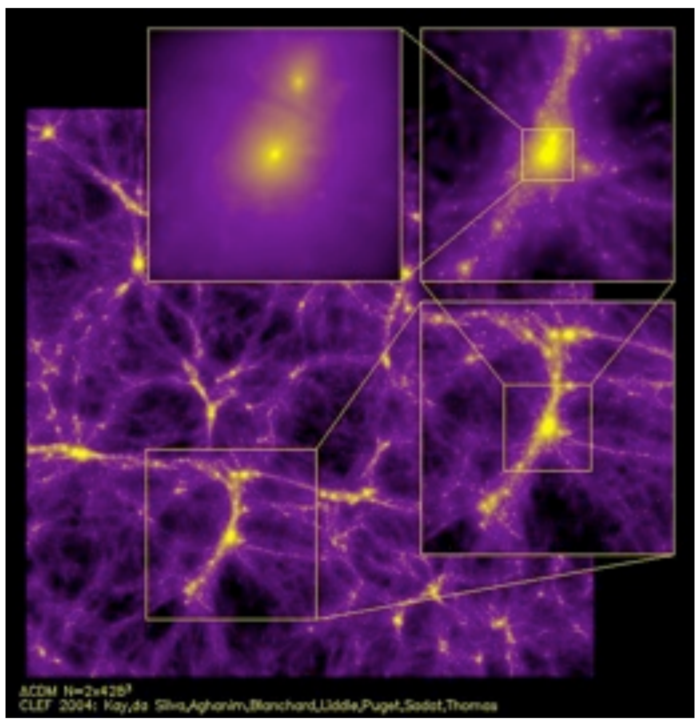
Assumes spherical gas distribution!

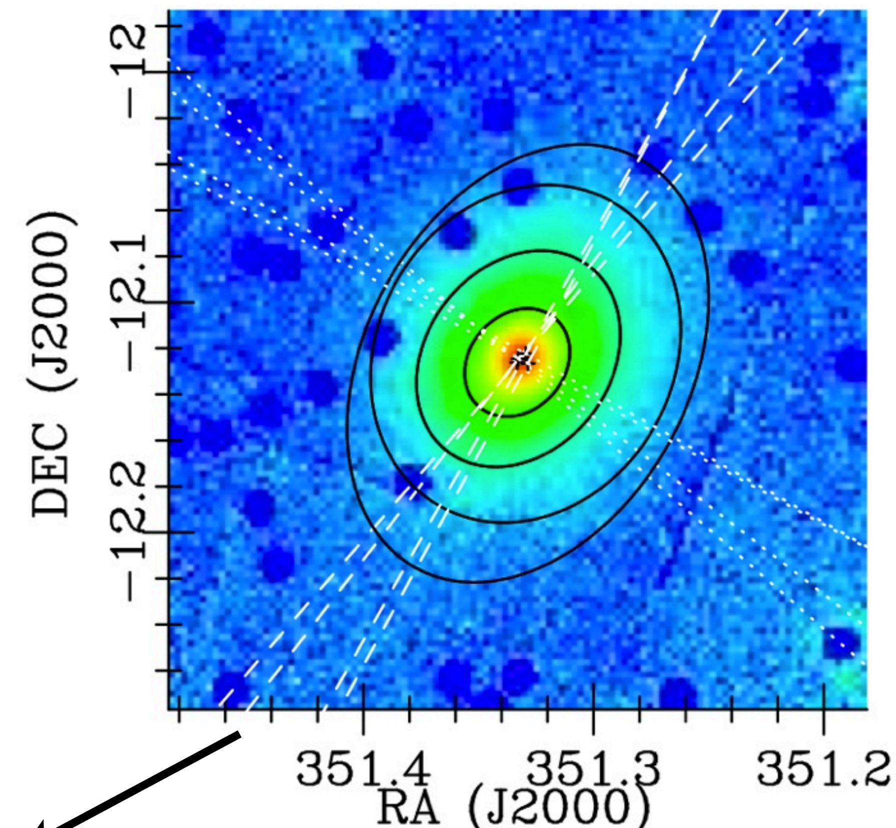
Non-spherical clusters

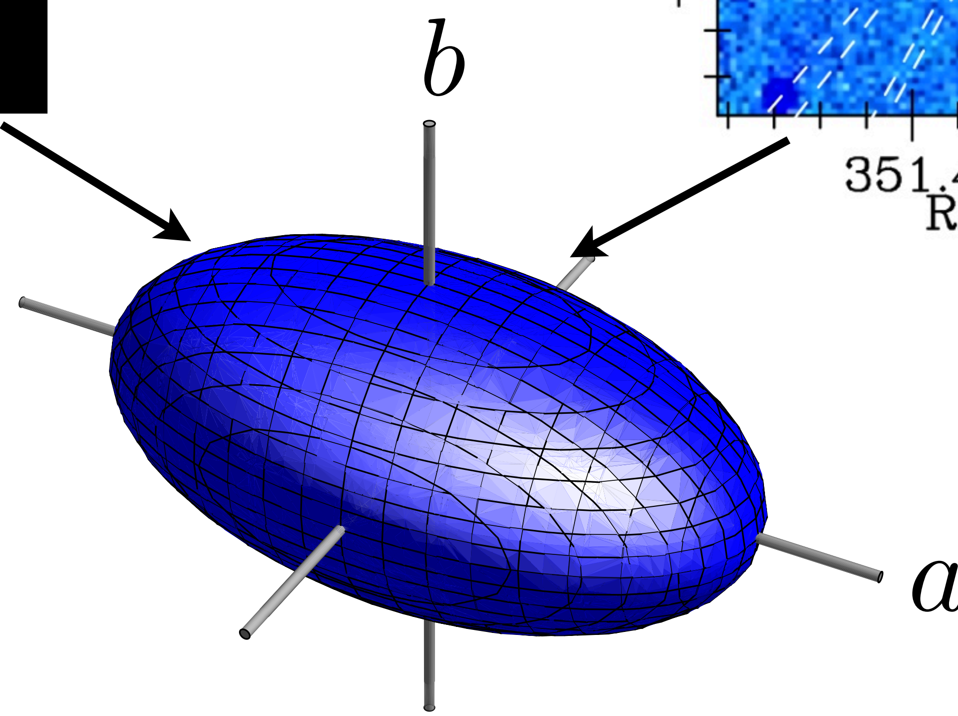
Dark matter

Simulations

Observations



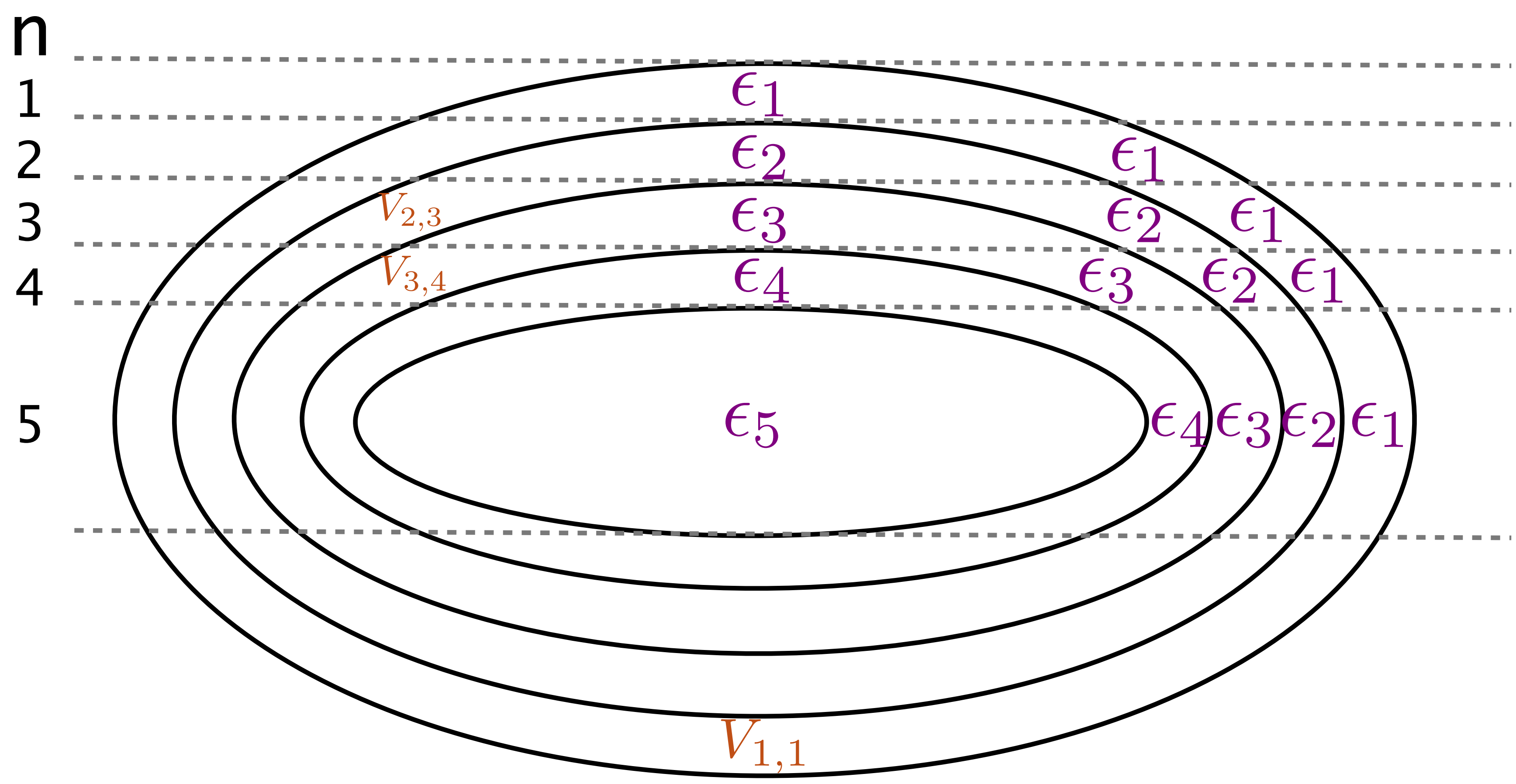




Non-spherical clusters

$$L_n = \sum_{i=1}^{n} \epsilon_i(T_i, \rho_i) V_{i,n}(\alpha, \beta)$$

Non-trivial volume elements: $V_{i,n}$'s



Non-spherical parameters: α, β

Maximum likelihood model testing

1. Model non-spherical cluster.

2. Determine posterior for parameters given data.

$$p(\theta|D) \propto p(D|\theta) = \mathcal{L}(\theta)$$

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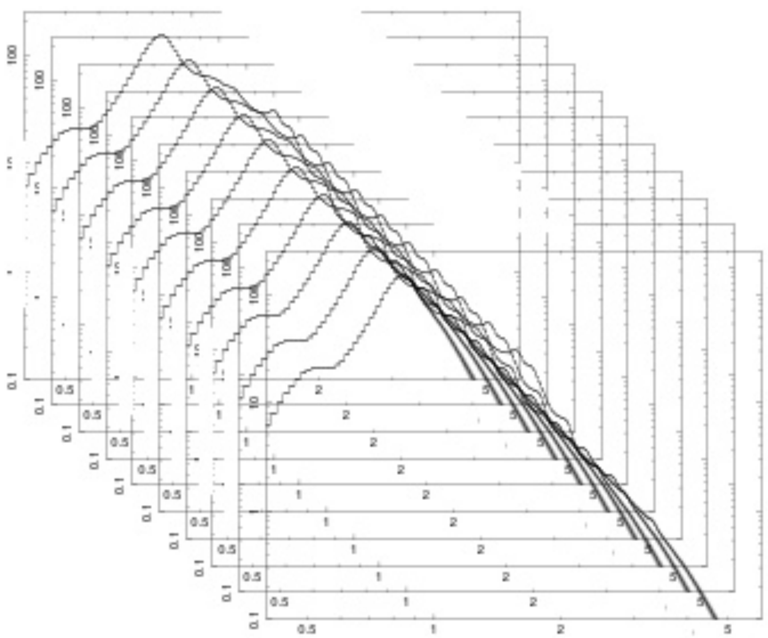
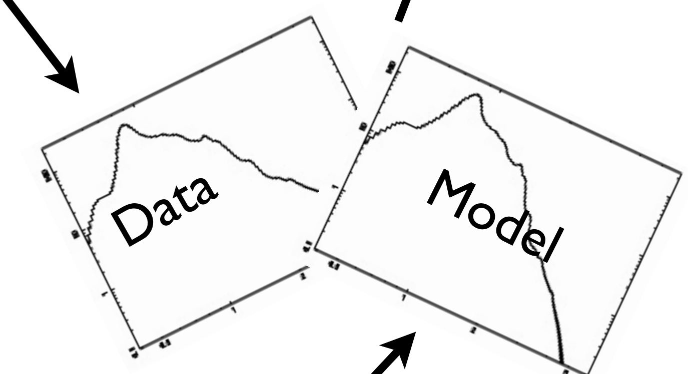
Non-spherical (de)projection

$$L_n = \sum_{i=1}^{n} \epsilon_i V_{i,n}$$

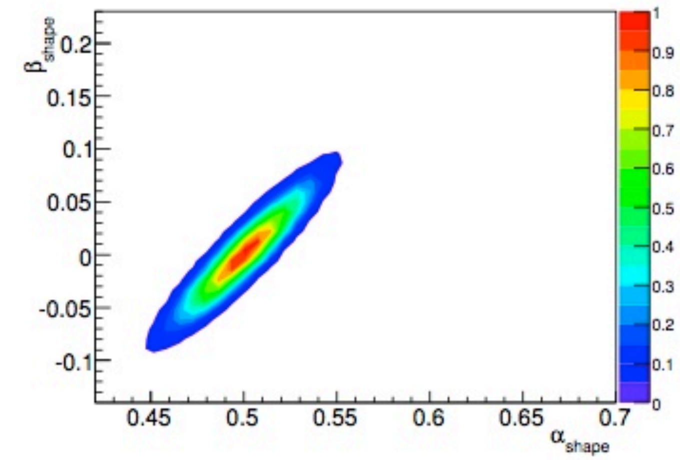
Fake spectra



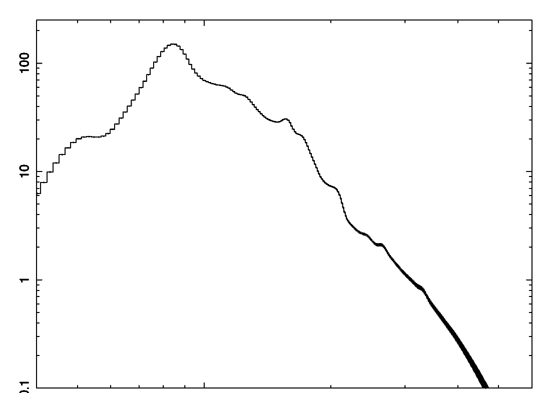
Measure



Calculate model likelihood



Combine



Compare

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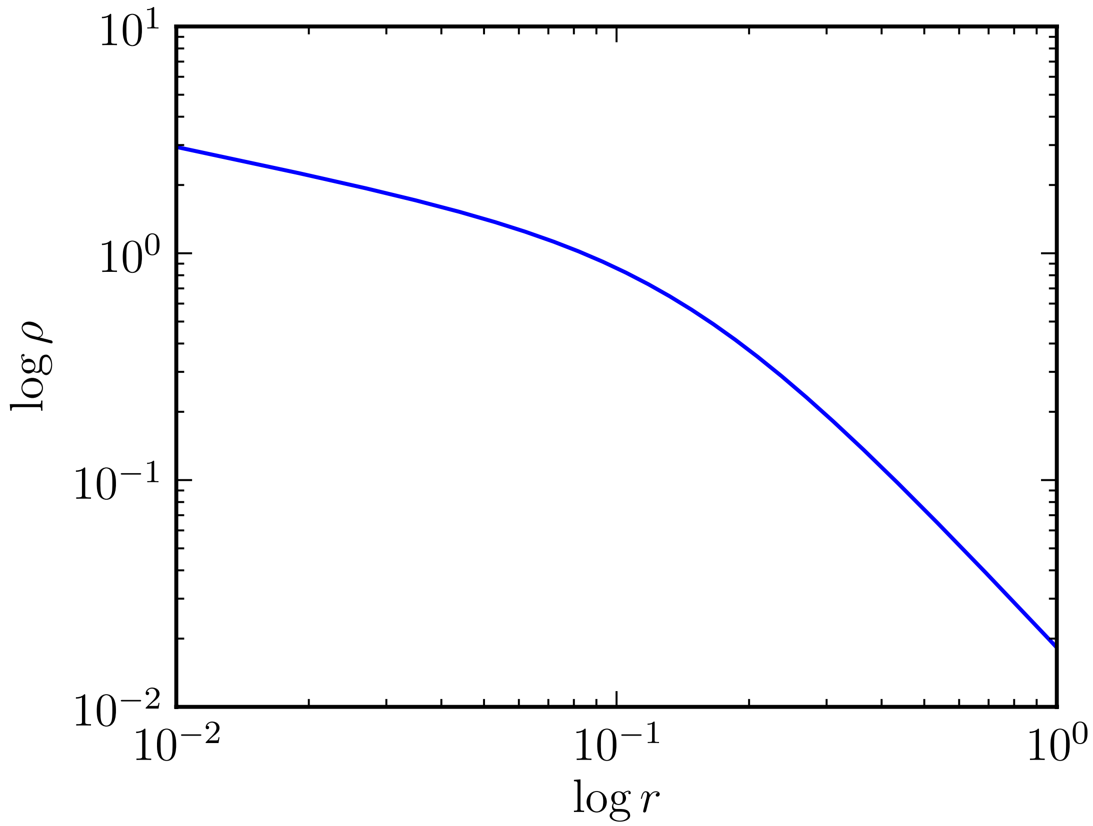
Temperature and density parametrization

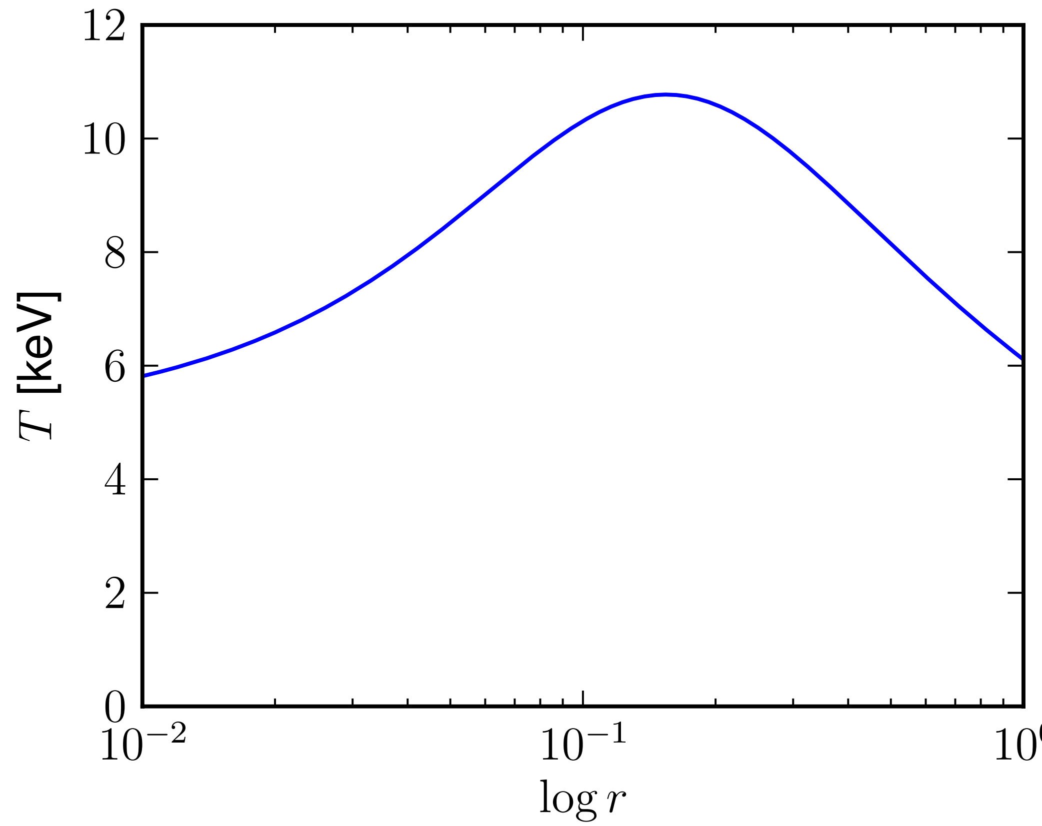
Density



$$\rho = \rho_0 \frac{R^{-\alpha/2}}{(1+R^2)^{3/2\beta-\alpha/4}}$$

Navarro et al. (1996)

Temperature

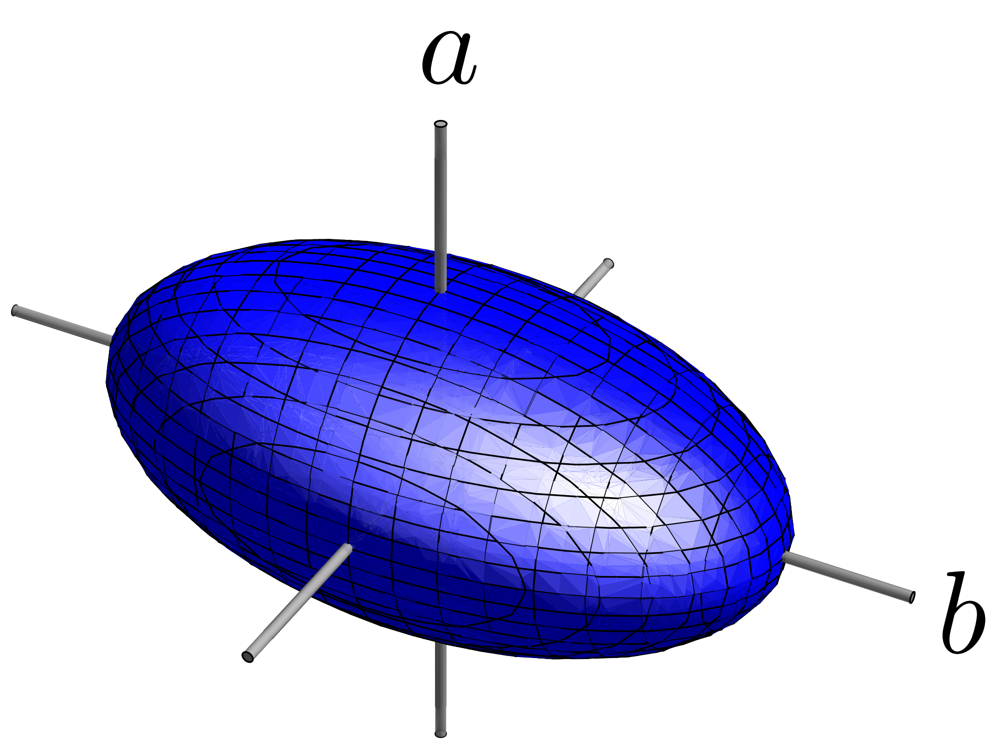


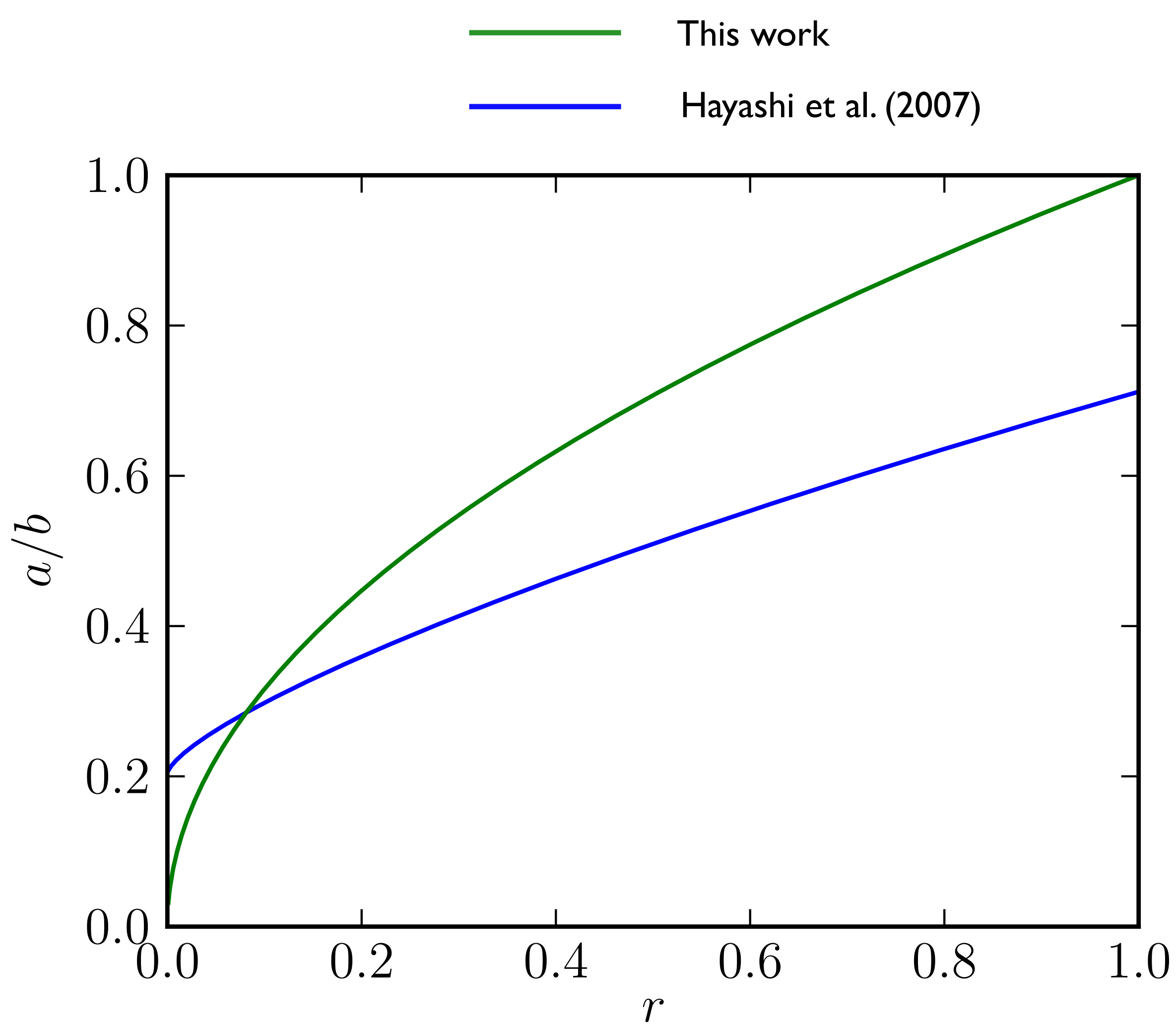
$$T = T_0 \frac{1+aR}{(1+R^2)^b}$$

Vikhlinin et al. (2006)

Non–linear shape parametrization

Assume a parametrization from numerical simulations





$$\log \frac{a}{b} = \alpha \log(r) + \beta$$

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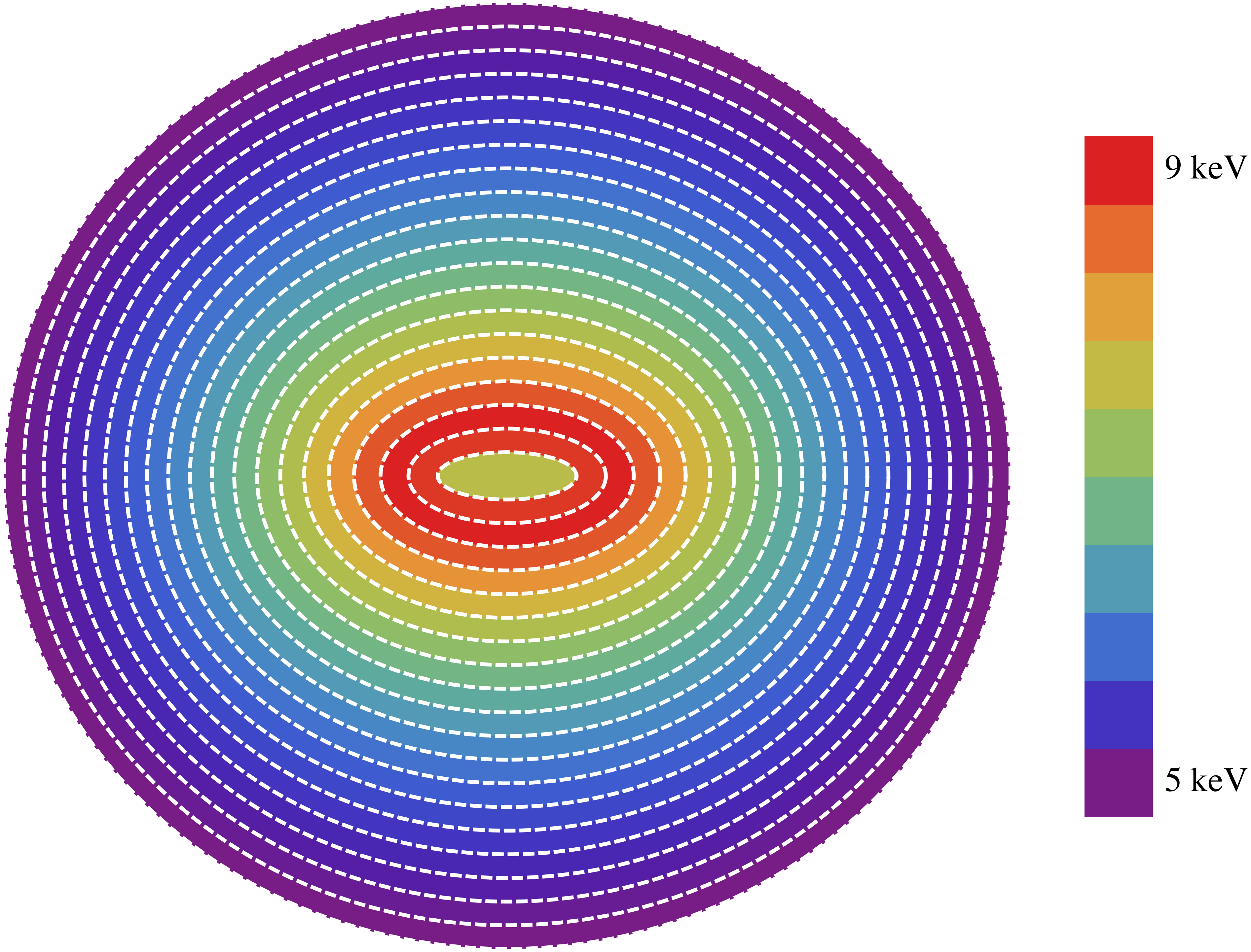
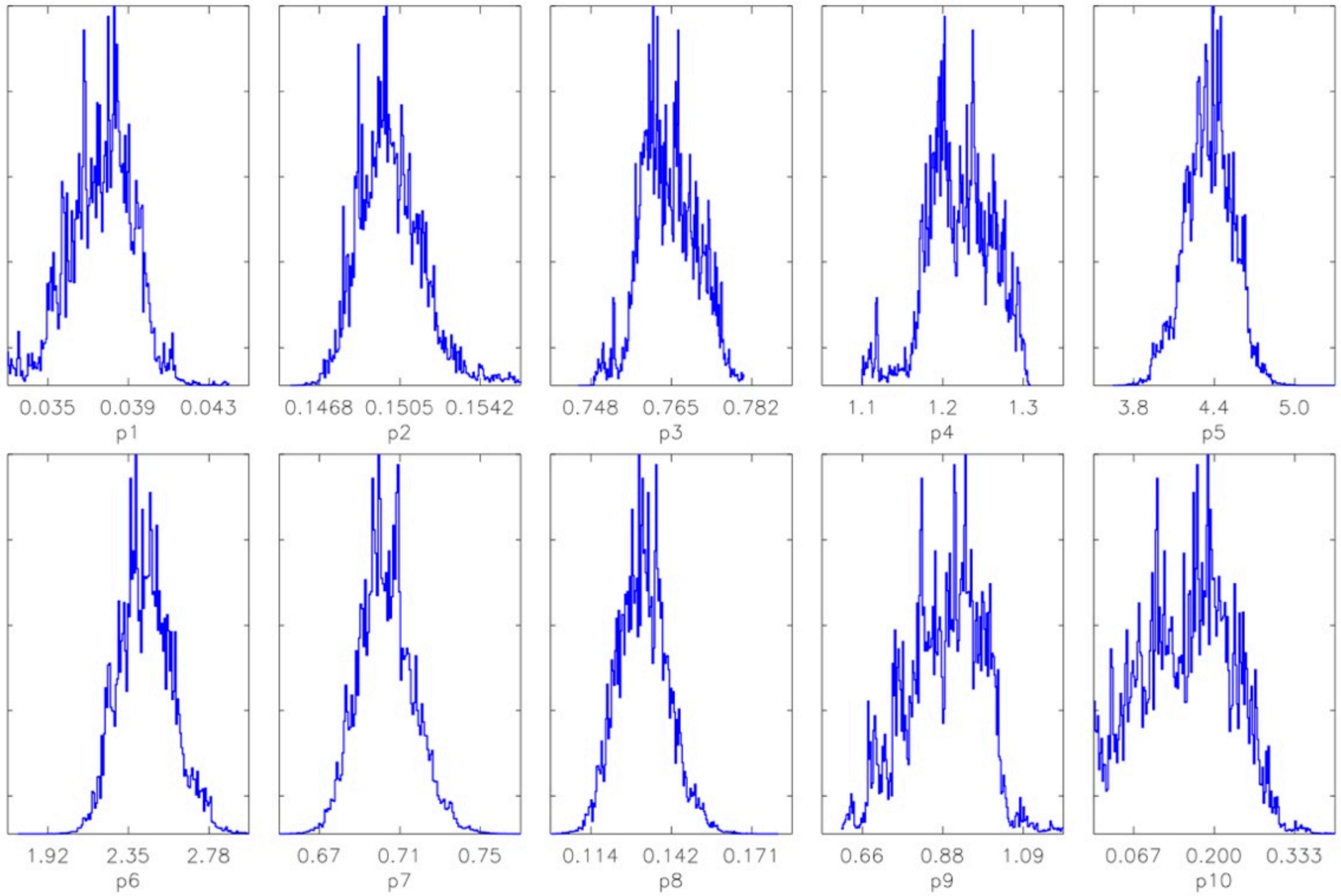
Model galaxy cluster

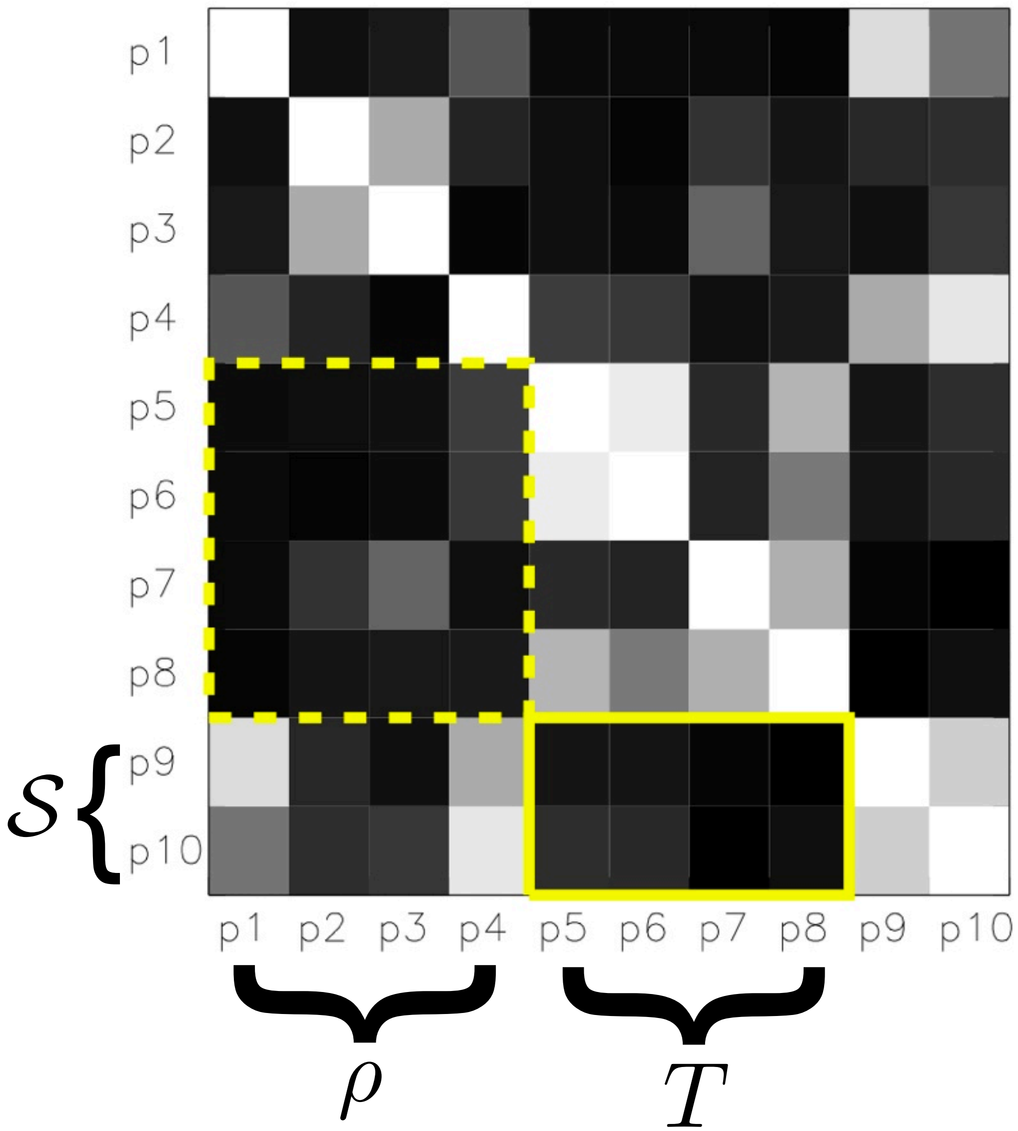


Constraining cluster gas and shape



(Samsing J., Skielboe A., & Hansen S.H. 2012, in review)

Correlation matrix



Conclusions

3D shape can be reconstructed using only X-rays

Unavoidable degeneracies

Can be combined with independent measurements to improve accuracy

Extra slides

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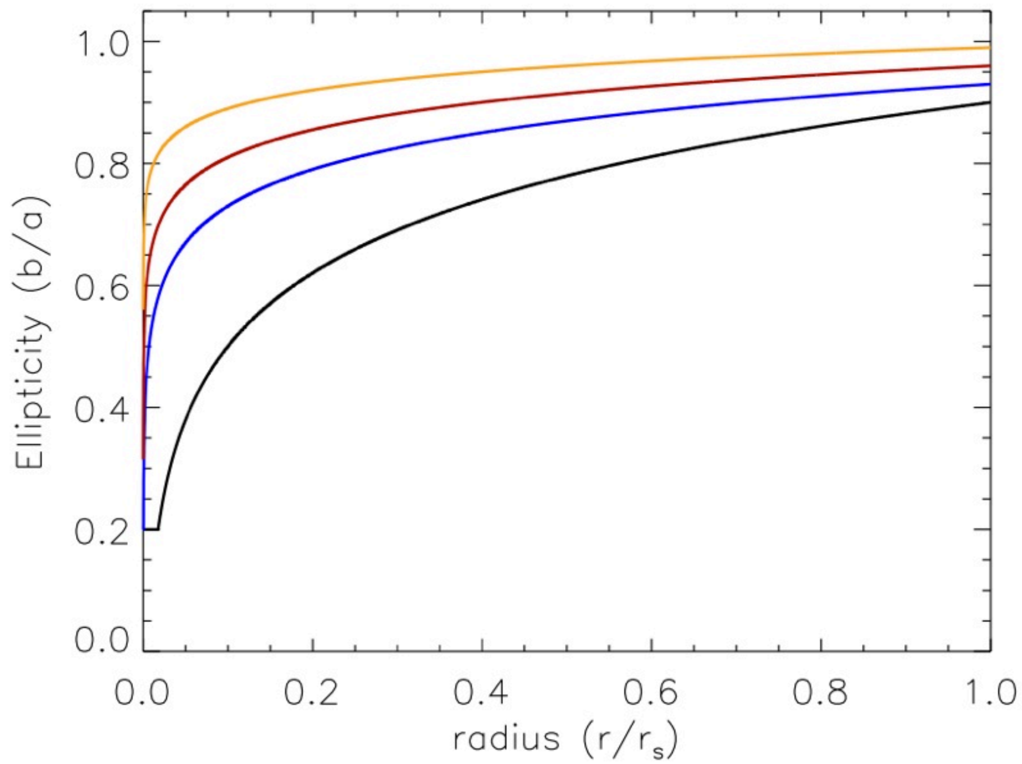
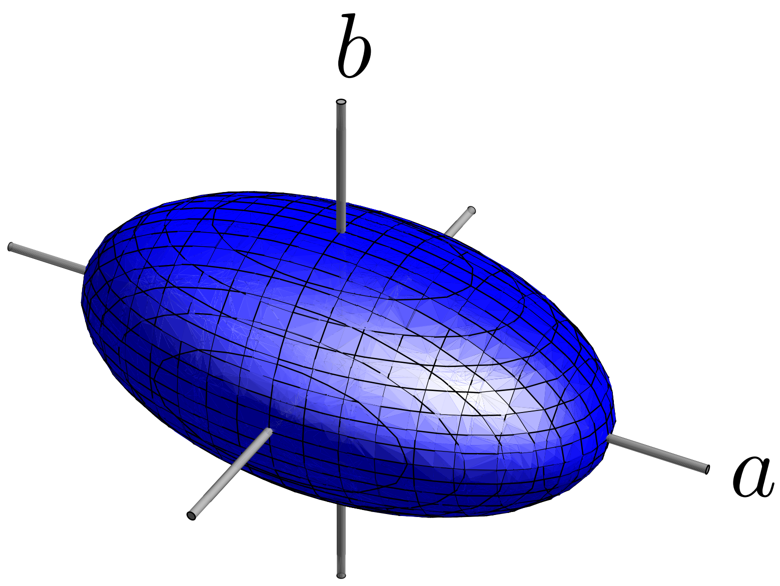
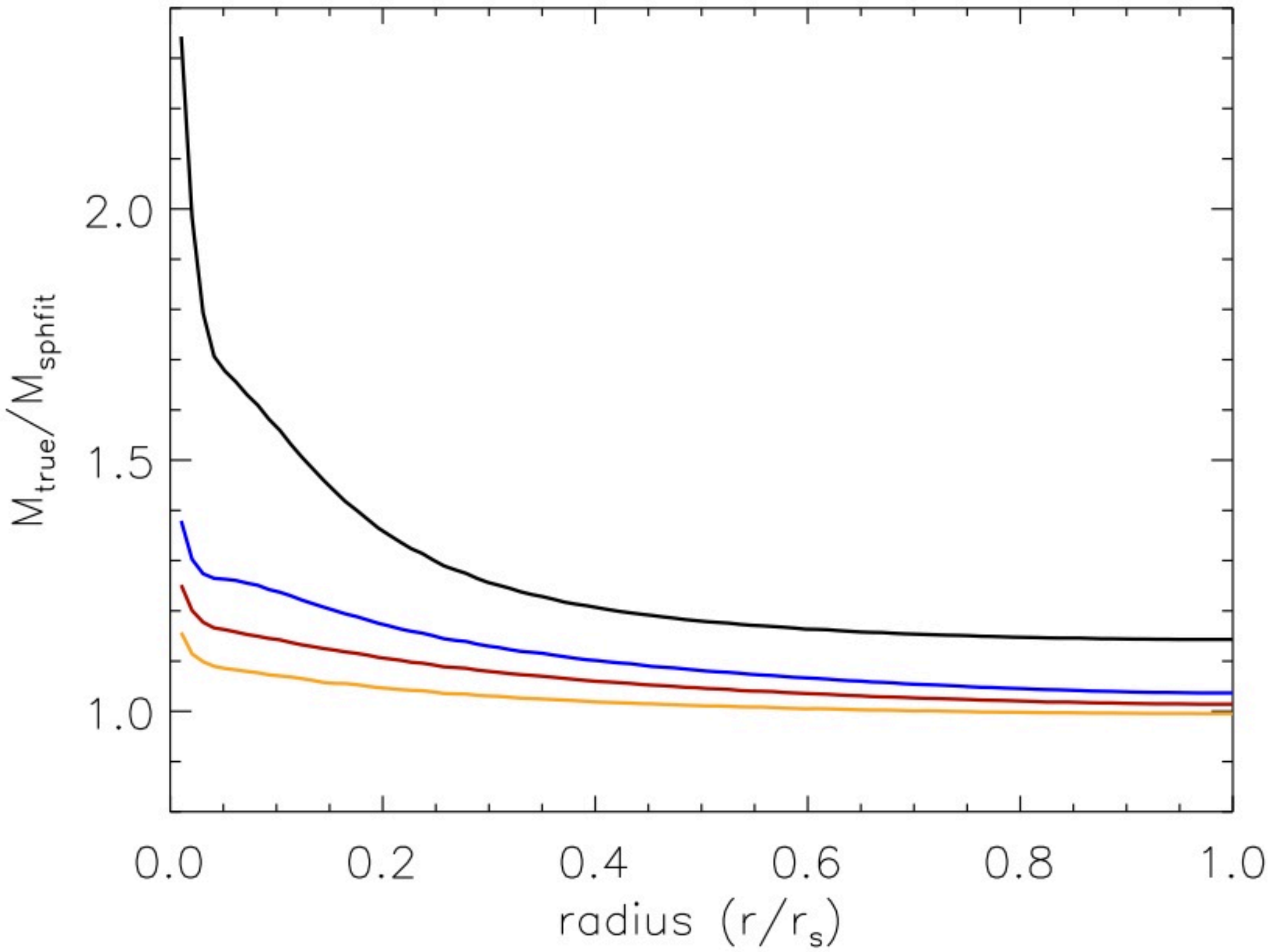
Mass bias





Error of order 10%



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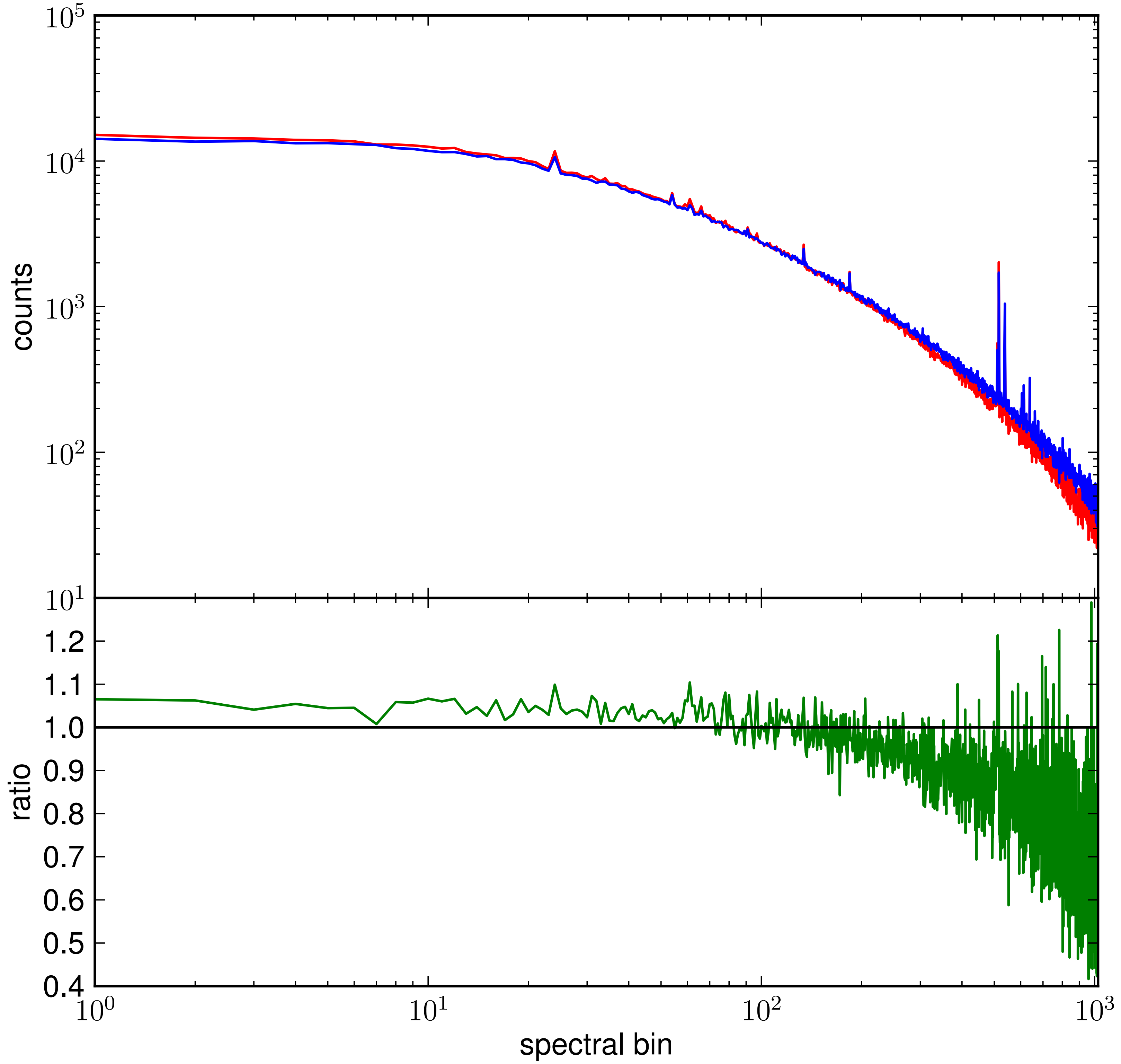
Spectrum ratio



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