Parameterisation Effects in the Analysis of Sunyaev-Zel'dovich Observations

Malak Olamaie
Astrophysics Group
Cavendish Laboratory
University of Cambridge

AMI Consortium: Zwart et al. 2010, arXiv1008.0443Z

AMI Consortium: Rodriguez-Gonzalvez et al. 2010, arXiv1011.0325

AMI Consortium: Shimwell et al. 2010, arXiv1012.4441S

AMI Consortium: Olamaie et al. 2010, arXiv1012.4996C

AMI Consortium: Rodriguez-Gonzalvez et al. 2011, arXiv1101.5589R

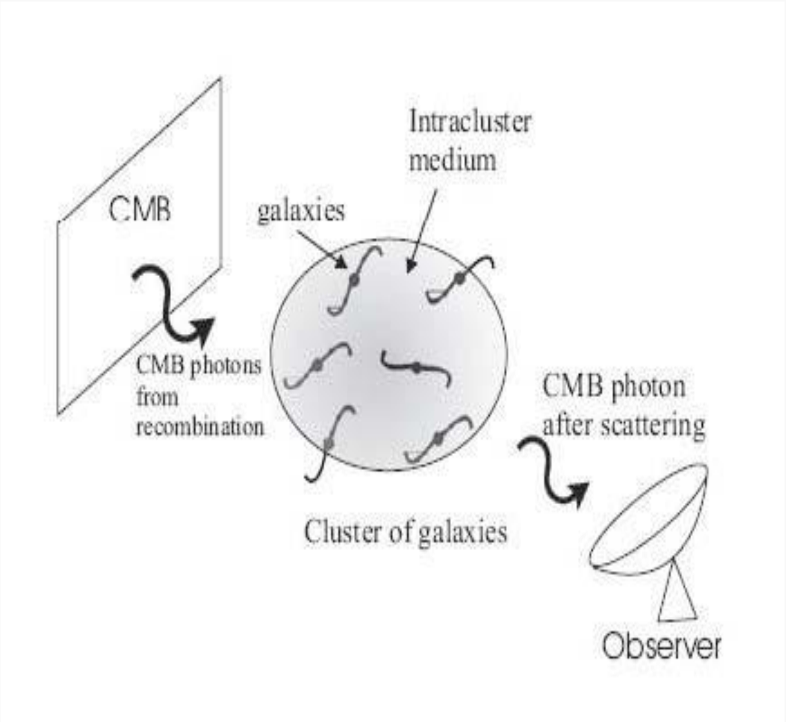
AMI Consortium: Shimwell et al. 2011, arXiv1101.5590S

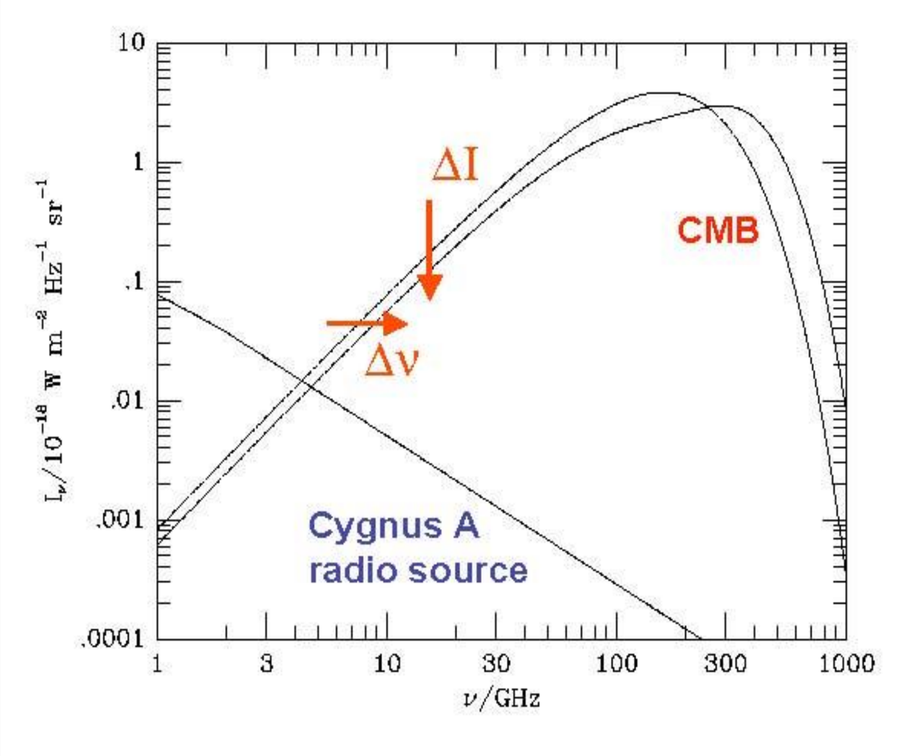
AMI Consortium: Hurley-Walker et al. 2011, arXiv1101.5912H

OUTLINE

- Sunyaev Zel'dovich Effect and ICM Models
- New SZ Interferometer — AMI
- Bayesian Analysis of Data- Parameterisation Effects

Sunyaev-Zel'dovich (SZ) Effect





- SZ effect is the secondary anisotropies in cosmic microwave background from the electrons in hot gas content of galaxy clusters.
- The hot gas scatter low energy CMB photons through inverse Compton scattering.
- The resulting effect causes a spectral distortion of the CMB radiations at the location of the cluster.

Sunyaev-Zeldovich (SZ) Effect

- The observed frequency dependent SZ effect can be described as:

$$\delta I_\nu = T_{CMB}\, y\, f(\nu)\, \frac{\partial B_\nu}{\partial T}\Big|_{T=T_{CMB}}$$

- The dimensionless quantity *y*, known as Compton y parameter is the fractional change in energy by the time photon leaves the region.

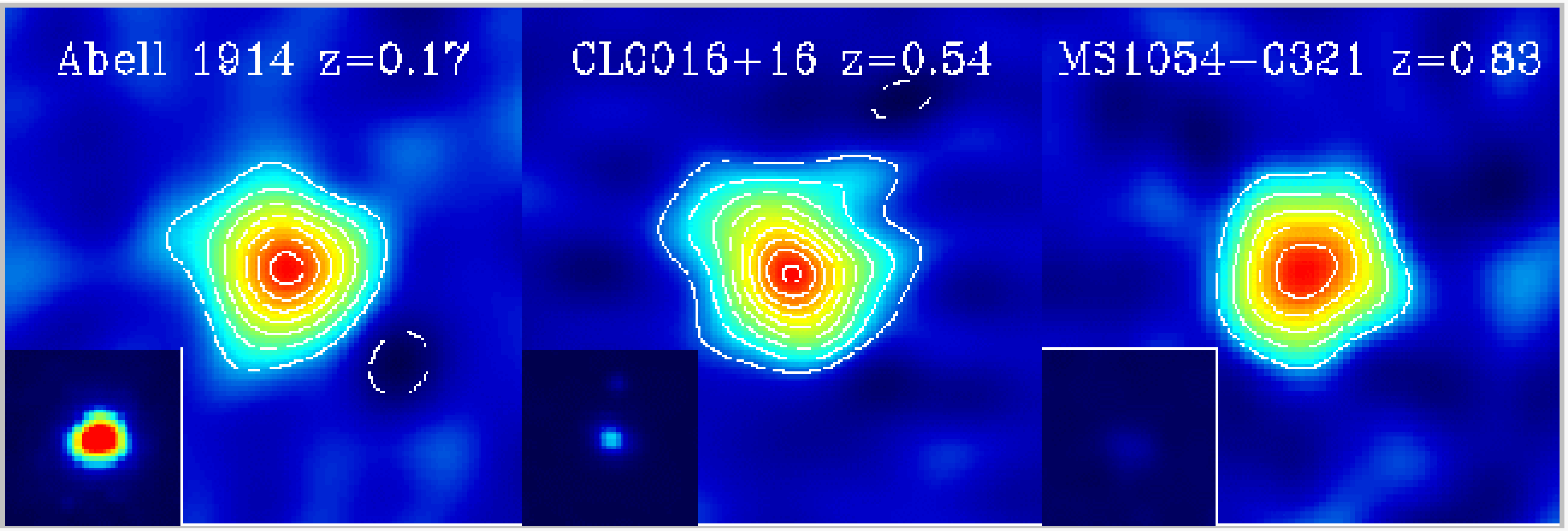
$$y = \frac{\sigma_T}{m_e c^2} \int_{-\infty}^{\infty} P_e(r)\, dl$$

- Volume integrated y parameter is proportional to the total thermal energy of the cluster and therefore is an indication of mass estimate.

$$Y_{sph}(r) = \frac{4\pi\sigma_T}{m_e c^2} \int_0^r P_e(r')\, r'\, dr'^2$$

SZ Effect

http://astro.uchicago.edu/sza/overview.html



- Sunyaev-Zel'dovich signal is independent of the red shift:

$$\delta I_\nu = T_{CMB}\, y\, f(\nu)\, \frac{\partial B_\nu}{\partial T}\Big|_{T=T_{CMB}}$$

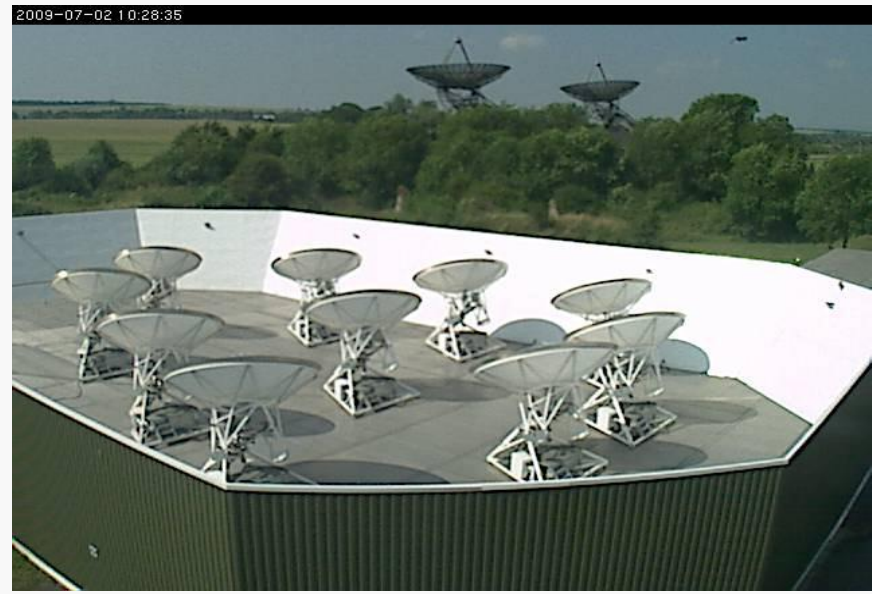
- Surface brightness from studying of galaxy clusters in X-ray band $\propto z^{-4}$

$$S_X = \frac{1}{4\pi(1+z)^4}\int n_e^2 \Lambda_{ee}(X,T)\,dl$$

Arcminute Microkelvin Imager (AMI)

Large Array- LA

Small Array - SA

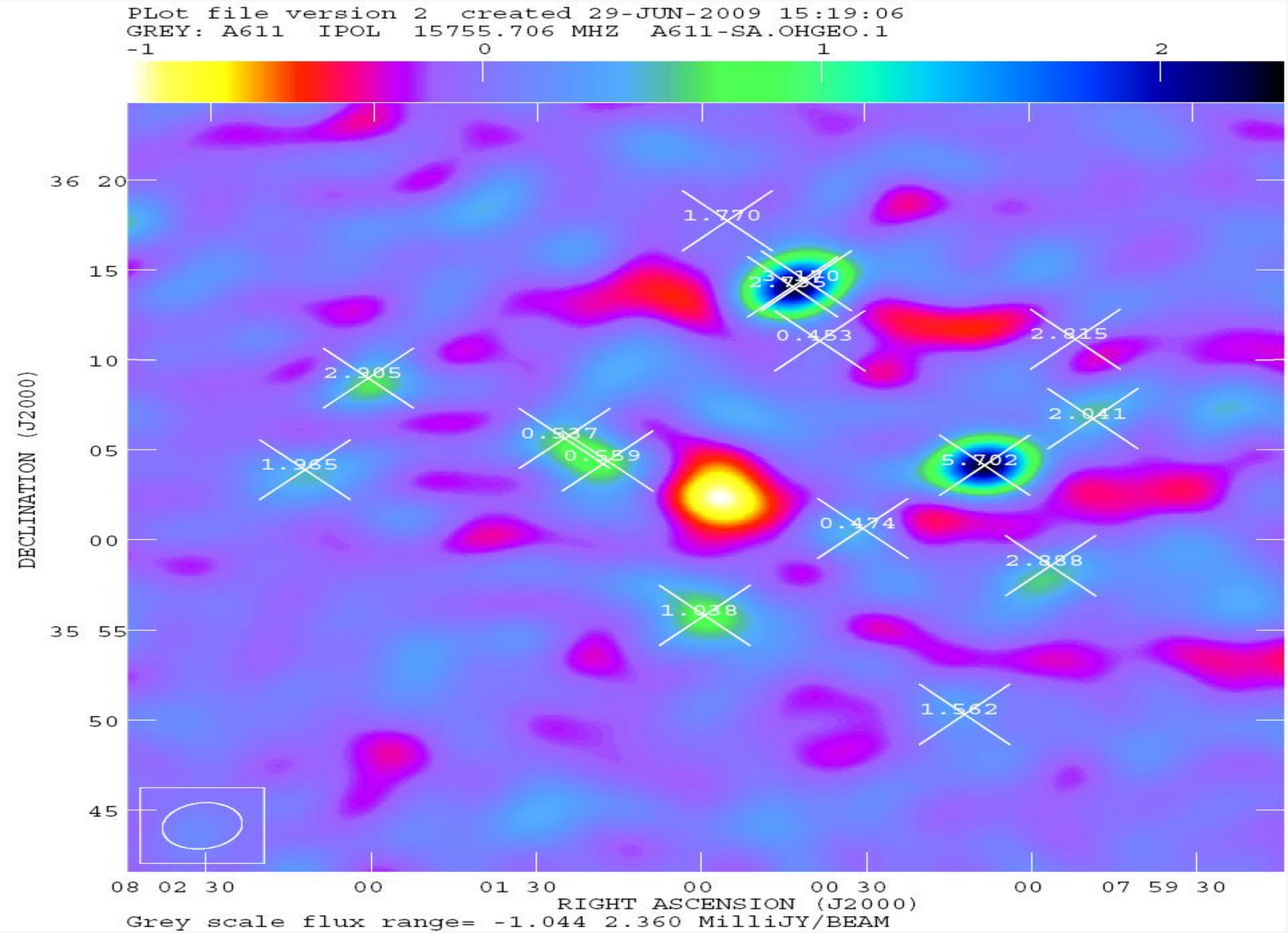


Both 16 GHz with 4.3 GHz bandwidth

Resolution ~30''

Resolution ~ 3'

AMI Observation of Galaxy Clusters



Generalised Noise Model

- There are three components that contribute to the generalised noise on the observed visibilities:

  - Instrumental noise which is Gaussian,

  - Primordial CMB, which we know its power spectrum

  - Radio point sources which have Poisson distribution

- Assuming the three contributions to the generalised noise
- are independent, the covariance matrix can be written as:

$$C_{\nu\nu'} = C_{\nu\nu'}^{rec} + C_{\nu\nu'}^{CMB} + C_{\nu\nu'}^{conf}$$

Modelling the cluster SZ signal

Research Group	Models	Assumptions
AMI	Gas density, temperature	HSE, M-T scaling
AMI	Gas pressure, entropy	HSE, M-T scaling
PLANCK AMI/PLANCK	Gas pressure	fixed slopes, gas concentration parameter
SZA	Gas pressure, density	HSE, iso-fgas
SZA	Dark matter density , gas pressure	Virial theorem, iso-fgas
SPT	Gas density, temperature	Iso-fgas, isothermality, HSE
SPT	Gas pressure, density	Iso-fgas, scaling relation

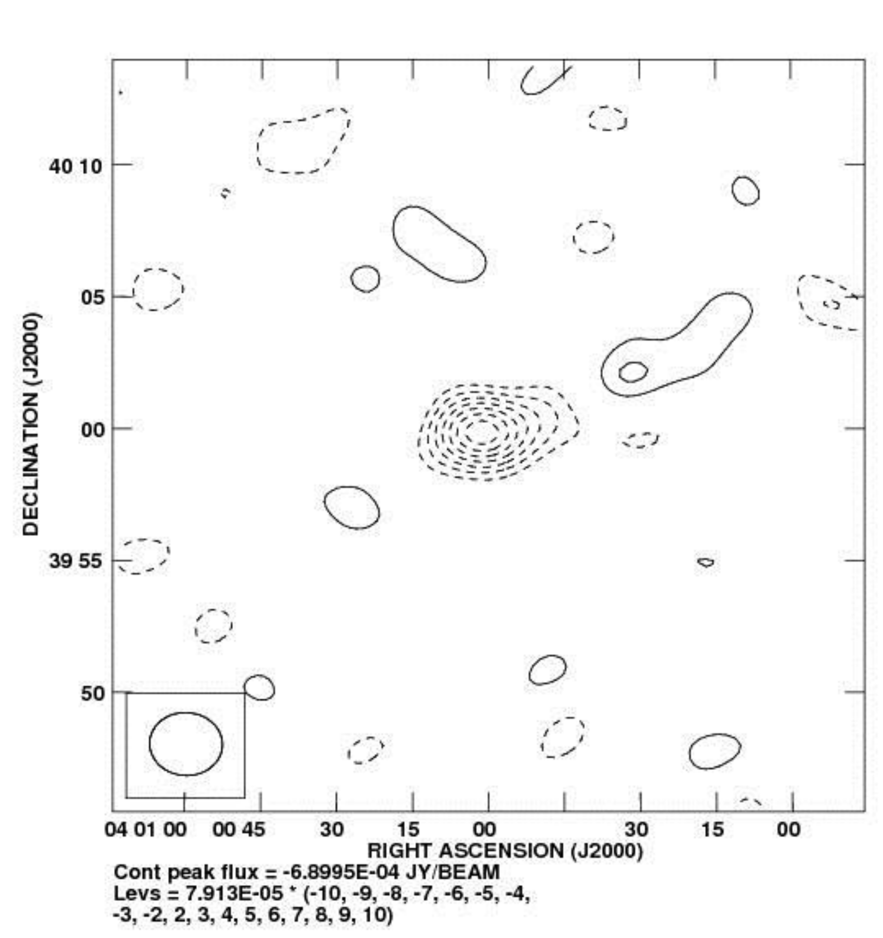
Modelling the cluster signal

I. The isothermal β model

$$n_e(r) = \frac{n_{e0}}{\left(1+\frac{r^2}{r_c^2}\right)^{3\beta/2}}$$

(Cavaliere and Fusco-Femiano 1978)

$$T_e(r) = T_g = const.$$

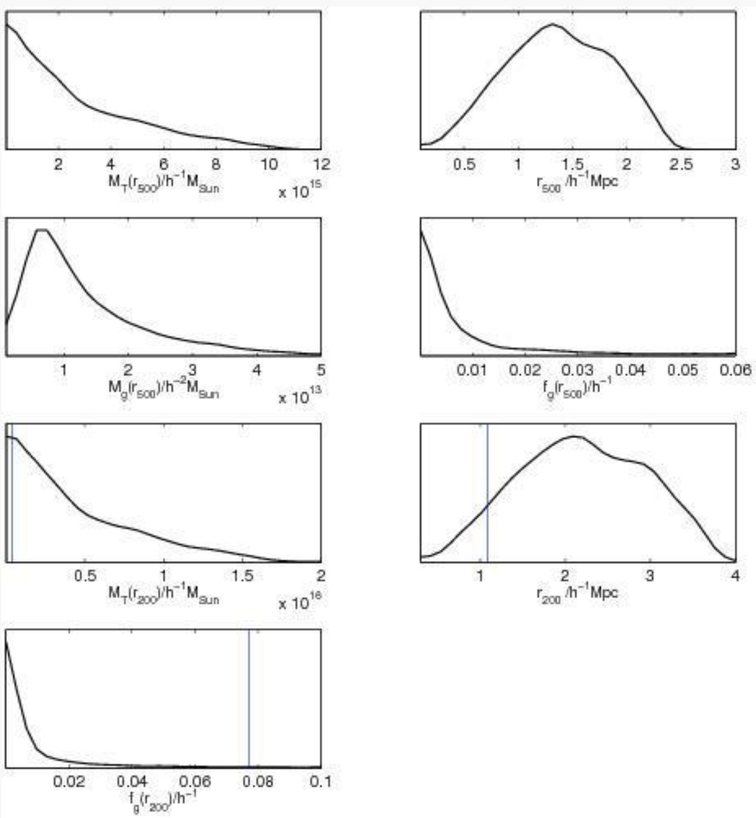


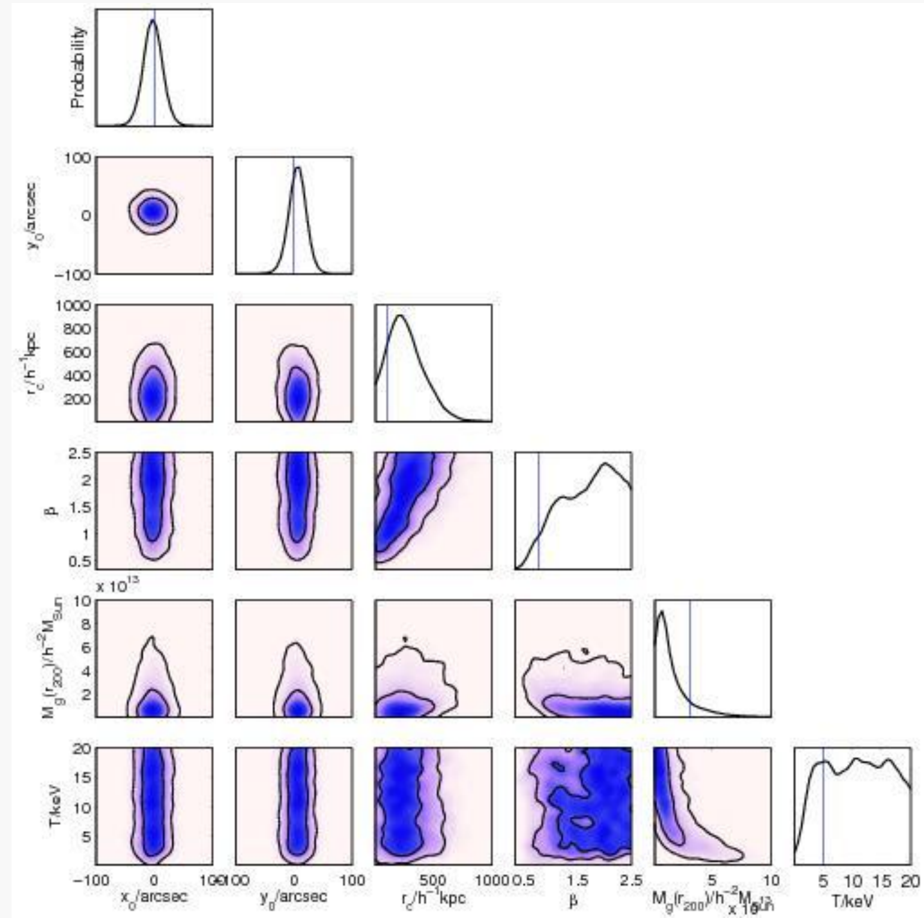
I. Estimating Cluster Physical Parameters

I. Prior $\pi(\mathbf{\Theta_c})$ on our cluster model parameters:

$$\Theta_c \equiv (x_c, y_c, r_c, \beta, T_g, M_g(r_{200}), z)$$

$$r_{200} = r_{200}(r_c, \beta, T_g, z)$$



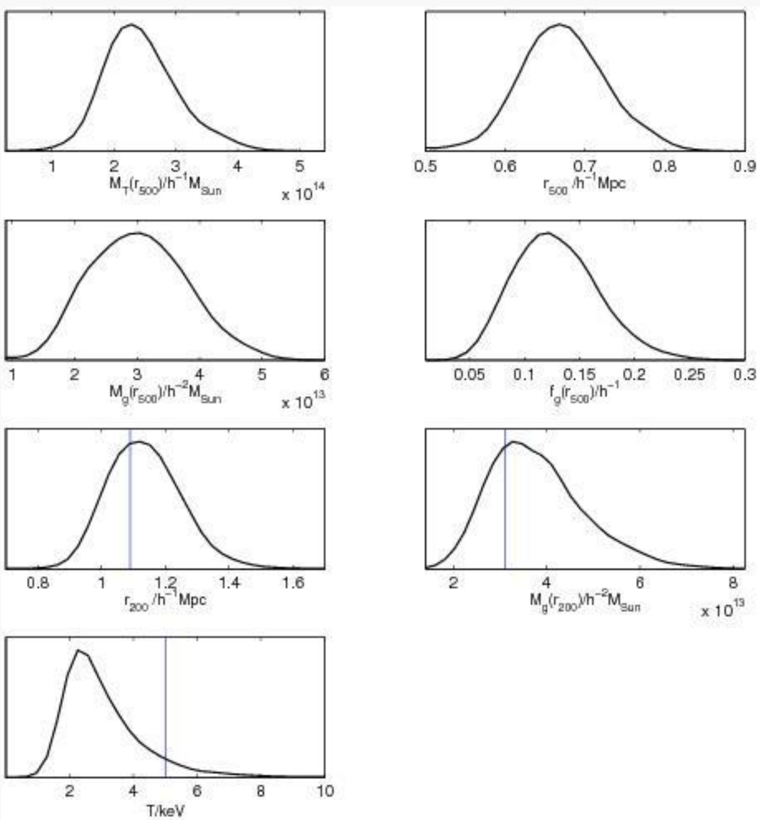


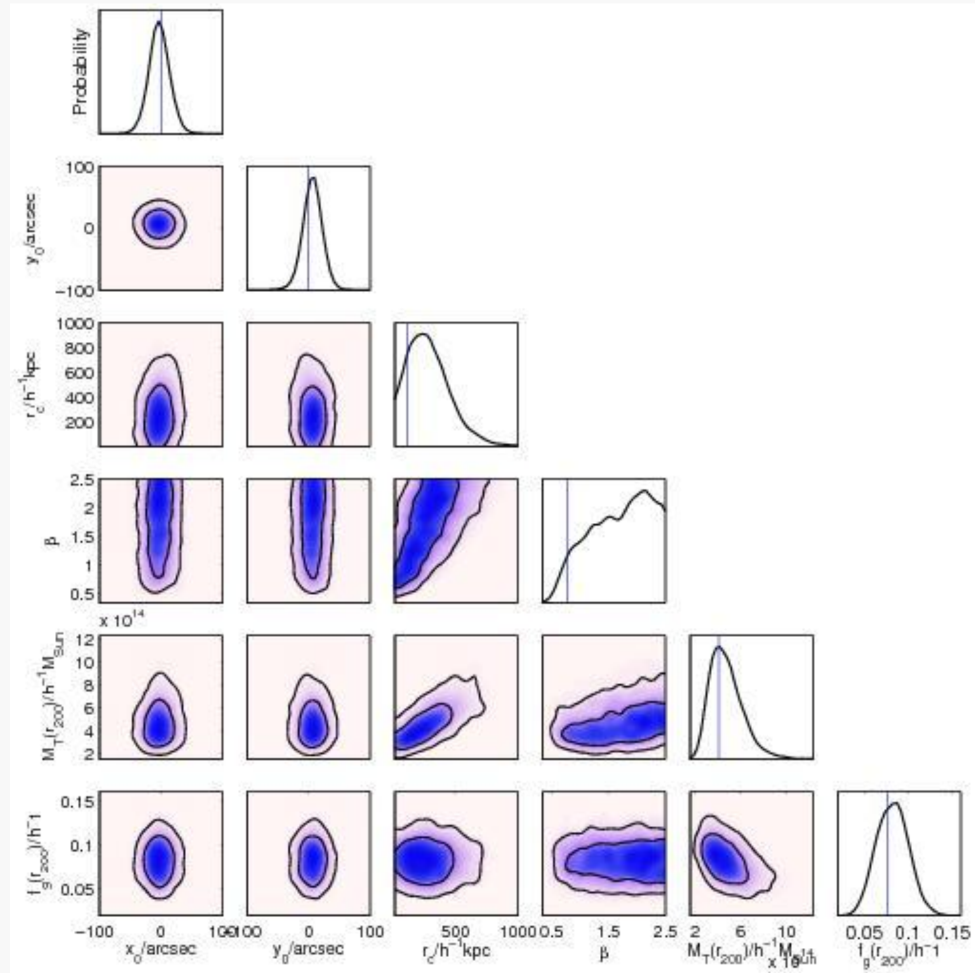
II. Estimating Cluster Physical Parameters

Prior $\pi(\boldsymbol{\Theta}_\mathbf{c})$ on our cluster model parameters

$$\Theta_c \equiv (x_c\,, y_c\,,\, r_c\,, \beta,\, f_g(r_{200}), M_T(r_{200}), z)$$

$$k_B T_g(r_{200}) = \frac{(4\pi\mu G)(200\rho_{crit}(z))(r_{200}^2 + r_c^2)}{9\beta}$$



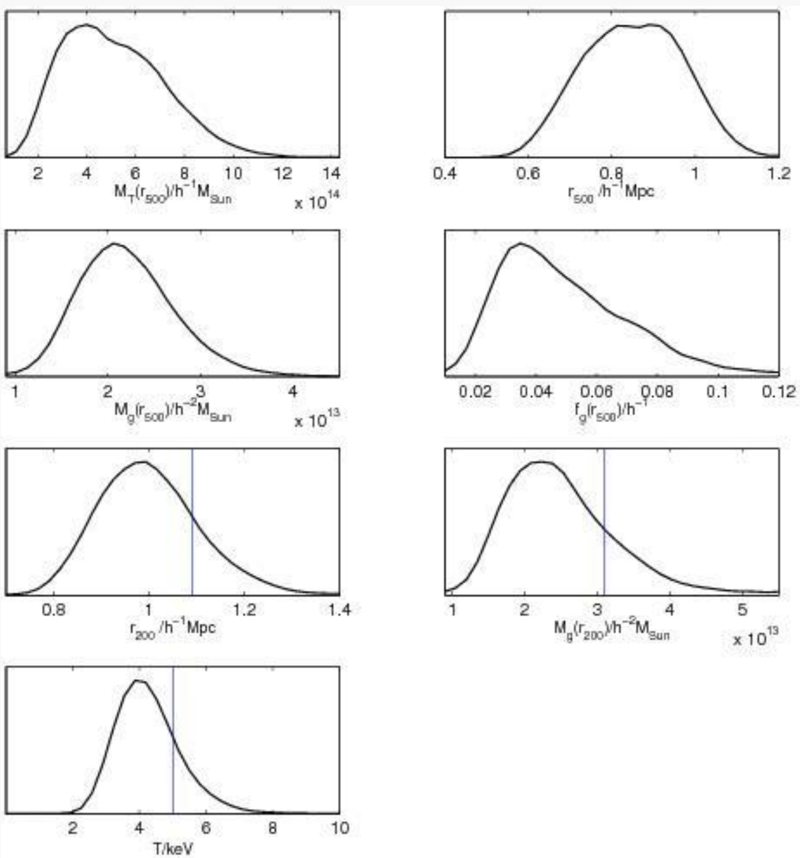


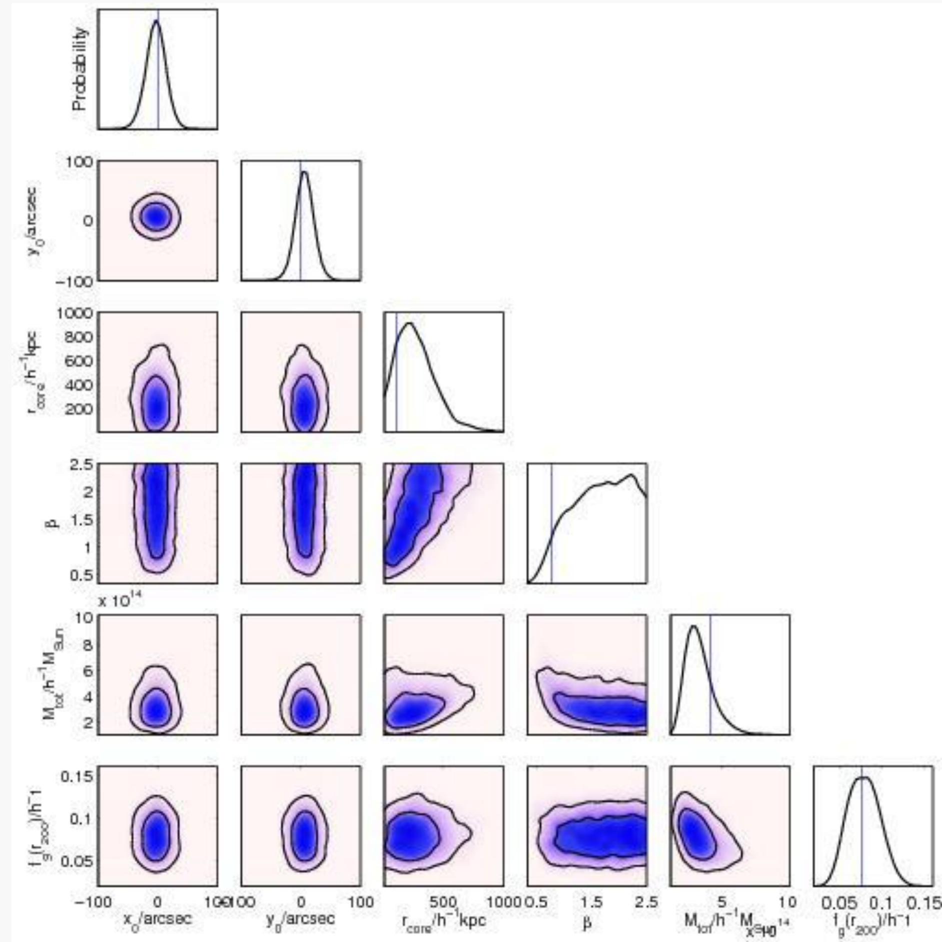
III. Estimating Cluster Physical Parameters

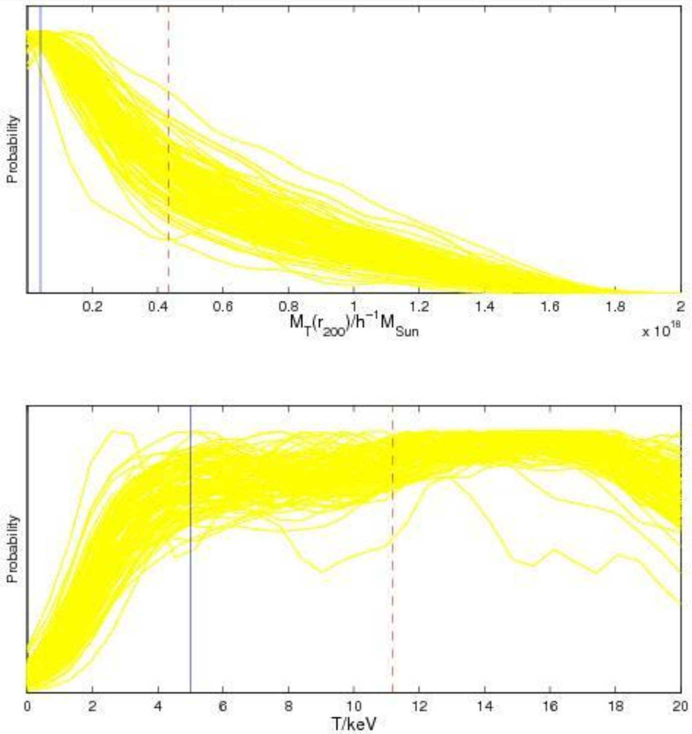
Prior $\pi(\boldsymbol{\Theta_c})$ on our cluster model parameters

$$\Theta_c \equiv (x_c\,, y_c\,, \, r_c\,, \beta, \, f_g(r_{200}), M_T(r_{200}), z)$$

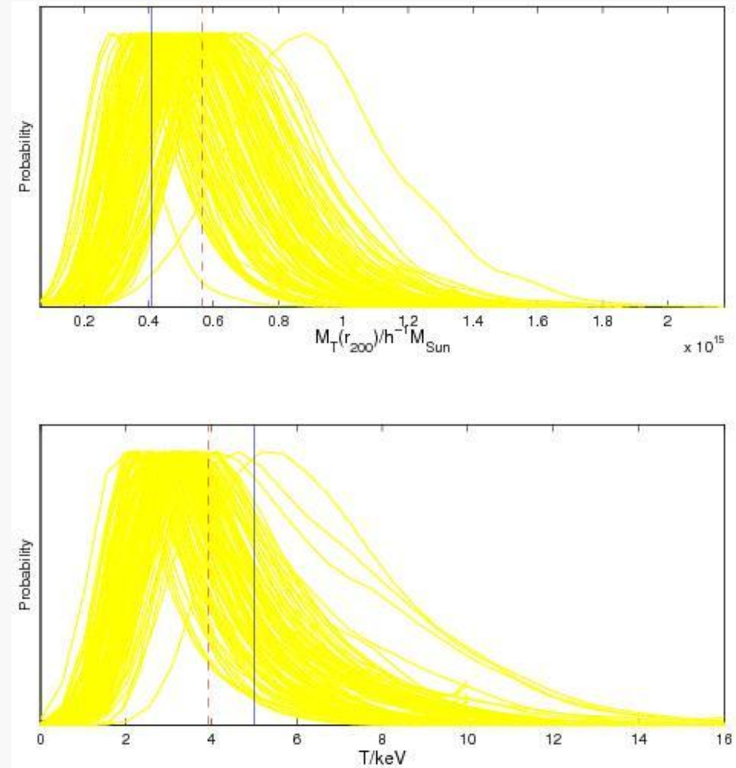
$$k_B T_g(r_{200}) = 8.2\left(\frac{M_T(r_{200})}{10^{15} h^{-1} M_{\mathrm{O}}}\right)^{2/3}\left(\frac{H(z)}{H_0}\right)^{2/3} \; keV$$



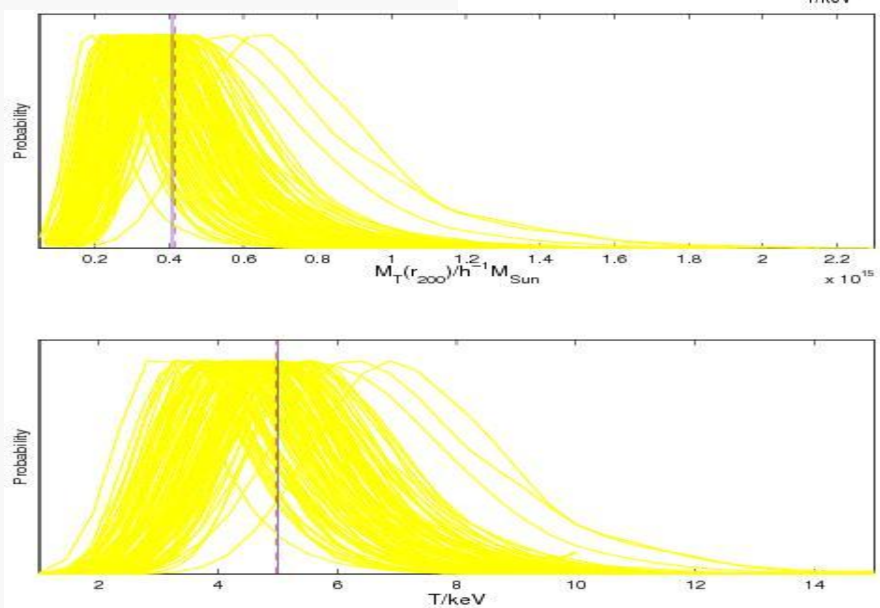



Probability
0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2
M_T(r_200)/h^-1 M_Sun
Probability
0 2 4 6 8 10 12 14 16 18 20
T/keV

(I)


Probability
0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2
M_T(r_200)/h^-1 M_Sun
x 10^15
Probability
0 2 4 6 8 10 12 14 16
T/keV

(II)


Probability
0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2
M_T(r_200)/h^-1 M_Sun
x 10^15
Probability
2 4 6 8 10 12 14
T/keV

(III)

II. Modelling the cluster signal

The Generalised NFW (GNFW) pressure model

$$P_e(r) = \frac{P_{ei}}{\left(\frac{r}{r_p}\right)^c \left[1+\left(\frac{r}{r_p}\right)^a\right]^{(b-c)/a}}$$

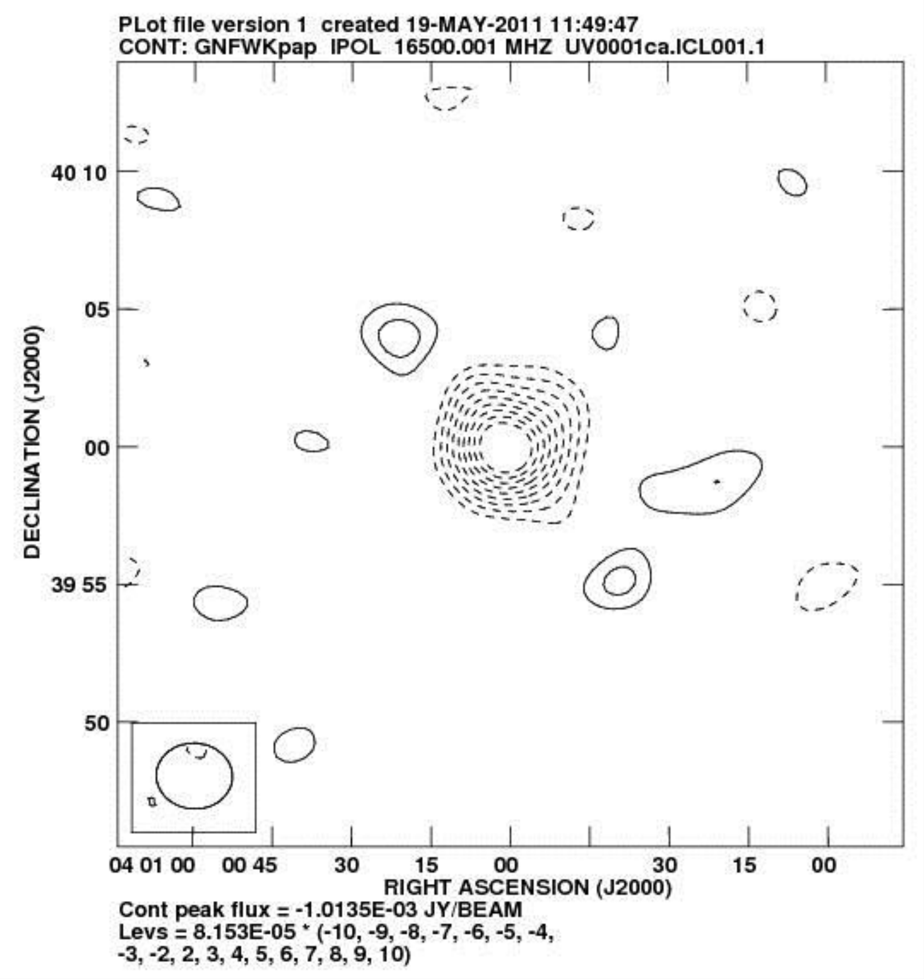
(Nagai et al. 2007)

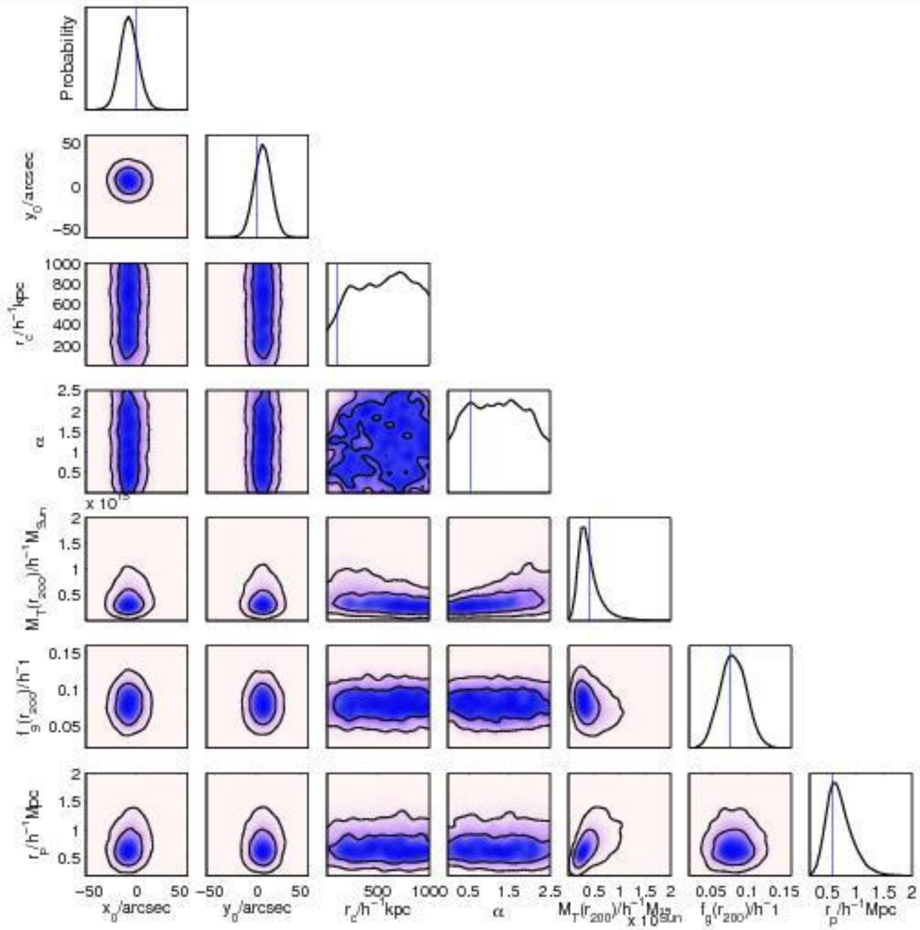
$$(a, b, c, c_{500}) = (1.0620, 5.4807, 0.3292, 1.156)$$

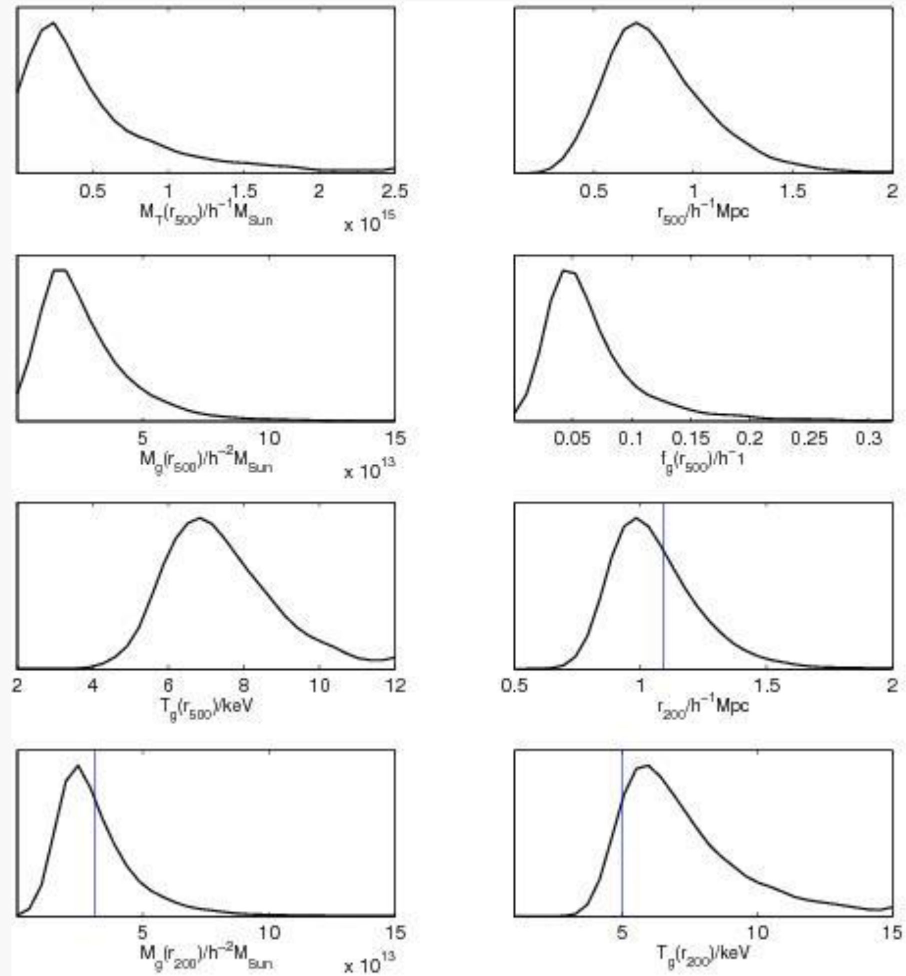
(Arnaud et al. 2010)

$$K_e(r) = K_{ei}\left(1+\frac{r^2}{r_c^2}\right)^{\alpha}$$

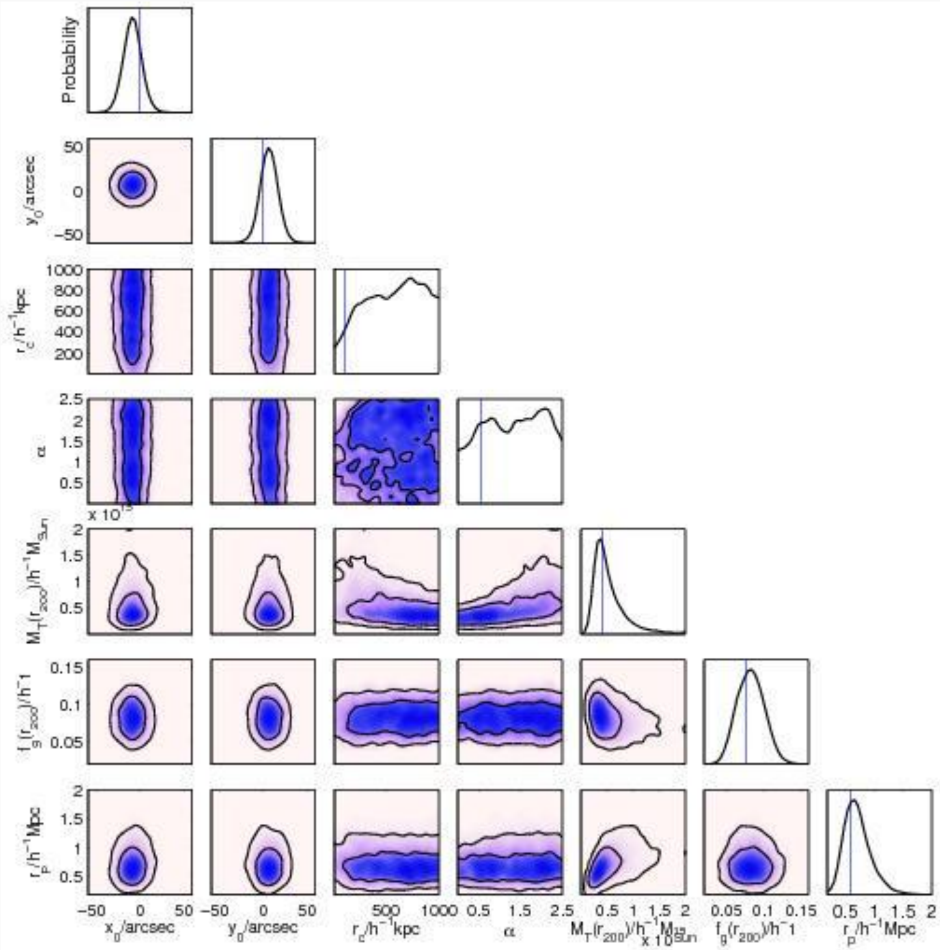
(Allison et al. 2011)

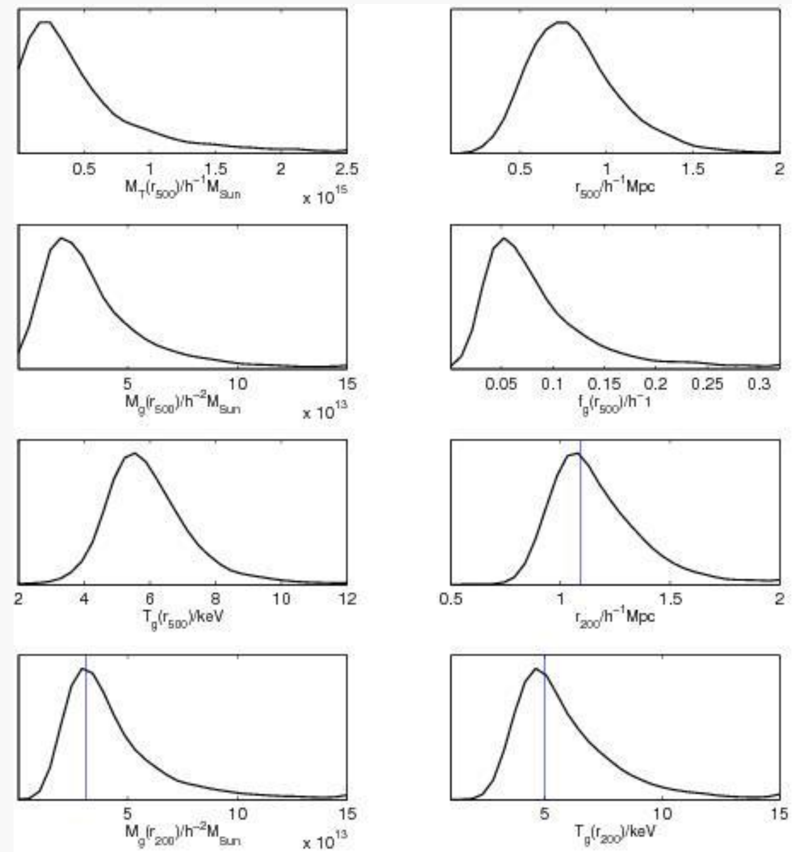






Parameterisation II





Parameterisation III

Conclusion

- **Different parameterisations introduce different constraints and biases into the cluster physical parameters.**
- **Joint analyses are favourable in constraining cluster parameters robustly.**
- **Studies on determining and constraining the slope of the mass-observable relation are on going.**