Introduction to galaxy formation: Evolution of large scale structures and galaxy properties.

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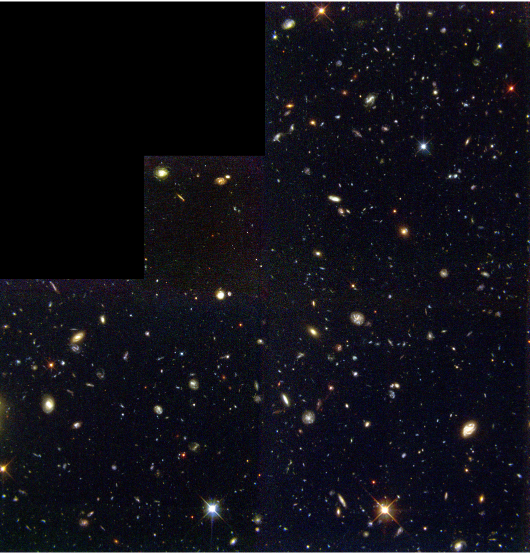
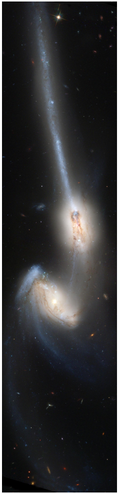
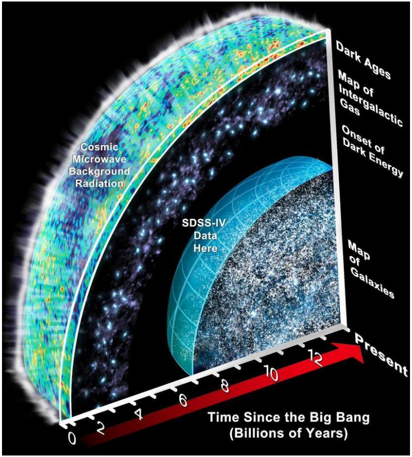
Modelling galaxies



- What is a galaxy?
- Why do we want to model galaxies?

Galaxies in a cosmological context





From galaxy scales (tens kpc), to the local group size (Mpcs) to the size of the observable Universe (tens of Gpc), however subpc processes affect properties at galactic scales.

Level of detail

In order to model galaxies in a cosmological context we need to cover from galaxy scales (tens kpc), to the local group size (Mpcs) to the size of the observable Universe (tens of Gpc), however subpc processes affect properties at galactic scales.
The level of detail in each stage depends on the problem we want to adress as resources are finite.
I'll focus on having a sample of model galaxies large enough to be representative of the observable Universe (about 10^{10} galaxies).
Add numbers from Millennium and Eagle and the extrapolations

How to proceed?

- How do we make a cake?

How to proceed?

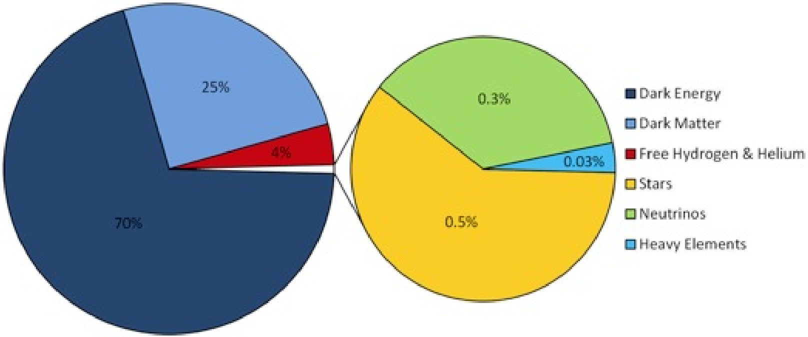
- How do we make a cake?

Ingredients → Recipe → Quality check

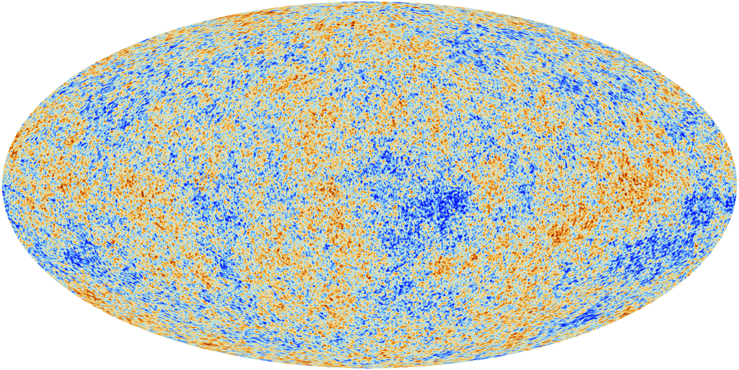
- How do we make a galaxy?

Components → Relevant physical processes → Comparisson to obser-vations

Overview: Components for modelling a galaxy



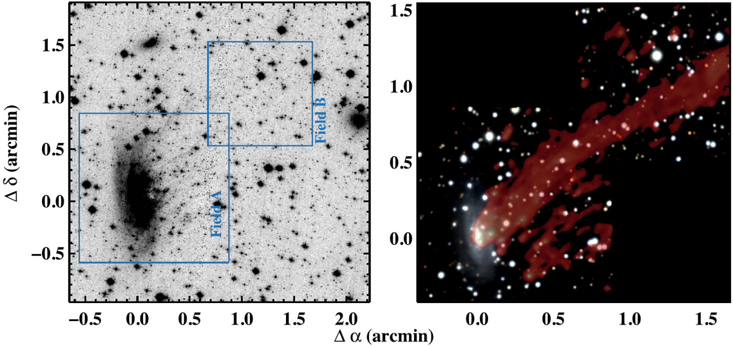
- Gravity is the main driver for the growth of structures.



Planck+15 Fumagalli+15

Overview: Relevant physical processes

- Gravity is the main driver for the growth of structures.
- Baryon physics: cooling of gas, flows of gas, star formation, etc.



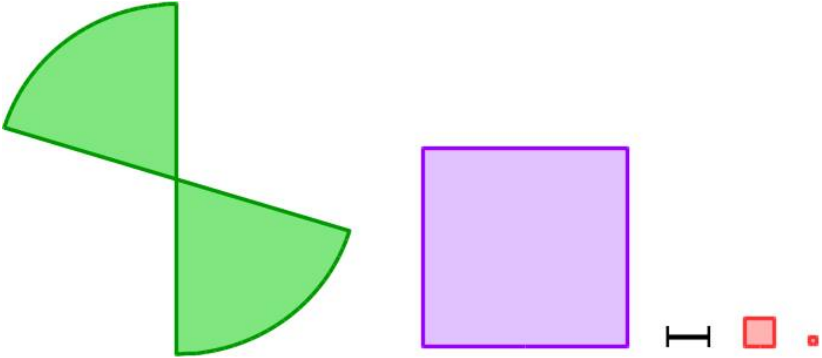
Planck+15 Fumagalli+15

Overview: Comparisson to observations

The fundamental observable when studying stars or galaxies is the light they emit measured by telescopes within a reduced wavelength range:

- **Luminosity** Energy emitted within a finite waveband per unit time. $\mathsf{L}_{\odot} = 3.846 \cdot 10^{33} \mathrm{erg} s^{-1}$.

How to proceed depends on your goal:



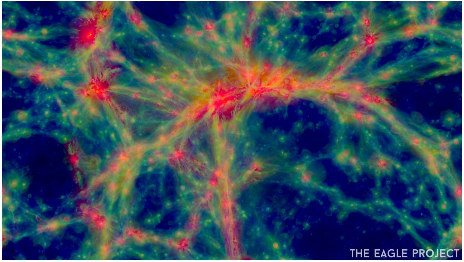
Example:
The final Eagle run took $4.5 \cdot 10^6$ CPU hours
$+ 40 \cdot 10^6$ CPU hours for calibration

CREDIT: Matthieu Schaller

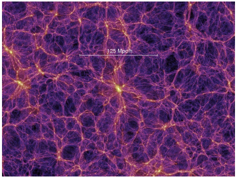
Modelling DM:

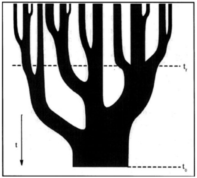
a) N-body simulations: Softening length and volume are the limiting factors.
b) Approximattive methods: (LPT, COLA, PINOCHIO, etc) They are calibrated in simulations, but they are useful for covariance matrices.

a) In parallel: hydrodynamical simulations



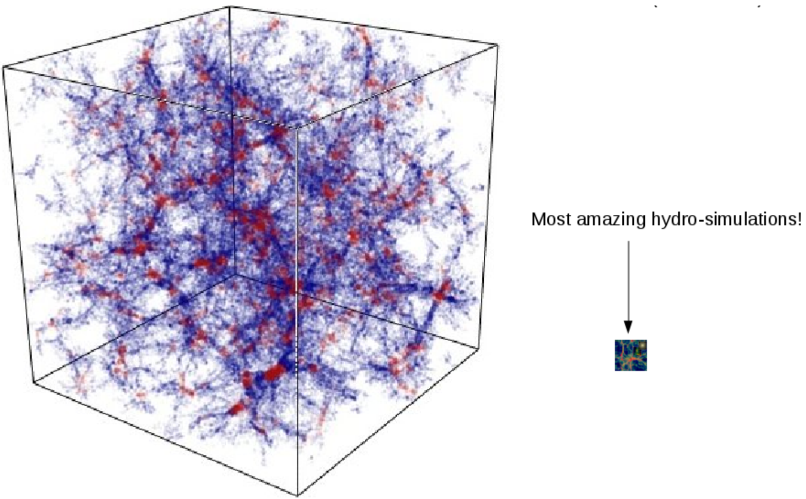
b) In series: SAMs, EMs, SHAMs, HOD modelling

1. 

2. 

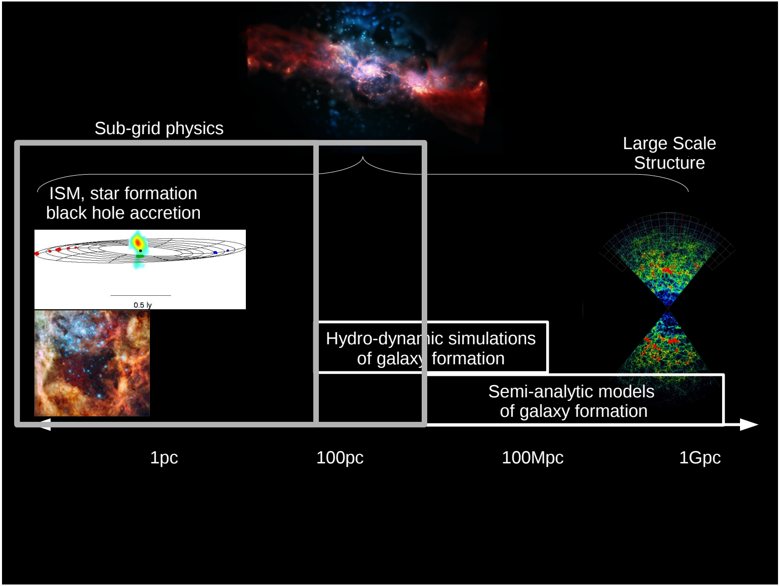
3. 

Simulated volumes:



CREDIT: Claudia Lagos

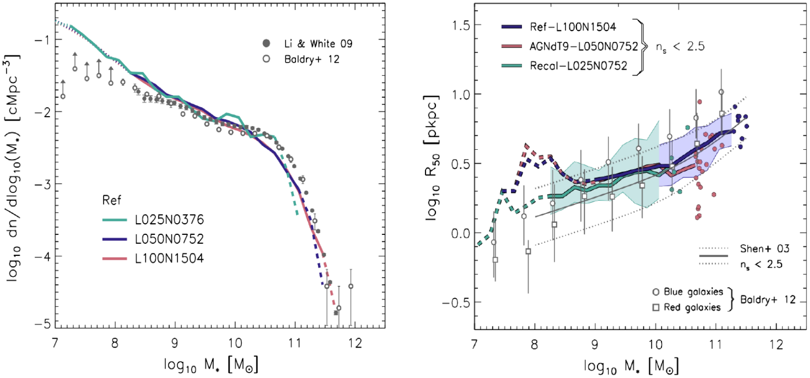
The modelling approach depends on the scientific question



CREDIT: Claudia Lagos

Focusing on model galaxies calibrated at $z = 0$

Many studies attempt to have statistically representative galaxies at $z = 0$ and study then how they evolve.



Schaye+15

Other approaches are needed for other purposes: have a catalogue of model galaxies that reproduce the spatial distribution of galaxies at a given z, produce a sample of galaxies with the same observed colours as LBG at $z = 3$, to study their evolution, etc.

From luminosities to flux

- **Flux** Total amount of energy that crosses a unit area per unit time.

$$\nu F_\nu = \frac{\nu_e L_{\nu_e}}{4\pi D_L^2(z)}$$

From the definition of redshift we have:

$$1 + z = \frac{\lambda_{\mathrm{observed}}}{\lambda_{\mathrm{emitted}}} = \frac{\nu_{\mathrm{emitted}}}{\nu_{\mathrm{observed}}} = \frac{\nu_{\mathrm{e}}}{\nu}$$

Thus:

$$F_\nu = (1+z)\frac{L_{(1+z)\nu}}{4\pi D_L^2(z)}$$

From flux to magnitudes

- **Magnitude**

$$m_1 - m_{ref} = -2.5log_{10}\left(\frac{\mathrm{Flux}_1}{\mathrm{Flux}_{ref}}\right)$$

- **Absolute magnitude, M:** The magnitude of an object placed 10pc from the observer.
- **Apparent magnitude, m:** $m = M + DM + K_e$

$$\begin{aligned} m - M &= -2.5log_{10}\left(\frac{F_\nu}{F_{\nu,\mathrm{10pc}}}\right) = \\ &= -2.5log_{10}\left((1+z)\frac{L_{(1+z)\nu}}{4\pi D_L^2(z)}\frac{4\pi(\mathrm{10pc})^2}{L_\nu}\right) \\ &= 5log_{10}\left(\frac{D_L(z)}{(\mathrm{10pc})}\right) - 2.5log_{10}\left((1+z)\frac{L_{\nu_e}}{L_\nu}\right) \end{aligned}$$

Statistical approach to galaxies

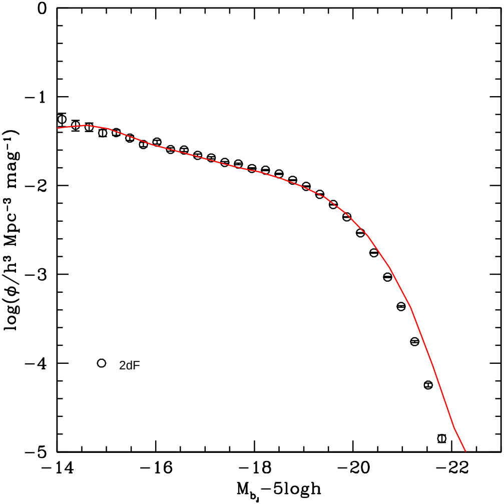
- Probability of finding one galaxy in a diferential volume: $dP = n\,dV$, with n as the mean number of objects in a finite volume, V, per unit volume.
- The average total number of objects will be $< N >= nV$.
- Probability of finding a galaxy within dV with a mass, $M_* - \frac{dM_*}{2} \leq M_* \leq M_* + \frac{dM_*}{2}$:

$$dP = \Phi(M_*, t) dM_* dV$$

- We refer to $\Phi(M_*, t)$ as the stellar mass function, i.e., the average number of galaxies per stellar mass bin per volume at a given time (or redshift), such that,

$$n = \int_{-\infty}^{\infty} \Phi(M_*, t) dM_*$$

The luminosity function



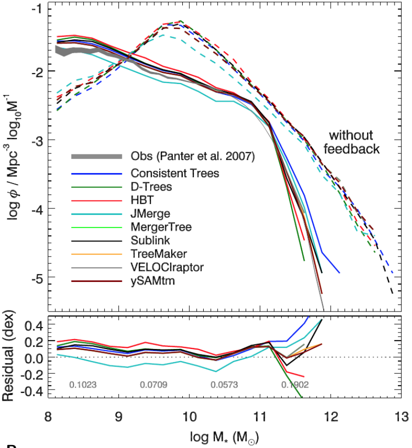
The observed mass/luminosity function

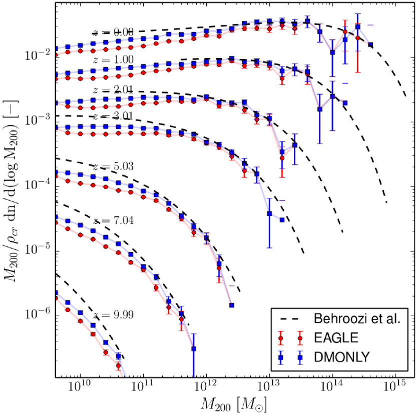
Typical Schechter function in terms of L and M.
How do we go from L to M? Assumptions needed to get stellar masses from luminosities

The dark matter merger trees

ΛCDM Cosmology

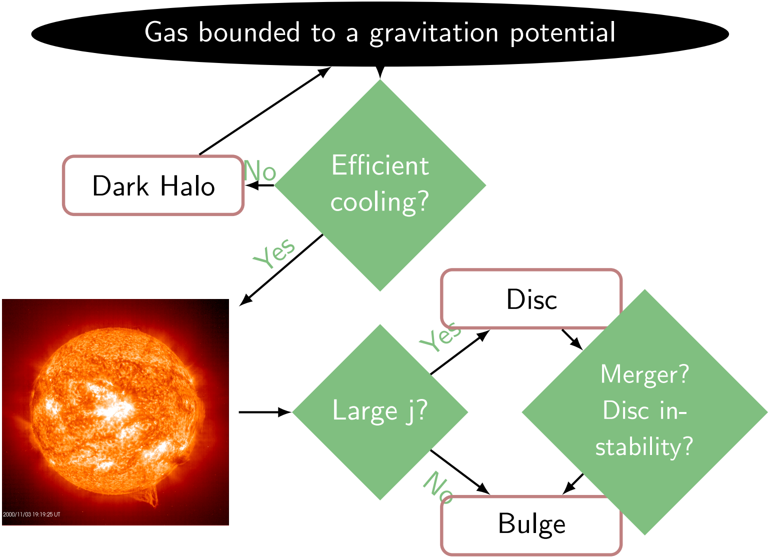
DM Merger trees

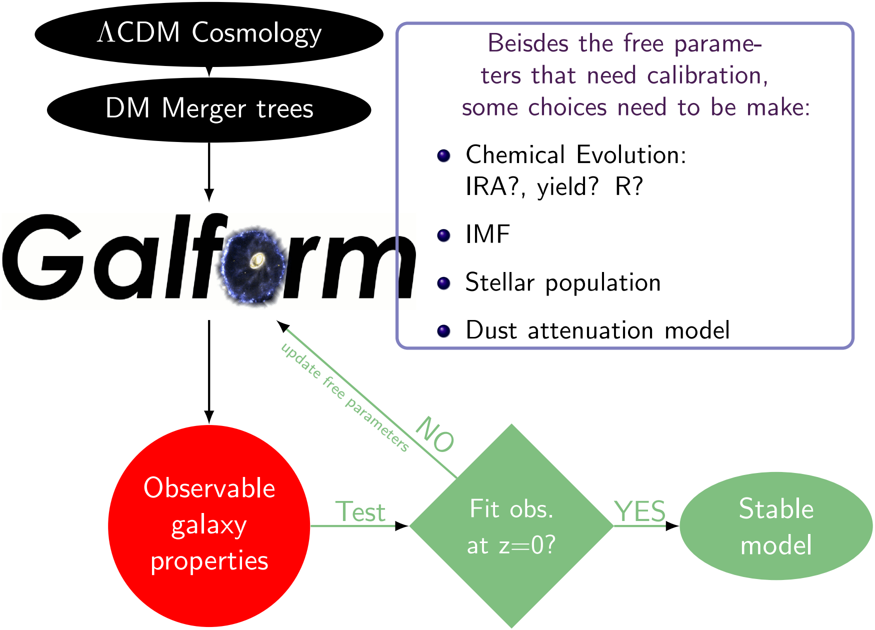




Credits: Lee+14, Schaller+15

Basic steps for modelling galaxies





Beisdes the free parameters that need calibration, some choices need to be make:

- Chemical Evolution: IRA?, yield? R?
- IMF
- Stellar population
- Dust attenuation model