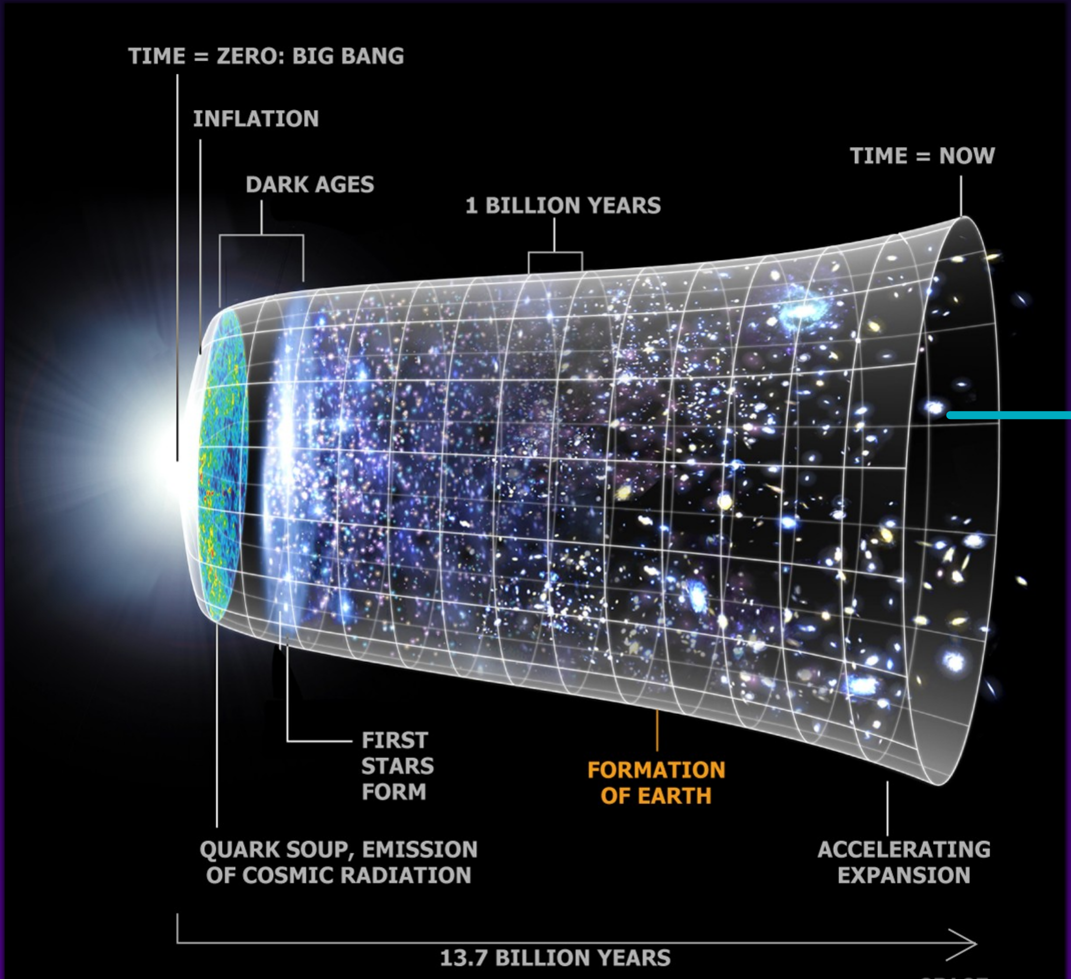
COS – Halo Mass Function mapping and cosmological parameters constraints

Théo Gayoux, LUTh

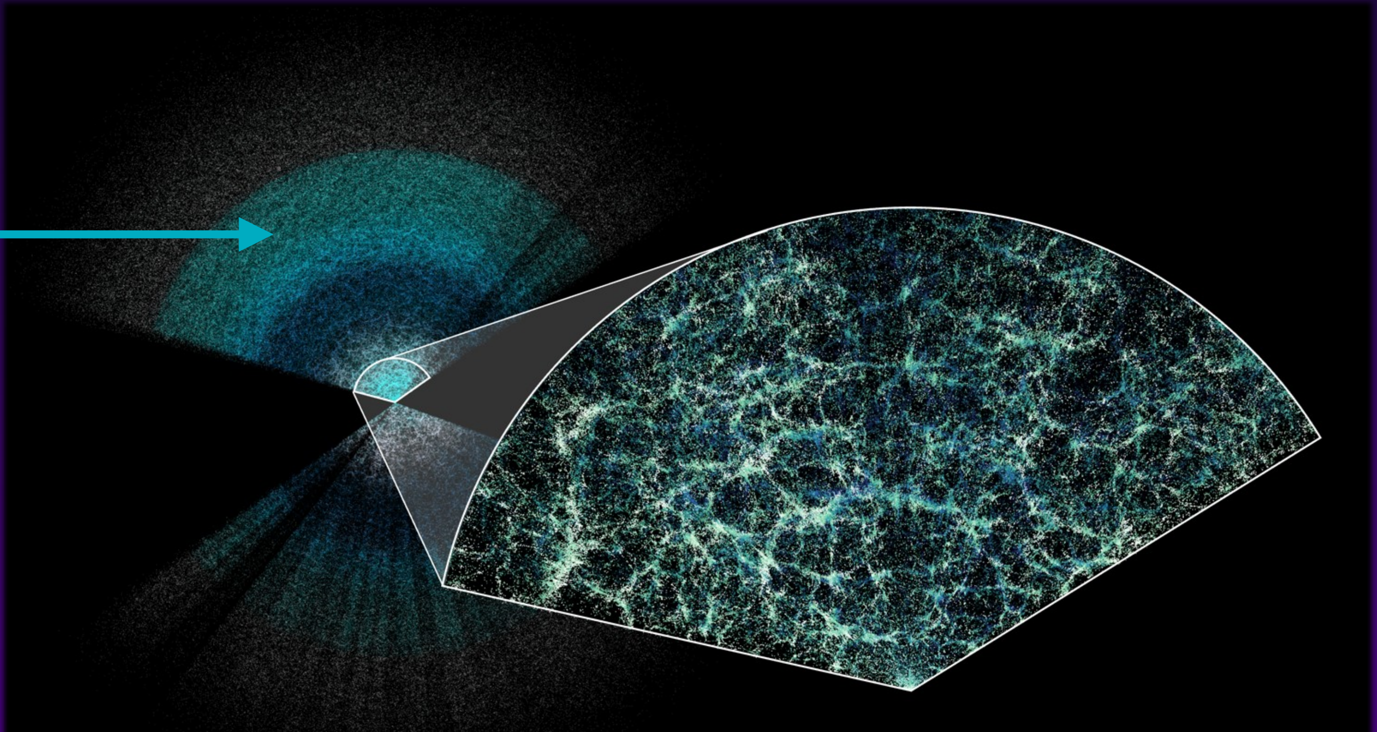
1) Cosmological Context

Standard cosmological model : ΛCDM (Λ : *Dark Energy*, CDM : *Cold Dark Matter*)



NASA/ LAMBDA Archive / WMAP Science Team

Galaxies trace cosmic filaments, cosmic voids and the most massives structures : ***Galaxy Clusters***



Claire Lamman/DESI collaboration

1) Galaxy clusters

Properties :

→ Largest structures gravitationnaly virialized in the Universe ($M > 10^{14} M_{\odot}/h$)

→ Multicomponent systems : **Dark Matter (~85%) & Baryons**

→ Abundance very sensitive to cosmological parameters

Origin :

→ Gravitational collapse of the largest overdensities in the primordial density field

→ Hierarchical structure formation

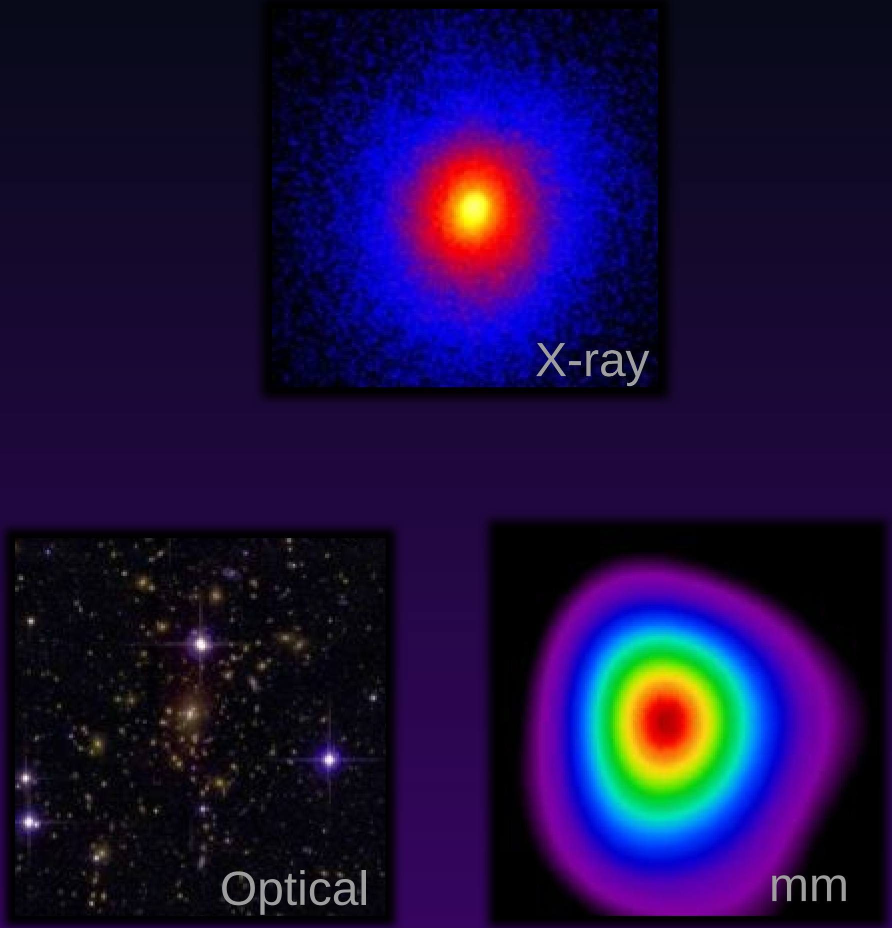
Multimessenger probes :

→ X-ray : **hot gas**

→ Optical and near-IR Wavelength : **galaxies**

→ High masses : **Gravitational lensing**

→ Millimeter : **Sunyaev-Zeldovich (SZ) effect**



Images of Abell 1835 (z = 0.25)

Cosmological surveys:
eROSITA
DESI
LSST
Euclid

1) Cosmology with Galaxy Clusters survey

- **Cluster counts:** Number of clusters of a given observable X and z within the survey area

$$\frac{dN(X;z)}{dX\,dz} = \frac{dV}{dz} f(X,z) \int_0^\infty \frac{dn(M,z)}{dM} \frac{dp(X|M,z)}{dX} dM$$

$\frac{dV}{dz}$ **Volume of the survey**

$p(X|M,z)$ **Probability** of X given its true mass M and redshift z → astrophysics

$f(X,z)$ **Selection function** : observational strategy

$\frac{dn(M,z)}{dM}$ **Halo Mass Function** : depends on non-linear structure formation

↳ Likelihood estimation + Fisher matrix → *MCMC* and constraints on cosmological parameters

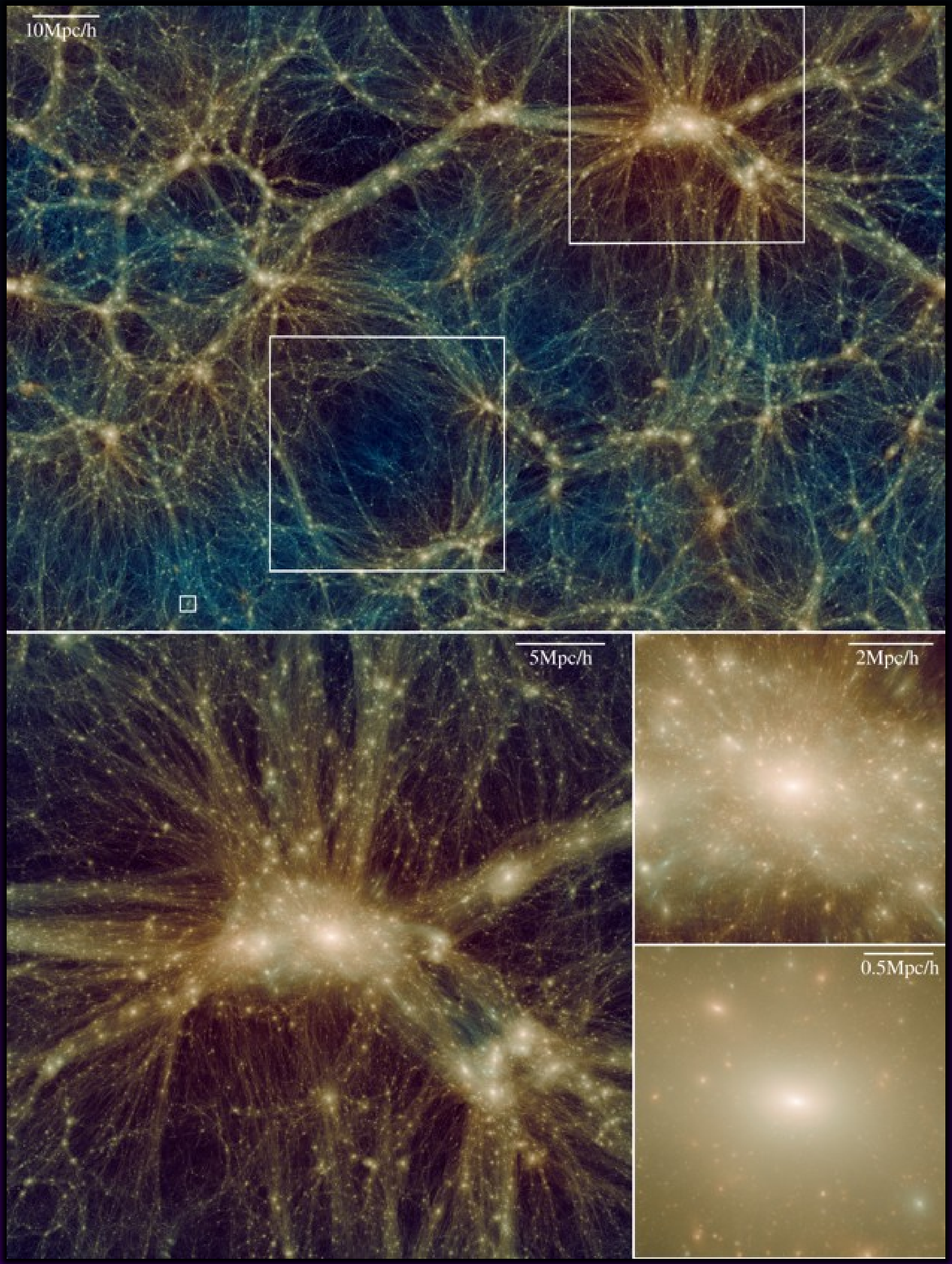
2) Nbody simulation

Goal : Study clusters in a theoretical point of view

Uchuu simulation

- Dark Matter (DM) only simulation
- 12800^3 DM particles
- $L_{box} = 2000\ Mpc/h$
- Standard ΛCDM cosmology (Planck-CMB 2015)

$\Omega_m = 0.31$ $\sigma_8 = 0.80$
$\Omega_\Lambda = 0.64$ $w = -1$
$h = 0.68$ $\Omega_b = 0.05$

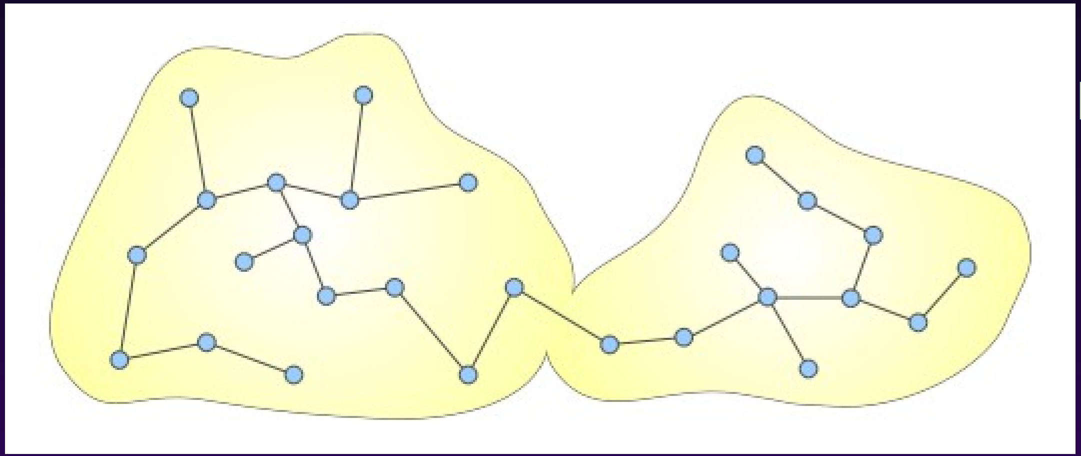


https://skiesanduniverses.org/Simulations/Uchuu/Visualize/

$d\ln(M)$

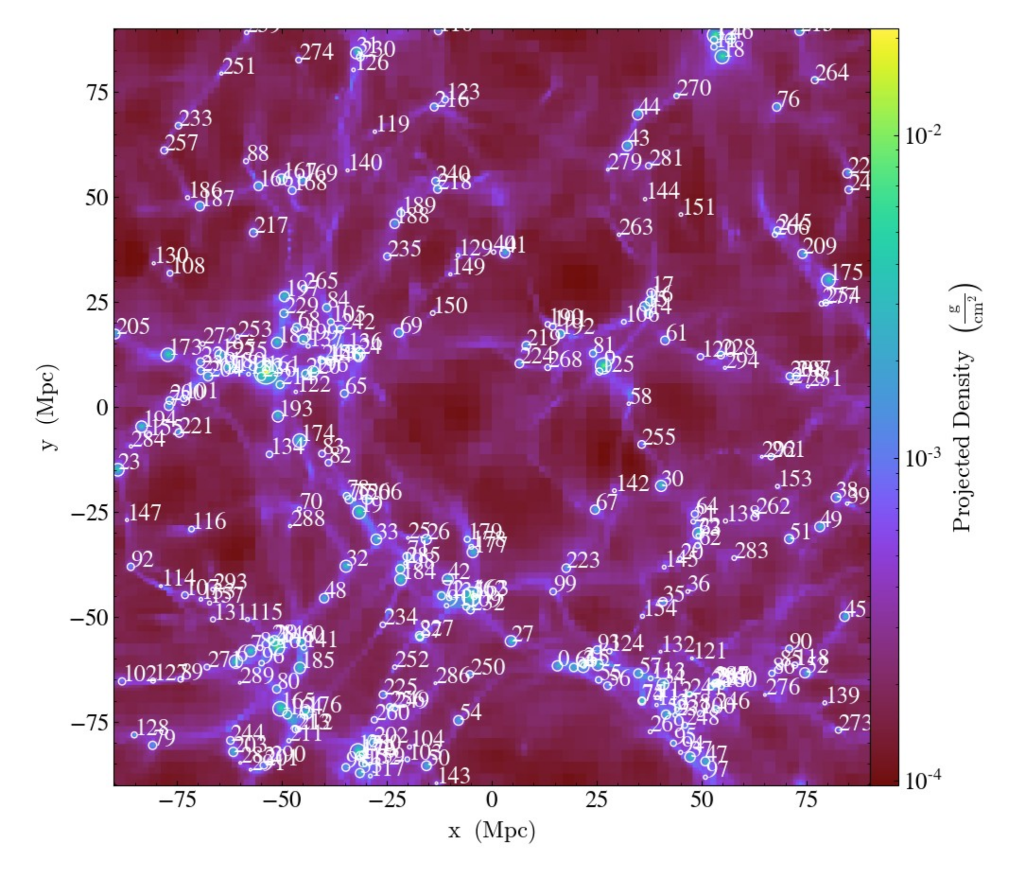
2) Halo finder - methods

Friend-Of-Friend : percolation algorithm



https://www.cosmosim.org/cms/data/halo-finders/

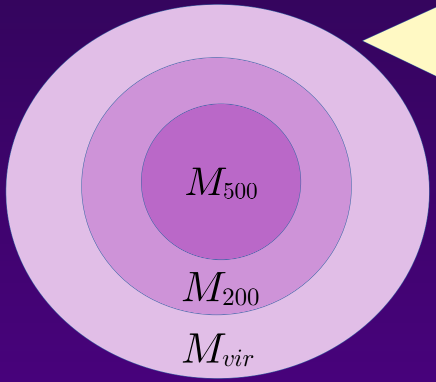
Halo catalogs M_{vir} at z



Deduction of the other (observable) masses:

$$M_{\Delta c} = \frac{4}{3}\pi R_{\Delta}^3 \Delta \rho_c$$

$\Delta = 200, 500\, etc$



→ **Masses observed in surveys**

2) Halo Mass Function

$$\frac{dn}{dlnM} = \bar{\rho}_m \frac{dln\sigma^{-1}}{dM} f(\sigma)$$

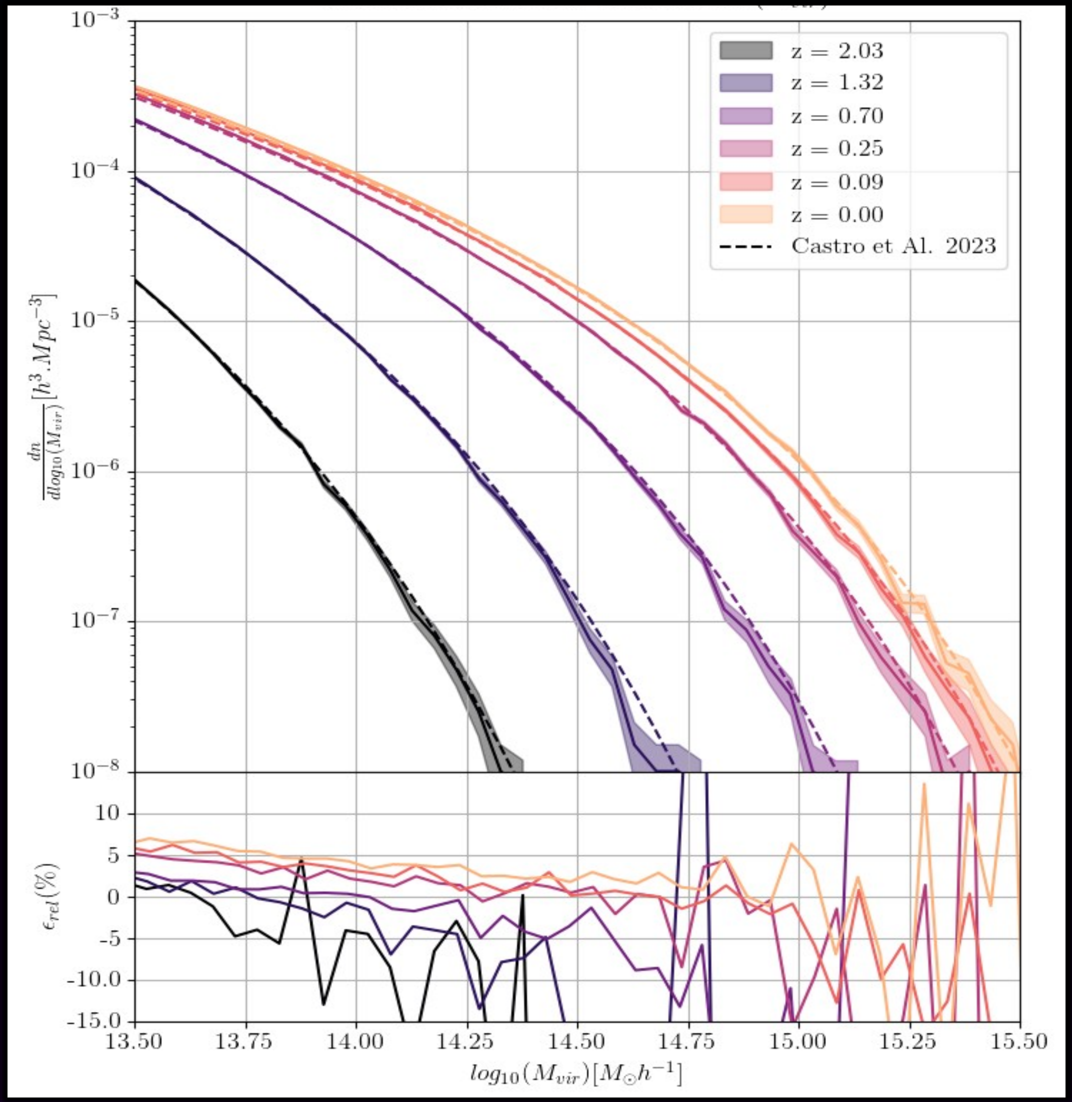
ρ_m : mean cosmic matter density

σ : variance of the linear matter density field

f: multiplicity function

→ Encodes non-linearities of gravitational collapses

→ Assumed to be Universal



Example : Euclid HMF (Castro et Al 2023) calibrated using M_{vir}

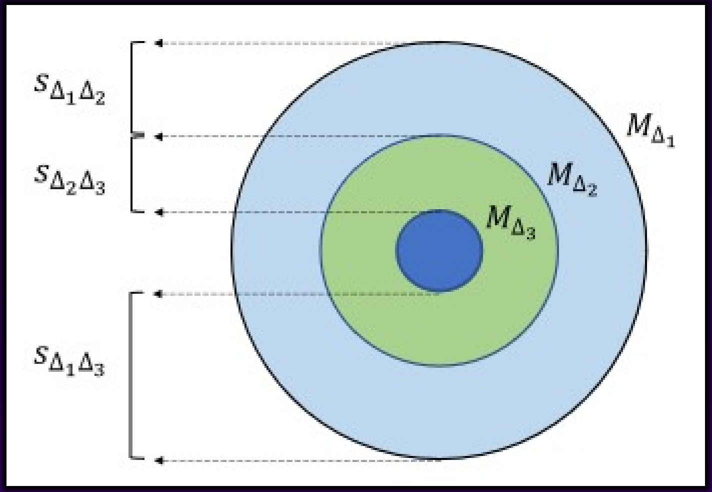
M_{vir} not observable (no SZ, X or lensing at R_{vir})
→ need to convert the HMF at $\Delta = 200{,}500\ etc$

3) Mapping of the HMF – 2 methods

→ How do we get $\frac{dn}{dM_{\Delta_2}}$ knowing $\frac{dn}{dM_{\Delta_1}}$?

<u>1st method : the sparsities</u> (Richardson & Corasaniti 2022,2023)

$$s_{\Delta_1,\Delta_2} = \frac{M_{\Delta_1}}{M_{\Delta_2}} \qquad \Delta_1 < \Delta_2$$



Corasaniti et Al 2022

Hypothesis : Stochastic nature of $M_{\Delta 1}$ and $M_{\Delta 2}$ and s

$$\frac{dn}{dM_{\Delta_2}}(M_{\Delta_2}) = \int_1^\infty s\,p_s(s|sM_{\Delta_2})\frac{dn}{dM_{\Delta_1}}(sM_{\Delta_2})ds$$

Conditional sparcity pdf

Theoretical calibrated HMF

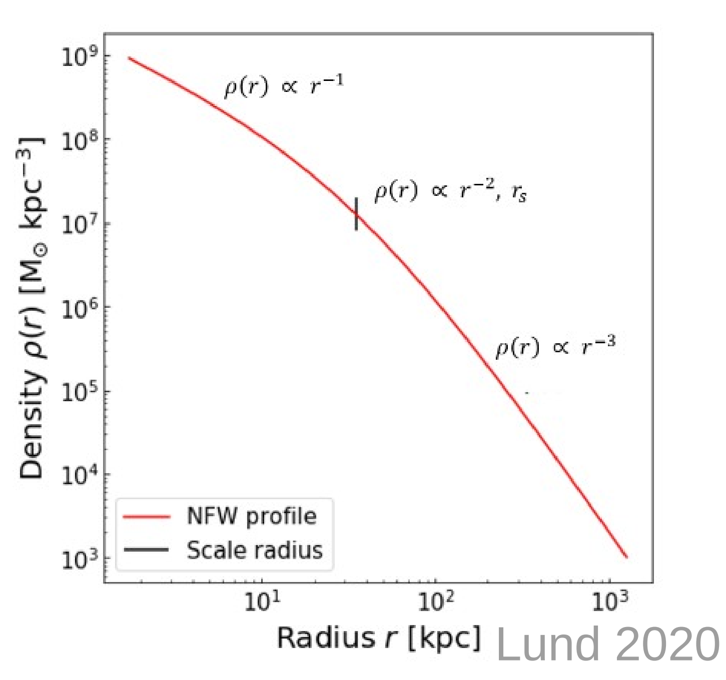
2nd method : the concentration-Mass relation

***Hypothesis*:**

1) Dark Matter density profile

$$\rho_{NFW}(r) = \frac{M_{\Delta_1}}{4\pi[ln(1+c) - c/(1+c)]} \times \frac{1}{r\left(\frac{r_{\Delta_1}}{c} + r\right)^2}$$

Knowing c and $M_{\Delta 1}$ we can deduce $M_{\Delta 2}$ by integrating ρ_{NFW} → $s^{NFW}(c)$



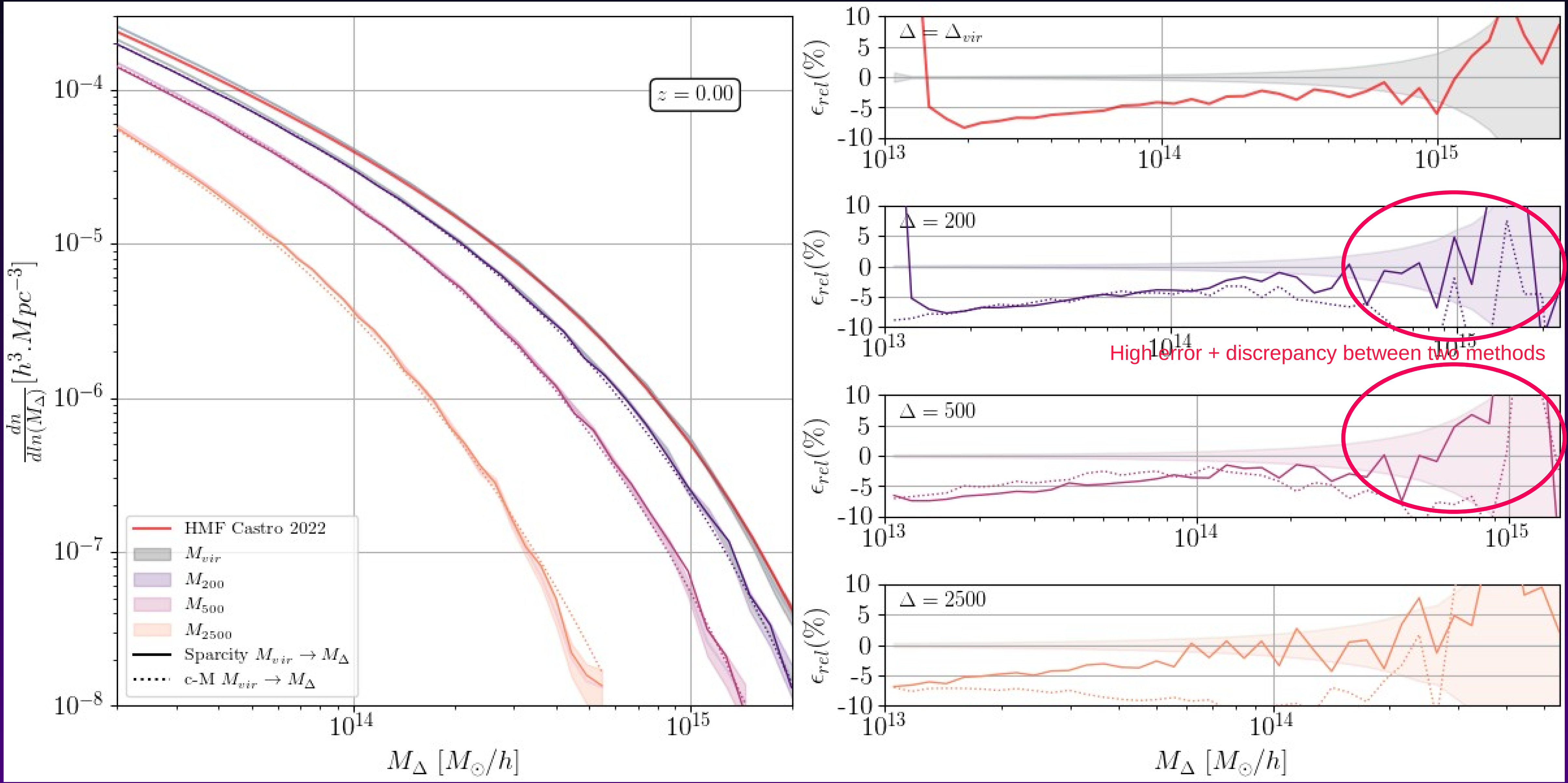
2) c-M relation (e.g. Ishiyama et Al 21)

$$c = f(M)$$ → Calibrated using Nbody simulation

3) Sparsities pdf highly peaked

$$\frac{dn}{dM_{\Delta_2}} = s^{NFW}(c)\frac{dn}{dM_{\Delta_1}}(s^{NFW}(c)M_{\Delta_2})$$

Some results

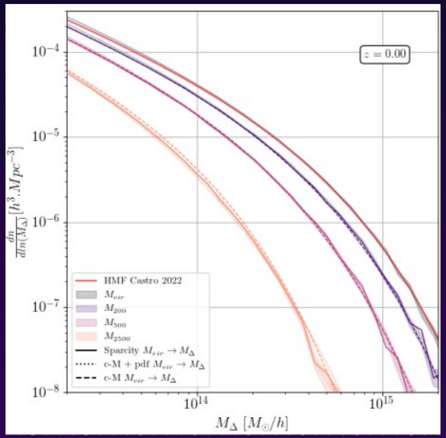


4) Perspectives

→ Quantify the impact of systematic differences between mapped fitting function and N-body results on the cosmological parameter constraints that will be inferred from the cluster counts of Euclid survey

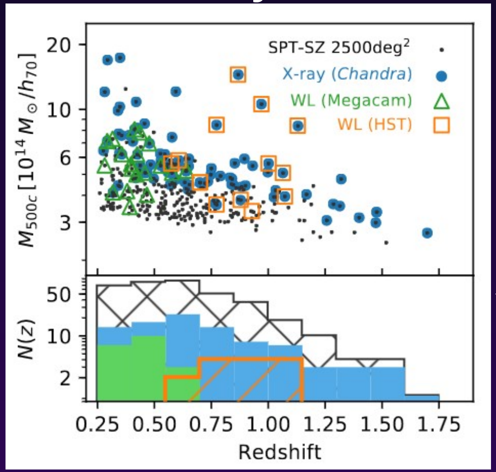
5) Conclusion

Mapped HMF



x

Survey data



Bocquet et al. 2019

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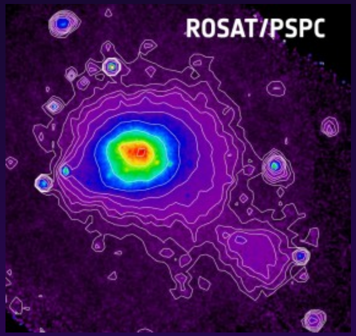
Mass-proxy

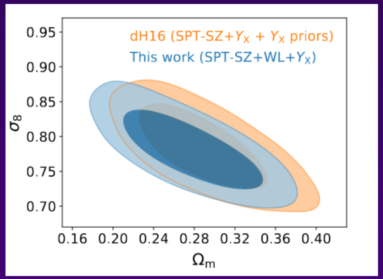


http://sci.esa.int/planck/
47695-the-coma-cluster/

x

Weak Lensing

NASA/ESA



Cosmological constraints

Thank you for your attention :)

Backup slides

- **Cluster counts:** Expected cluster number counts in a given redshift and observed mass (M^{ob}) bin for a survey with a sky coverage Ω_{sky}

$$N_{l,m} = \Delta\Omega_{sky} \int_{z_l}^{z_{l+1}} dz \frac{dV}{dz d\Omega} \int_{M^{ob}_{l,m}}^{M^{ob}_{l,m+1}} \frac{dM^{ob}}{M^{ob}} \int_0^{+\infty} dM \frac{dn(M,z)}{dM} p(M^{ob}|M)$$

$\frac{dV}{dz d\Omega}$ **Comoving volume** element per z per solid angle

$\Delta\Omega_{sky}$ **Sky coverage**

$\frac{dn(M,z)}{dM}$ **Halo Mass Function** : depends on non-linear structure formation

$p(M^{ob}|M)$ Probability of a galaxy cluster with true mass M to have an observed mass M^{ob}

Likelihood estimation + Fisher matrix → *MCMC* and constraints on cosmological parameters