



News From the Dark -May 2019, Montpellier



# Cosmological simulation of spiral galaxies Baryonic physics and dark matter distribution.

Arturo Núñez-Castiñeyra

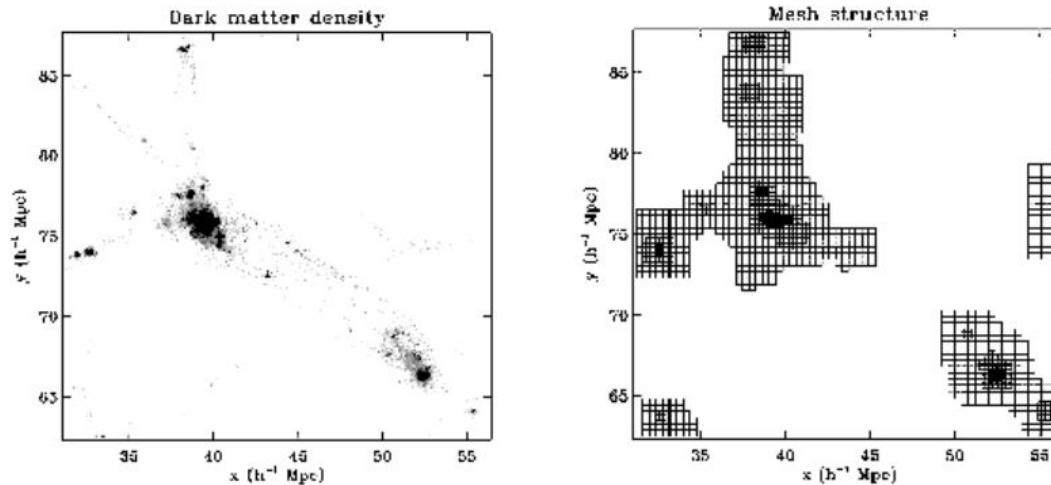
## Colaborations:

Emmanuel Nezri (LAM), Vincent Bertin (CPPM), Pol Mollitor (LAM) Julien Devriendt (Oxford) Romain Teyssier (Zurich), Thomas Iacobucci (Madrid), Martin Stref (LUPM), Julien Lavalle (LUPM), Jean-Charles Lambert (LAM)

# Adaptive Mesh Refinement

At each grid level, the force softening is equal to the local grid size. For pure dark matter simulations, using a quasi-Lagrangian strategy, the particle shot noise is kept roughly constant.

**RAMSES** (Teyssier et al. 2002)

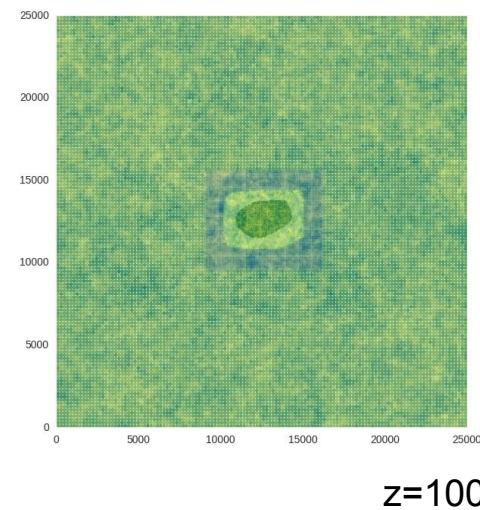
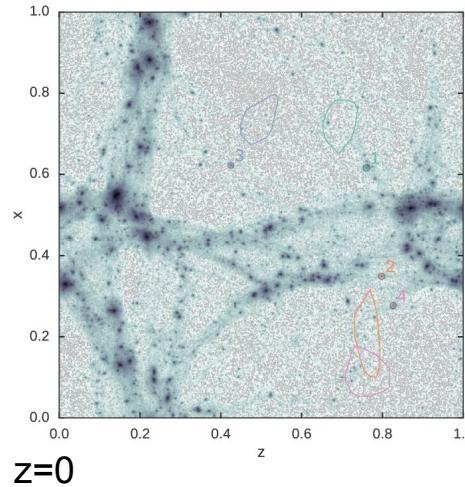
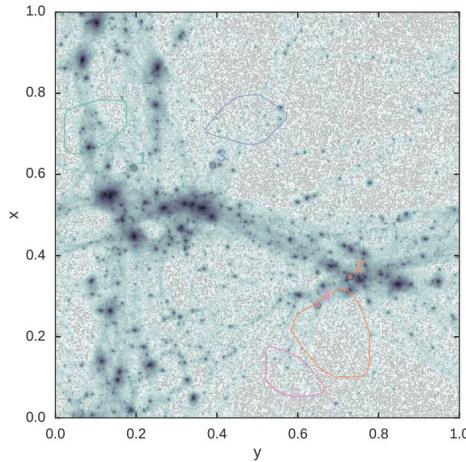


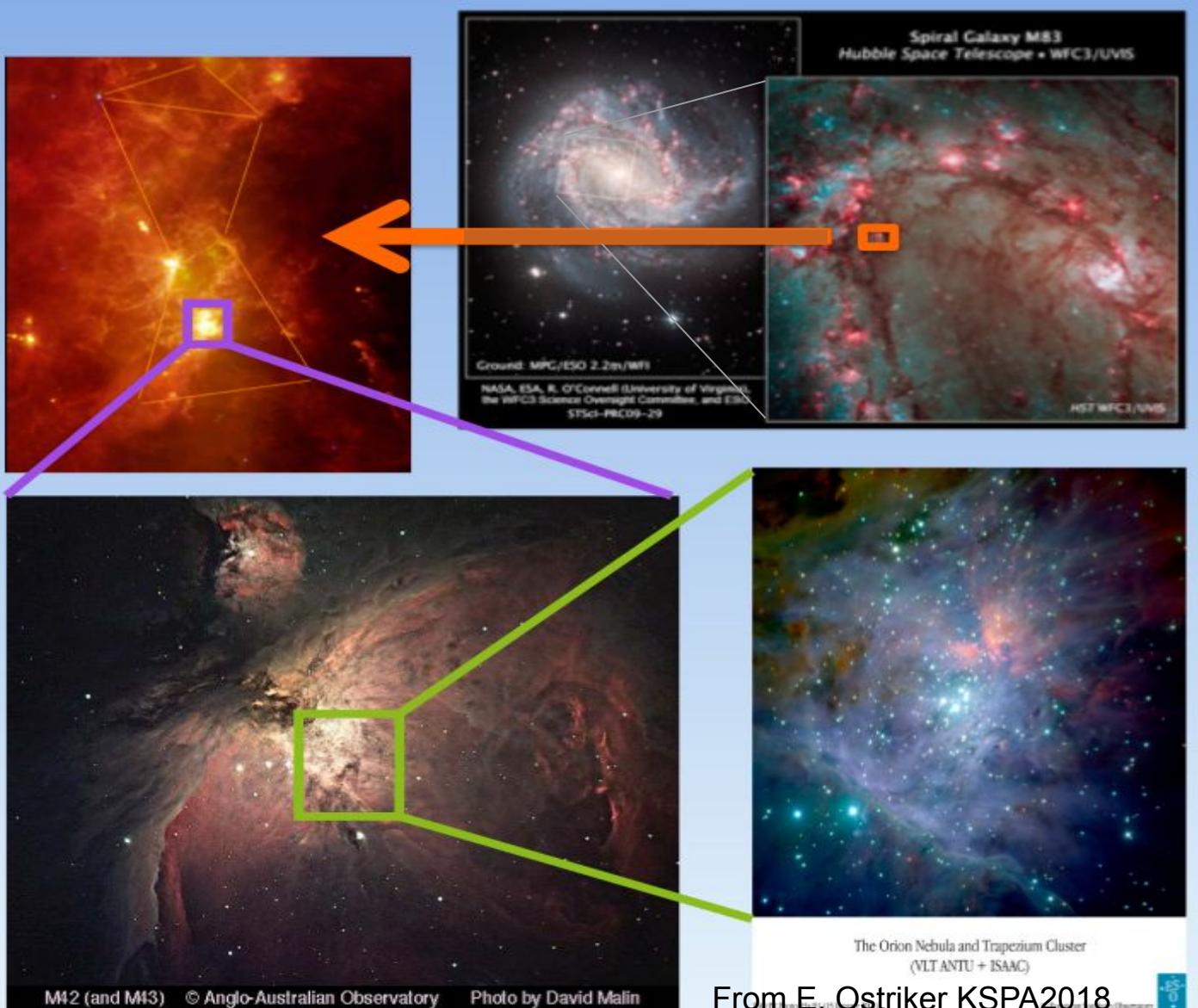
## Initial conditions

- **MUSIC**: a new IC generator by **Oliver Hahn**: <http://www.stanford.edu/~ohahn/> (hahn & Abel 2011)
- Cosmological inputs
- analytical power spectrum from **Eisenstein & Hu**, ApJ, 1998, 496, 605 (or your favorite function)
- cosmo parameters: omega\_m, omega\_lambda, omega\_b, n\_s, sigma\_8

# Zoom-in Simulations

1. detect one halo of interest in a cosmological simulation.
2. compute the Lagrangian volume in the low resolution IC
3. generate high-resolution IC by adding high frequency waves to the low resolution initial Gaussian random field
4. use the Lagrangian volume as a map to initialize high resolution particles.
5. do the high resolution simulation and check for contamination
6. eventually, compute a better initial Lagrangian volume and re-do the simulation



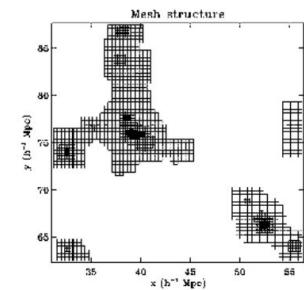


This processes happen in a huge dynamical range (24 orders of magnitude in density)

Simulations have to be divided in:

- Diffuse ISM
- Molecular clouds
- Core collapse

So how to model this for cosmological simulations?



# Star formation

Schmidt law for star formation:

$$\dot{\rho}_* = \epsilon_* \frac{\rho_g}{t_{\text{ff}}} \text{ for } \rho > \rho_*$$

Krumholz & Tan (2007).

Option 1: constant efficiency Governato et al (2007).

Scannapieco et al (2009). Agertz et al (2011)

From Federrath & Klessen (2012)

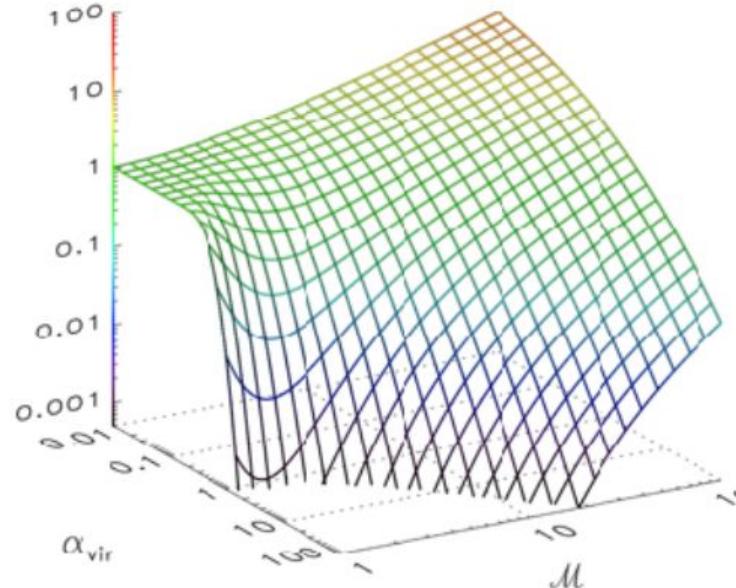
Option 2: calculated efficiency

$$p(s) = \frac{1}{\sqrt{2\pi\sigma_s^2}} \exp\left(-\frac{(s + \frac{1}{2}\sigma_s^2)^2}{2\sigma_s^2}\right)$$

$$\sigma_s^2 = \ln(1 + b^2 \mathcal{M}^2) \quad \mathcal{M} = \frac{\sigma_T}{c_s}$$

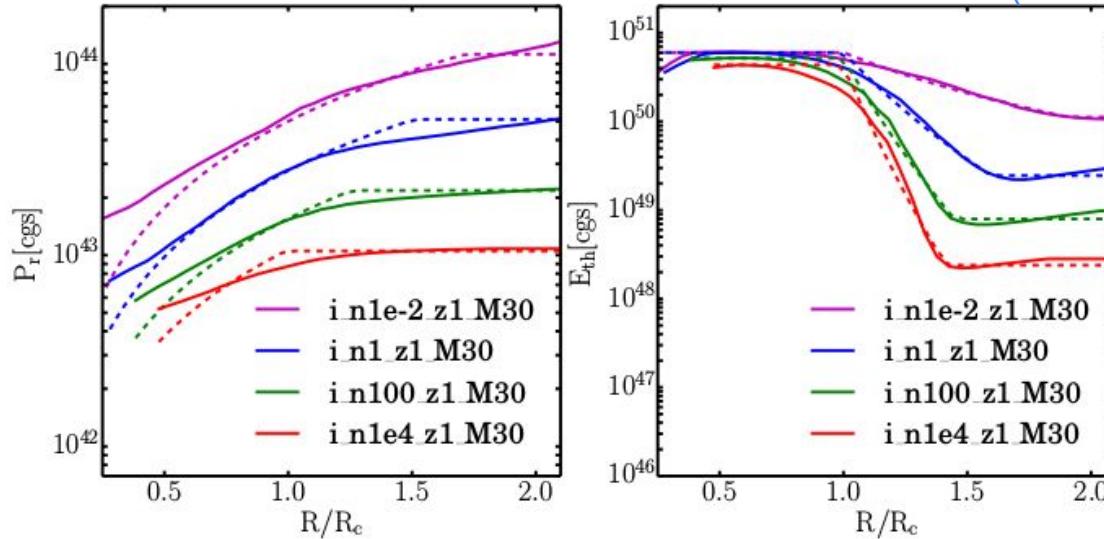
Krumholtz & McKee (2005), Hennebelle & Chabrier (2011)

$$\rho_{\text{crit}} \propto \alpha_{\text{vir}} \mathcal{M}^2 \quad \alpha_{\text{vir}} = \frac{\sigma_T^2}{G\rho_0 \Delta^2}$$



$$\epsilon_{ff} = \exp\left(\frac{3}{8}\sigma_s^2\right) \left(1 + \text{erf}\left(\frac{\sigma_s^2 - s_{\text{crit}}}{\sqrt{2\sigma_s^2}}\right)\right)$$

# SN Feedback



Delayed Cooling:

Teyssier et al. 2013

Inject directly a non-thermal energy corresponding to the SN explosion

$$\rho \frac{D\epsilon_{turb}}{Dt} = \dot{E}_{inj} - \frac{\rho\epsilon_{turb}}{t_{diss}}$$

Mechanical Feedback:

Kimm et al 2015

Model the two phases of the SN explosion and inject the corresponding momentum

$$p_{SN,snow} \approx 3 \times 10^5 \text{ km s}^{-1} M_\odot E_{51}^{16/17} n_H^{-2/17} Z'^{-0.14}$$

$$p_{SN} = \begin{cases} p_{SN,ad} = \sqrt{2\chi M_{ej} f_e E_{SN}} & (\chi < \chi_{tr}) \\ p_{SN,snow} & (\chi \geq \chi_{tr}) \end{cases}$$

$$\chi \equiv dM_{swept}/dM_{ej}$$

$$\chi_{tr} \equiv 69.58 E_{51}^{-2/17} n_H^{-4/17} Z'^{-0.28}$$



$z=1.89$

Stars



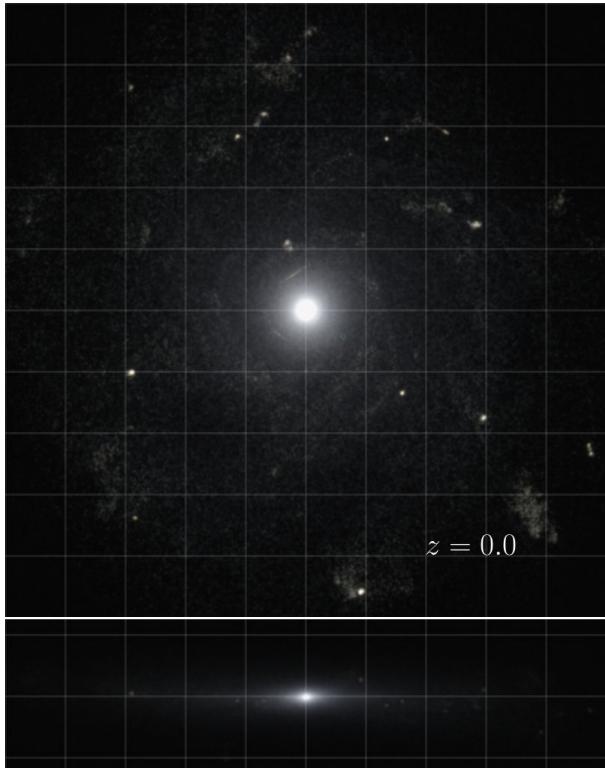
$z=1.89$

DM

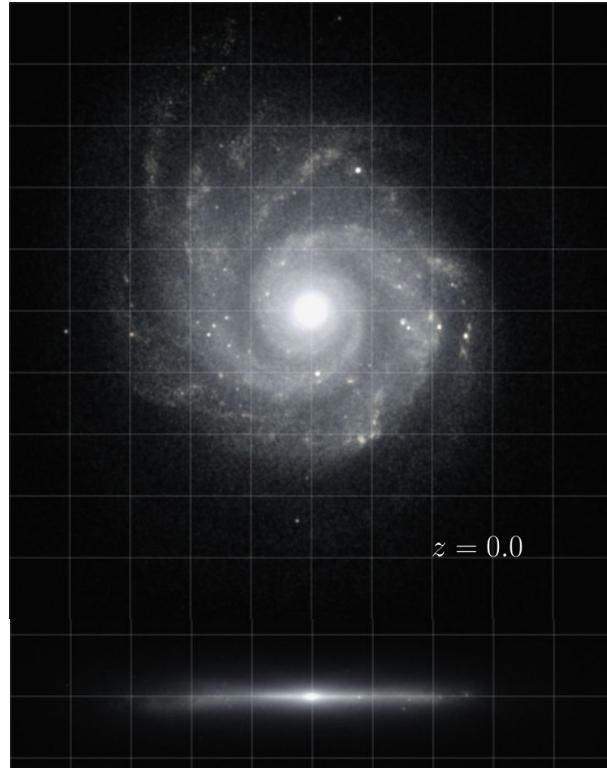


# Mochima Stars

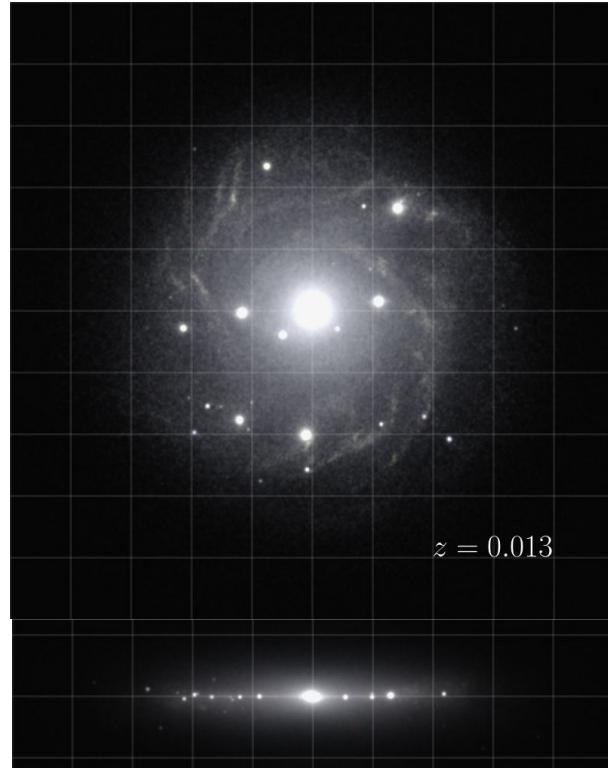
(Boxsize: 36 Mpc,  $M_H = 0.9 \times 10^{12} M_{\text{sun}}$ ,  $M_{\text{dm}} = 1.8 \times 10^5$ ,  $\Delta x = 35$  pc)



SF: Schmidt law (KT13)  
FB: Delayed Cooling(T13)

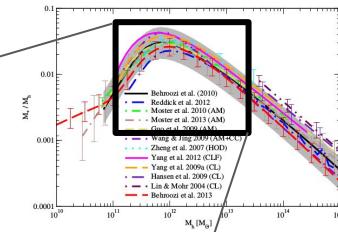
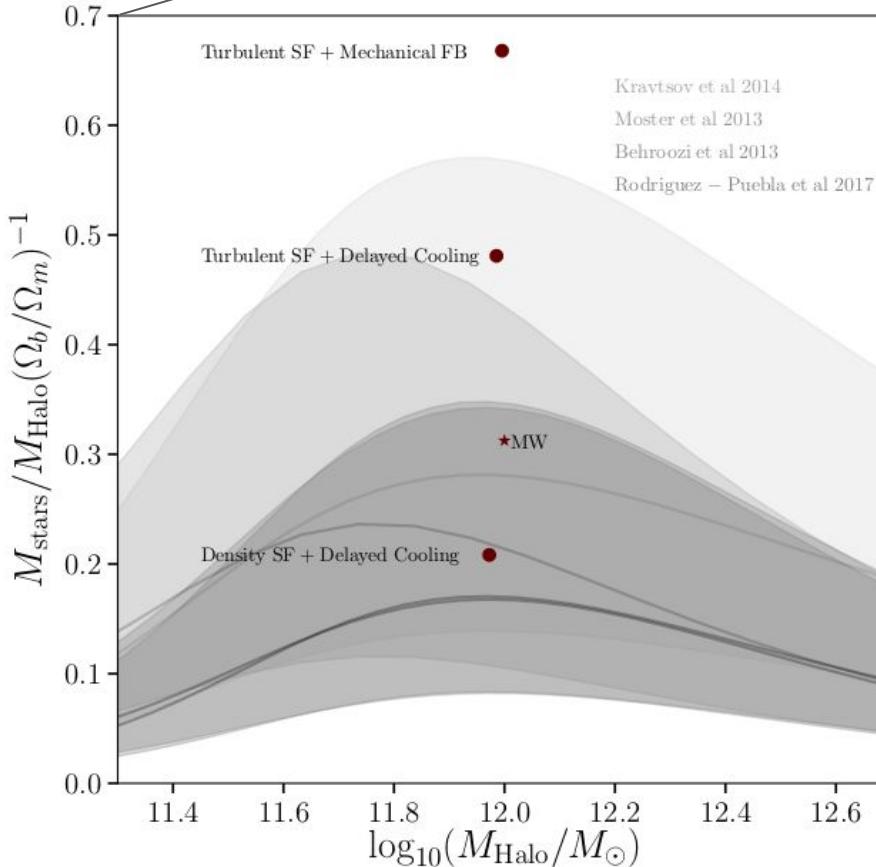


SF: Turbulent SF (KM05)  
FB: Delayed Cooling (T13)

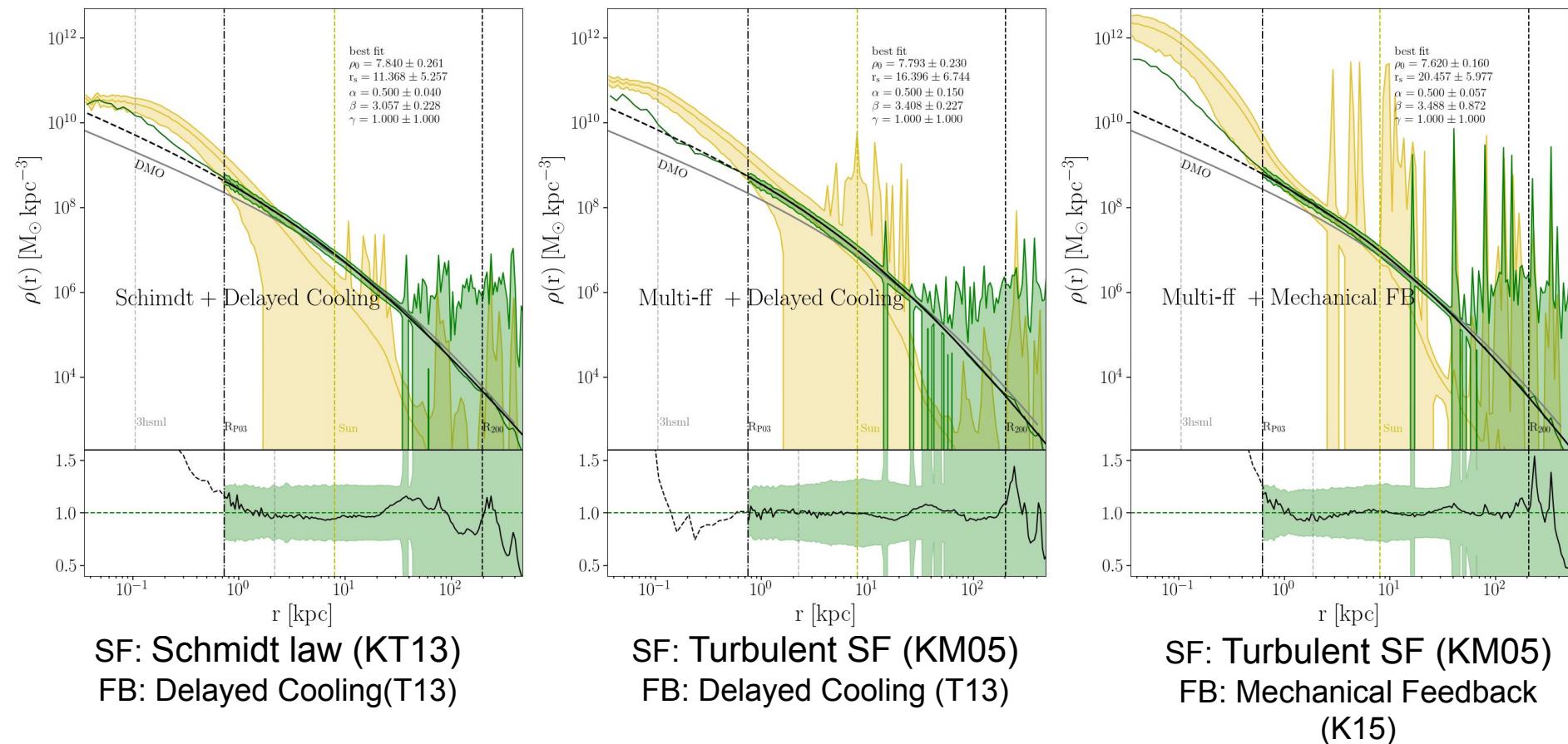


SF: Turbulent SF (KM05)  
FB: Mechanical Feedback  
(K15)

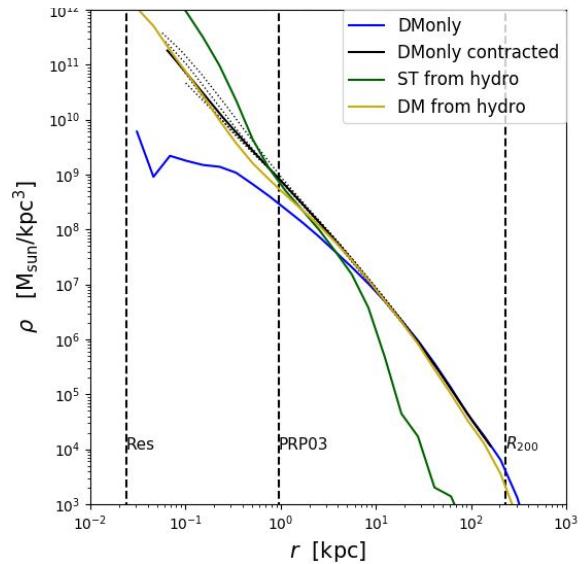
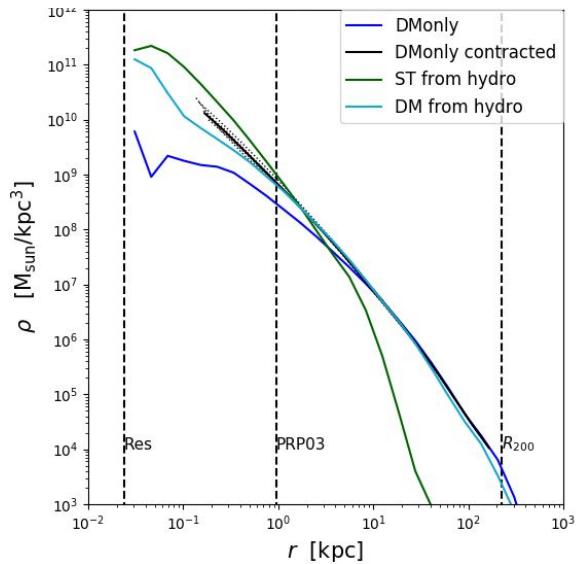
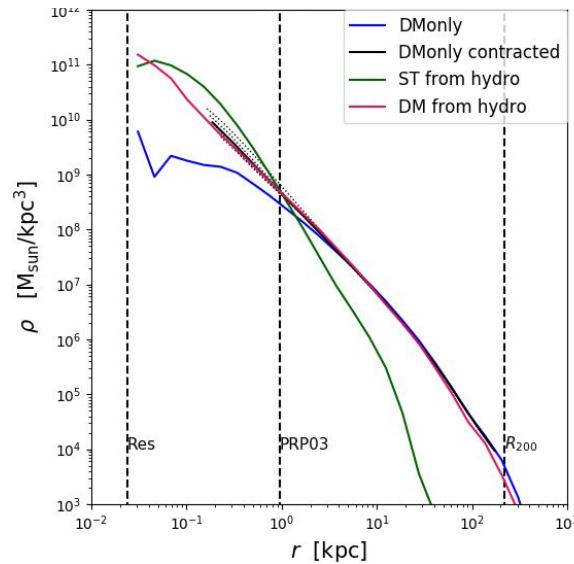
# General comparisons SHMR



# Dark matter profile



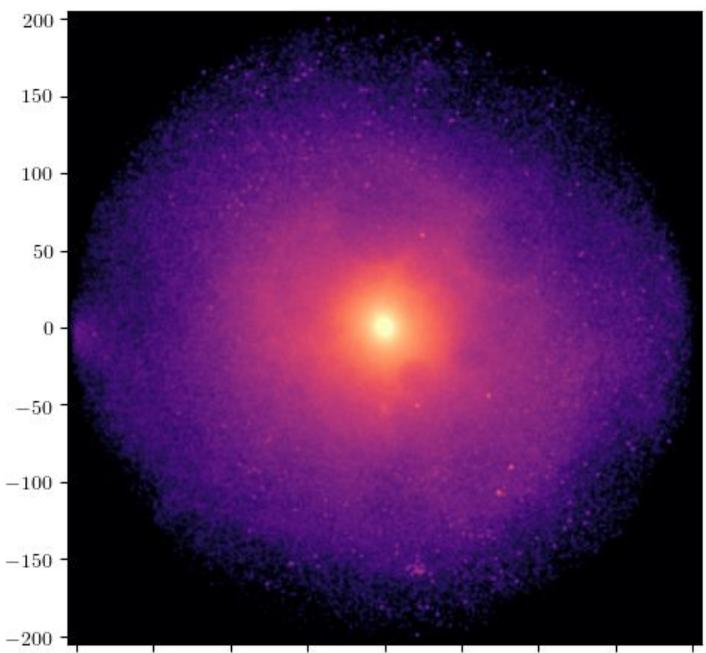
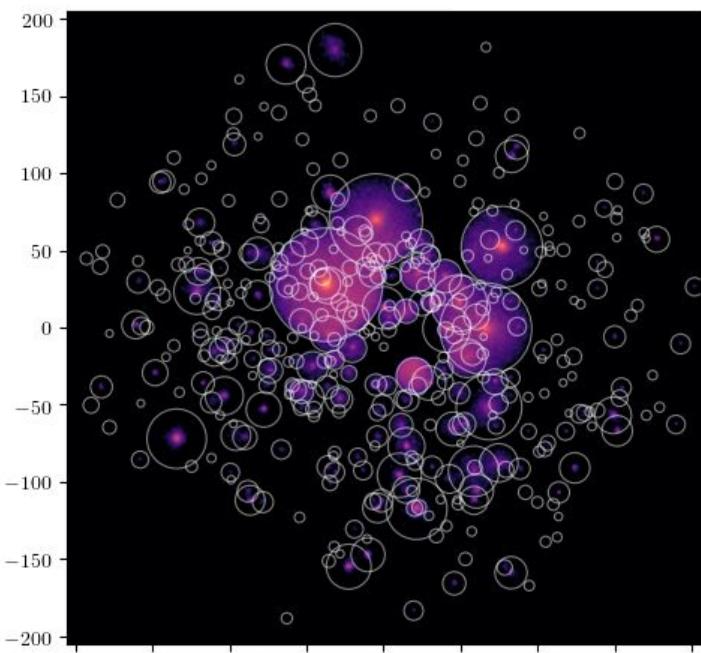
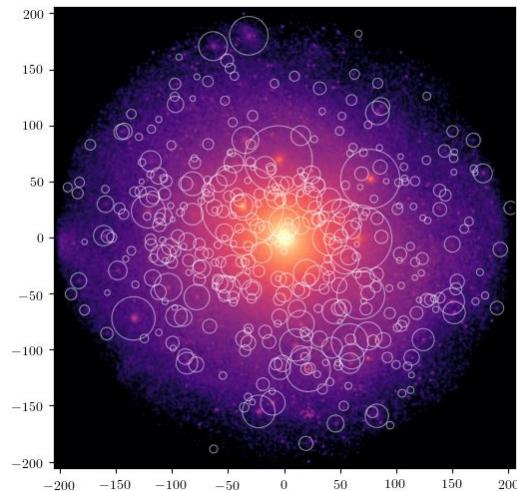
# Contraction of the DM profile?



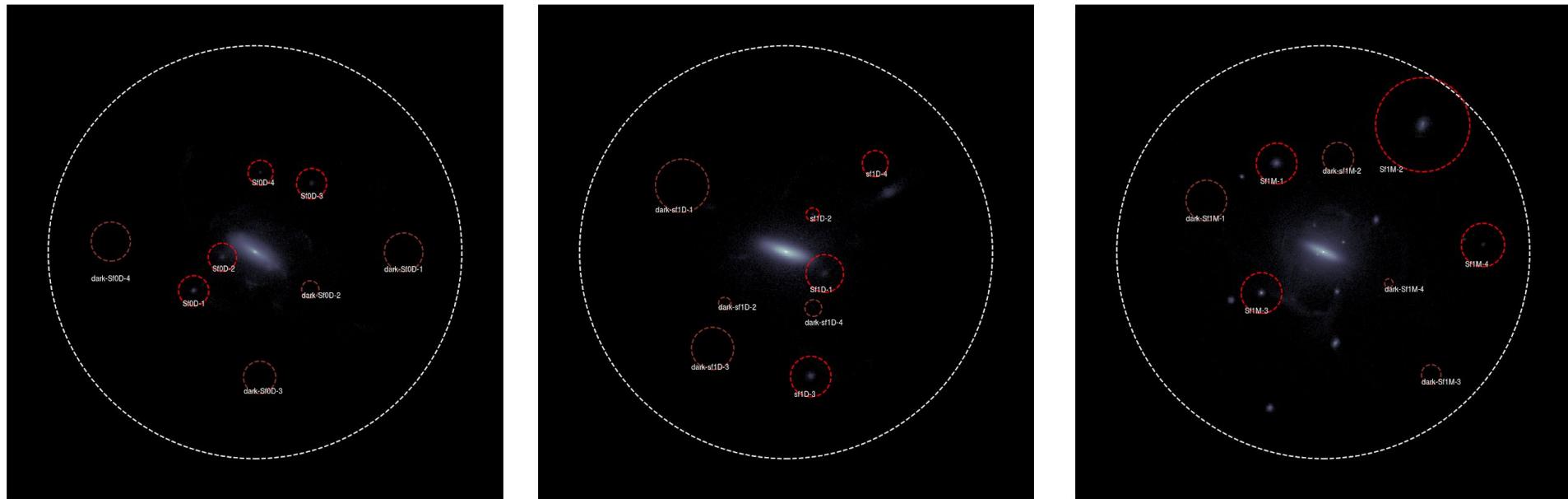
$$M_{dm}(r_i) r_i = (M_{dm}(r_f) + M_{dm}(r_f)) r_f$$

(Blumenthal et al, 1986)

# The halo sub structures



# The galaxies and its satellites

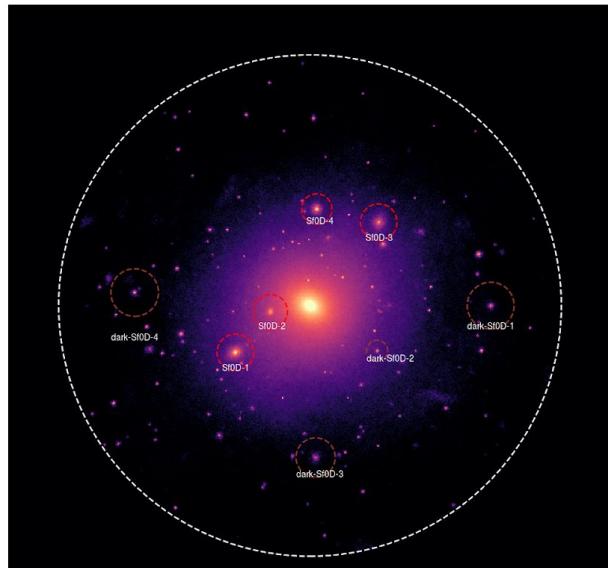


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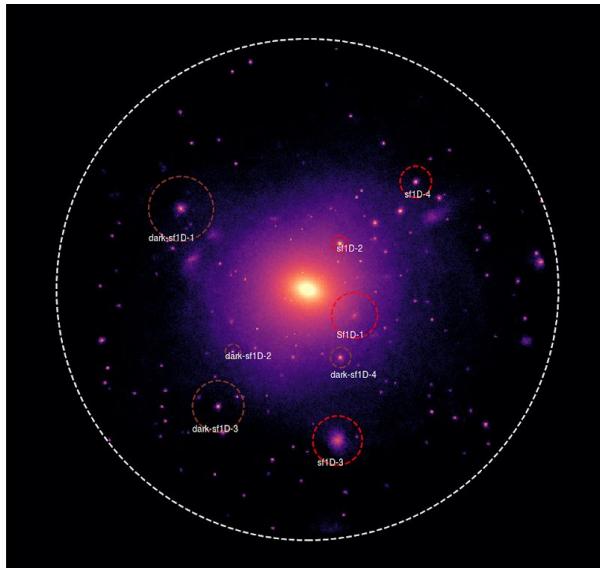
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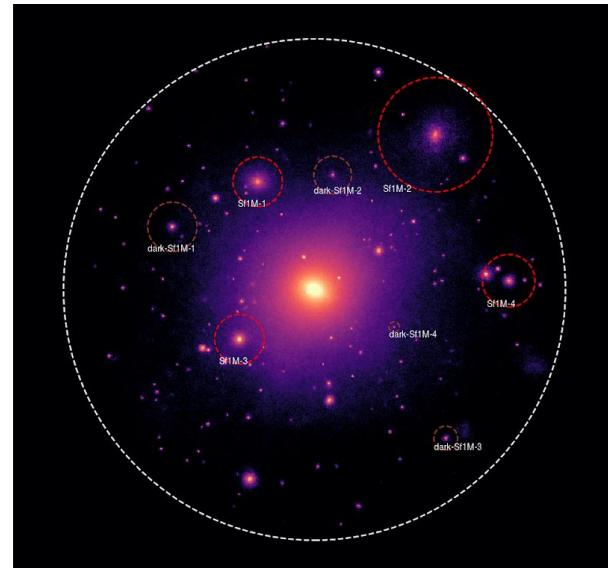
# Their Dark Matter sub-halos



SF: Schmidt law (KT13)  
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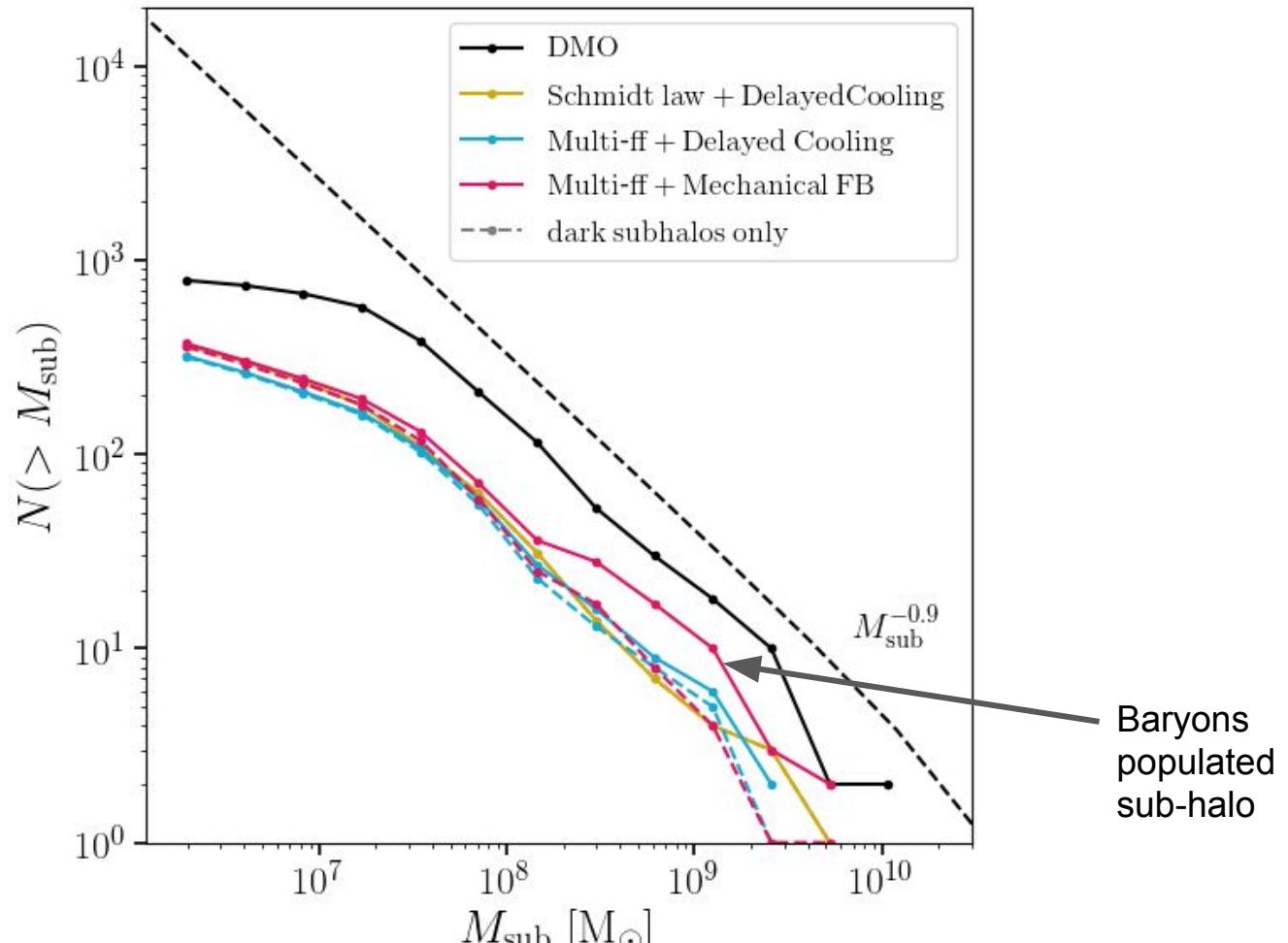


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# Sub halo distributions



# Consequences

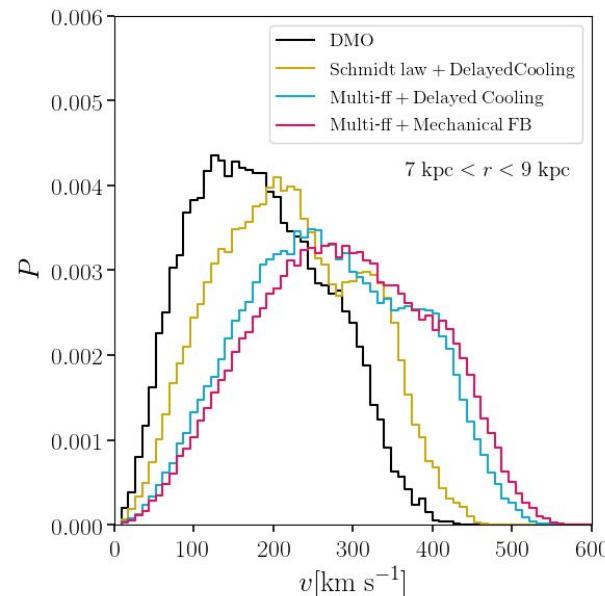
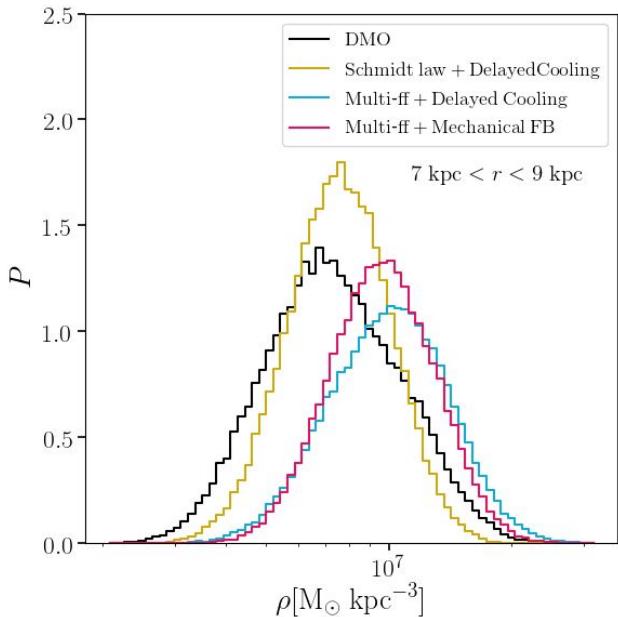
- Detection from the halo (gamma, neutrino...)

$$\Phi_{\gamma, \nu, \bar{p}, (e^+)}^{source} \propto \rho_{DM}^2 \text{ (inner cusp, clump spectrum, concentration)}$$

- Local dark matter (in)direct detection (direct and neutrinos from the Sun)

# Consequences

- Detection from the halo (gamma, neutrino...)
  - $\Phi_{\gamma,\nu,\bar{p},(e^+)}^{source} \propto \rho_{DM}^2$  (inner cusp, clump spectrum, concentration)
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# Consequences and conclusions

- Detection from the halo (gamma, neutrino...)
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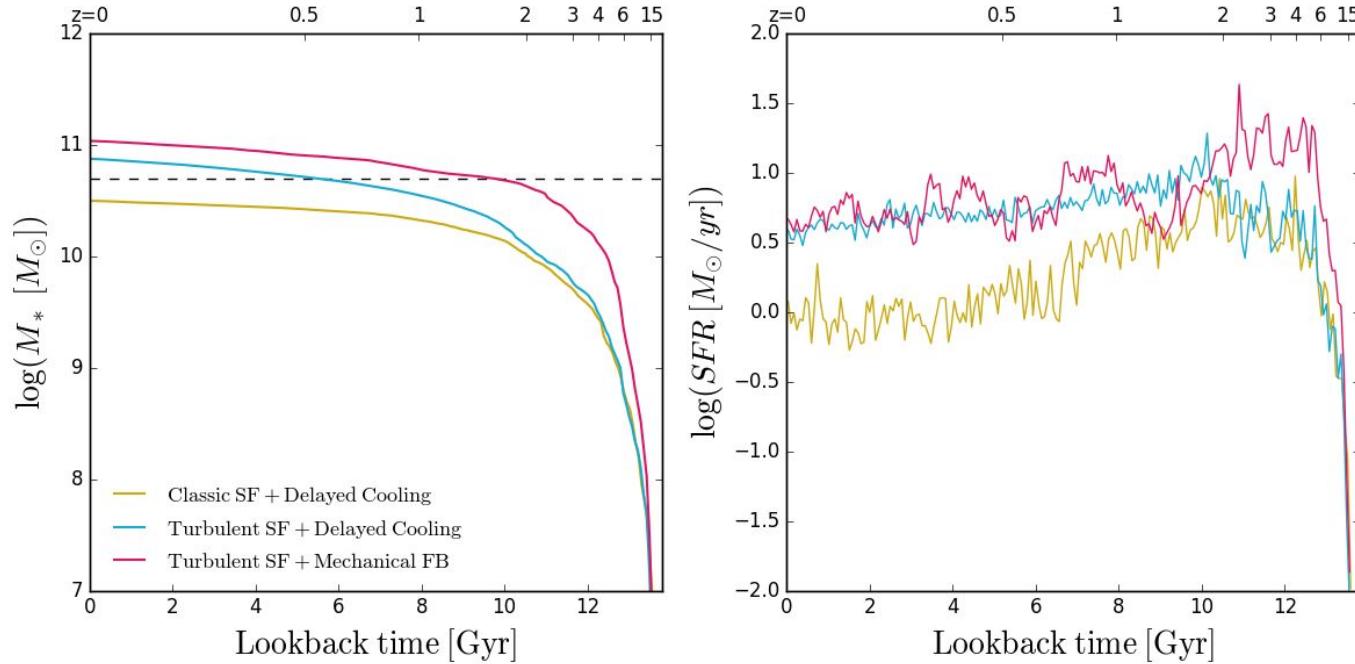
Baryonic physics:

- A determining topic for galaxy formation
- Also a strong issue when it comes to relevant assumptions in DM detection...

Next: step improve simulation, baryonic schemes and galaxy bank, more galaxies like this.

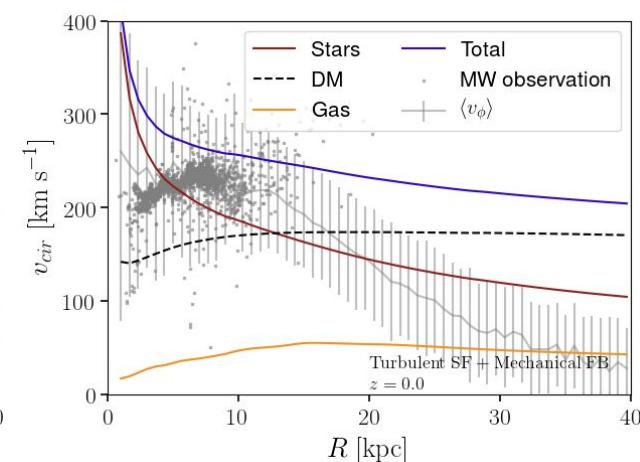
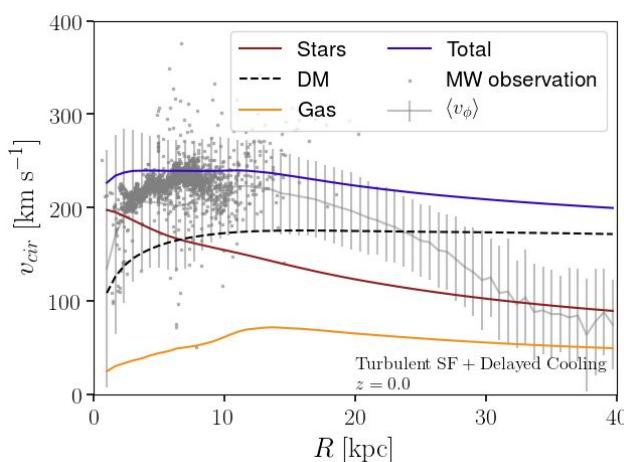
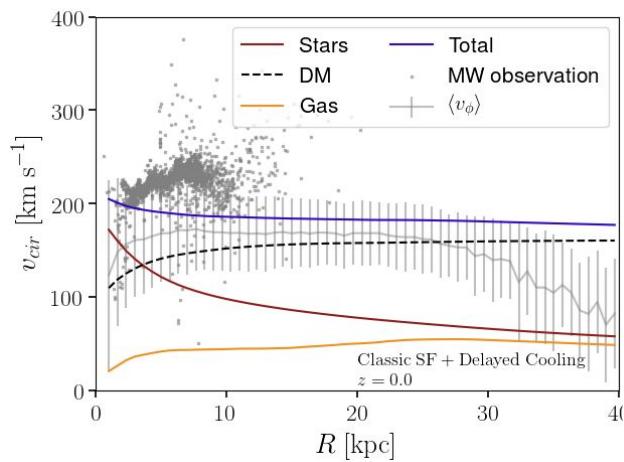
Thanks

# Star Formation history



# Mochima (Boxsize: 36 Mpc, $M_H = 0.9 \times 10^{12} M_{\text{sun}}$ , $M_{\text{dm}} = 1.8 \times 10^5$ , $\Delta x = 35$ pc)

## Rotation curves

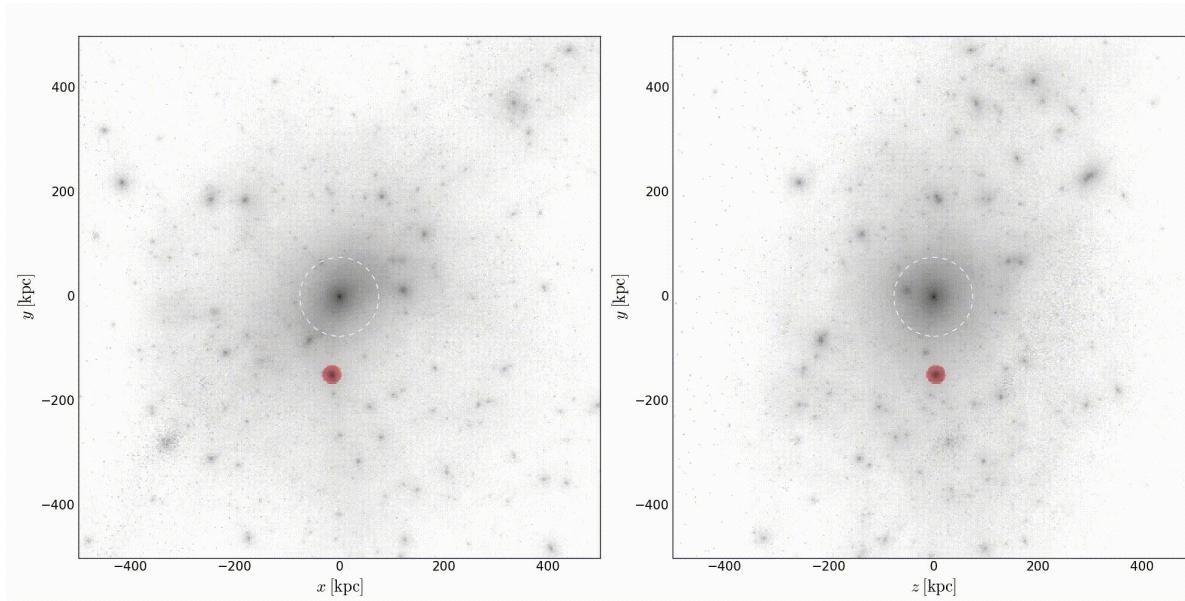


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# The Dark Matter connection



"Milky Way like " simulation are the great lab of DM dynamics:

- Phase space distribution
- Indirect/Direct Dark Matter detection
- Sub-structure mass spectrum, spatial distributions and phase space features
- DM mass distributions

# Star formation

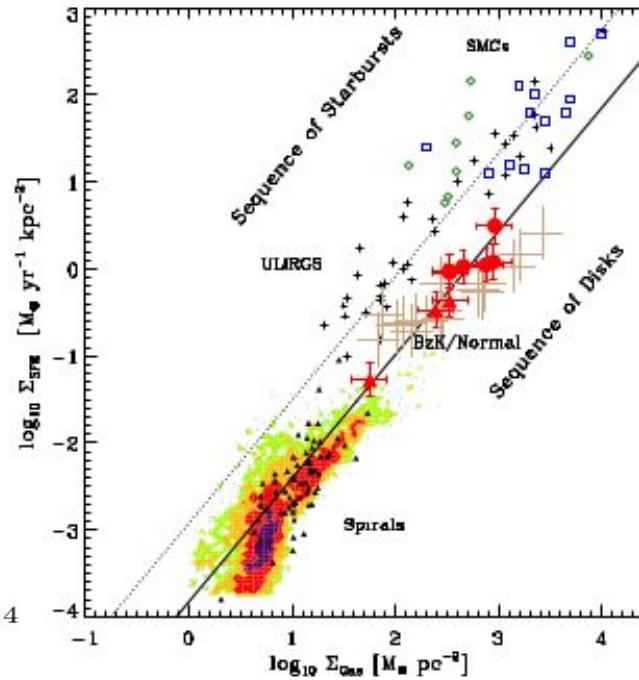
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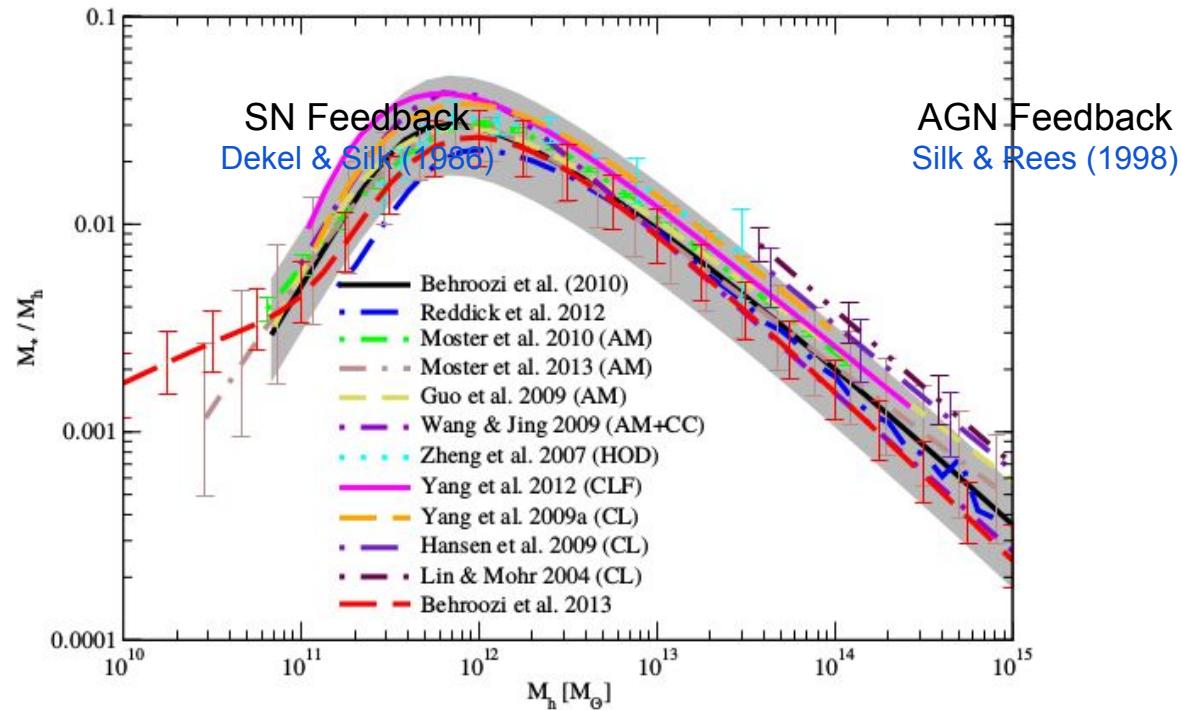
Option 1: constant efficiency

The aim is to calibrate parameters to  $\Sigma_{\text{SFR}} = (2.5 \pm 0.7) \times 10^6 \left( \frac{\Sigma_{\text{gas}}}{M_{\odot} \text{pc}^{-2}} \right)^{1.4}$   
reproduce Kennicutt (1998) relation:



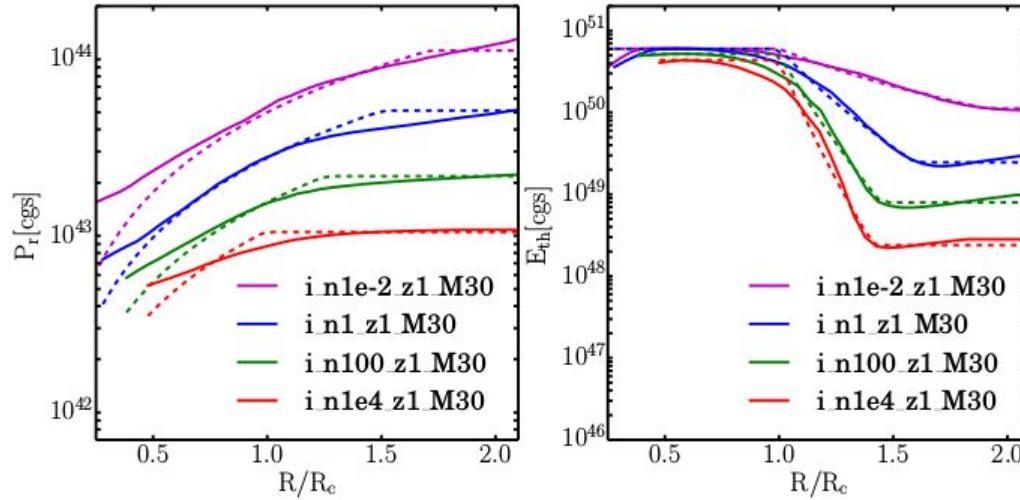
Daddi et al. (2010)

# Feedback



Behroozi et al. (2013)

# SN Feedback



At early time, energy-conserving Sedov phase.

At late time, momentum-conserving snow-plow phase.

cooling radius:  $R_c \approx 3\text{pc} * (n_h/(100 \text{ H/cc}))^{-(1/5)}$

If cooling radius is not resolved, inject terminal radial momentum

# Cosmological Simulations

