Dark
Energies
Survey

Physical Interpretation of Cluster Pressure Profile in CMB Observation

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Galaxy clusters provide valuable information on cosmology, from the nature of dark energy to the physics driving galaxy and structure formation. Clusters are filled with hot ionized gas that can be studied both in X-ray and through the thermal Sunyaev-Zel’dovich (SZ) effect.

Perseus Cluster

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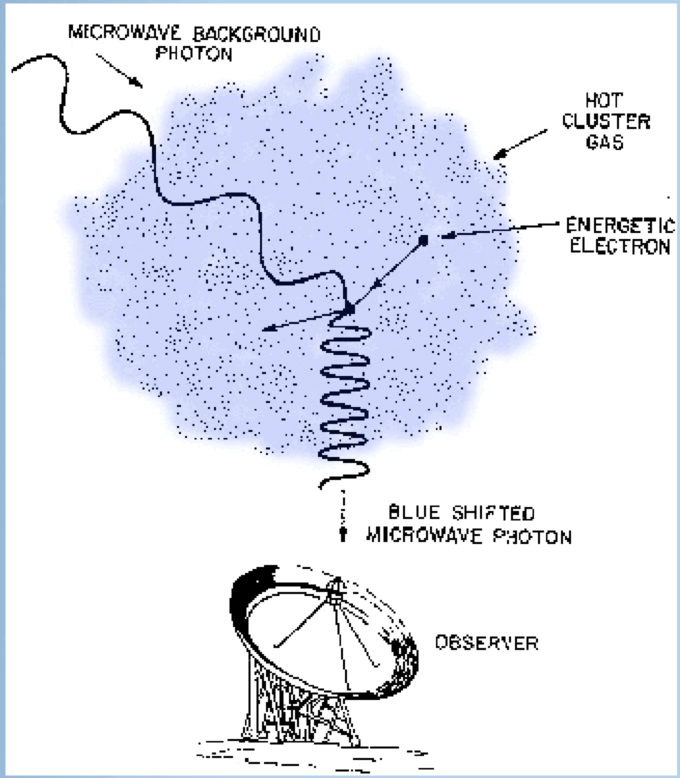
Sunyaev-Zel'dovich effect

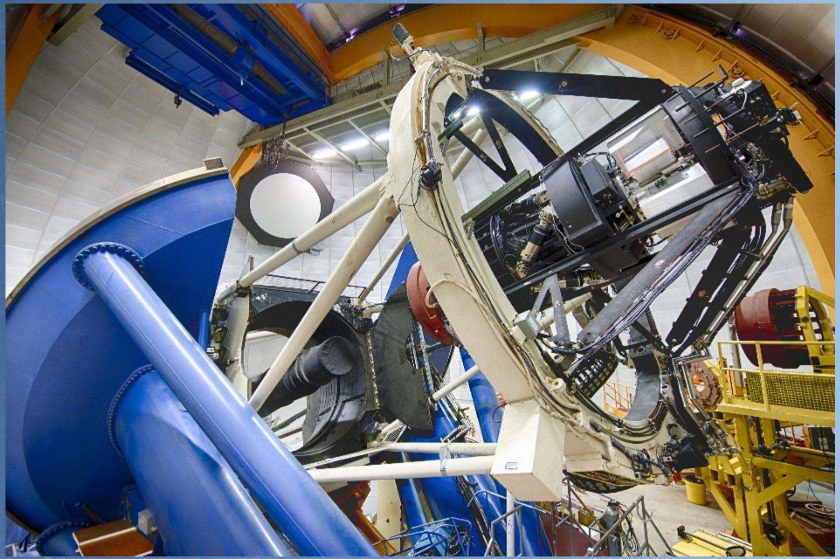
- spectral distortion of the cosmic microwave background (CMB) generated via inverse Compton scattering of CMB photons by the free electrons;
- Its magnitude is proportional to the *y*-Compton parameter, a measure of the gas pressure integrated along the line-of-sight :

$$y = \frac{\sigma_T}{m_e c^2} \int P dl \quad ; \quad P = n_e T$$



Representation of Sunyaev-Zel'dovich Effect

- DECam → DES clusters catalog
- *Planck* telescope → SZ maps



Dark Energy Camera (DECam) on Blanco Telescope (Reidar Hahn, Fermilab)

Planck's large telescope, *Planck* collaboration

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Understand one and two halo term in the cross correletion function

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Analysis of one and two halo term with mock data

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Analyze the observational data

The key quanity of interest is the average *y*-Compton parameter at a projected co-moving distance *r* from a halo of mass *M*.

$$\xi_{y,g}(r|M) = \frac{\sigma_T}{m_e c^2} \int_{-\infty}^{+\infty} \frac{d\chi}{1+z}\, \xi_{h,p}(\sqrt{\chi^2 + r^2}|M)$$

The halo-pressure correlation function describes the average excess pressure around halos as a function of the distance from the halo center.

$$\xi_{h,P}(r|M) = \xi_{h,P}^{one-halo}(r|M) + \xi_{h,P}^{two-halo}(r|M)$$

In ordert to compute the halo-presure correlation function, we have to determine the gas/electron thermal presure as a function of distance from halo center, namely the pressure profile, for halos of various mass.

$$\bar{P}_{fit} = P_0\,(x/x_c)^{\gamma}\left[1 + (x/x_c)^{\alpha}\right]^{-\beta} \quad ; \quad par = par_0\left(M_{200}/10^{14} M_{\odot}\right)^{\alpha_m}(1+z)^{\alpha_z}$$

METHODOLOGY. The expected y(r) signal in λ bin.

$$\bar{y}_{r_0,z,\lambda_1,\lambda_2} = \int P(M|z,\lambda_1,\lambda_2)\, y_{r_0}(M,z)dM = \int \frac{1}{2}\left[erfc\big(\chi_1(M)\big) - erfc\big(\chi_2(M)\big)\right]P(M|z)\, y_{r_0}(M,z)dM$$

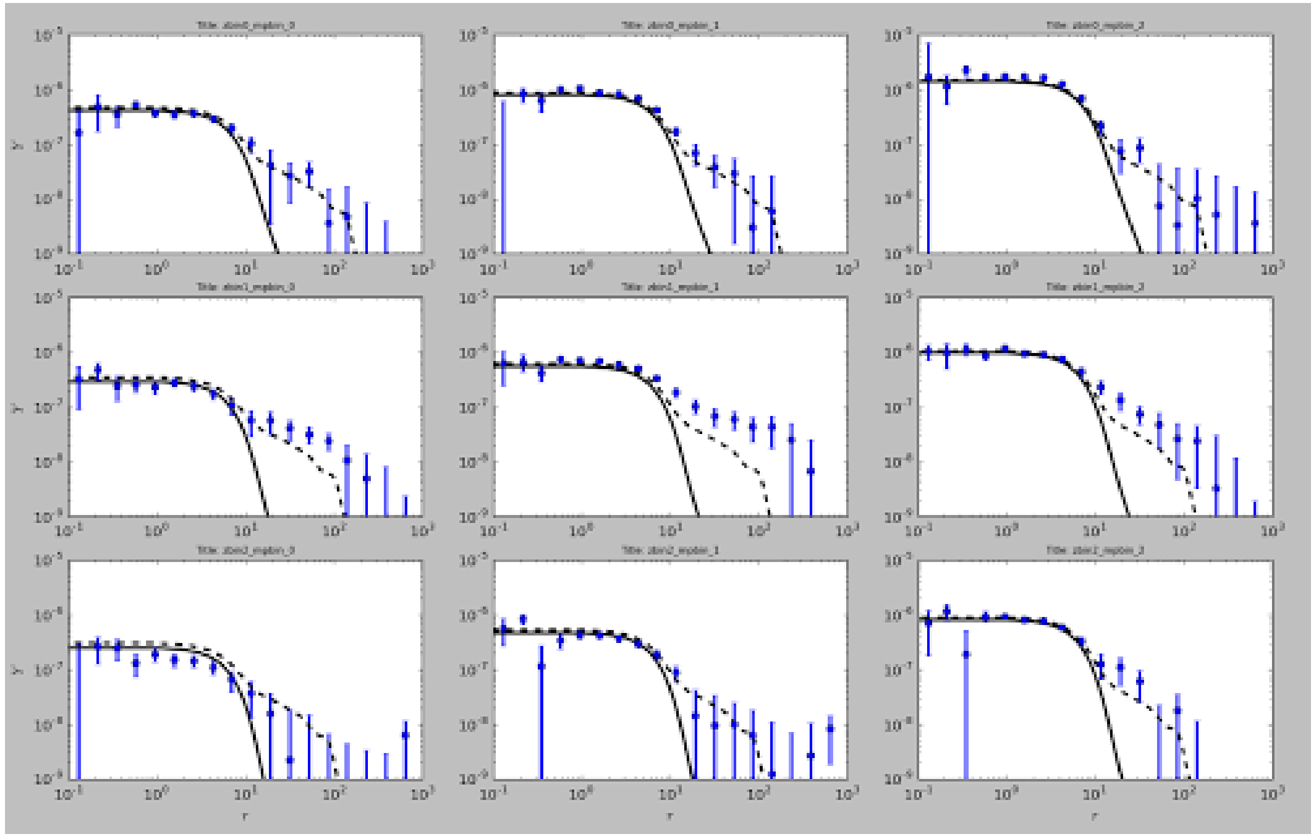
$$\chi_i(M) = \frac{logM_i - logM}{\sqrt{2\sigma^2_{\log(\lambda_i|M)}/B^2_\lambda}}$$

Where we assume that λ follows a log-Normal distribution with mean value and standard deviation as follow. Moreover, the relation between richness and mass is indicated below.

$$log\lambda = \mathcal{N}\left(A_\lambda + B_\lambda logM\,;\, \sigma^2_{\log(\lambda|M)}\right)\,;\; M(\lambda,z) \equiv \langle M|\lambda,z\rangle = M_0\left(\frac{\lambda}{\lambda_0}\right)^{F_\lambda}\left(\frac{1+z}{1+z_0}\right)^{G_z}$$

$$\sigma^2_{\log(\lambda|M)} = \frac{1}{e^{\left(A_\lambda + B_\lambda logM + \frac{1}{2}\sigma_0^2\right)}} + \sigma_0^2$$

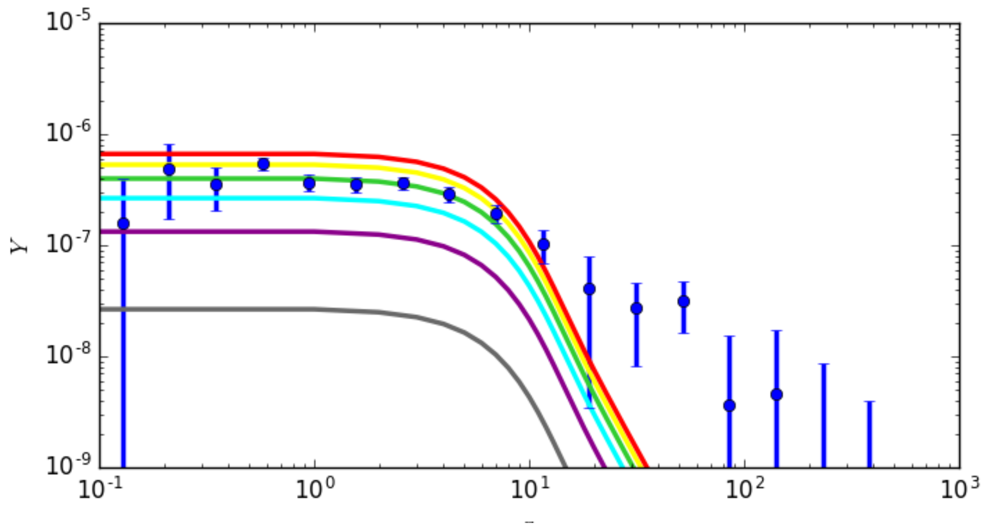
		Richness bins		
		0	1	2
Redshift bins	0	[0.2; 0.35] [20;30]	[0.2; 0.35] [30;45]	[0.2; 0.35] [45;60]
	1	[0.35; 0.5] [20;30]	[0.35; 0.5] [30;45]	[0.35; 0.5] [45;60]
	2	[0.5; 0.65] [20;30]	[0.5; 0.65] [30;45]	[0.5; 0.65] [45;60]



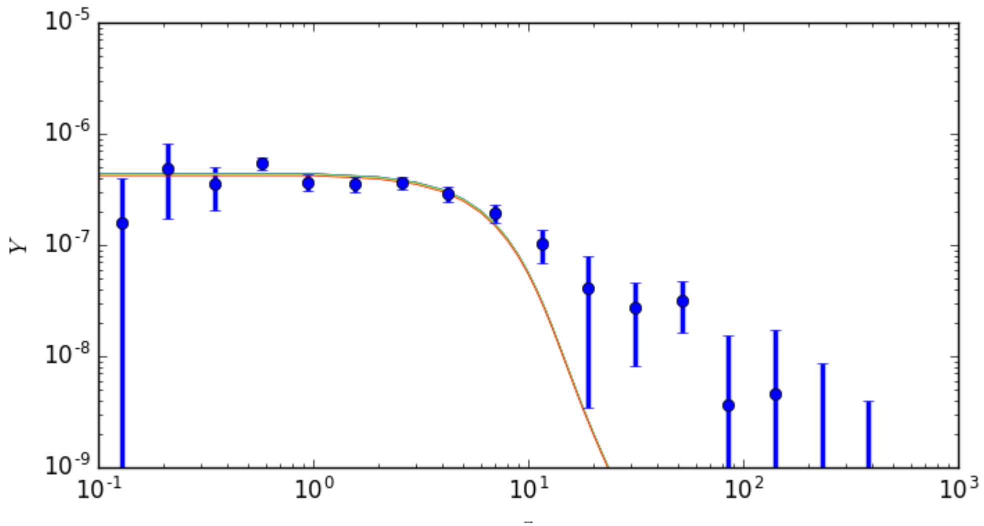
$$\xi_{h,P}(r|M) = \xi_{h,P}^{one-halo}(r|M) + \xi_{h,P}^{two-halo}(r|M)$$

ONE-HALO TERM. Study of parameters.

- $P = A_P \left(\frac{M_{200}}{10^{14} M_\odot}\right)^{B_P} (1+z)^{C_P}$ → A_P
- $\sigma^2_{\log(\lambda|M)} = \frac{1}{e^{\left(A_\lambda + B_\lambda \log M + \frac{1}{2}\sigma_0^2\right)}} + \sigma_0^2$ → σ_0



Behaviour of $A_P = [5;\ 10; 15;\ 20; 25; 30]$



Behaviour of $\sigma_0 = [0.10; 0.15; 0.20; 0.25; 0.30; 0.35]$

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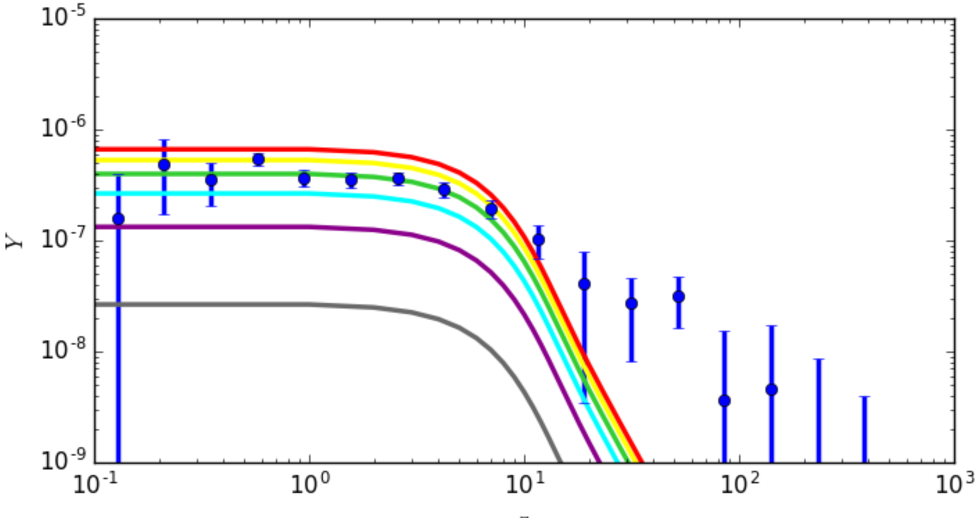

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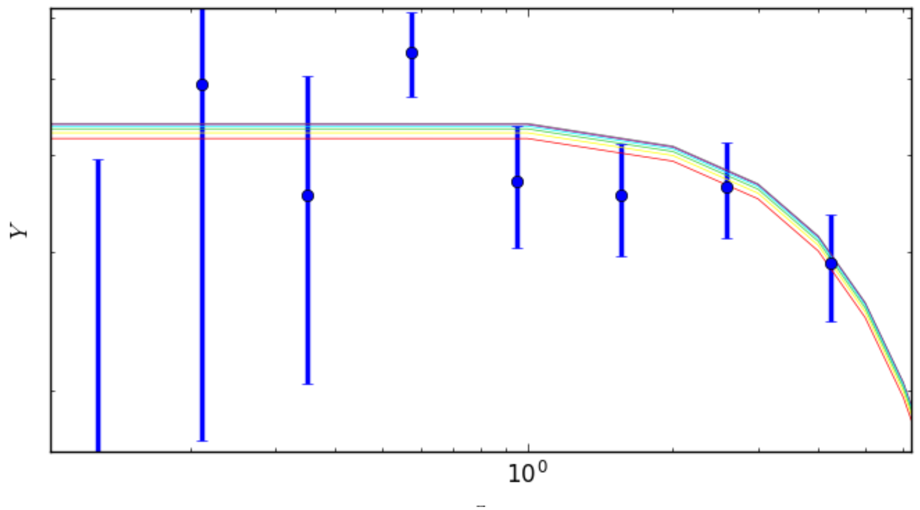


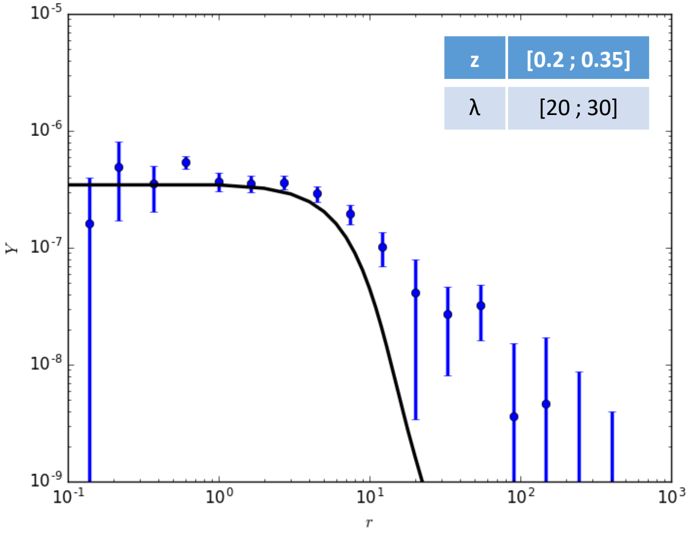
Behaviour of $\sigma_0 = [0.10; 0.15; 0.20; 0.25; 0.30; 0.35]$

ONE-HALO TERM. Analysis with MOCK data.

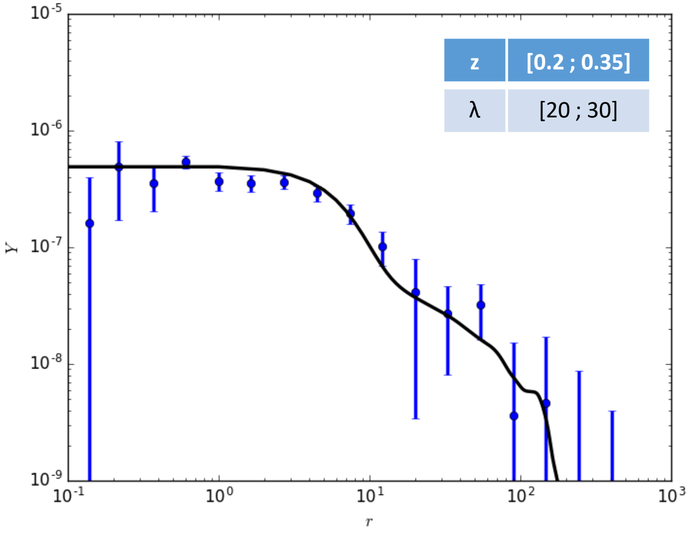
- Instead using the experimental data for MCMC analysis, I used the output of the model with certain value of parameters in order to test the fitting code. I produced MOCK data sets with different configurations, which are listed in the table below.

	Data sets	
1 halo	$A_p = 18.1$	$A_p = 18.1$; $\sigma_0 = 0.225$
1 and 2 halos	$A_p = 18.1$	$A_p = 18.1$; $\sigma_0 = 0.225$

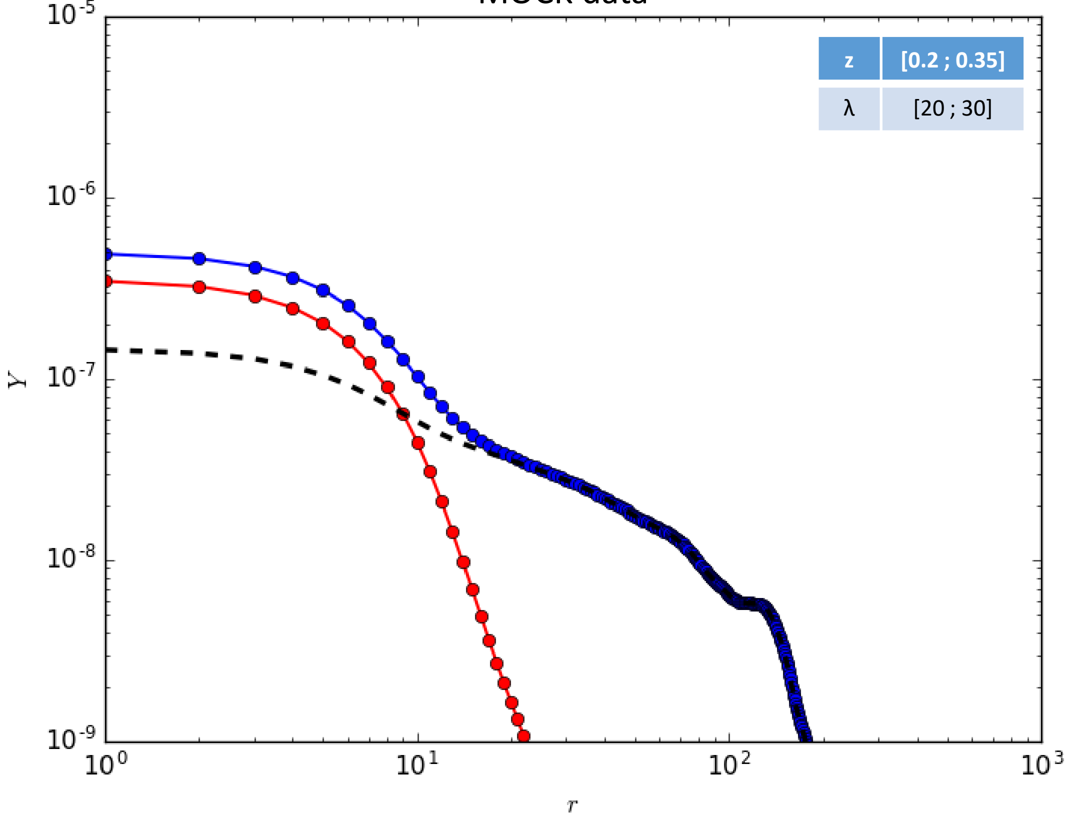
1 halo term



1 and 2 halo terms

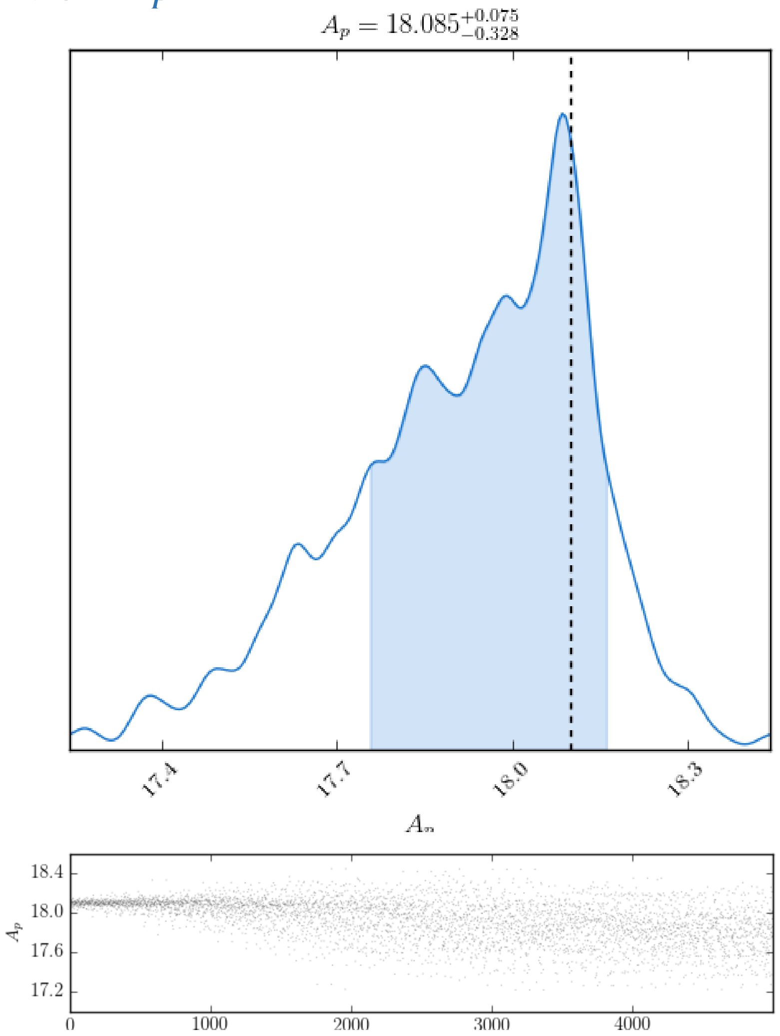


Difference between the two MOCK data

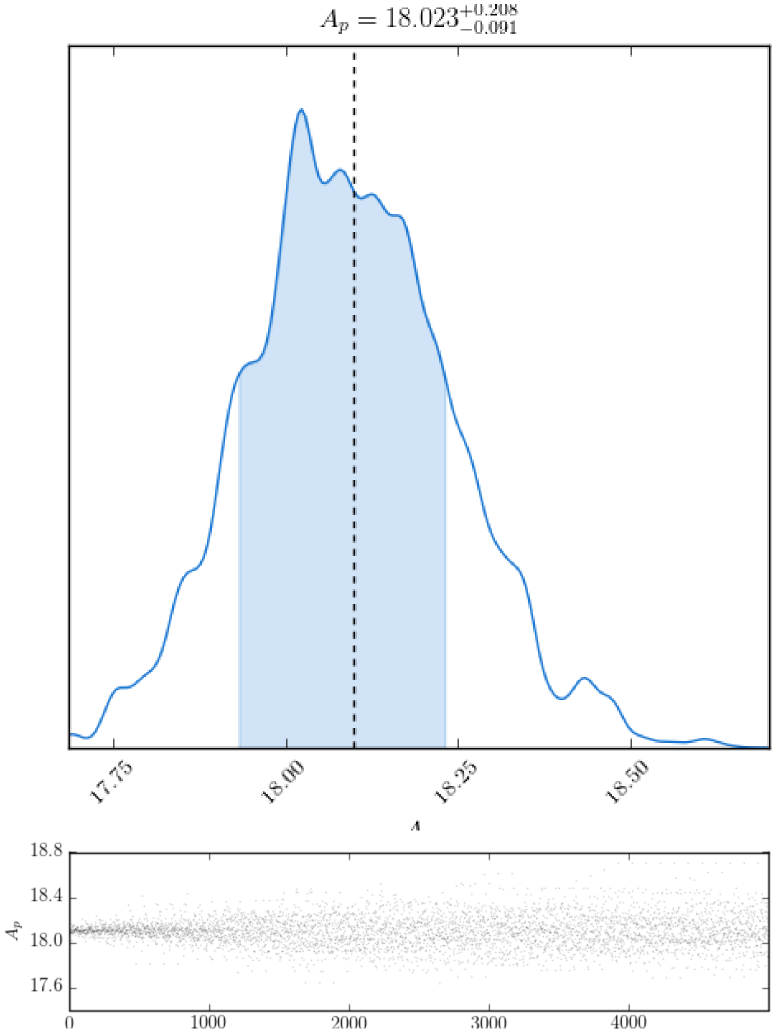


ANALYSIS OF PARAMETERS. Comparison between one halo model and one plus two halo model.

- Constraint on A_P.



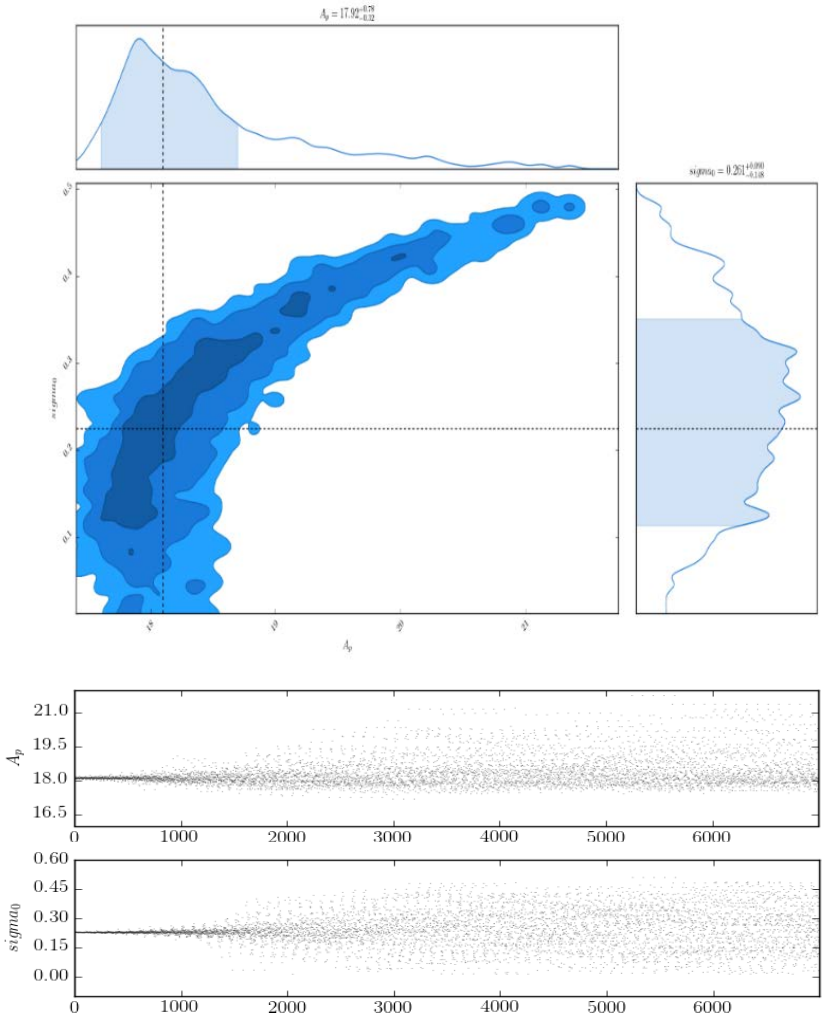
1 halo term



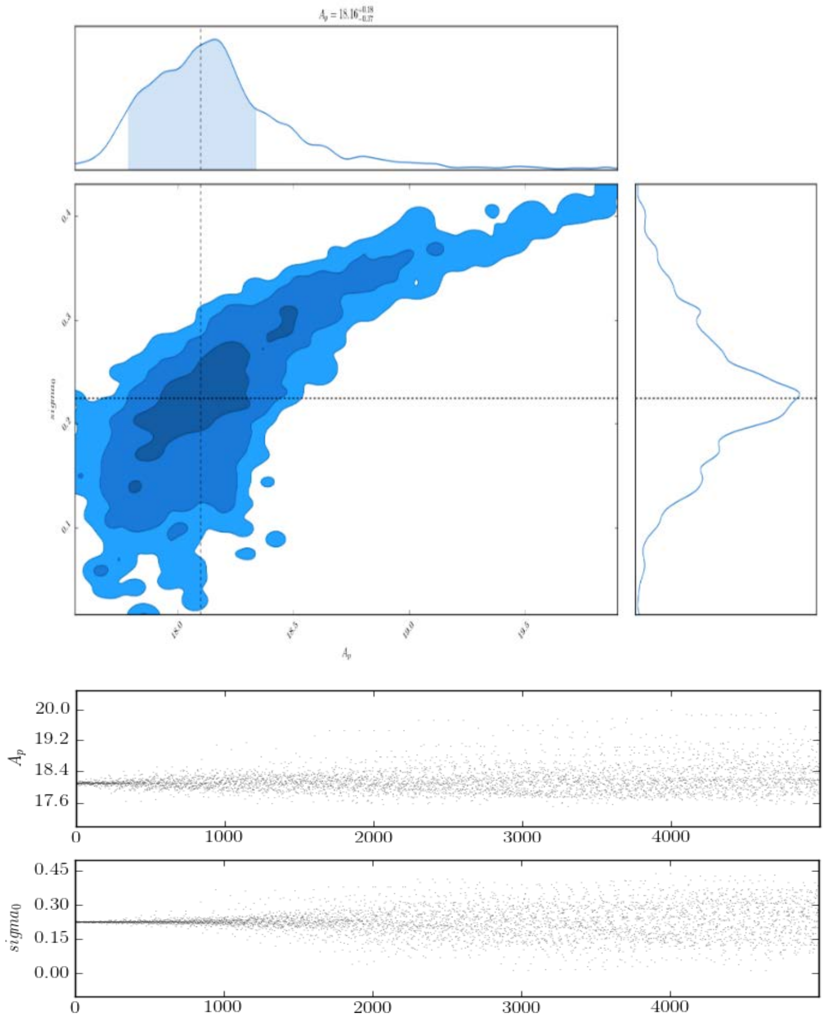
1 and 2 halo terms

ANALYSIS OF PARAMETERS. One halo model fitting results of one plus two halo MOCK data, using different sets of parameters.

- Constraint on A_P and σ_0.



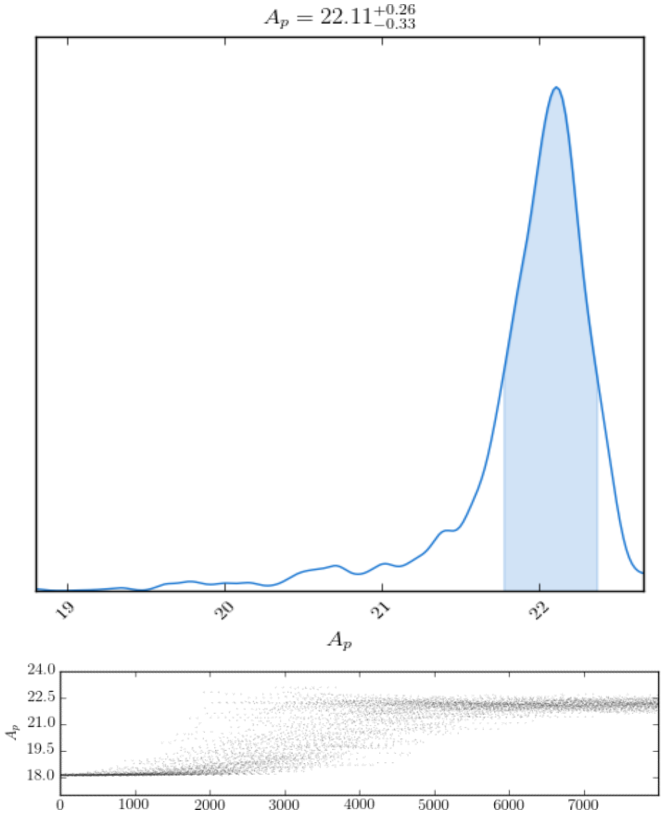
1 halo term



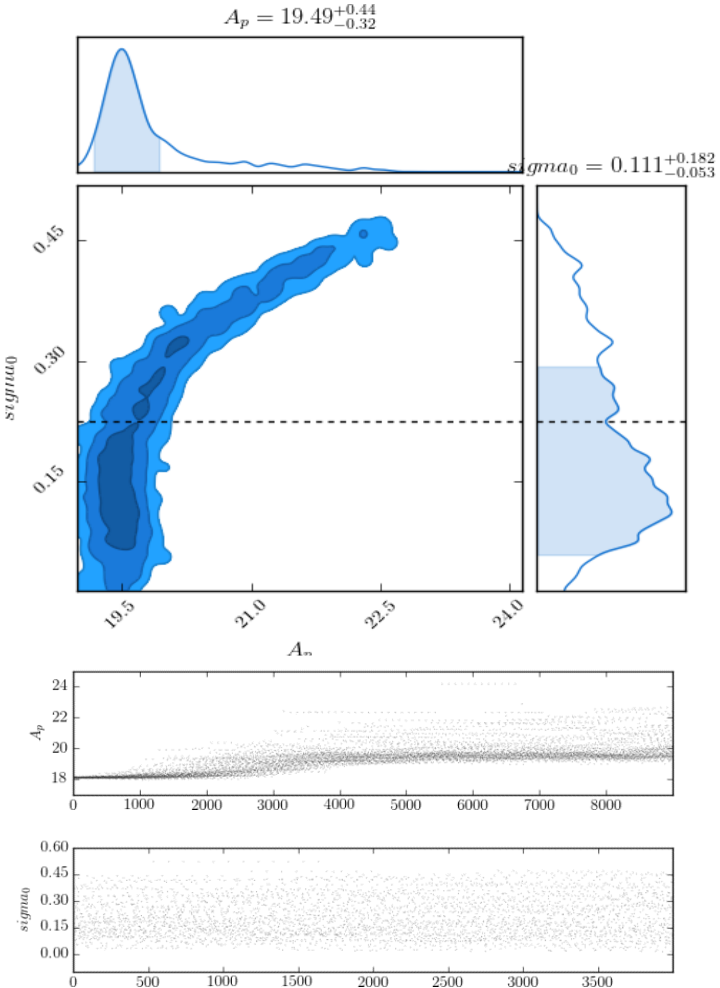
1 and 2 halo terms

ANALYSIS OF PARAMETERS. One halo model fitting of result of one plus two halo MOCK data, using different sets of parameters.

Constraint on A_P

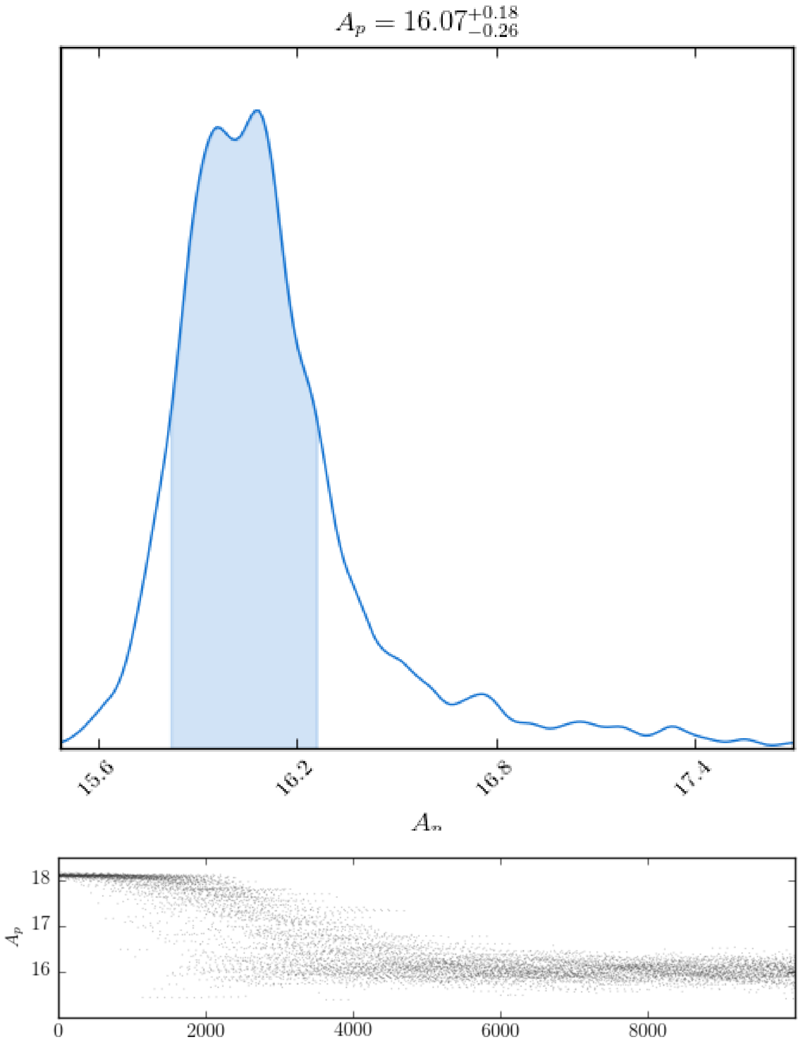


Constraint on A_P and σ_0.

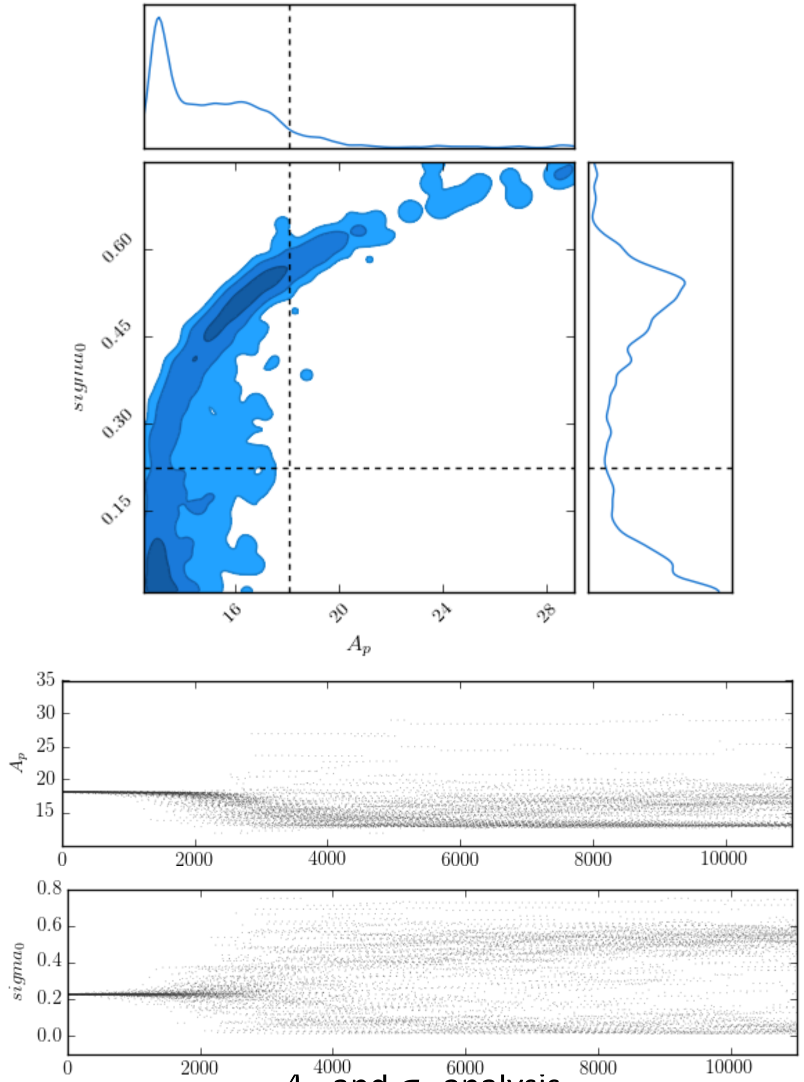


Free parameters	A_P Bias
A_P	22.25 %
A_P and σ_0	8.76 %

ANALYSIS OF PARAMETERS. Constraints from observational data, fitted with the one halo model.



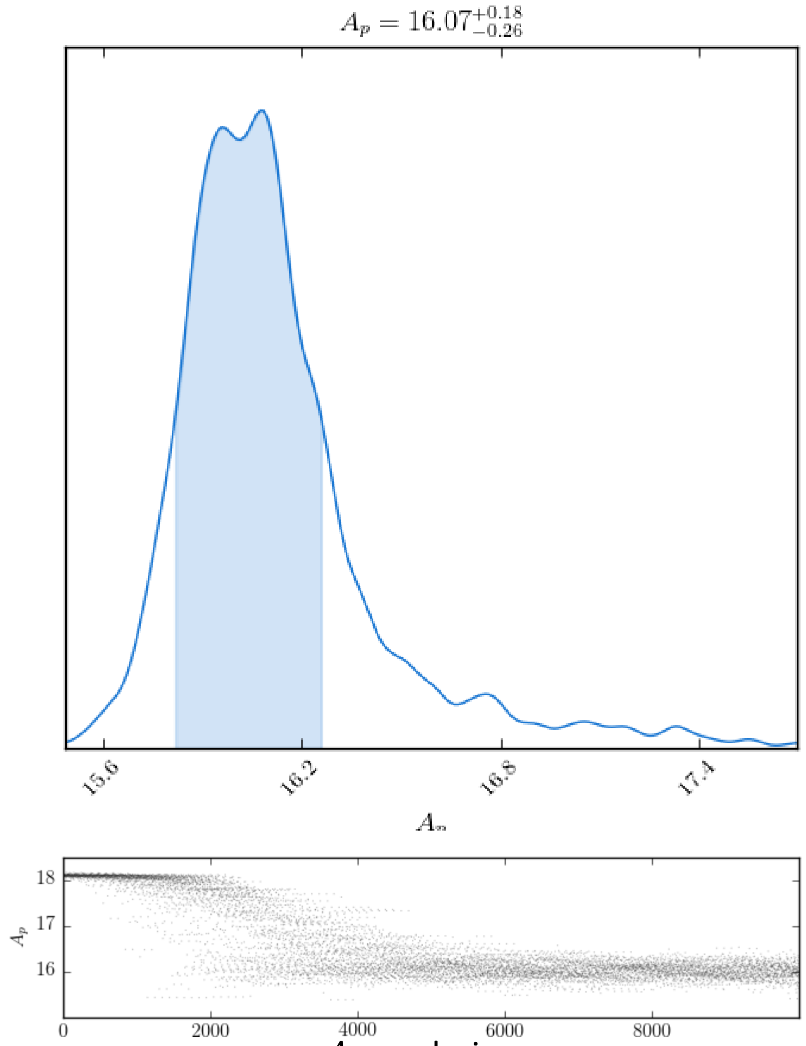
A_P analysis



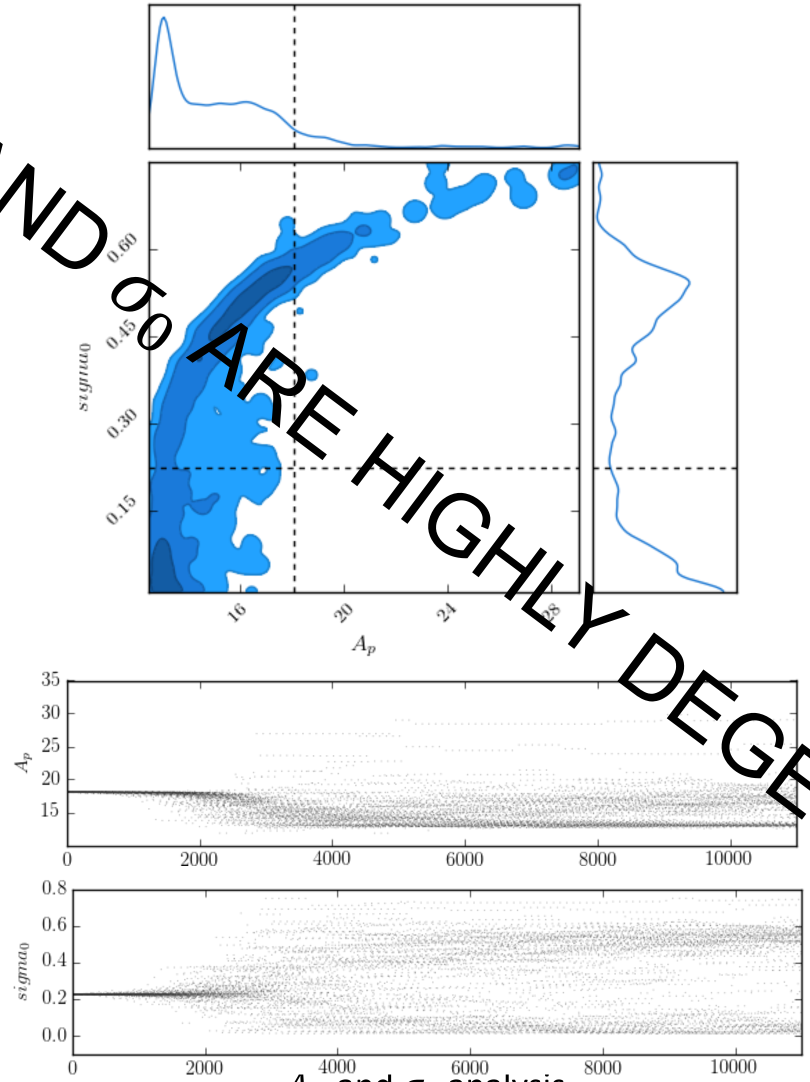
A_P and σ_0 analysis

ANALYSIS OF PARAMETERS. Constraints from observational data, fitted with the one halo model.

A_P AND σ_0 ARE HIGHLY DEGENERATE



A_P analysis



A_P and σ_0 analysis

SUMMARY:

- Can we do parameter estimation?

→ With MOCK data we recover the input value of parameters;

→ Using the observational data in MCMC analysis we get a smaller value of A_P with respect to simulation study;

→ A_P and σ_0 appear degenerate in both analyses;

Future Prospect

Addittional data sets
South Pole Telescope data

Additional parameters
Mass and redshift evolution.

Thank you for your attention !

Reidan Hahn

Fermilab Summer Student 2017

"'We will miss you'" by Derek Plant

As autumn sets in, it is time for many visiting students to return to their universities and homes. Lessons have been learned, experiences had, and friendships made. The youthful exuberance of summer students is always a shot in the arm. Good luck! (everyday objects)