Galaxy cluster population synthesis

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Motivation

Reference: MPA-garching

1) Study systematics
2) Study statistical methods
3) Predictions for upcoming surveys

Outline

Introduction

Halo mass function

Galaxy clusters

Upcoming X-ray survey: eROSITA

Galaxy cluster population synthesis tool

Overview

Methods

Results

Outlook

Halo mass function

Halo

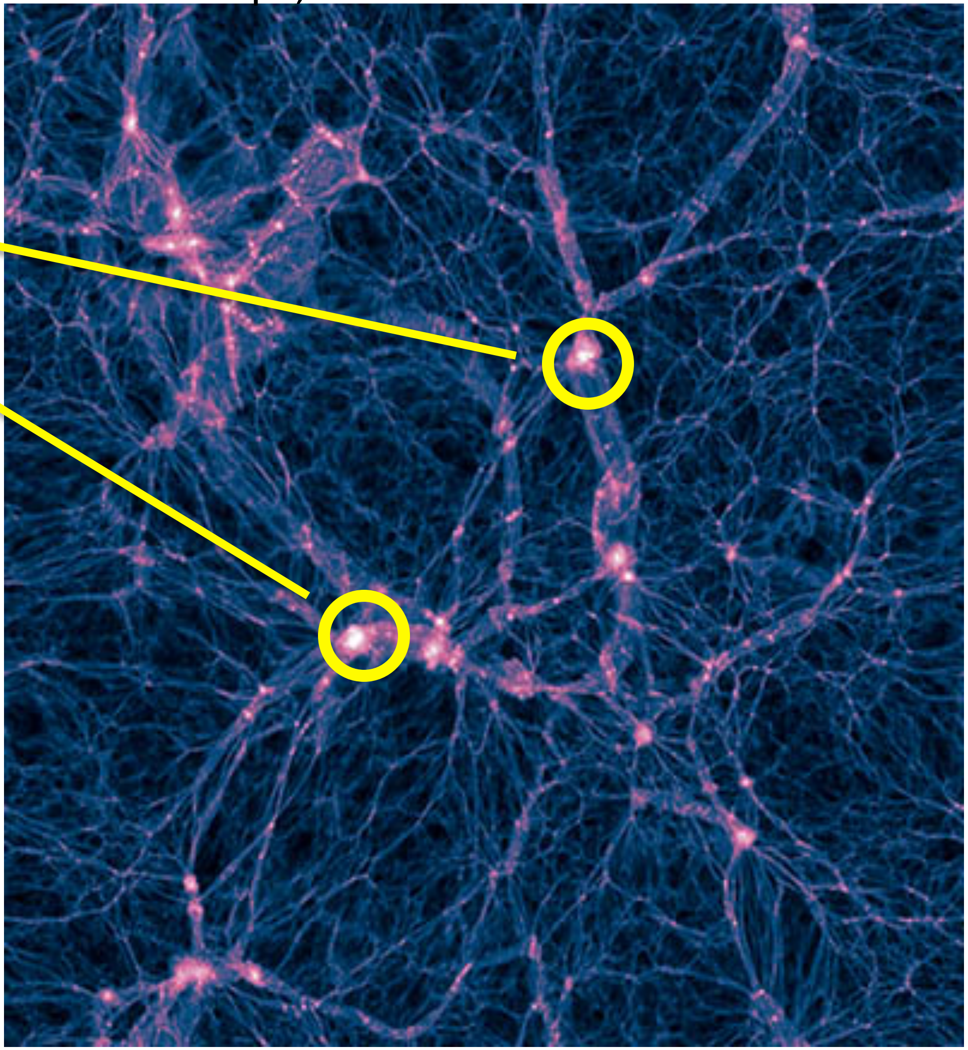
$$\frac{dN}{dV\,dM}$$

Press-Schechter (1974)
Analytical (Spherical Collapse)

This project uses: Tinker (2008)
Callibration (Simulations)

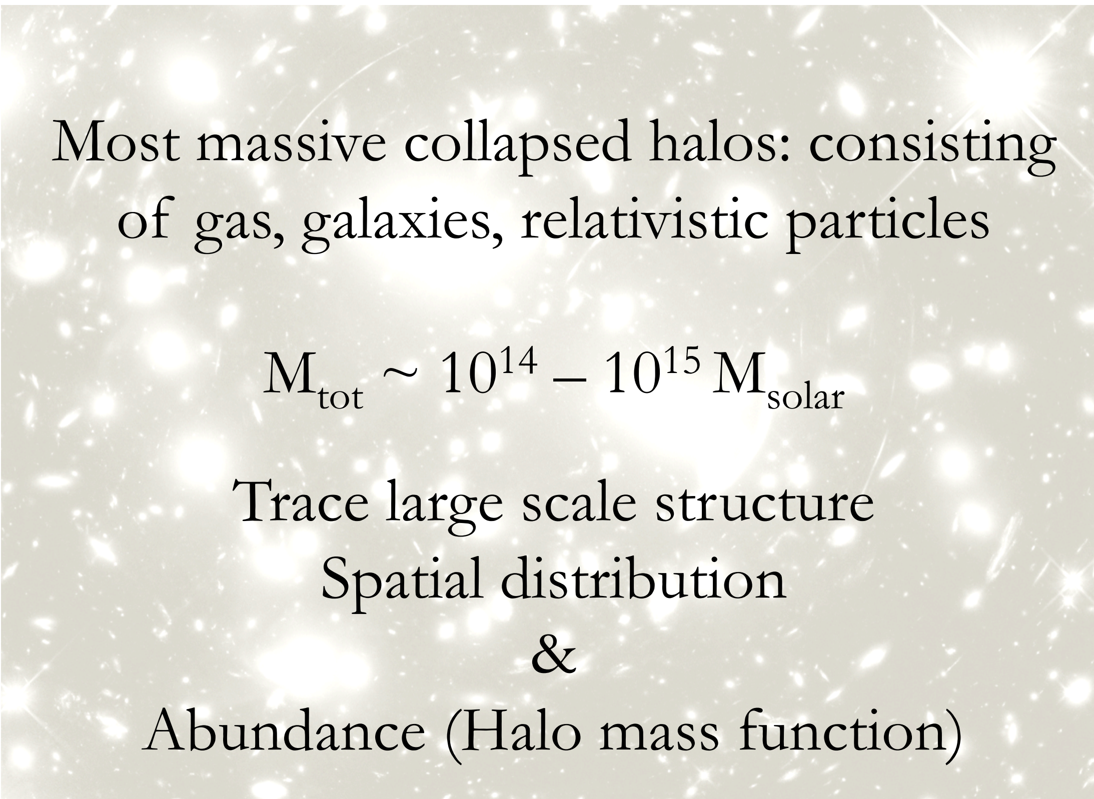
Many others...

L = 106.5 Mpc, z=0



Reference: ILLUSTRIS Simulation

Galaxy clusters



Most massive collapsed halos: consisting of gas, galaxies, relativistic particles

$M_{tot} \sim 10^{14} - 10^{15} M_{solar}$

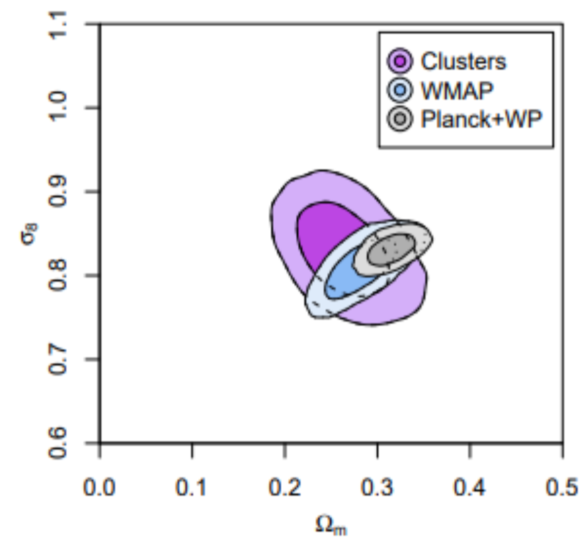
Trace large scale structure

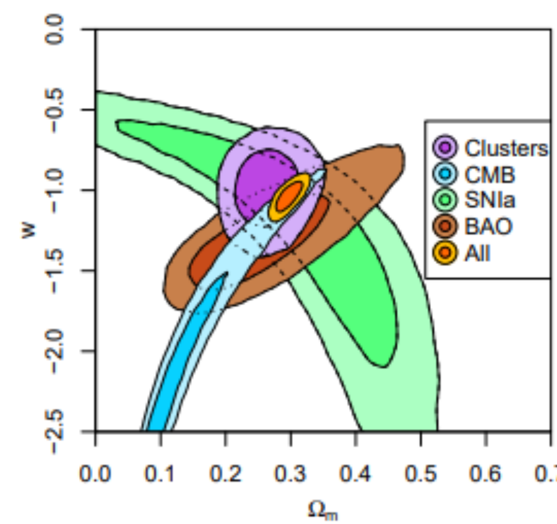
Spatial distribution

&

Abundance (Halo mass function)

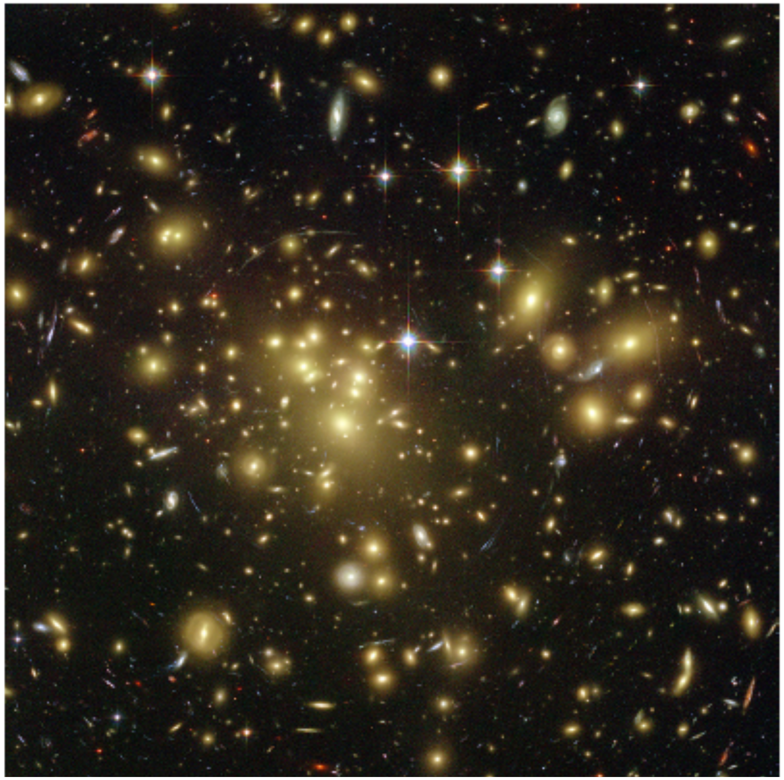
Reference: ABELL 370 apod.nasa.gov/apod/ap170506.html





Reference: Mantz et al (2015)

Galaxy clusters in X-ray



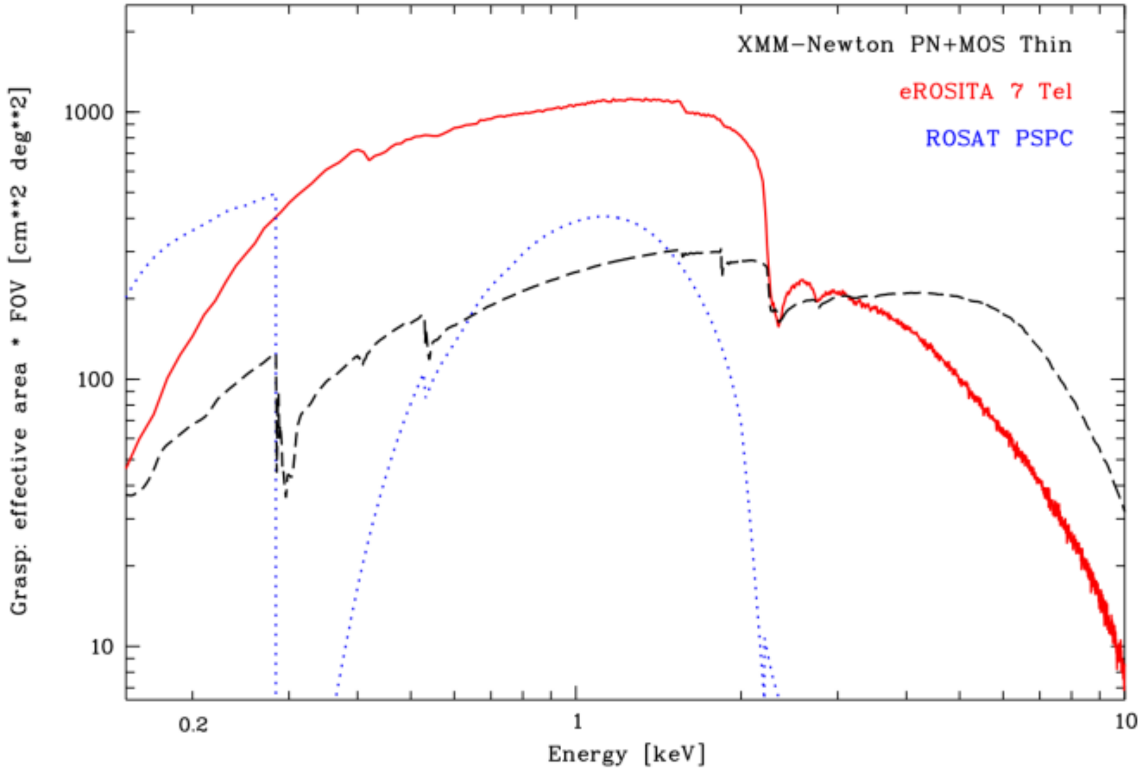

Reference: http://chandra.harvard.edu/photo/2008/a1689/

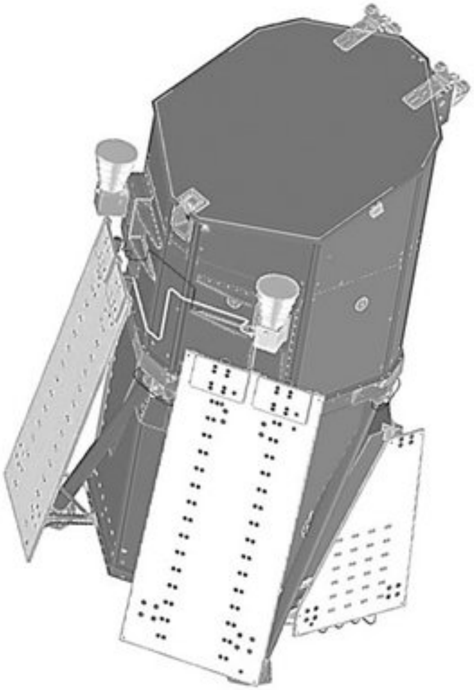
Intra cluster medium (ICM) emit in X-ray : Thermal bremsstrahlung emission

X-ray observable tightly correlated with $M_{cluster}$ → Halo(cluster) mass function

Upcoming X-ray surveys: eROSITA (June 21st 2019)

eROSITA (extended ROentgen Survey with an Imaging Telescope Array)





Reference: eROSITA Science book

Galaxy cluster population synthesis

Scheme

Fast tool (semi-analytic modelling) to create mock Galaxy cluster populations

User selectable:

1) Cosmology
2) Cluster physics
3) Instrumental selection effects

Purpose

Public tool for future users

Cosmological constraints from

1) Scaling relations of X-ray properties
2) Cluster mass function

Correction of selection bias

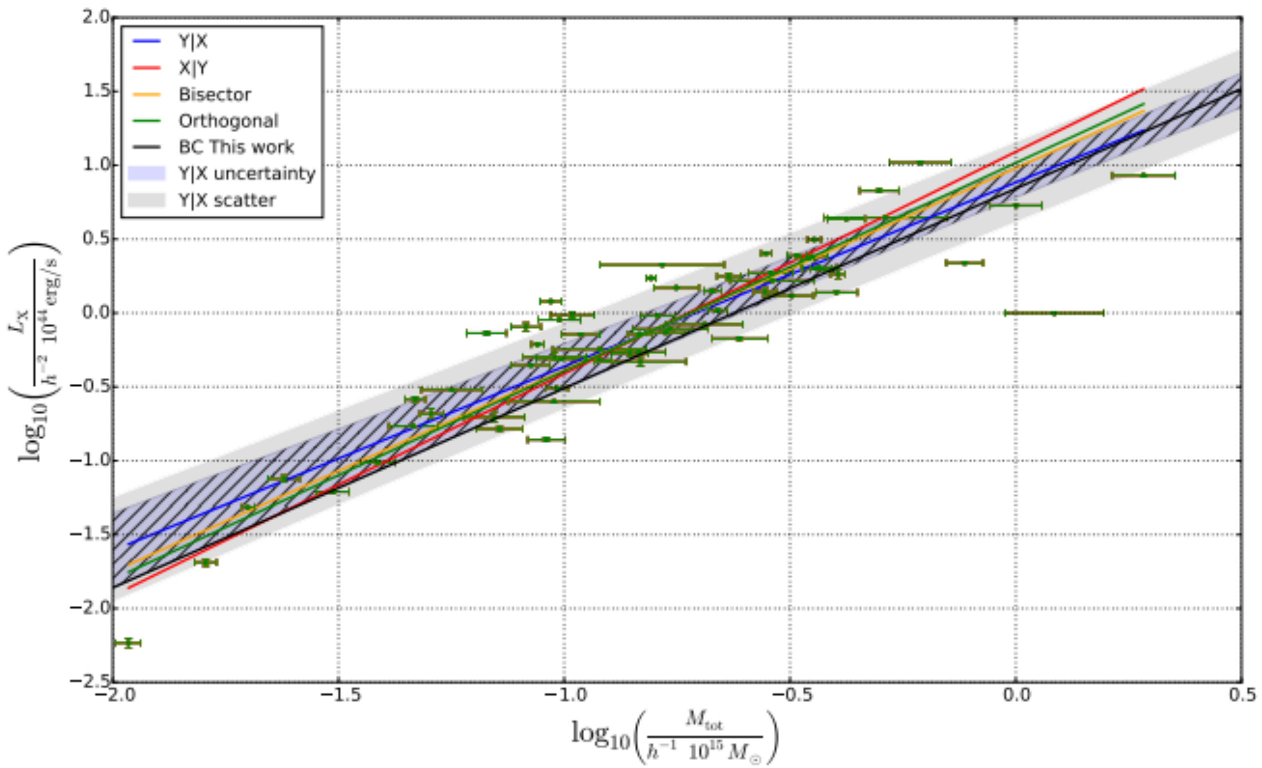
1) Flux-limited sample
2) X-ray counts-limited sample
3) Volume-limited sample

Overview

Cosmology → Abundance $\frac{dN}{dVdM}$ → **Cluster Population** f (M,z)

↓

Scaling Relations
$L_x - M$, $T - M$,
$Y_{comp} - M$



Reference: Schellenberger et al. (2017)

Overview

Cosmology →

Abundance
$$\frac{dN}{dV\,dM}$$

→

<u>Cluster Population</u>

f (M,z)

↓

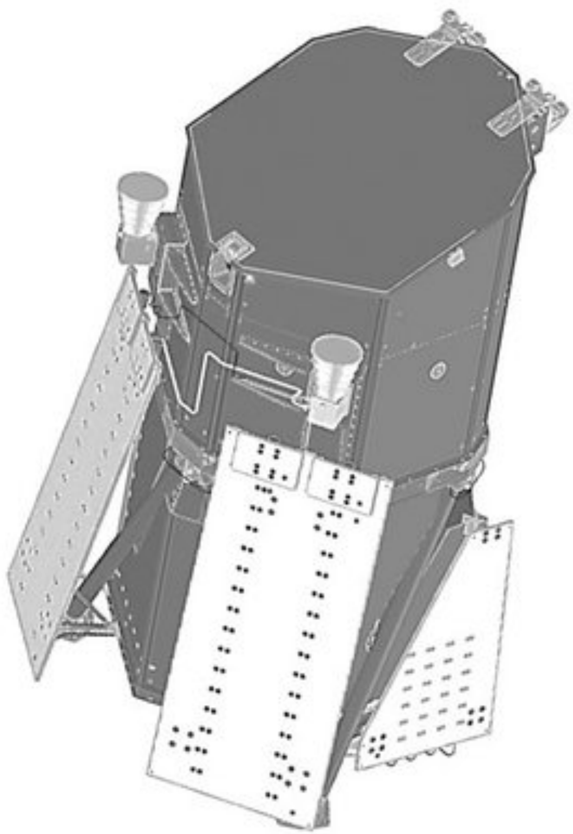
<u>Scaling Relations</u>

$L_x - M$, $T - M$,

$Y_{comp} - M$

←

eROSITA



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<u>Mock Catalog</u>

X-ray Flux

Count-rates

Methods: Selecting Cosmology

Cosmology

Initial Cosmology

H_0	100.0 h km/s/Mpc
$\Omega_m(0)$	0.270
$\Omega_b(0)$	0.047
$\Omega_{DE}(0)$	0.730
$T_{CMB}(0)$	2.73 K

Mass function parameters

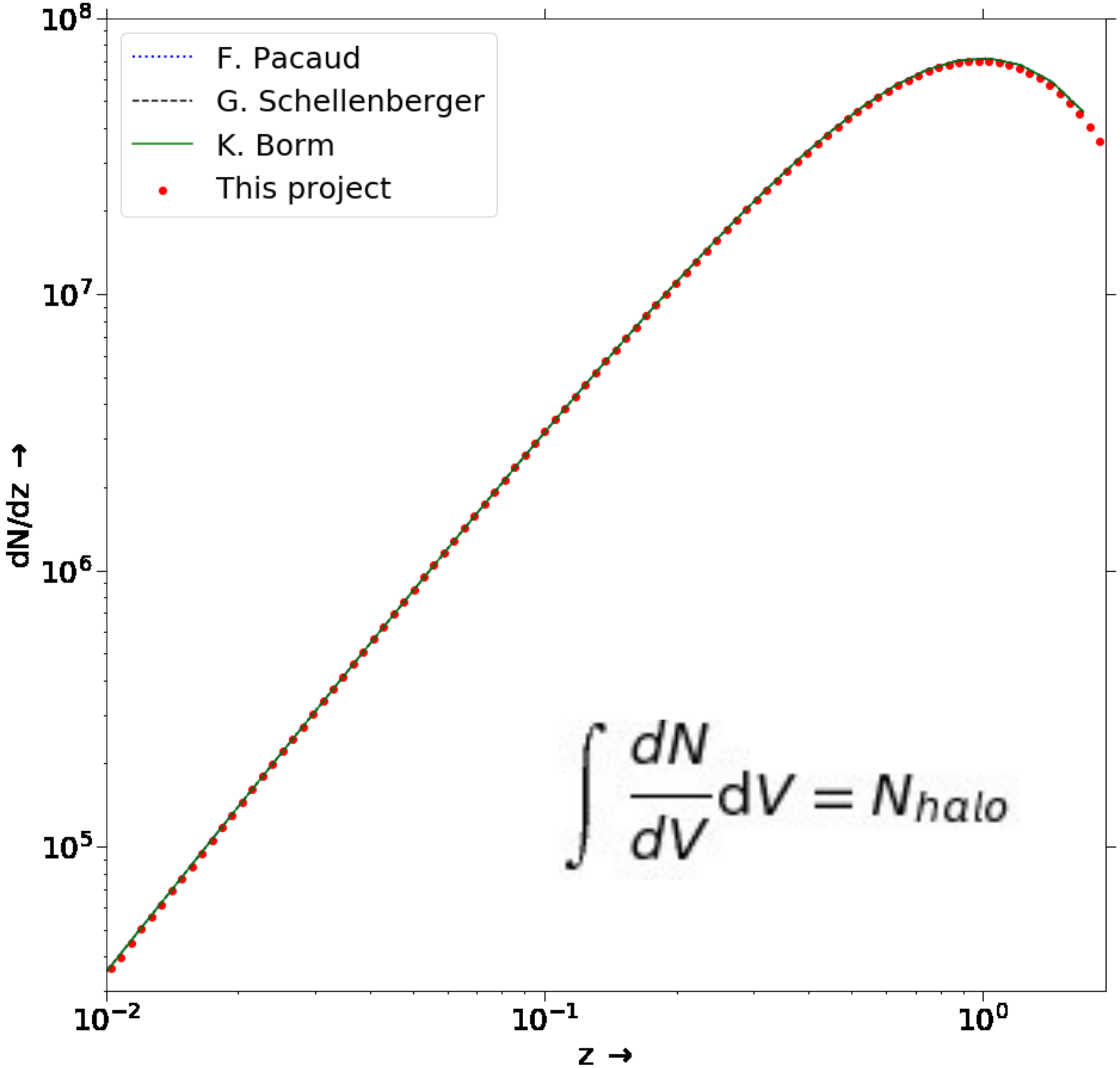
HMF Model	Tinker (2008)
Δ_{halo}	500
Δ_{halo} w.r.t	Critical density
$M_{min}(0)$	$10^{13} M_{\odot}/h$
$M_{max}(0)$	$10^{15} M_{\odot}/h$

$$\int \frac{dN}{dV\,dM}\,dM = \frac{dN}{dV}$$

$$\int \frac{dN}{dV}\,dV = N_{halo}$$

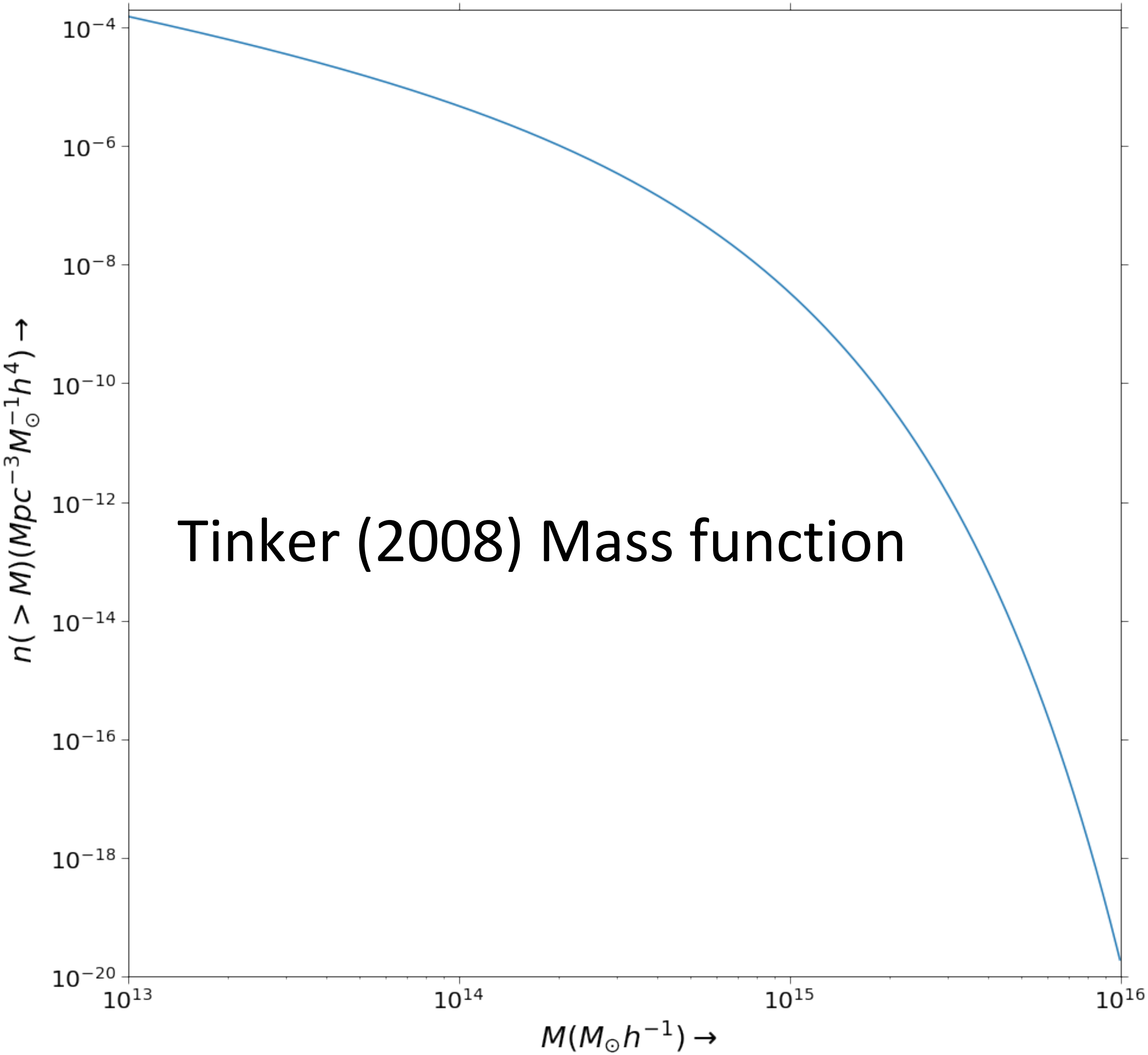
Reference: Murray, Power and Robotham (2013)

Methods: Number of halos

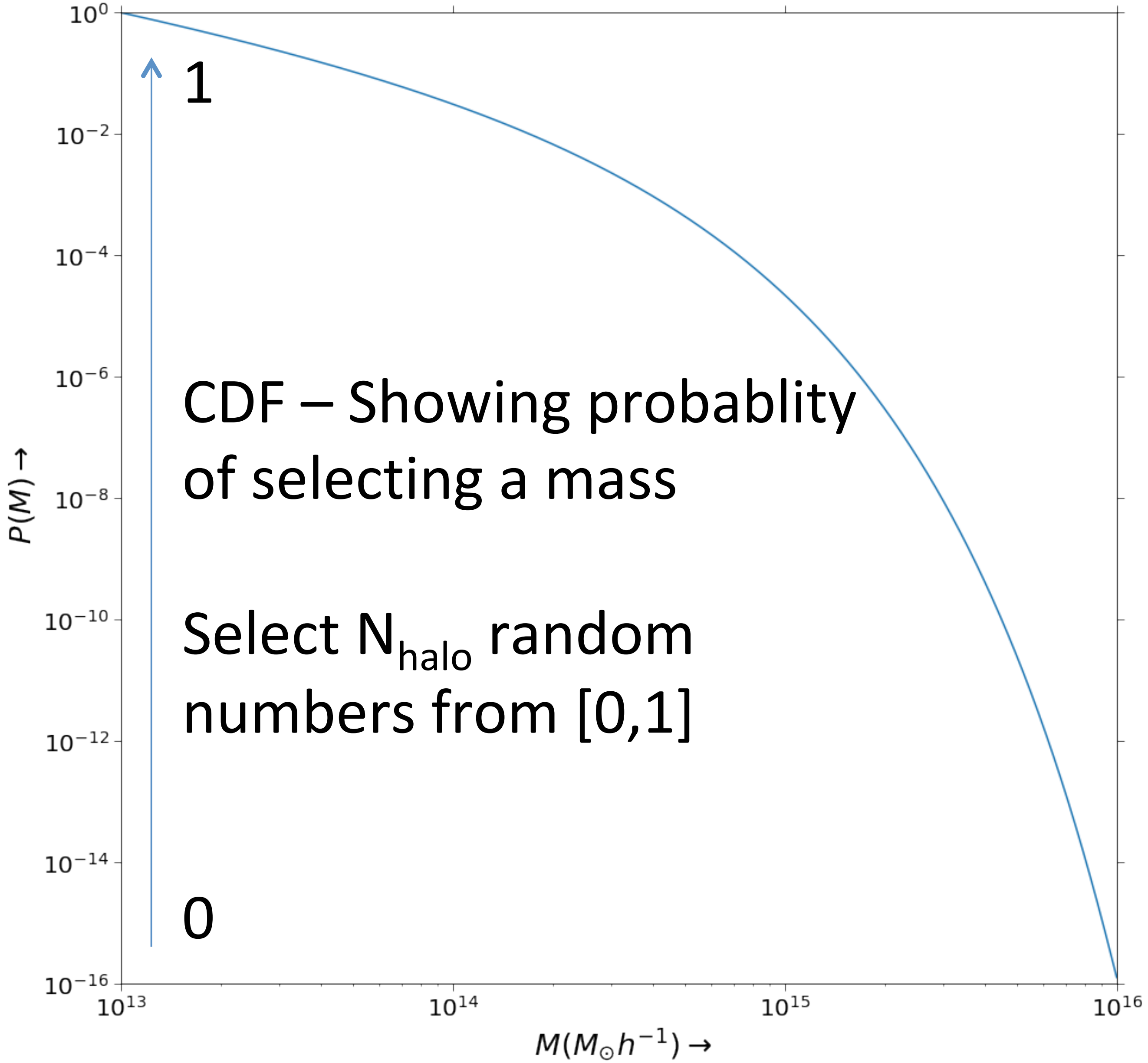


Total N_{halo}
$z[0,3] \sim 10^7$

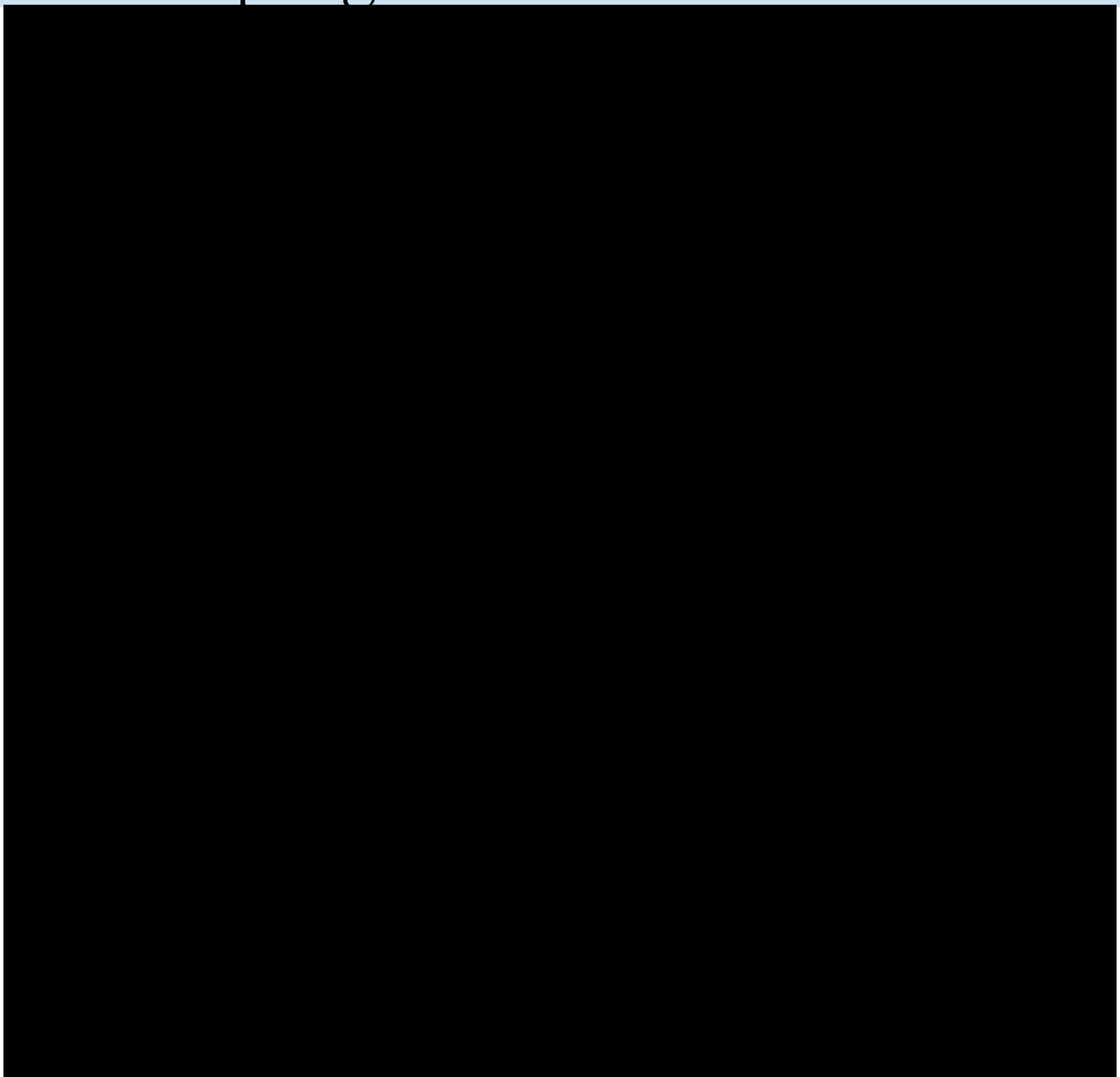
Methods: Sampling masses



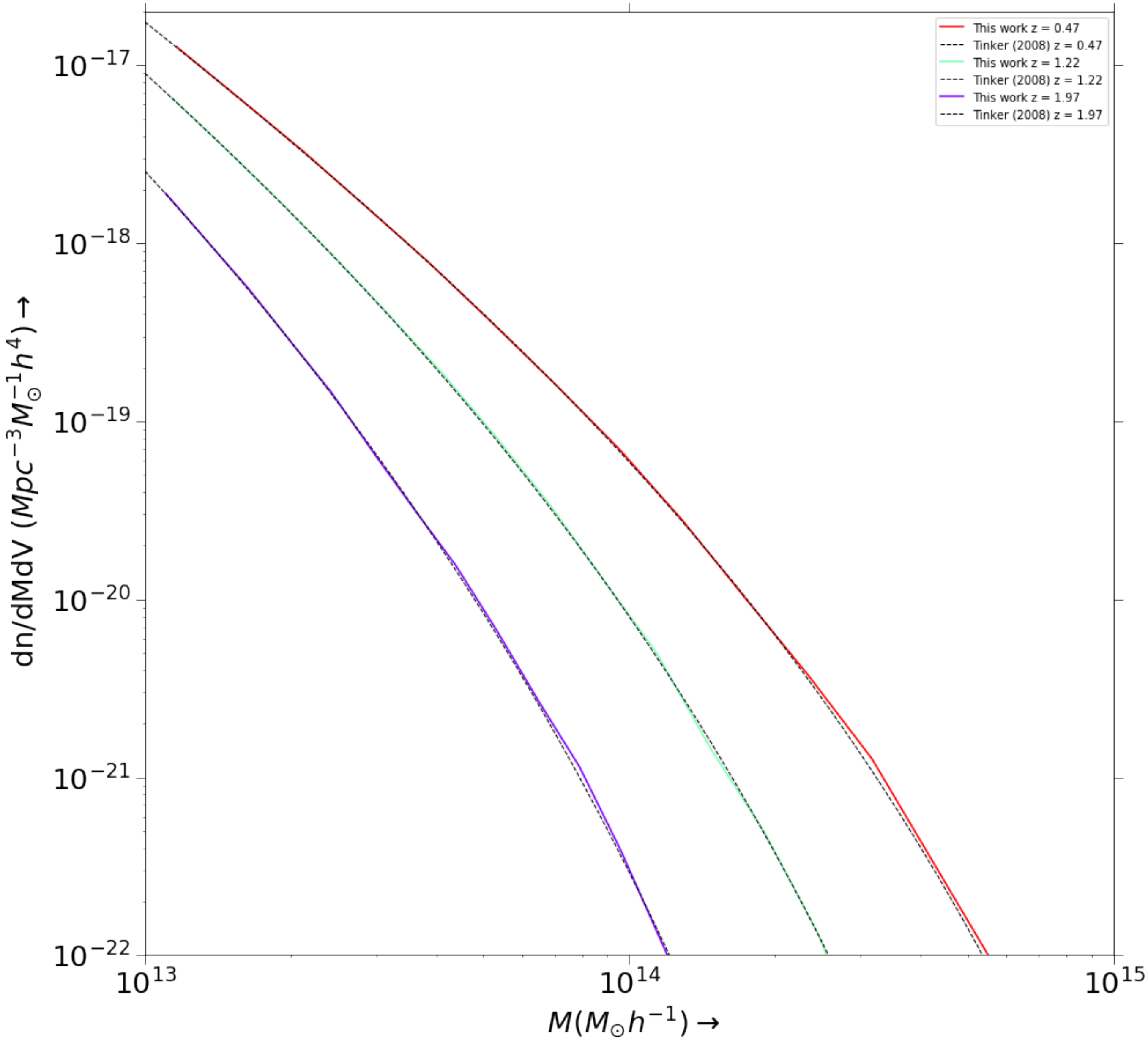
Methods: Sampling masses



Methods: Sampling masses



Results: Mass function from generated sample



Methods: Scaling relations

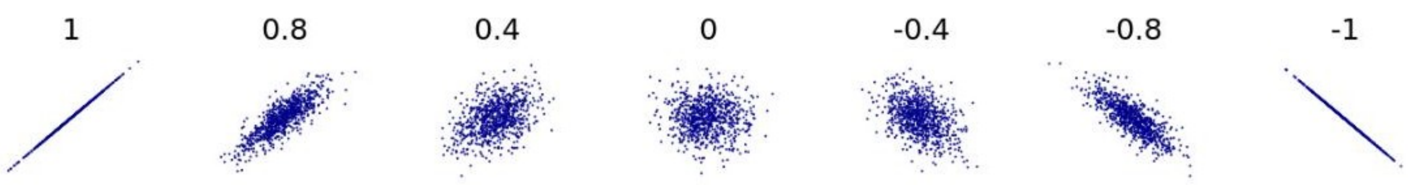
$L_x - M$ — **G. Schellenberger et al (2017)**

$M - T$ — **L. Lovisari et al. (2015)**

$Y_{comp} - M$ — **Planck (2013)**

Correlation factor

r_{X_i,X_j}



Reference: Wikipedia

Methods: Instrument response

Simulate X-ray Spectrum

APEC (**Astrophysical Plasma Emission Code**) Model:
X-ray emission spectrum Model

Xspec

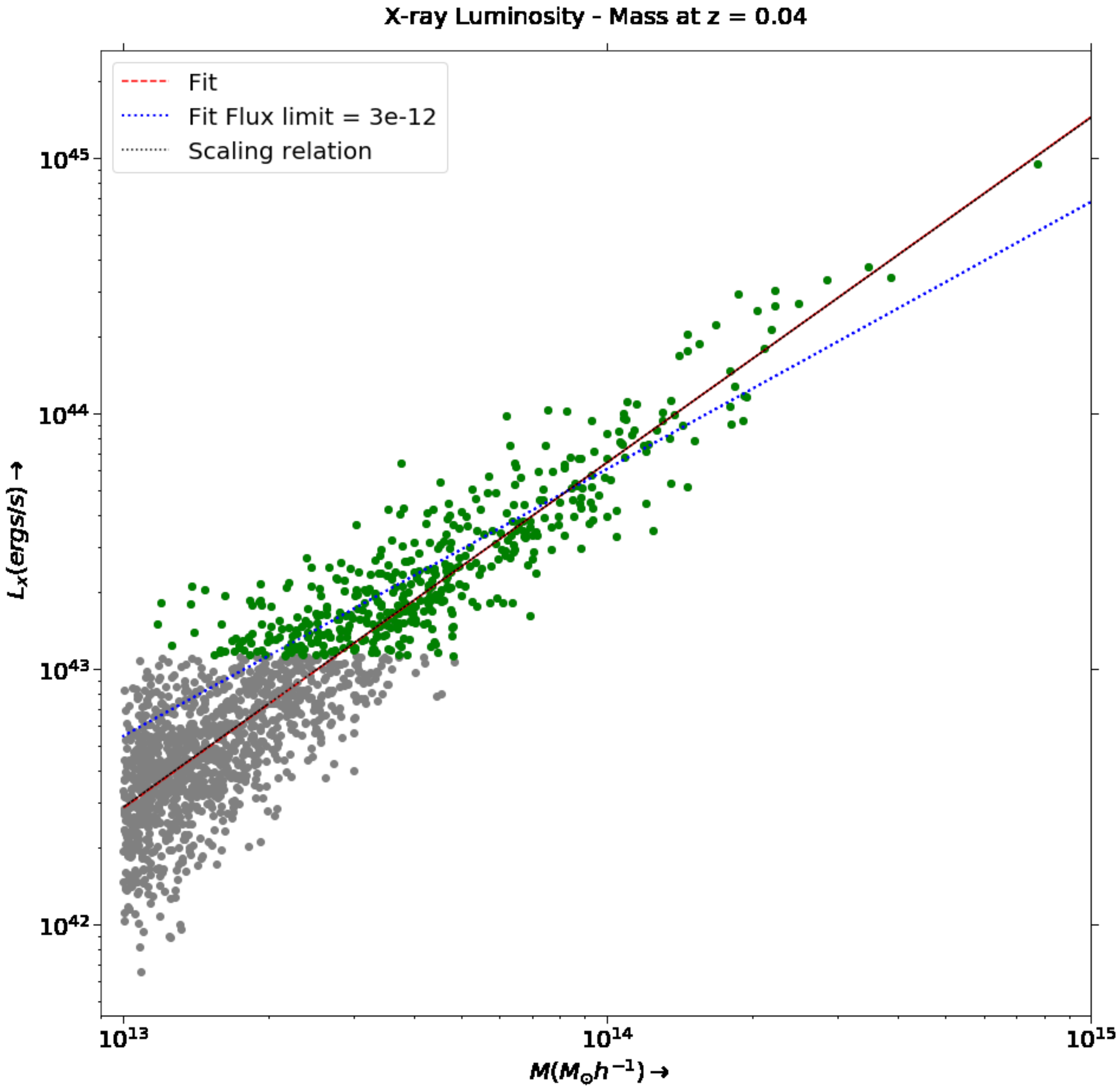
Reference: Arnaud, K.A., 1996

<u>For X-ray spectrum model fitting</u>
Temperature
z (redshift)
Metal abundance
Normalization

<u>Response:</u>
Effective area,
Spectral response: efficiency of detection in every energy bands

<u>Mock Catalog</u>
X-ray Flux
Count-rates

Results: Scaling relations



Results: Flux-limited samples

Using different selection criteria
&
Comparing with previous samples of clusters

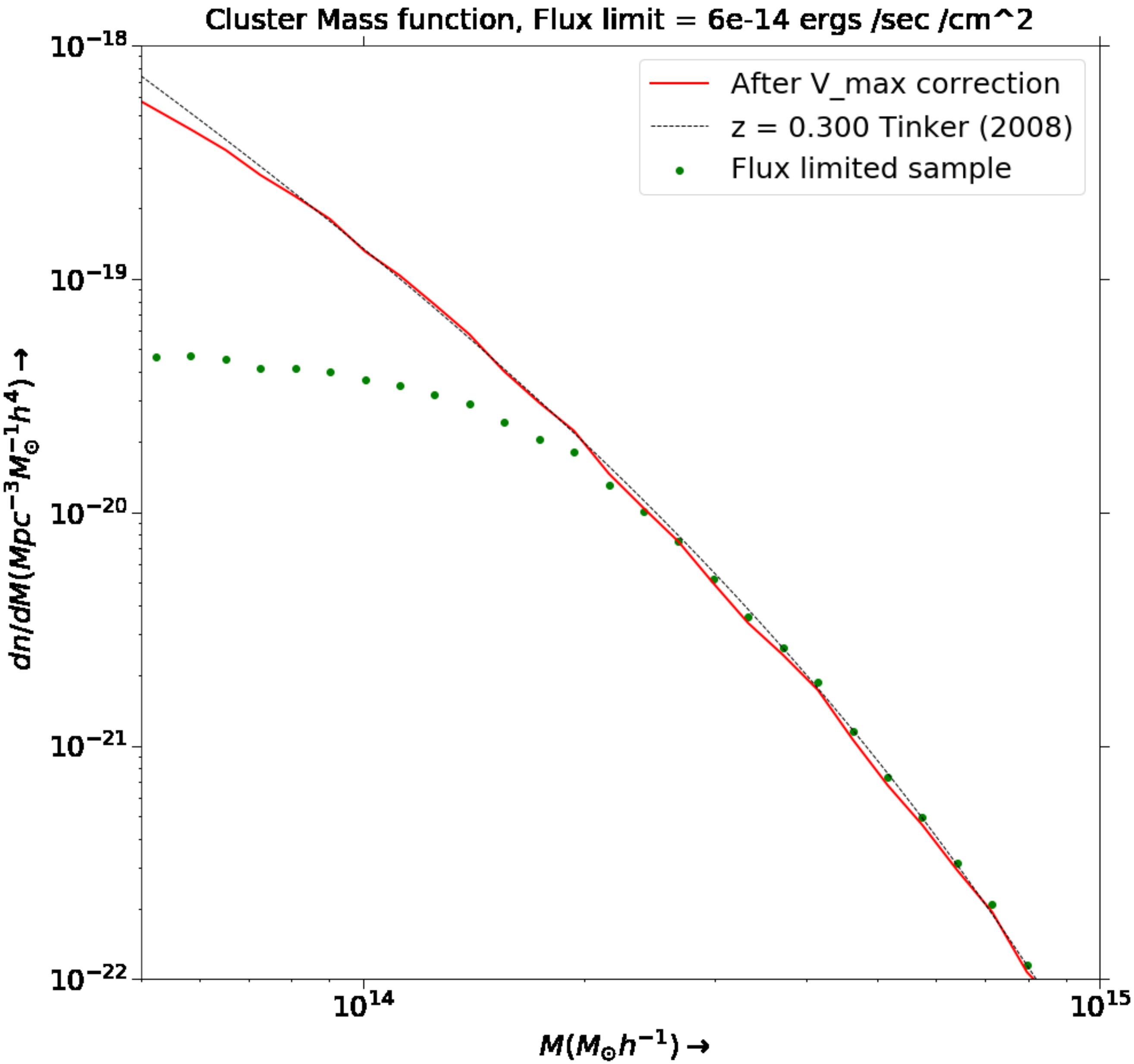
Sample	Selection	Sky coverage	WMAP - 9 Cosmology (Zandanel et al. 2018)	This work
HiFluGCS (Reiprich & Bohringer 2002)	$f_x(0.1-2.4keV) \geq 2.0 \times 10^{-11} ergs/s/cm^2$	0.650	109	164
REFLEX (Bohringer et al. 2001)	$f_x(0.1-2.4keV) \geq 3.0 \times 10^{-12} ergs/s/cm^2$	0.340	632	977
eROSITA $M_{500} \geq 1 \times 10^{13} h^{-1}_{cosmo} M_{\odot}$	cts (0.5 - 2 keV) $\geq 50, t_{obs} = 1.6ks$	0.658	135132	328458
eROSITA $M_{500} \geq 5 \times 10^{13} h^{-1}_{cosmo} M_{\odot}$	cts (0.5 - 2 keV) $\geq 50, t_{obs} = 1.6ks$	0.658	95882	145857
eROSITA $M_{500} \geq 1 \times 10^{14} h^{-1}_{cosmo} M_{\odot}$	cts (0.5 - 2 keV) $\geq 50, t_{obs} = 1.6ks$	0.658	66017	55445

Outlook

1) Simulate Galaxy cluster catalog ~ 4hrs
2) Maximum – likelihood method for flux-limited sample correction of L-M relation
3) V_{max} method for flux-limited sample correction of mass function
4) Python module – Public tool for future users

Thank you for your attention!

Results: Mass function



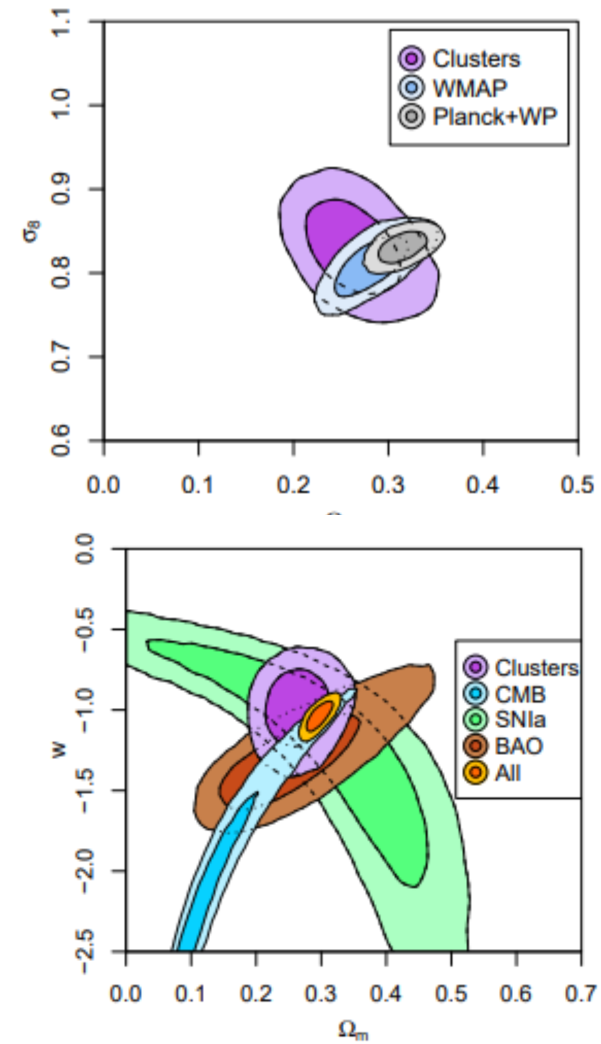
Cluster constraints

Planck + WP : Planck +WMAP polarization data

CMB: WMAP 9

SNIa: Suzuki et al 2012

BAO: data from the combination of results from the 6-degree Field Galaxy Survey (6dF; z = 0.106; Beutler et al. 2011) and the Sloan Digital Sky Survey (SDSS, z = 0.35 and 0.57; Padmanabhan et al. 2012; Anderson et al. 2014)



Reference: Mantz et al (2015)

Methods: Vmax

- Needed to correct for bias that fainter clusters(lower masses) have smaller surveyed volume as compared to brighter clusters

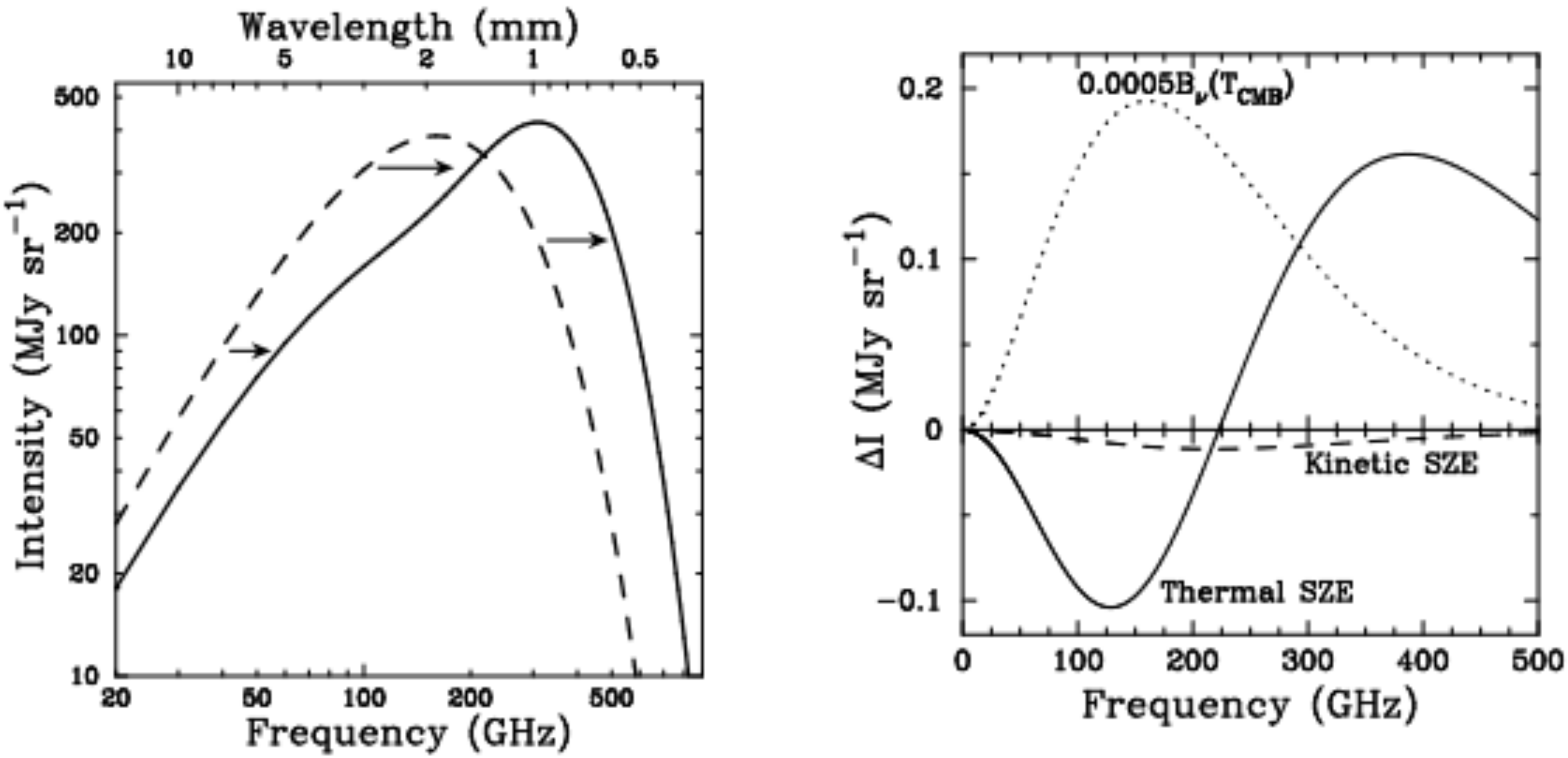
- Find the largest distance at which a cluster with given luminosity and a given mass M can be observed accounting for the flux limit.

- Volume of the sample corresponding the distance is Vmax. This is the volume available for the cluster. The cluster could have been anywhere inside the volume.

- Select all clusters with masses in the range (M,M+dM). An estimate of the mass function is:

- $\Phi(M)dM = \sum[1/V_{max}(i)]$

SZ effect

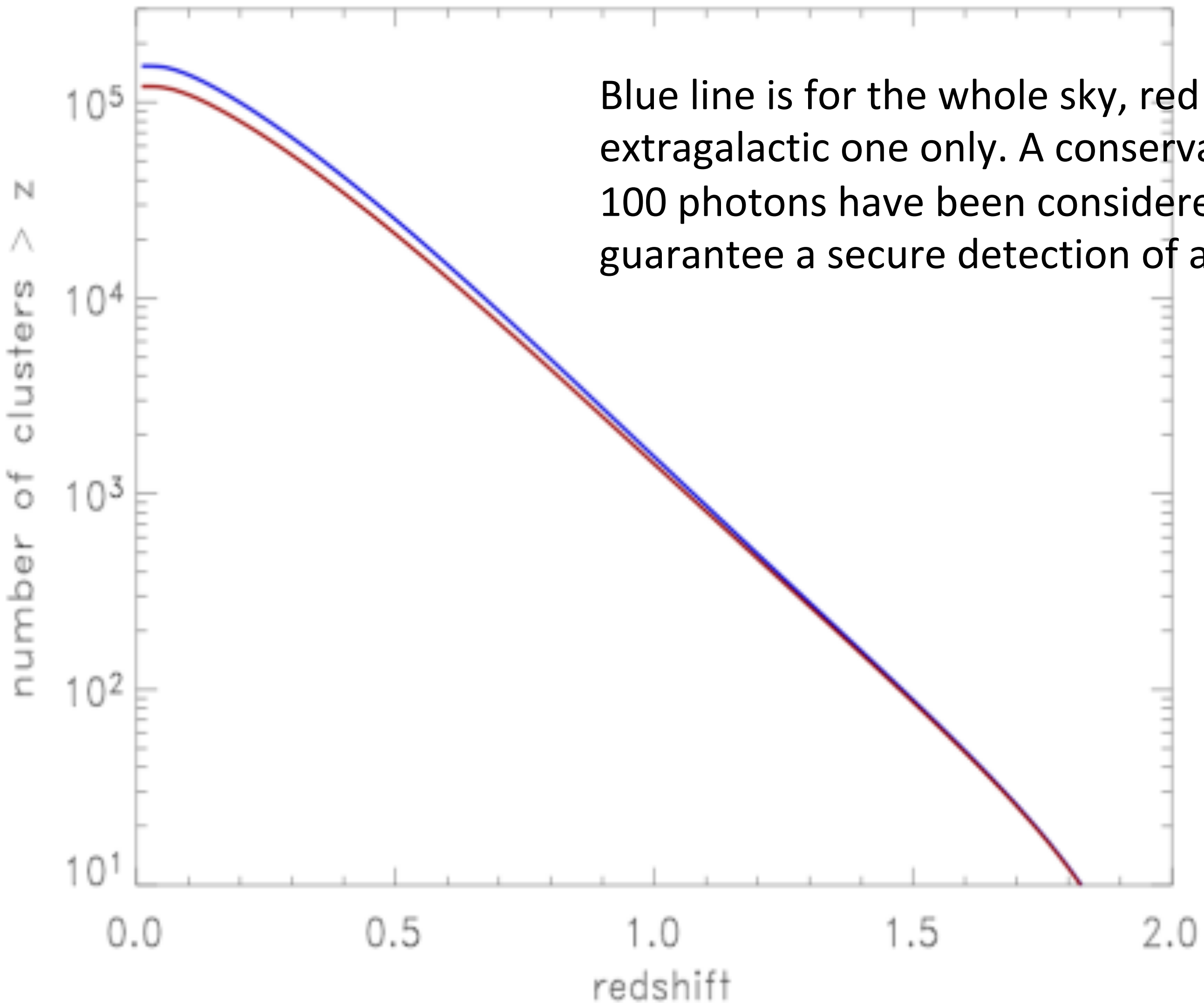


(a) Undistorted CMB spectrum (dashed) and CMB spectrum distorted by the presence of a cluster (solid). Note that the effect is dramatically exaggerated for illustrational purposes.

(b) Spectral distortion of the CMB by the SZ effect. The net effect of the thermal SZ effect vanishes at a characteristic frequency of ~ 218GHz.

Figure 1.10 Illustration of the Sunyaev-Zel'dovich effect as shown in Carlstrom et al. (2002).

eROSITA (100,000 clusters)



Blue line is for the whole sky, red for the extragalactic one only. A conservative limit of 100 photons have been considered in order to guarantee a secure detection of a cluster

Reference: eROSITA Science book

Methods: Number of halos

Abundance

$$\int \frac{dN}{dVdM} dM = \frac{dN}{dV}$$

Reference: Murray, Power and Robotham (2013)

$$D_H = \frac{c}{H_0} = 3000 h^{-1}_{cosmo} Mpc$$

$$\Omega_0 = \Omega_m + \Omega_r + \Omega_{DE}$$
$$\Omega_k = 1 - \Omega_0$$

$$E(z) \equiv \sqrt{\Omega_m (1+z)^3 + \Omega_k (1+z)^2 + \Omega_{DE}}$$

$$D_C = D_H \int_0^z \frac{dz'}{E(z')}$$

$$D_M = \begin{cases} D_H \frac{1}{\sqrt{\Omega_k}} sinh[\sqrt{\Omega_k} \frac{D_C}{D_H}] & \Omega_k > 0 \\ D_C & \Omega_k = 0 \\ D_H \frac{1}{\sqrt{|\Omega_k|}} sin[\sqrt{|\Omega_k|} \frac{D_C}{D_H}] & \Omega_k < 0 \end{cases}$$

$$D_A = \frac{D_M}{(1+z)}$$

$$dV = D_H \frac{(1+z)^2 D_A^2}{E(z)} d\Omega dz$$

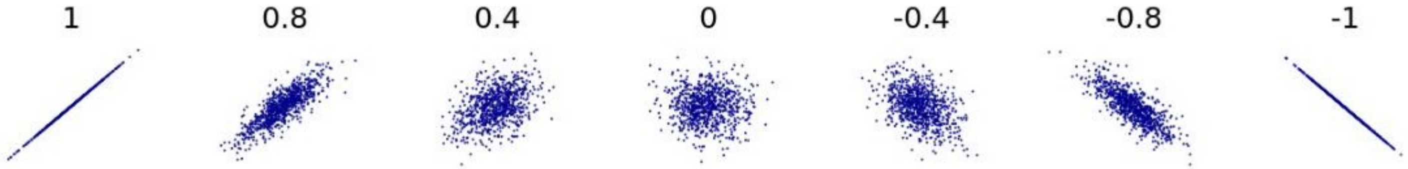
$$\int \frac{dN}{dV} dV = N_{halo}$$

Methods: Scaling relations – Correlation [L_x, T, Y_{comp}]

$$\vec{X} = (L, Y_{comp}, T)^T$$
$$\vec{\mu} = E[\vec{X}]$$
$$\Sigma_{i,j} =: E[(X_i - \mu_i)(X_j - \mu_j)] = Cov[X_i, X_j]$$

$$Cov[X_i, X_i] = E[(X_i - \mu_i)(X_i - \mu_i)] = E[(X_i - \mu_i)^2] = \sigma^2_{X_i}$$
$$Cov[X_i, X_j] = r_{X_i,X_j} \cdot \sigma_{X_i}\sigma_{X_j}$$

Correlation factor r_{X_i,X_j}



$$\begin{bmatrix} \sigma^2_{L}x(M,z) & r_{L_x,Y_{comp}} \cdot \sigma_{L_x}(M,z) \cdot \sigma_{Y comp} & r_{L_x,T} \cdot \sigma_{L_x}(M,z) \cdot \sigma_T \\ r_{L_x,Y_{comp}} \cdot \sigma_{L_x}(M,z) \cdot \sigma_{Y_{comp}} & \sigma^2_{Y_{comp}} & r_{Y_{comp},T} \cdot \sigma_{Y_{comp}} \cdot \sigma_T \\ r_{L_x,T} \cdot \sigma_{L_x}(M,z) \cdot \sigma_T & r_{Y_{comp},T} \cdot \sigma_{Y_{comp}} \cdot \sigma_T & \sigma^2_T \end{bmatrix}$$

Methods: Scaling relations

$L_x - M$ **G. Schellenberger et al (2017)**

Scatter evolution

$$\sigma_{intr} = 0.25$$

$$\sigma(M,z) = \sigma_0 \cdot \left[1 + log_{10}\left(\frac{M}{M_{pivot}}\right)\right]^{\beta} \cdot (1+z)^{\alpha}$$

$$M_{pivot} = 10^{13} M\odot$$

$M - T$ **L. Lovisari et al. (2015)**

$Y_{comp} - M$ **Planck (2013)**

Methods: Scaling relations – Correlation [L_x, T, Y_{comp}]

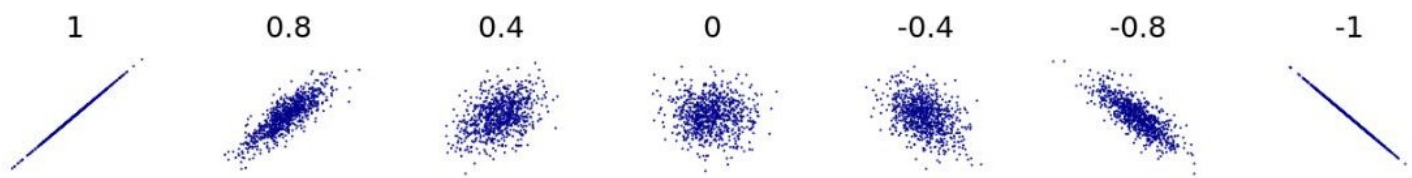
Covariance

$$Cov[X_i, X_j] = r_{X_i,X_j} \cdot \sigma_{X_i}\sigma_{X_j}$$

$$\begin{bmatrix} \sigma^2_{L_x}(M,z) & r_{L_x,Y_{comp}} \cdot \sigma_{L_x}(M,z) \cdot \sigma_{Y_{comp}} & r_{L_x,T} \cdot \sigma_{L_x}(M,z) \cdot \sigma_T \\ r_{L_x,Y_{comp}} \cdot \sigma_{L_x}(M,z) \cdot \sigma_{Y_{comp}} & \sigma^2_{Y_{comp}} & r_{Y_{comp},T} \cdot \sigma_{Y_{comp}} \cdot \sigma_T \\ r_{L_x,T} \cdot \sigma_{L_x}(M,z) \cdot \sigma_T & r_{Y_{comp},T} \cdot \sigma_{Y_{comp}} \cdot \sigma_T & \sigma^2_T \end{bmatrix}$$

Correlation factor

$$r_{X_i,X_j}$$



Reference: Wikipedia