Las subestructuras en un modelo cosmológico

Mauro Cabrera. UDELAR. Examen de cosmología

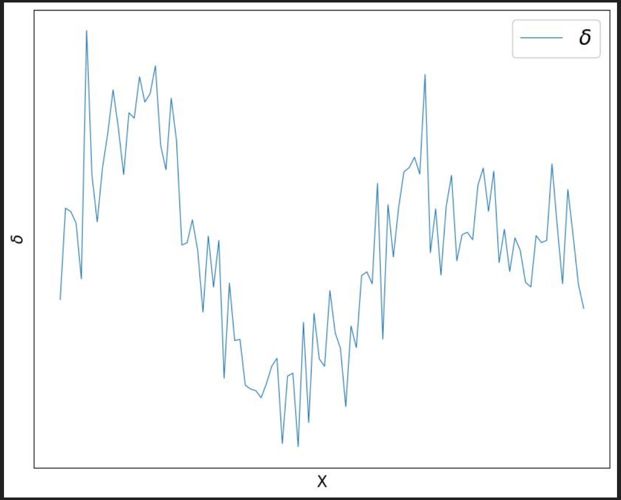
Perturbaciones en la densidad

$$\delta(\vec{x}) = \frac{\rho(\vec{x}) - \bar{\rho}}{\bar{\rho}}$$

Para $|\delta| \ll 1$, linealizando las ecuaciones de fluidos y, usando que la densidad esta dominada por la materia, se llega a:

$$\delta(\vec{x}, t) = D(t)\delta_0(\vec{x})$$

$$D(a) \propto \frac{H(a)}{H_0} \int_0^a \frac{da'}{[\Omega_m/a' + \Omega_\Lambda a'^2 - (\Omega_m + \Omega_\Lambda - 1)]^{3/2}}$$



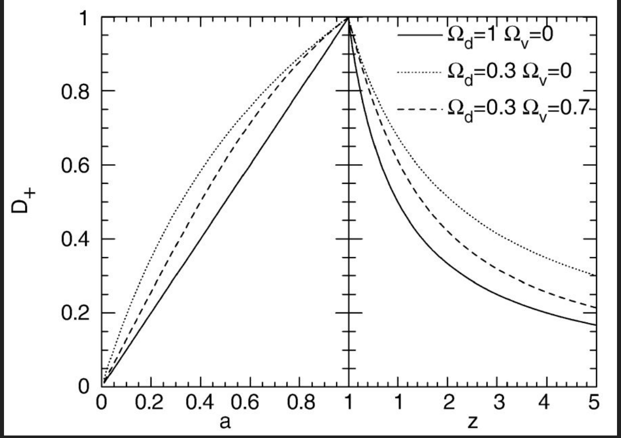
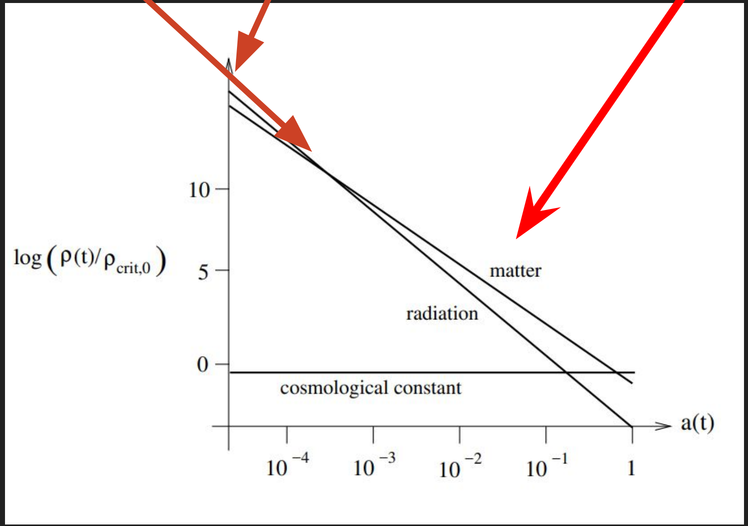
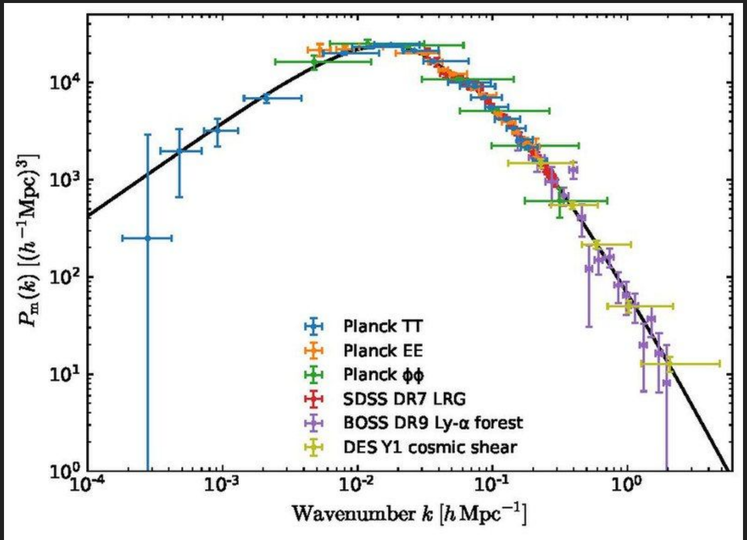


Fig 7.8 Schneider.

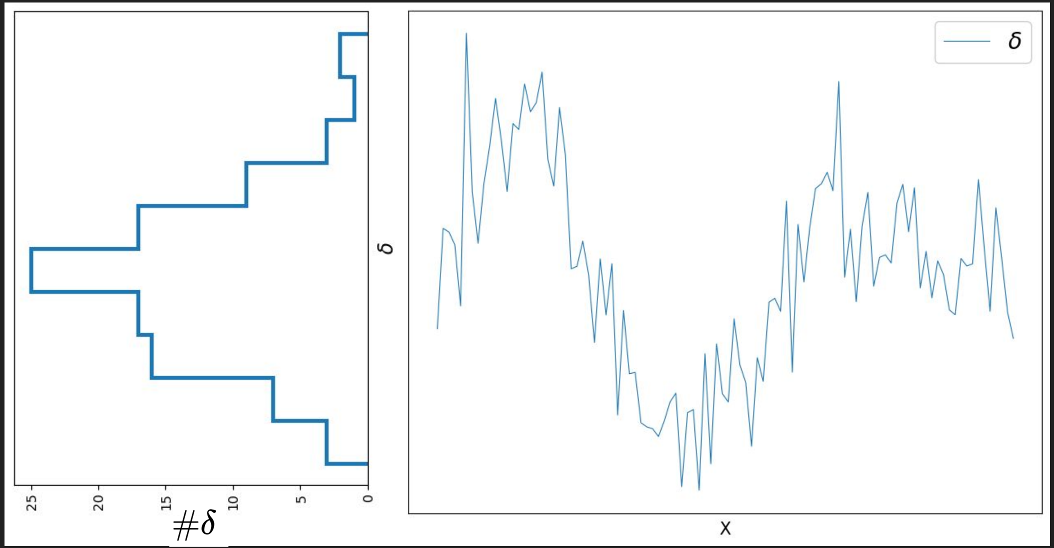
Perturbaciones origen y evolución

$$P_0(k) = A k^{n_s} T^2(k) \qquad P(k,t) = D^2(t) P_0(k) \text{ Cuando la materia domina}$$





Enfoque estadístico:
Momentos de δ



$$\delta(\vec{x}) = \frac{\rho(\vec{x}) - \bar{\rho}}{\bar{\rho}}$$

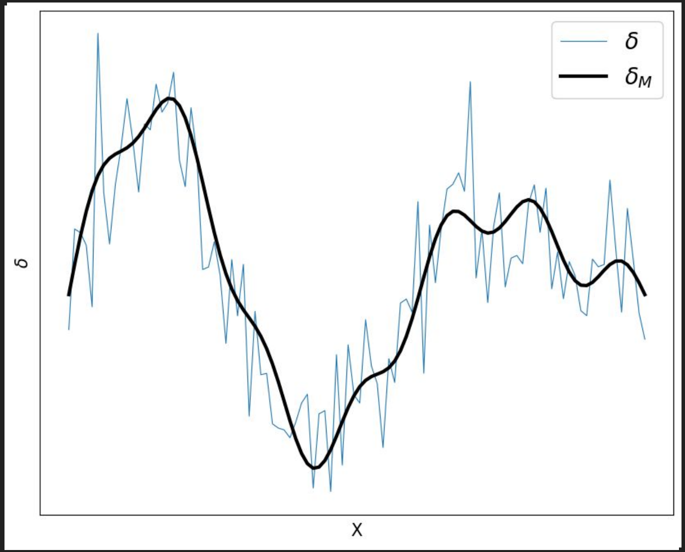
$$\langle * \rangle_{realizaciones} = \langle * \rangle_{\vec{x}}$$

$$\langle \delta \rangle = 0$$

$$\sigma^2 = \langle \delta^2 \rangle = \frac{1}{V} \int \delta^2(\vec{x}) d^3x$$

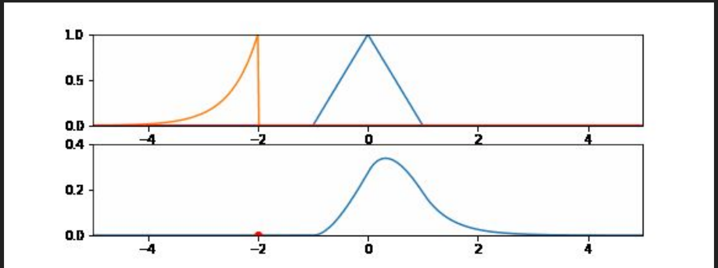
$$\xi(r) = \langle \delta(\vec{x})\delta(\vec{x}+\vec{r}) \rangle = \frac{1}{(2\pi)^3} \int P(k) e^{i\vec{k}\cdot\vec{r}} d^3\vec{k} \quad \sigma^2 = \xi(0) = \frac{1}{(2\pi)^2} \int P(k) k^2 dk$$

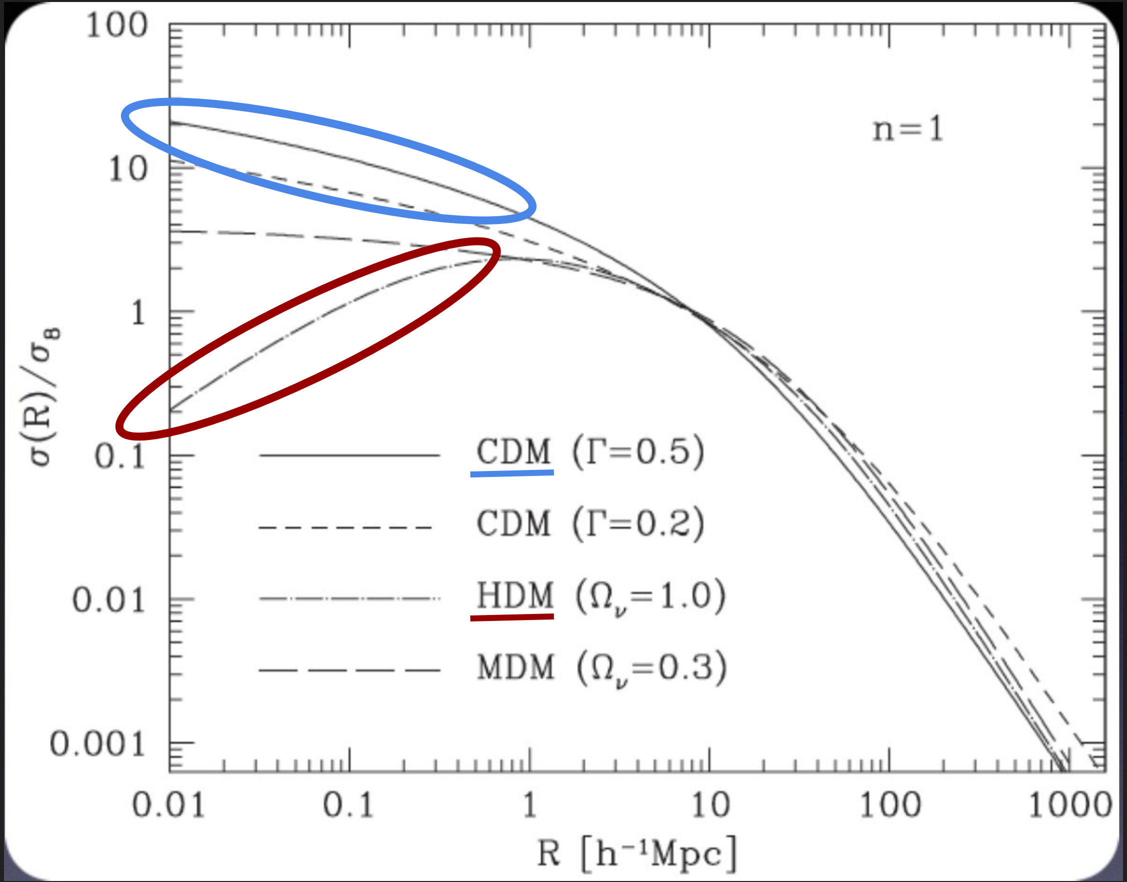
$$\delta(\vec{x};R) = \int \delta(\vec{x}')W(\vec{x}+\vec{x}';R)d^3x'$$



$$\sigma^2(R) = \langle\delta(\vec{x};R)\rangle$$

$$\sigma^2(R) \iff \sigma^2(M)\,;\; M = \gamma_f\bar{\rho}R^3$$





Lecture 9. Frank van den Bosch

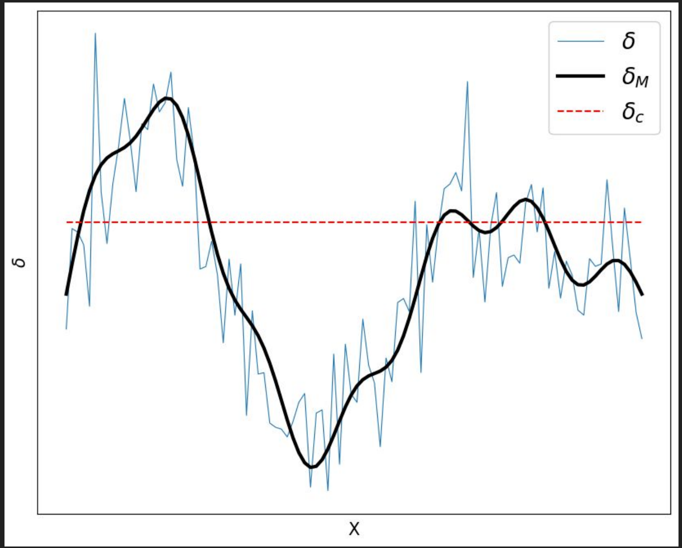
En CDM “siempre” se encuentra más estructuras a escalas más pequeñas. En HDM no. Existe una “escala característica”.

En las escalas pequeñas se buscan las discrepancias con CDM.

Press-Schechter formalismo

Comparison with Numerical Simulations. The Press–Schechter model is a very simple model, based on assumptions that are not really justified in detail. Nevertheless, its predictions are in astounding agreement with the number density of halos determined from simulations, and this model, published in 1974, has for nearly 25 years predicted the halo density with an accuracy that was difficult to achieve in numerical simulations.

Press-Schechter formalismo



$$\delta(\vec{x}, t) > \delta_c = 1.686 \quad \delta(\vec{x}, t) = D(t)\delta_0(\vec{x})$$

$$\delta_0(\vec{x}) > \frac{\delta_c}{D(t)}$$

$$\delta(\vec{x}) > \delta_c(t)$$

$$\delta_M(\vec{x}) > \delta_c(t) \Rightarrow \text{Se forma un halo de masa} > M$$

$$\mathcal{P}(\delta_M > \delta_c) = \text{Prob de que se forme UN halo de masa >M}$$

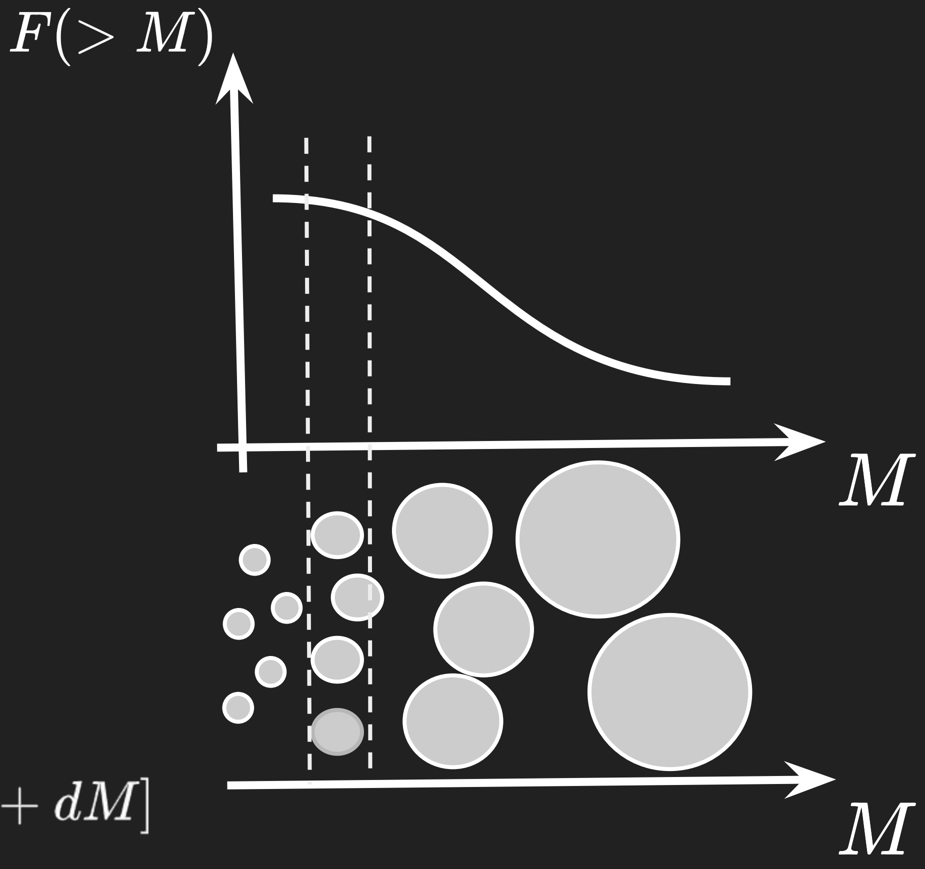
$F(> M) =$ Cantidad de masa en halos con masa mayor a M, divido la M_{tot} (en un volumen V)

$\left|\frac{\partial F(>M)}{\partial M}\right| dM =$ Cantidad de masa en halos con masa entre M y $M + dM$, sobre M_{tot}

$$\Rightarrow M_{tot}\left|\frac{\partial F(>M)}{\partial M}\right| dM \Rightarrow \frac{M_{tot}}{M}\left|\frac{\partial F(>M)}{\partial M}\right| dM$$

$$\boxed{\Rightarrow \frac{\bar{\rho}}{M}\left|\frac{\partial F(>M)}{\partial M}\right| dM = n(M)dM}$$

$n(M)dM = \#$ de halos con $M \in [M, M + dM]$ por unidad de volumen



Press-Schechter formalismo

$$F(>M) = \mathcal{P}(\delta_M > \delta_c)$$

$$\mathcal{P}(\delta_M)d\delta_M = \frac{1}{\sqrt{2\pi}\sigma_M}\exp[-\frac{\delta_M^2}{2\sigma_M^2}]d\delta_M$$

$$\mathcal{P}(\delta_M > \delta_c) = \frac{1}{\sqrt{2\pi}\sigma_M}\int_{\delta_c}^{\infty}\exp[-\frac{\delta_M^2}{2\sigma_M^2}]d\delta_M = \frac{1}{2}\mathrm{erfc}[\frac{\delta_c}{2\sigma_M}]$$

$$F(>M) = \frac{1}{2}\mathrm{erfc}[\frac{\delta_c}{2\sigma_M}] \quad \Longrightarrow \quad n(M,t)dM = \frac{\bar{\rho}}{M}\frac{\partial\mathcal{P}(\delta_M>\delta_c)}{\partial M}dM$$

Obs: $\lim_{M\to 0}\sigma_M = \infty \Rightarrow \mathrm{erfc}(0) = 1 \Rightarrow F(>0) = 1/2$

Pres

EXCURSION SET MASS FUNCTIONS FOR HIERARCHICAL GAUSSIAN FLUCTUATIONS

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ABSTRACT

Most schemes for determining the mass function of virialized objects from the statistics of the initial density perturbation field suffer from the "cloud-in-cloud" problem of miscounting the number of low-mass clumps, many of which would have been subsumed into larger objects. We propose a solution based on the theory of the excursion sets of $F(\mathbf{r}, R_f)$, the four-dimensional initial density perturbation field smoothed with a continuous hierarchy of filters of radii R_f. We identify the mass fraction of matter in virialized objects with mass greater than M with the fraction of space in which the initial density contrast lies above a critical overdensity when smoothed on some filter of radius greater than or equal to $R_f(M)$. The differential mass function is then given by the rate of first upcrossings of the critical overdensity level as one decreases R_f at constant position $\mathbf{r}$. The shape of the mass function depends on the choice of filter function. The simplest case is "sharp k-space" filtering, in which the field performs a Brownian random walk as the resolution changes. The first upcrossing rate can be calculated analytically and results in a mass function identical to the formula of Press and Schechter—complete with their normalizing "fudge factor" of 2. For general filters (e.g., Gaussian or "top hat") no analogous analytical result seems possible, though we derive useful analytical upper and lower bounds. For these cases, the mass function can be calculated by generating an ensemble of field trajectories numerically. We compare the results of these calculations with group catalogs found from N-body simulations. Compared to the sharp k-space result, less spatially extended filter functions give fewer large-mass and more small-mass objects. Over the limited mass range probed by the N-body simulations, these differences in the predicted abundances are less than a factor of 2 and span the values found in the simulations. Thus the mass functions for sharp k-space and more general filtering all fit the N-body results reasonably well. None of the filter functions is particularly successful in identifying the particles which form low-mass groups in the N-body simulations, illustrating the limitations of the excursion set approach. We have extended these calculations to compute the evolution of the mass function in regions that are constrained to lie within clusters or underdensities at the present epoch. These predictions agree well with N-body results, although the sharp k-space result is slightly preferred over the Gaussian or top hat results.

Subject headings: cosmology — galaxies: clustering — numerical methods

$f_{PS} =$

Press-Schechter

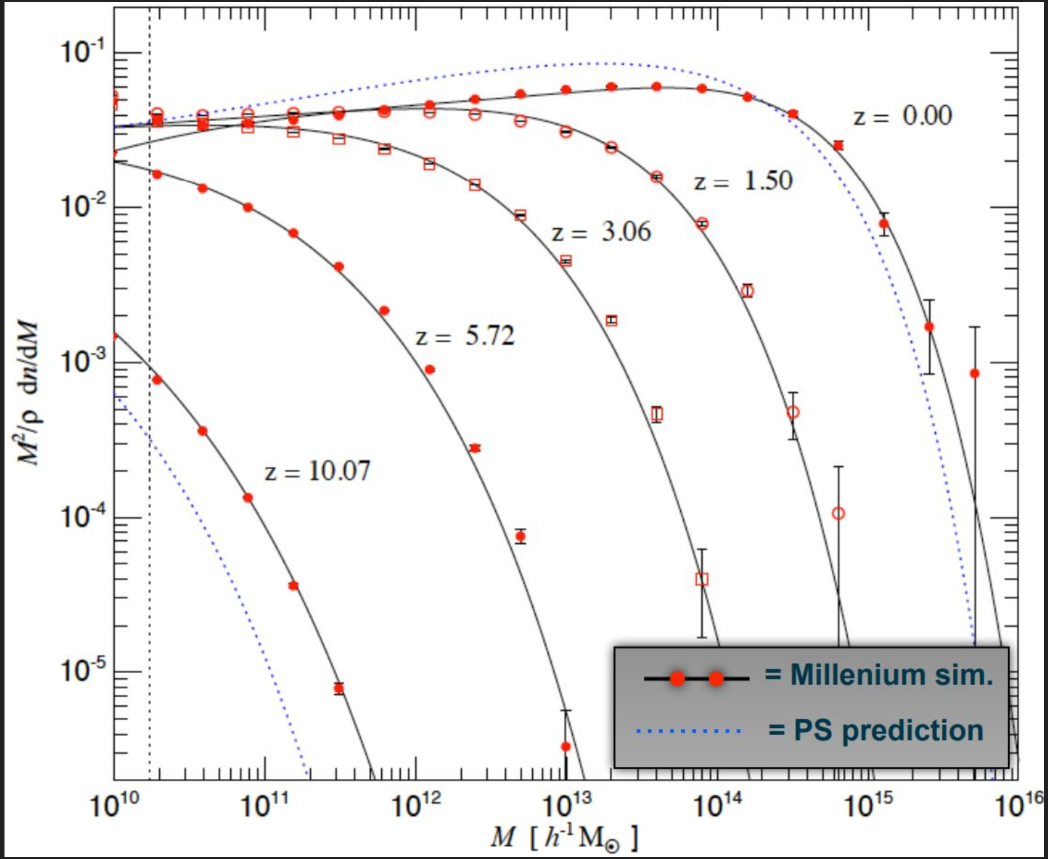
$$F(>M) = 2\mathcal{P}(\delta_M > \delta_c)$$

$$n(M,t)dM = 2\frac{\bar{\rho}}{M}\frac{\partial \mathcal{P}(\delta_M > \delta_c)}{\partial M}dM$$

$$n(M,t)dM = \sqrt{\frac{2}{\pi}}\frac{\bar{\rho}}{M^2}\frac{\delta_c}{\sigma_M}\exp[-\frac{\delta_c^2}{2\sigma_M}]\left|\frac{d\ln\sigma_M}{d\ln M}\right|dM$$

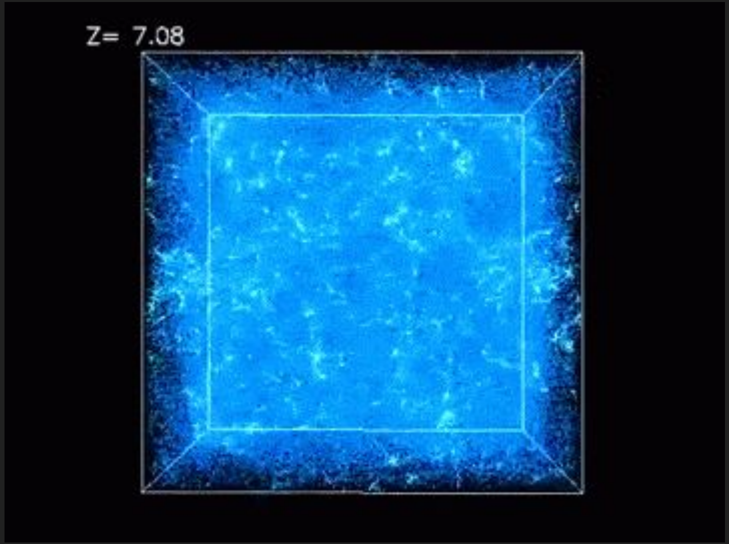
$$f_{PS} = \sqrt{\frac{2}{\pi}}\nu\exp[-\nu^2/2] \quad \nu = \frac{\delta_c}{\sigma_M}$$

$$n(M,t)dM = \frac{\bar{\rho}}{M^2}f_{PS}(\nu)\left|\frac{d\ln\nu}{d\ln M}\right|dM$$

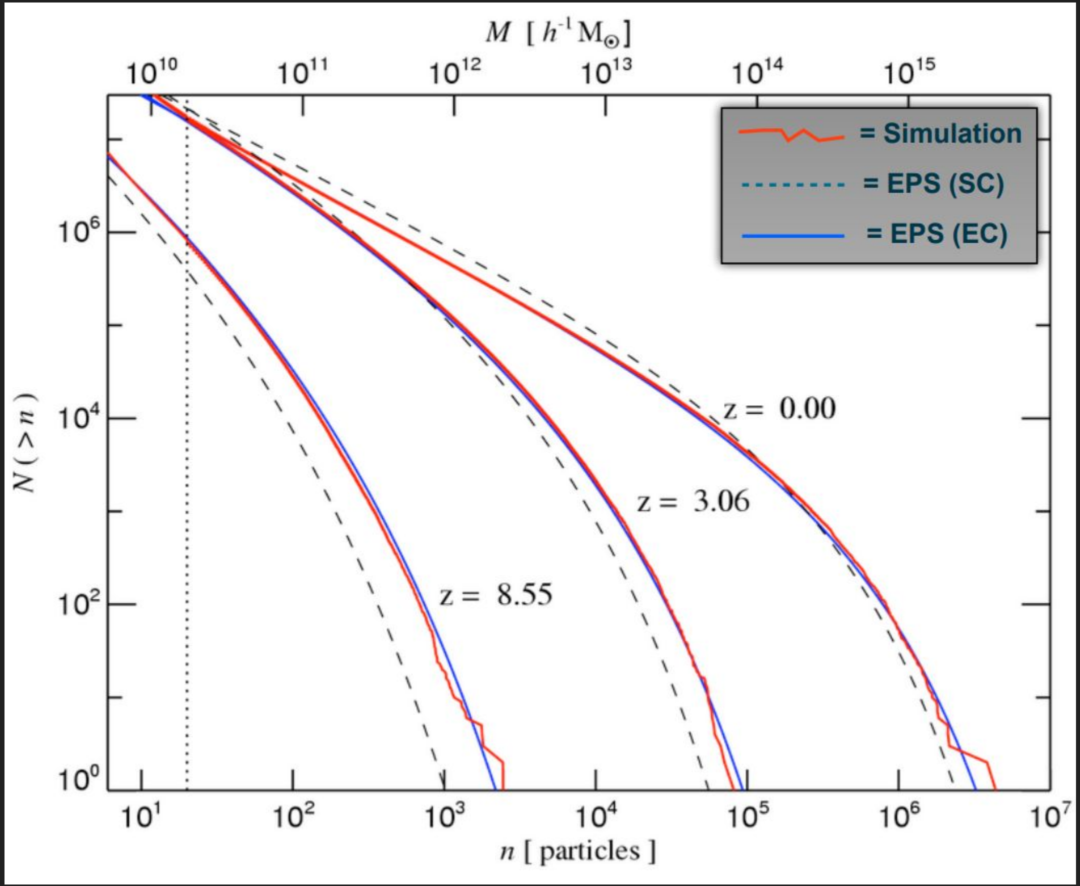


Lecture 9. Frank van den Bosch

La predicción cualitativa de PS esta bien. En lo cuantitativo...



Corrección con colapso elipsoidal



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Si se considera colapso elipsoidal (más realista) la distribución cambia y se obtiene mejor acuerdo con las simulaciones.

$$f_{EC}(\tilde{\nu}) = 0.322\left[1 + \frac{1}{\tilde{\nu}^{0.6}}\right] f_{PS}(\tilde{\nu})$$

$$\tilde{\nu} = 0.84\nu$$

Nota: Útil para medir los parámetros cosmológicos

Recordemos que la evolución de la función de masa PS depende de los parámetros cosmológicos adoptados.

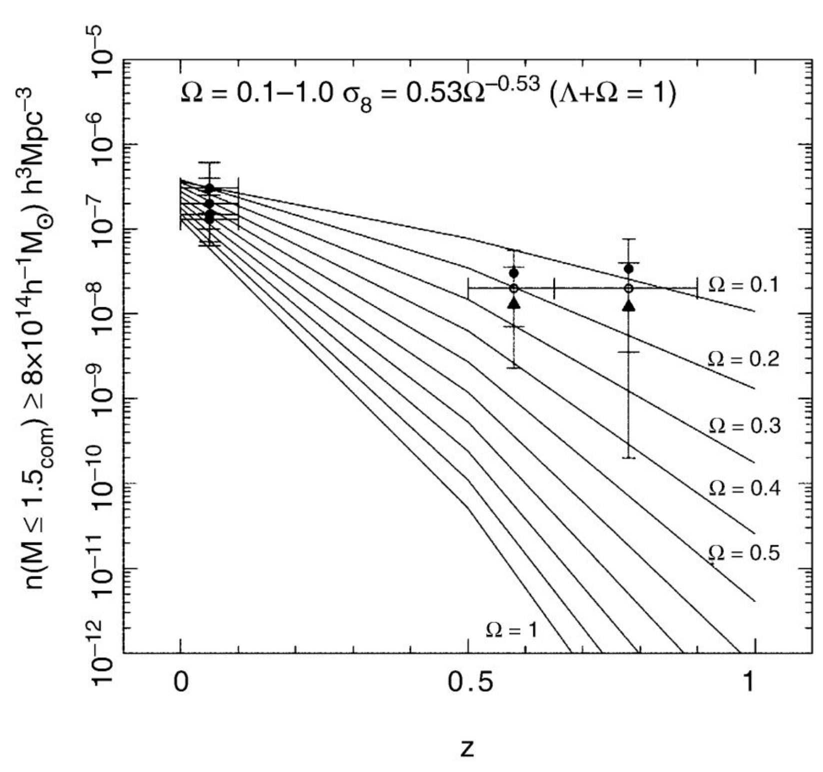
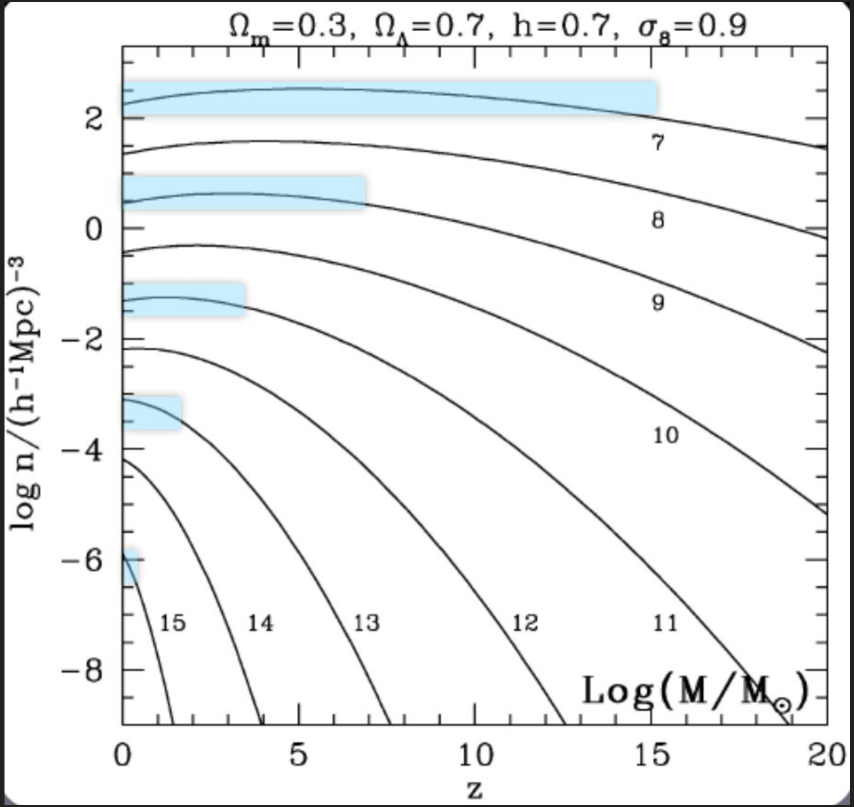


Fig 7.8 Schneider.

Evolución de la función de masa



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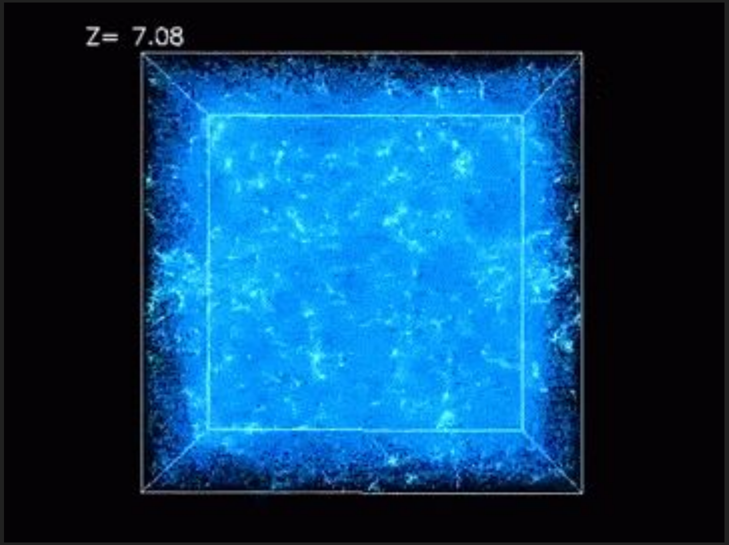
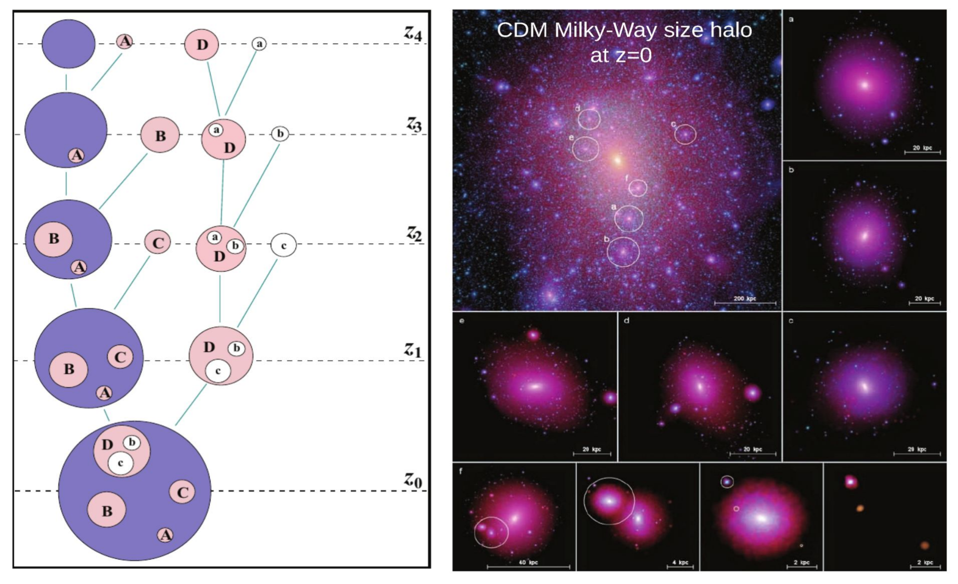
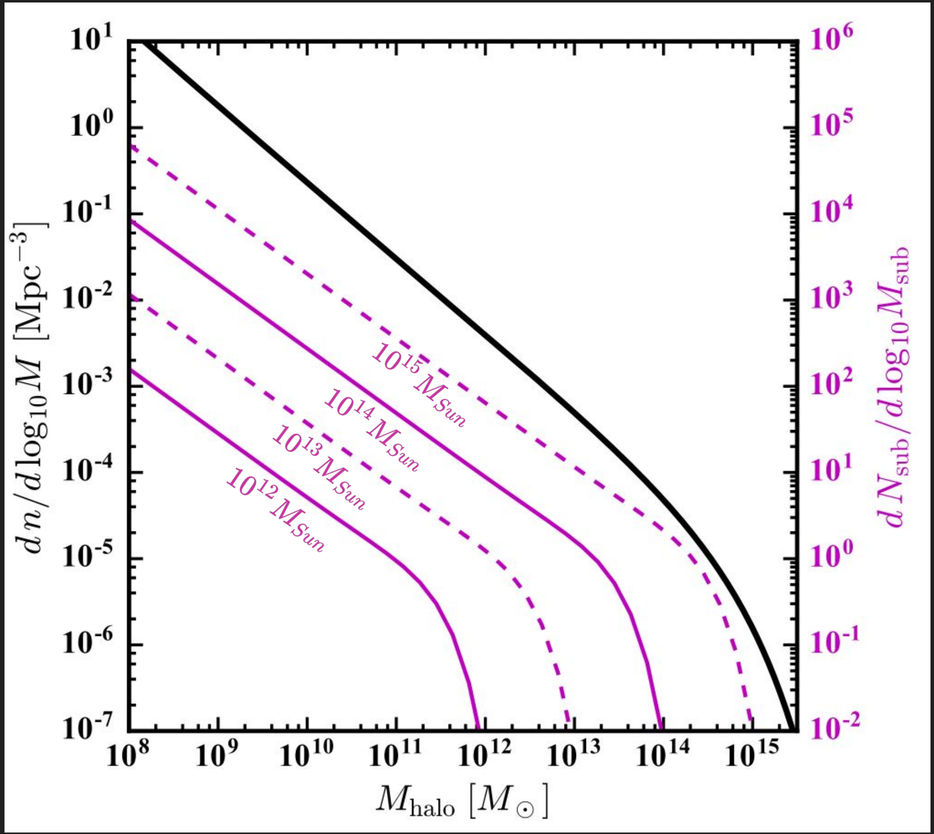
La formación jerárquica se evidencia en cómo evolucionan las distintas distribuciones



Los halos tienen subestructura interna.

Los halos pequeños sobreviven a las fuerzas de marea





Esto depende del modelo cosmológico.
Con WDM esperaríamos menos halos.

Bullock and Boylan-Kolchin 2019

Dos consecuencias de la formación de subestructura en los halos

+ Missing satellite problem: No vemos tantas subestructuras

+ Tanta subestructura genera una dinámica que se puede testear con streams (Hic sunt dracones.)

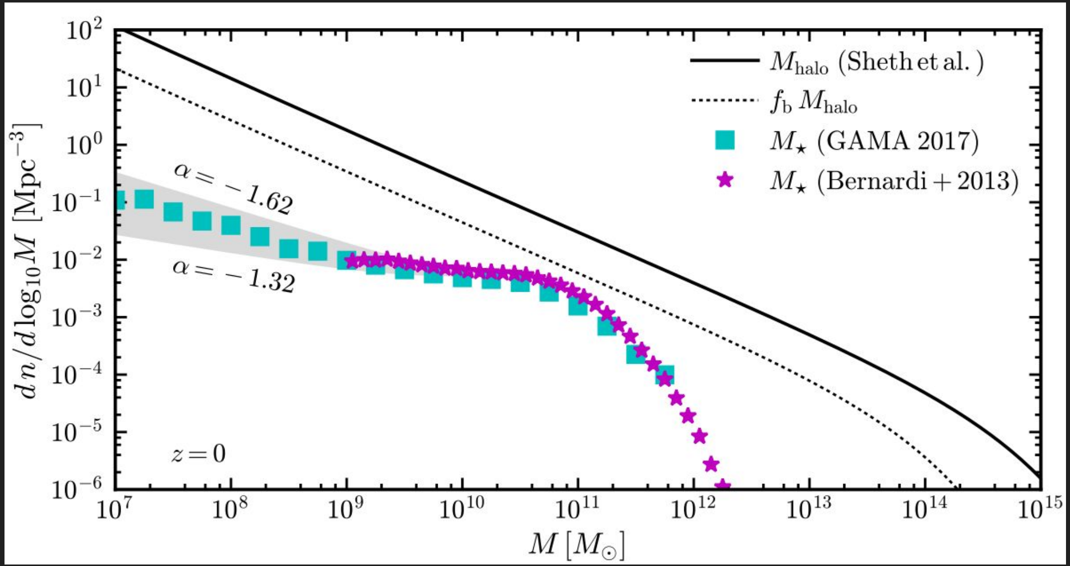
¿Cómo se asocia un halo de DM a una galaxia?

Las galaxias observadas, son una fracción de los halos formados?

$$M_* = \epsilon_* f_b M_H$$

No todos los halos tienen la misma eficiencia en formar galaxias

$$\epsilon_*(M_H)$$



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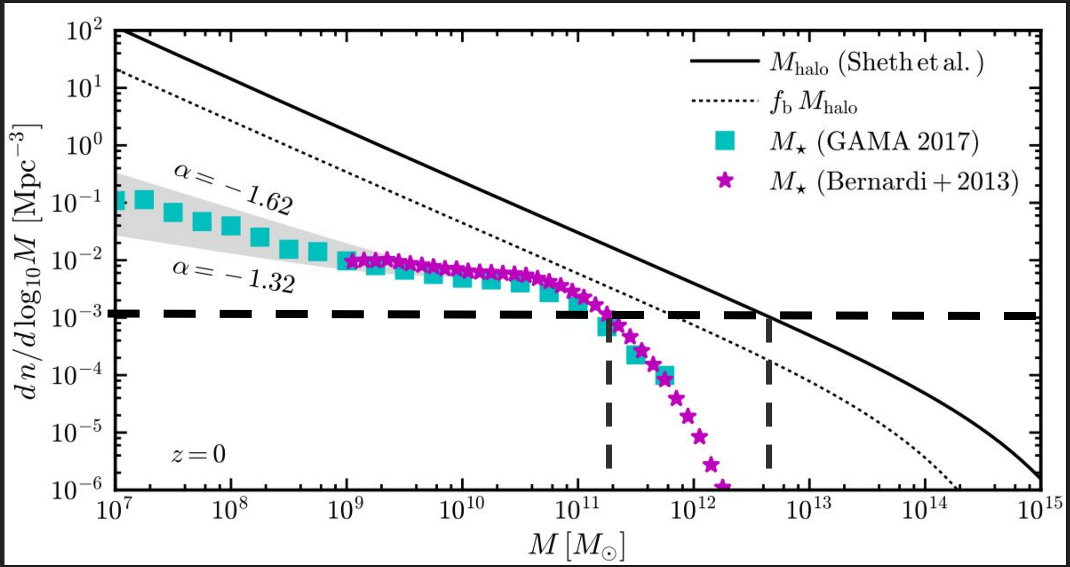
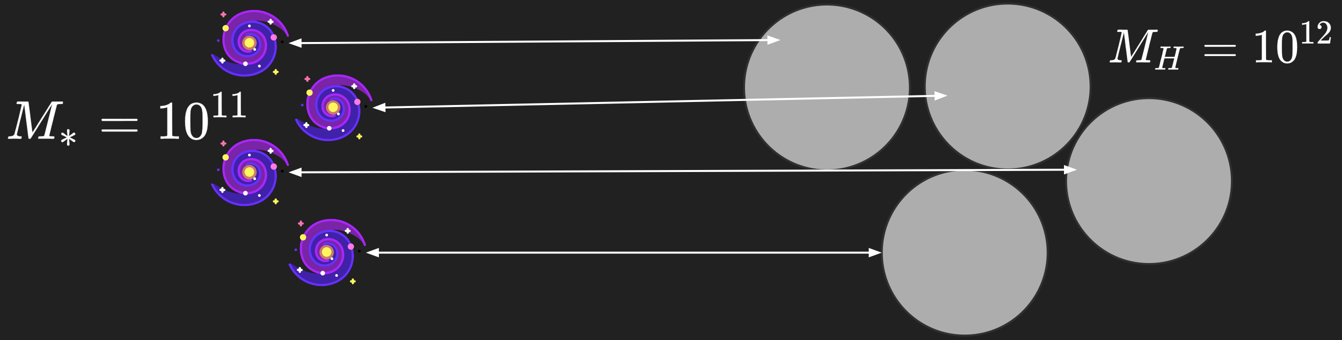
Abundance Matching (AM): Correspondencia un halo una galaxia

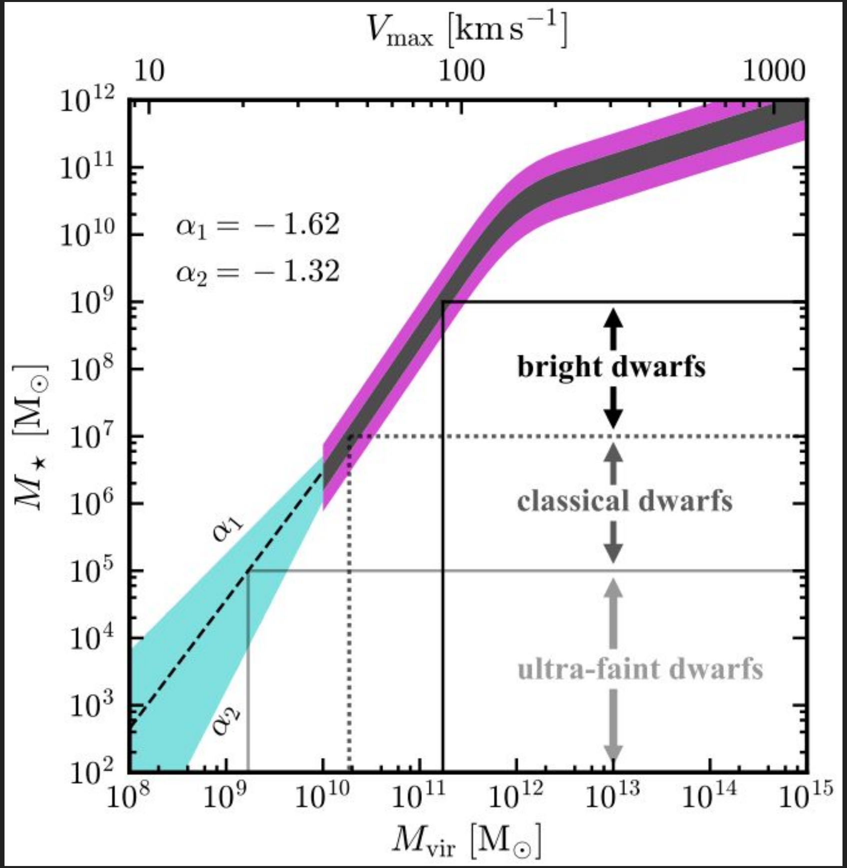


$$M_*(M_H)$$



$$M_*(M_H)$$

Con AM podemos generar funciones de masas de galaxias a partir de conteos en simulaciones puramente de materia oscura.



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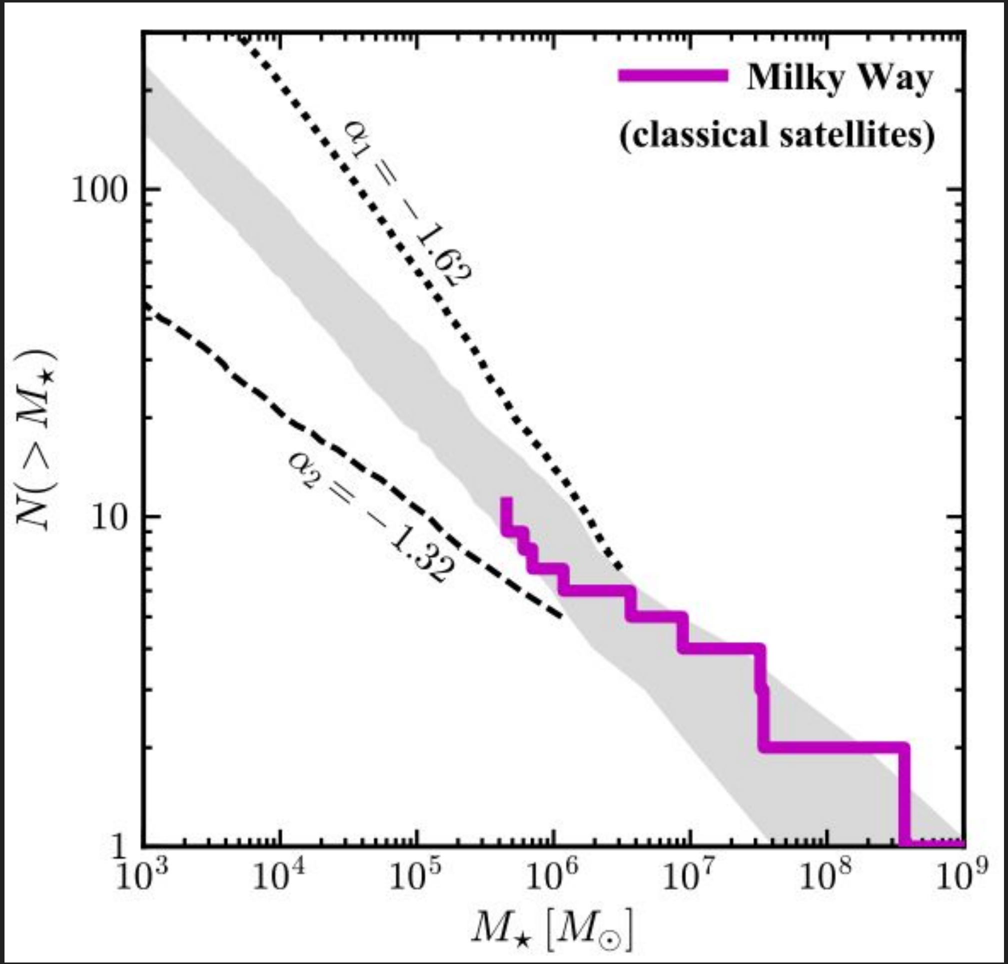
AM y observaciones

La banda gris es la predicción de la función de masa de galaxias a partir de simulaciones de halos de materia oscura y AM.



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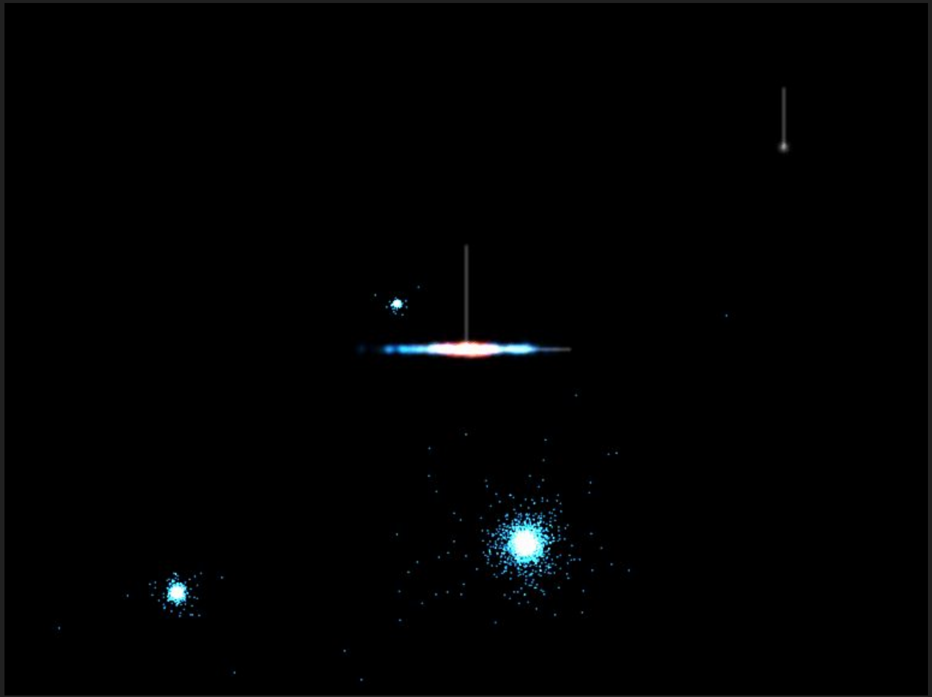
La caída en un halo

La caída de galaxias enanas genera "corrientes estelares" (pla. streams)

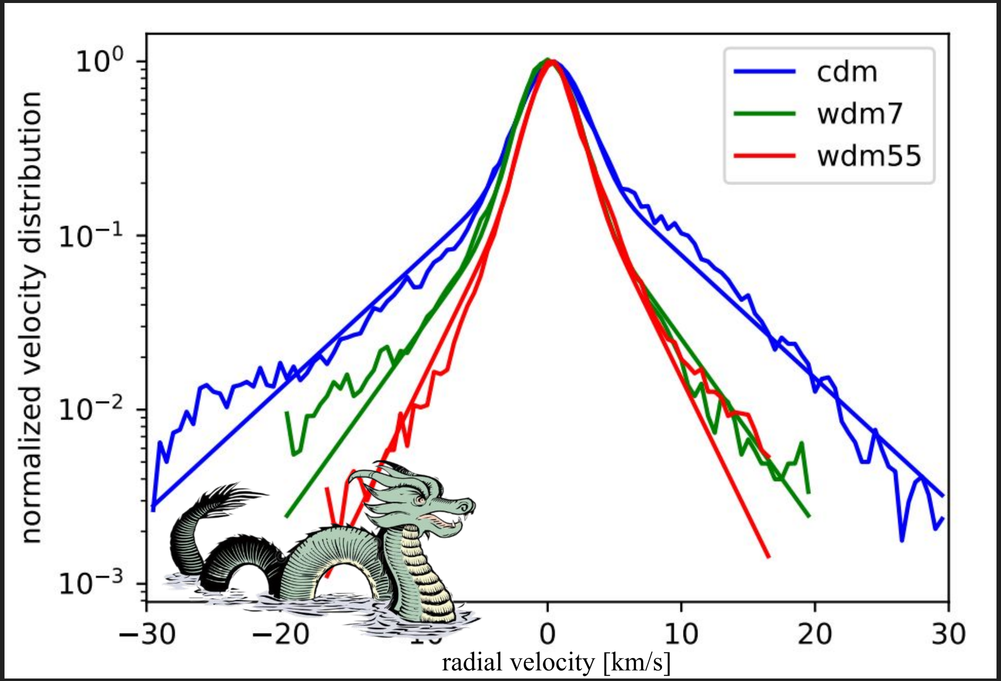


Streams en los halos: CDM o HDM?

Terra nova.

La interacción con sub-halos genera dispersión de velocidad en los streams.

La estadística de los streams con sus velocidades podría ayudar a restringir la naturaleza de la DM



Carlberg et al. 2024. arxiv: 2405.18522

FIN.

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