SF2A-May-2019 Nice

Cosmological simulation of spiral galaxies

Baryonic physics and dark matter distribution.

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Colaborations:
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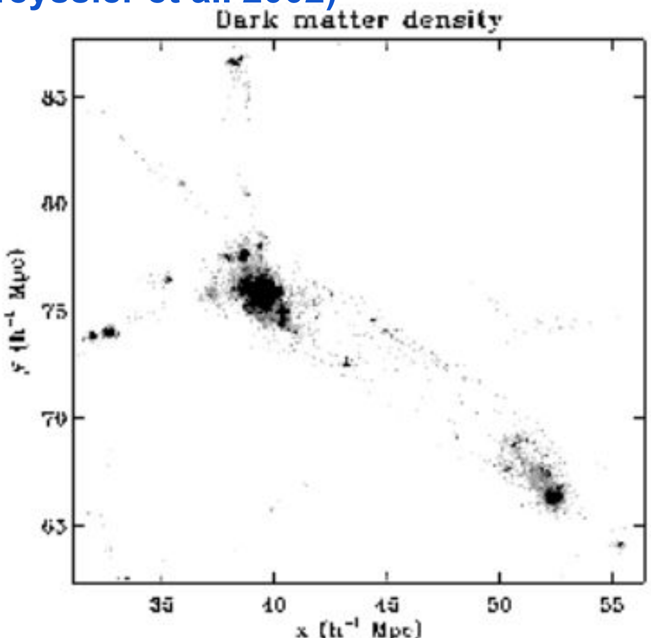
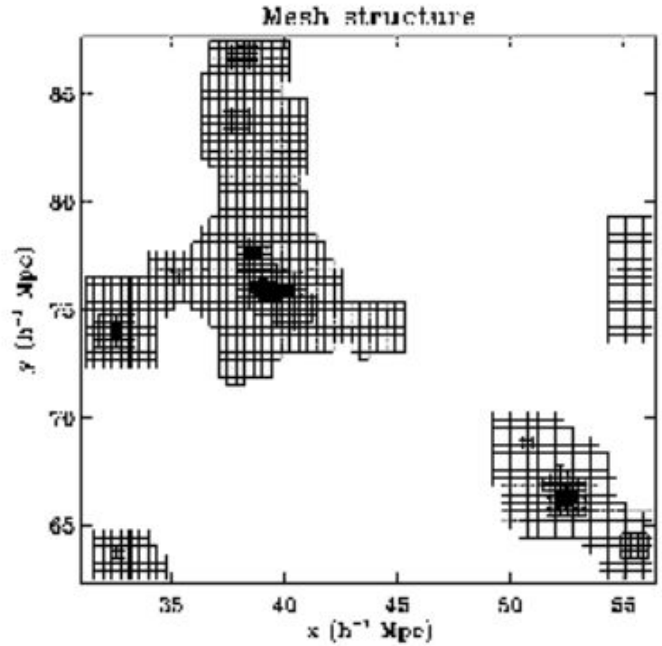
Adaptive Mesh Refinement

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)



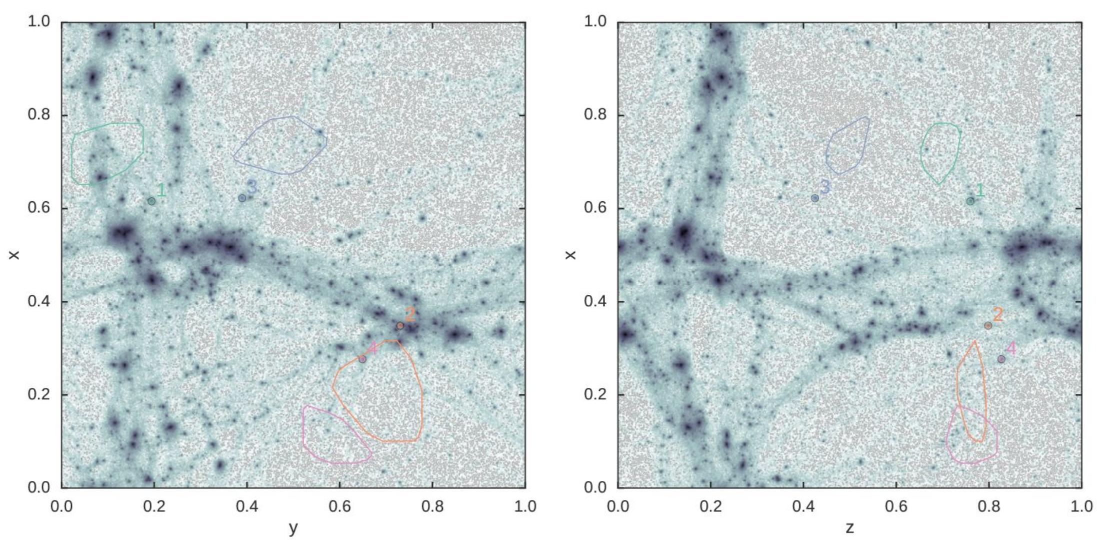


Initial conditions

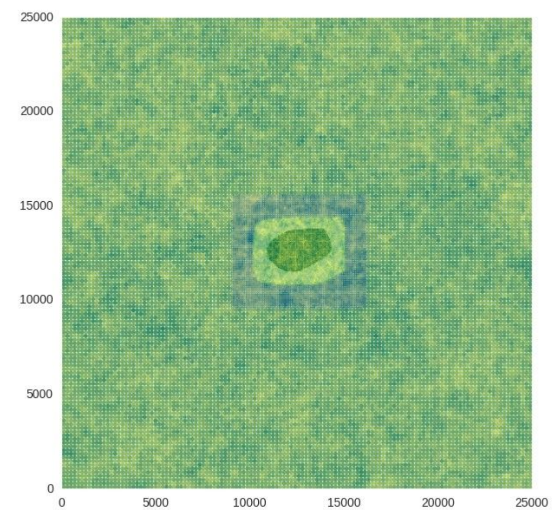
- **MUSIC**: a new IC generator by **Oliver Hahn**: http://www.stanford.edu/~ohahn/ (hahn & Abel 2011)
- Cosmological inputs
- analytical power spectrum from Eisenstein & Hu, ApJ, 1998, 496, 605 (or your favorite function)
- cosmo parameters: omega_m, omega_lambda, omega_b, n_s, sigma_8

Zoom-in Simulations

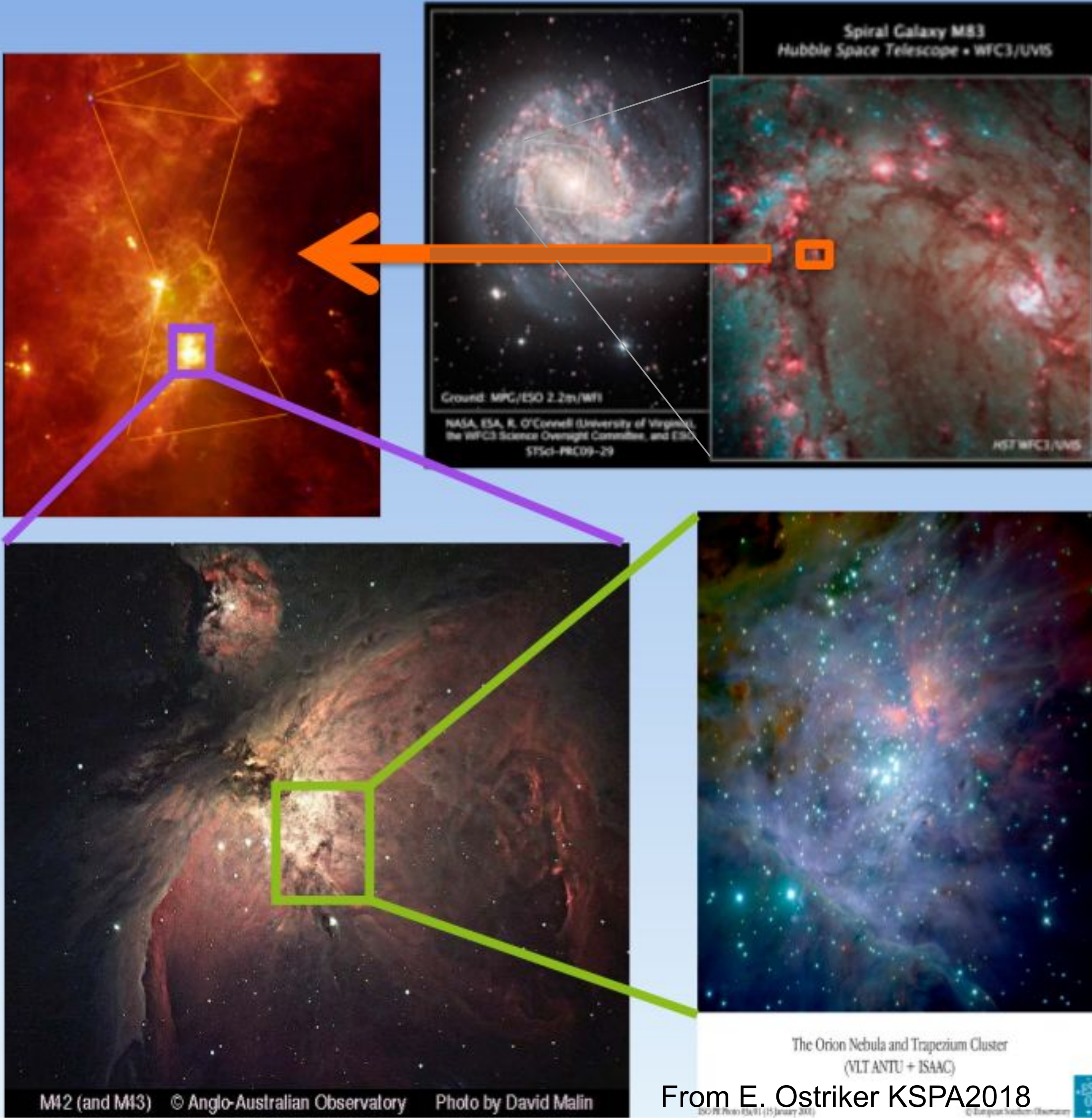
1. detect one halo of interest in a cosmological simulation.
2. compute the Lagrangian volume in the low resolution IC
3. generate high-resolution IC by adding high frequency waves to the low resolution initial Gaussian random field
4. use the Lagrangian volume as a map to initialize high resolution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



z=0



z=100

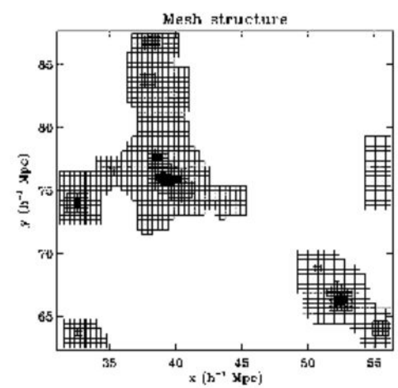


This processes happen in a huge dynamical range (24 orders of magnitude in density)

Simulations have to be divided in:

- Diffuse ISM
- Molecular clouds
- Core collapse

So how to model this for cosmological simulations?



From E. Ostriker KSPA2018

Star formation

Schmidt law for star formation:

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

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

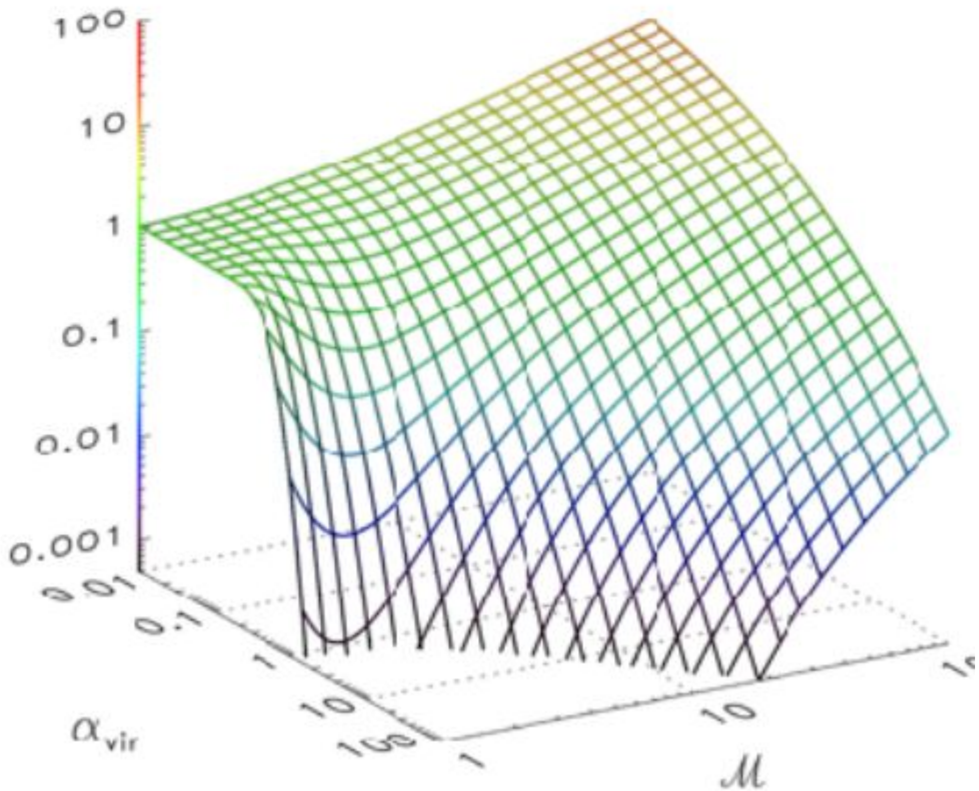
$$p(s) = \frac{1}{\sqrt{2\pi\sigma_s^2}} \exp\left(-\frac{\left(s + \frac{1}{2}\sigma_s^2\right)^2}{2\sigma_s^2}\right)$$

$$\sigma_s^2 = \ln\left(1 + b^2\mathcal{M}^2\right) \qquad \mathcal{M} = \frac{\sigma_{\rm T}}{c_s}$$

Among some of the models we use:

Krumholtz & McKee (2005)

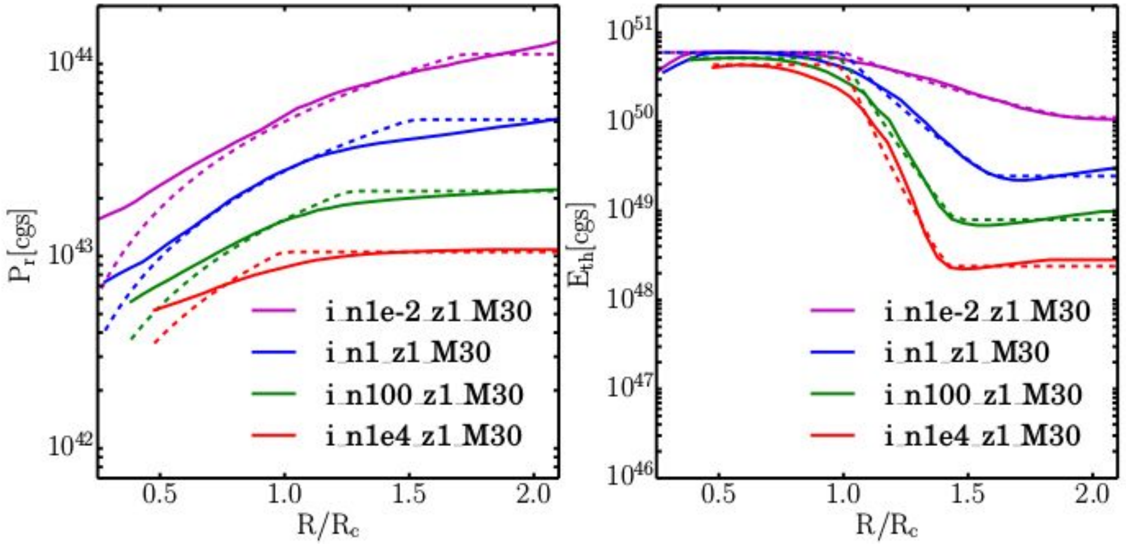
$$\rho_{\rm crit} \propto \alpha_{\rm vir}\mathcal{M}^2 \qquad \alpha_{\rm vir} = \frac{\sigma_{\rm T}^2}{G\rho_0\Delta^2}$$



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

SN Feedback

Martizzi et al. (2015)



Delayed Cooling:

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

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

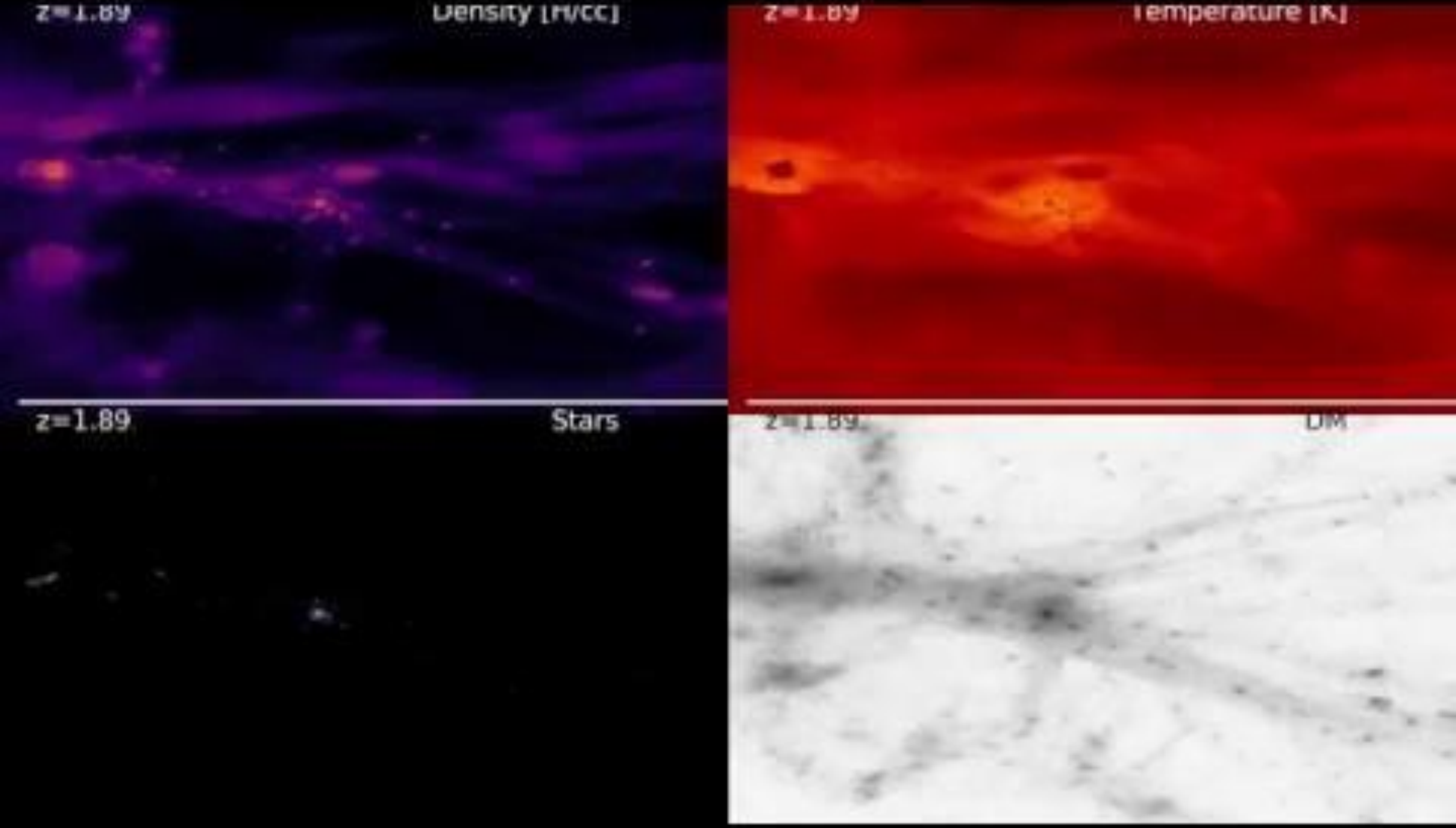
Mechanical Feedback:

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

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

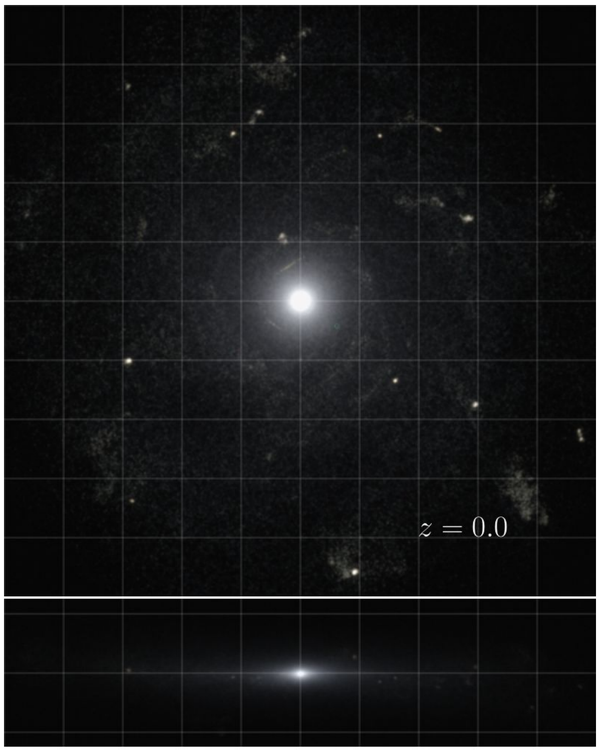
$$p_{\rm SN} = \begin{cases} p_{\rm SN,ad} = \sqrt{2\chi\, M_{\rm ej}\, f_e\, E_{\rm SN}} & (\chi < \chi_{\rm tr}) \\ p_{\rm SN,snow} & (\chi \geq \chi_{\rm tr}) \end{cases}$$

$$\chi \equiv dM_{\rm swept}/dM_{\rm ej} \qquad \chi_{\rm tr} \equiv 69.58\, E_{51}^{-2/17} n_{\rm H}^{-4/17}\, Z'^{-0.28}$$

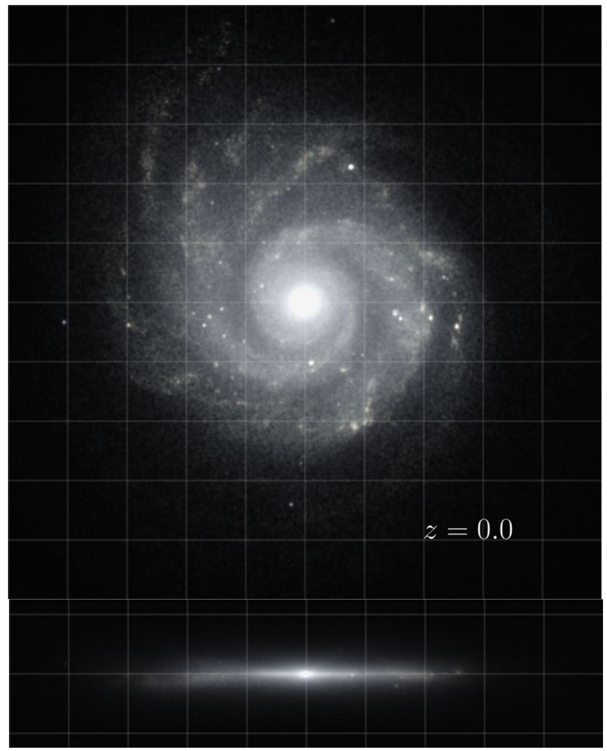


z=1.89
Density [H/cc]
Temperature [K]
z=1.89
Stars
DM

Mochima (Boxsize: 36 Mpc, M_H= 0.9x 10^{12} M_{sun}, M_{dm}=1.8x 10^5, Δx=35 pc)
Stars



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



SF: Turbulent SF (KM05)
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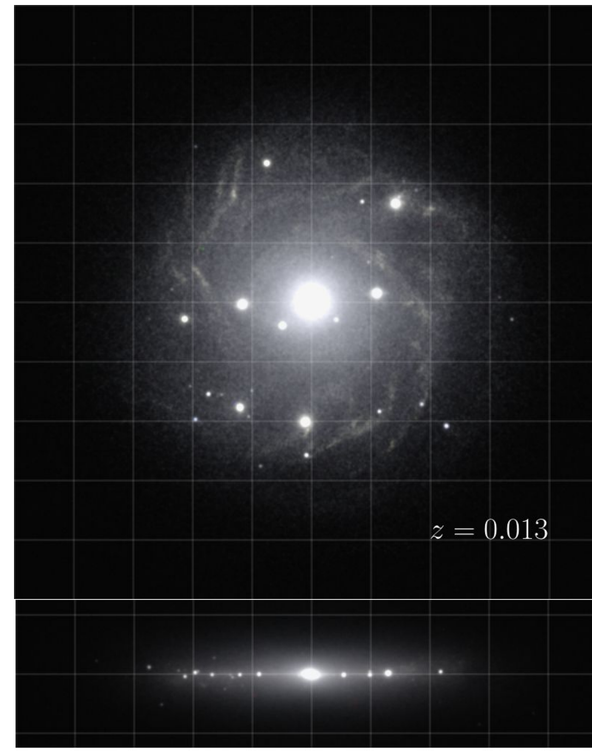

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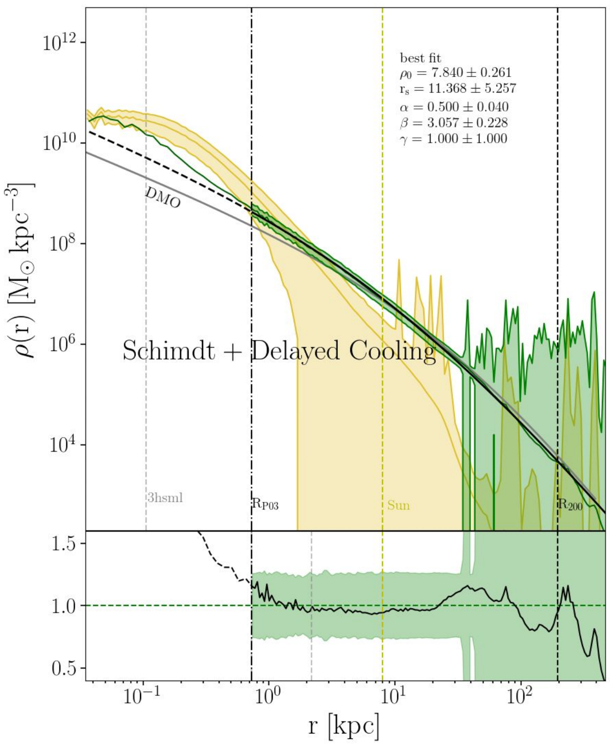
Dark matter profile



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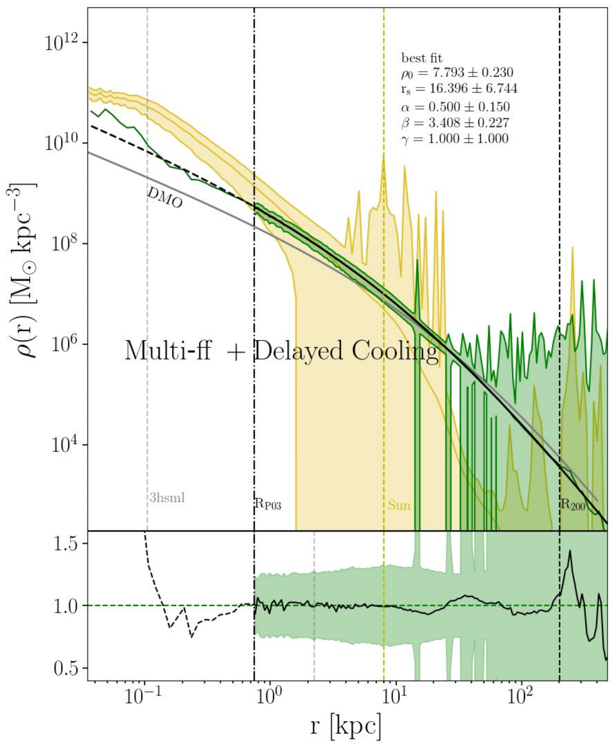

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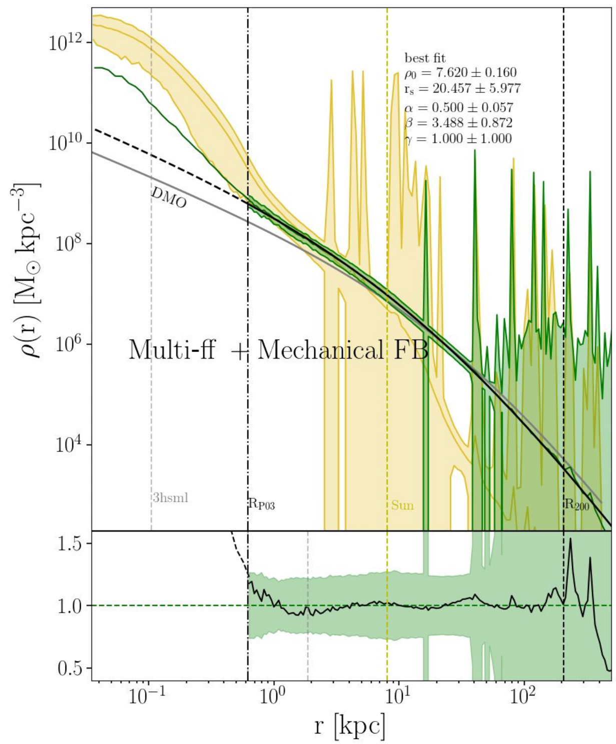

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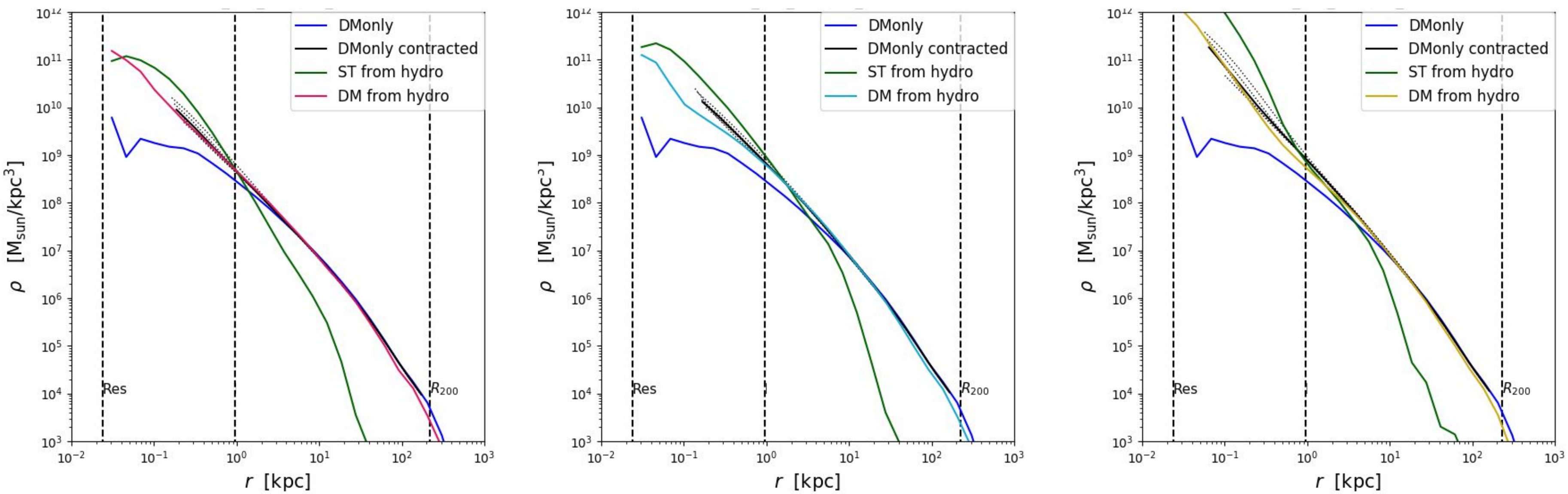
(K15)

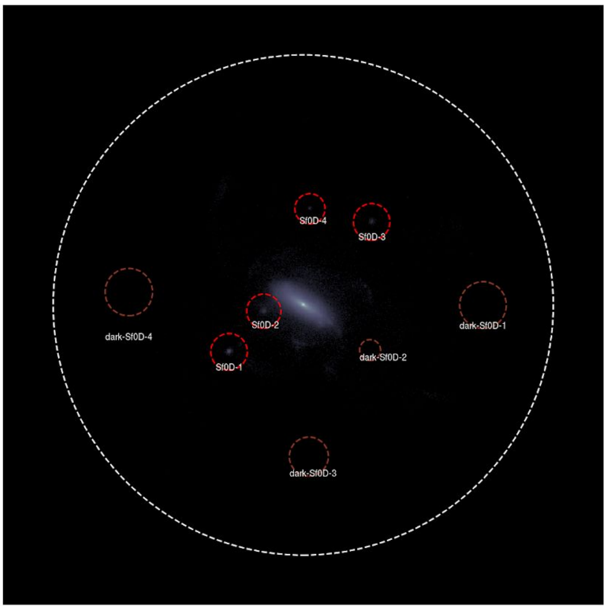
Contraction of the DM profile?



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

(Blumenthal et al, 1986)

The galaxies and its satellites



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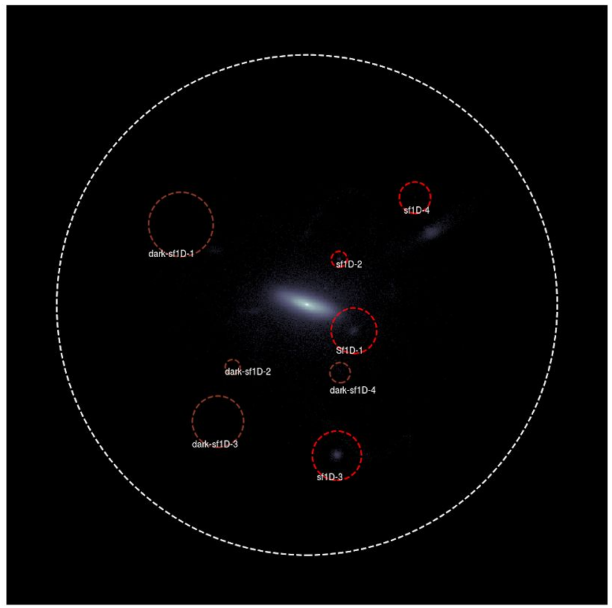

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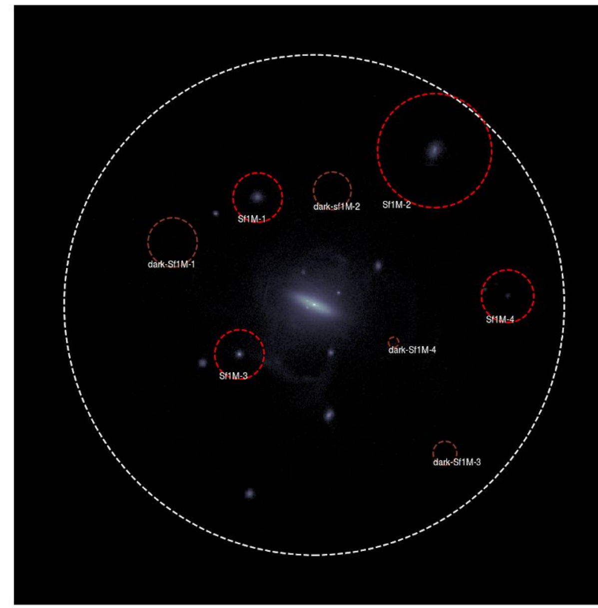

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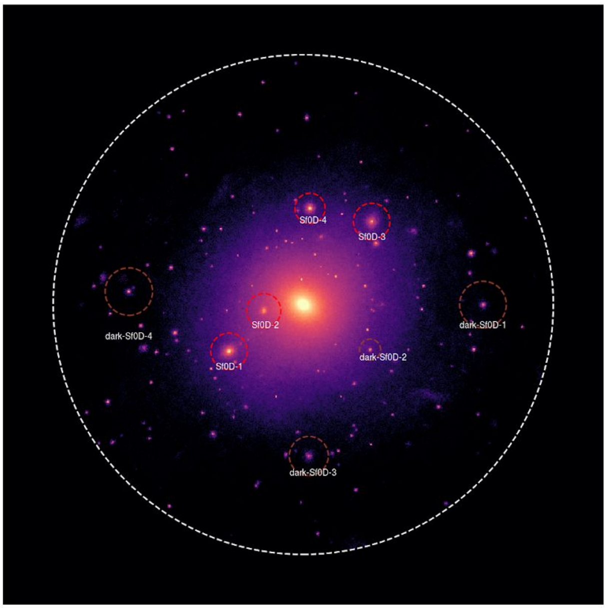
Their Dark Matter sub-halos



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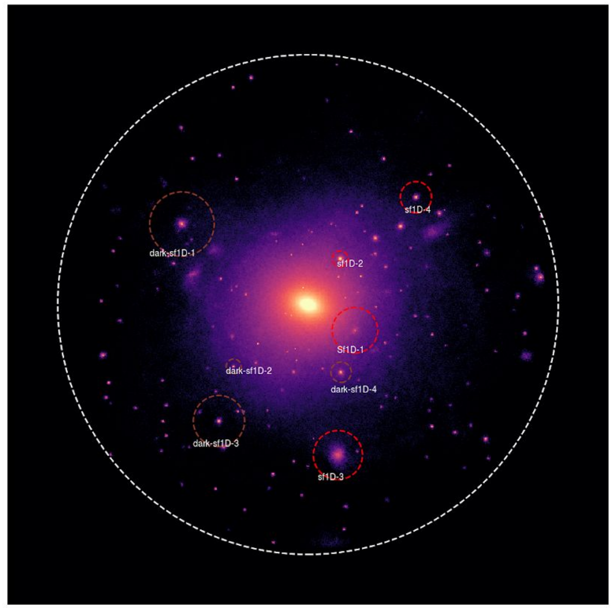

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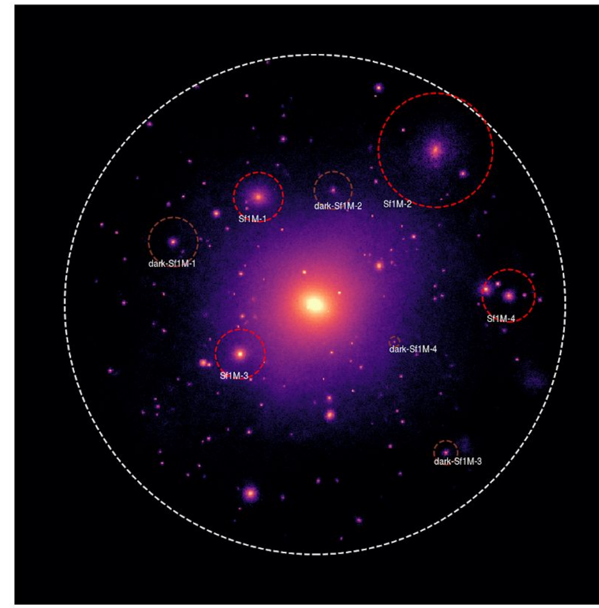

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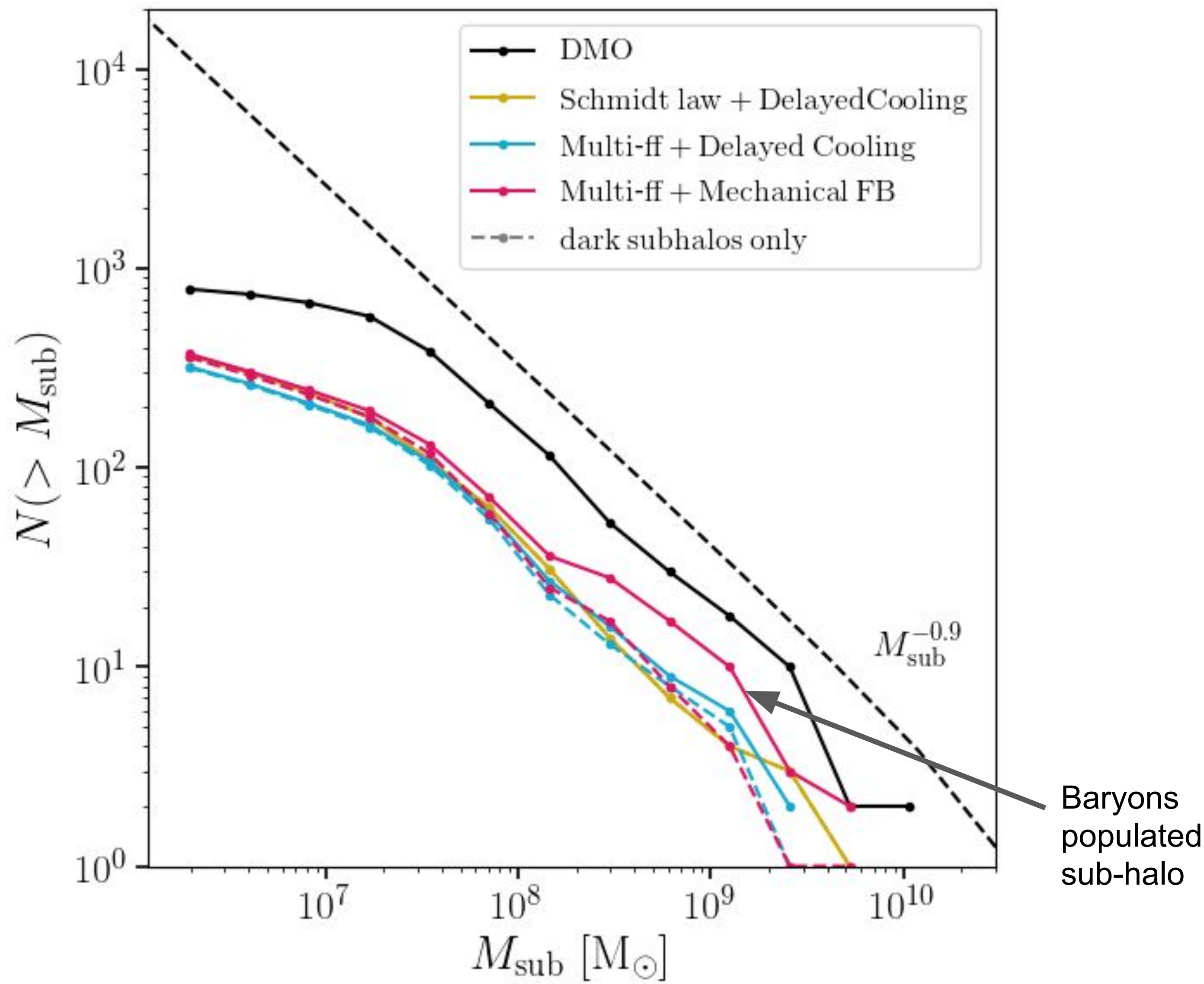
Sub halo distributions



Consequences

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

  - $\Phi^{source}_{\gamma,\nu,\bar{p},(e^+)} \propto \rho^2_{DM}$ (inner cusp, clump spectrum,concentration)

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

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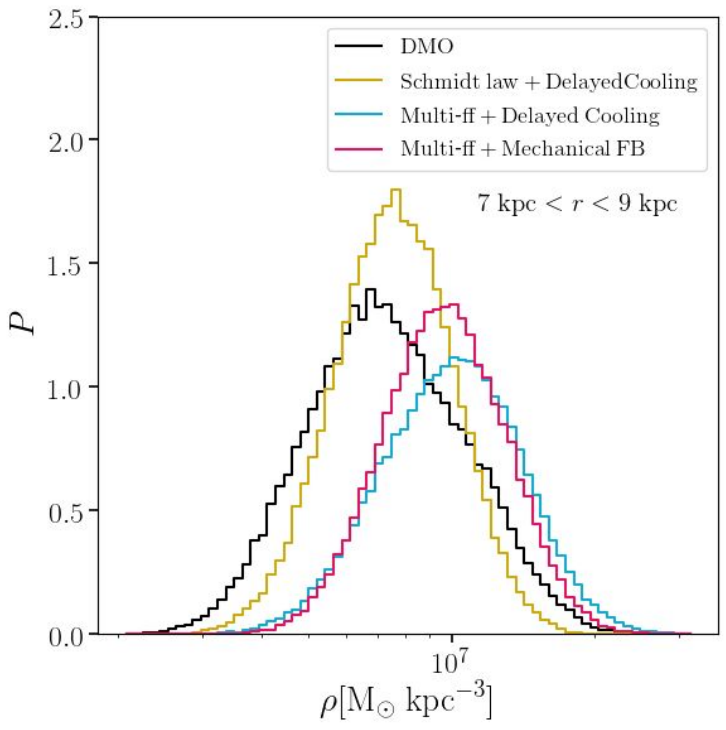
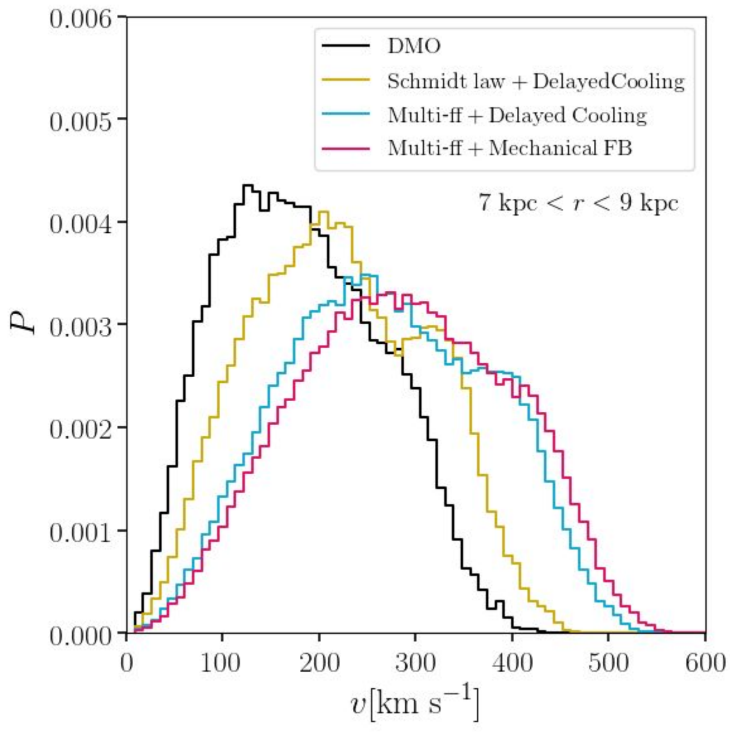




Consequences and conclusions

- Detection from the halo (gamma, neutrino...)
  - $\Phi^{source}_{\gamma,\nu,\bar{p},(e+)} \propto \rho^2_{DM}$ (inner cusp, clump spectrum,concentration)
  - Local dark matter (in)direct detection (direct and neutrinos from the Sun)

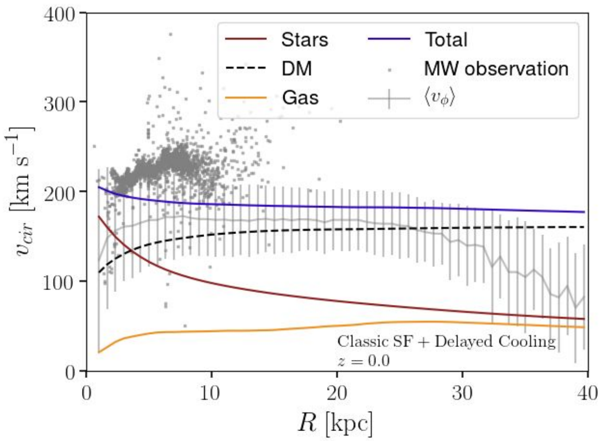
Baryonic physics:

- 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

Mochima (Boxsize: 36 Mpc, M_H= 0.9x 10^{12} M_{sun}, M_{dm}=1.8x 10^5, Δx=35 pc)
Rotation curves



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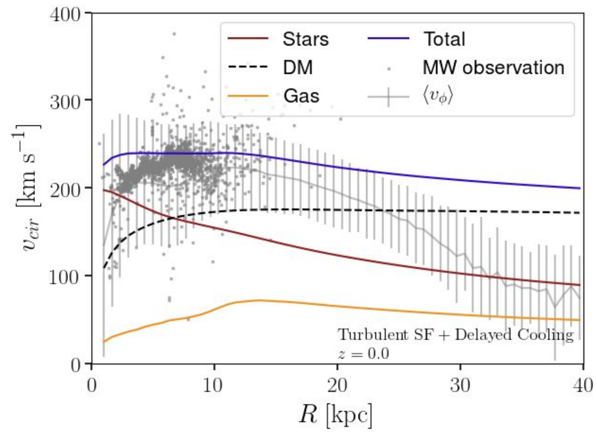

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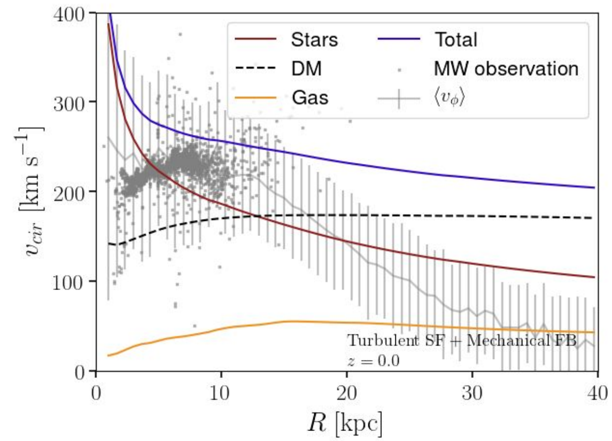

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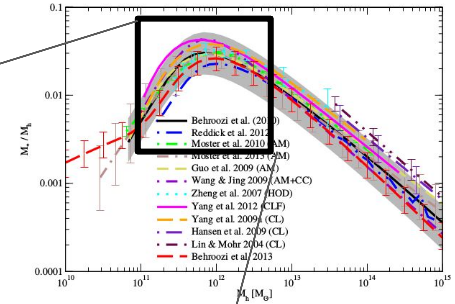
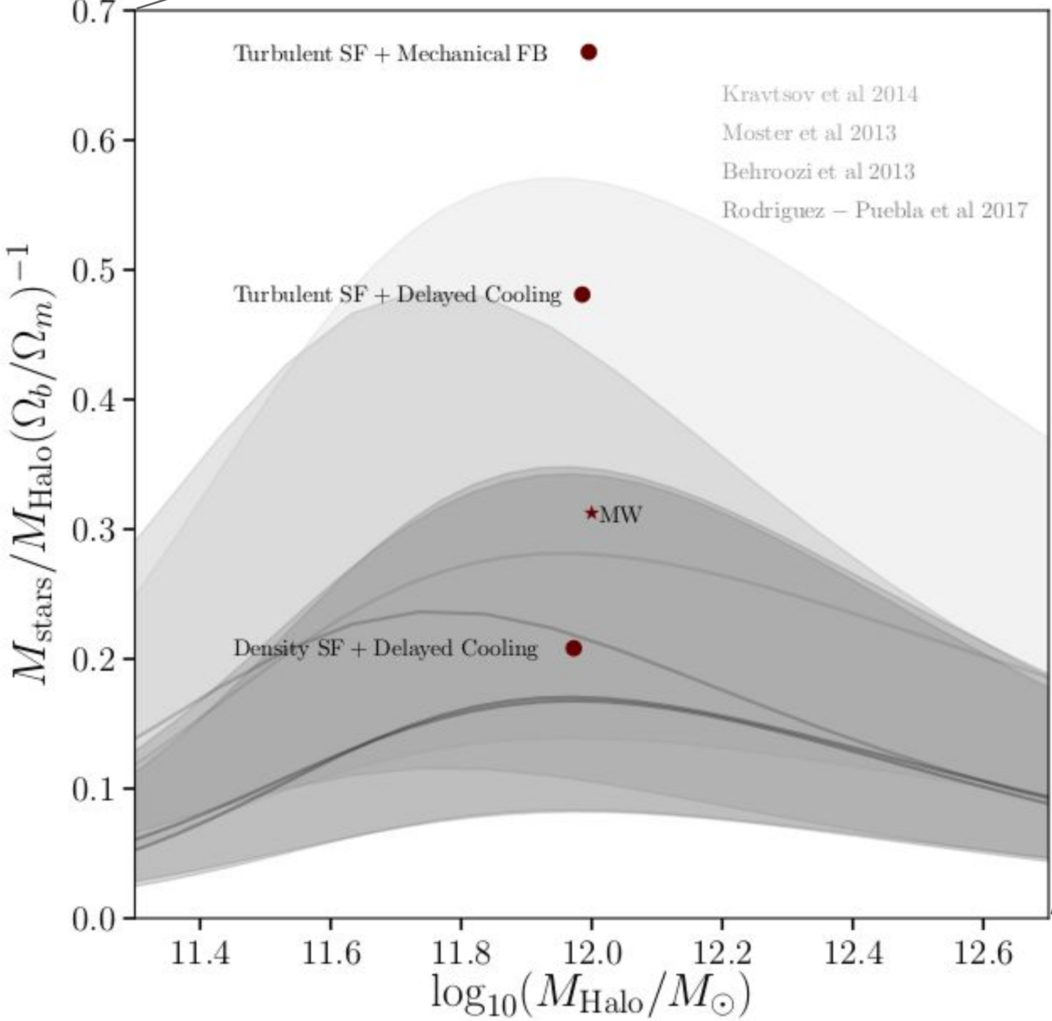
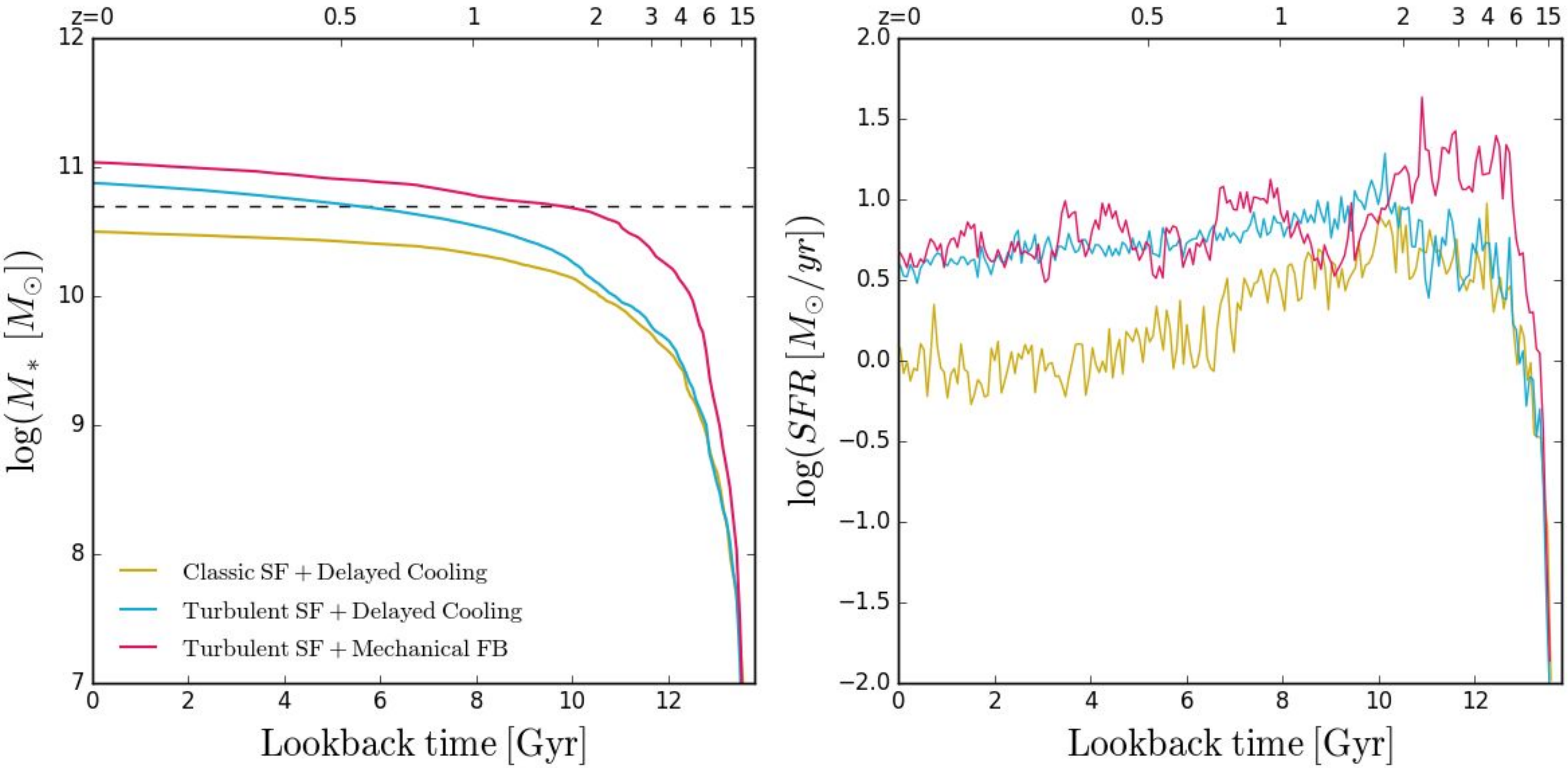
Comparison with observation
SHMR

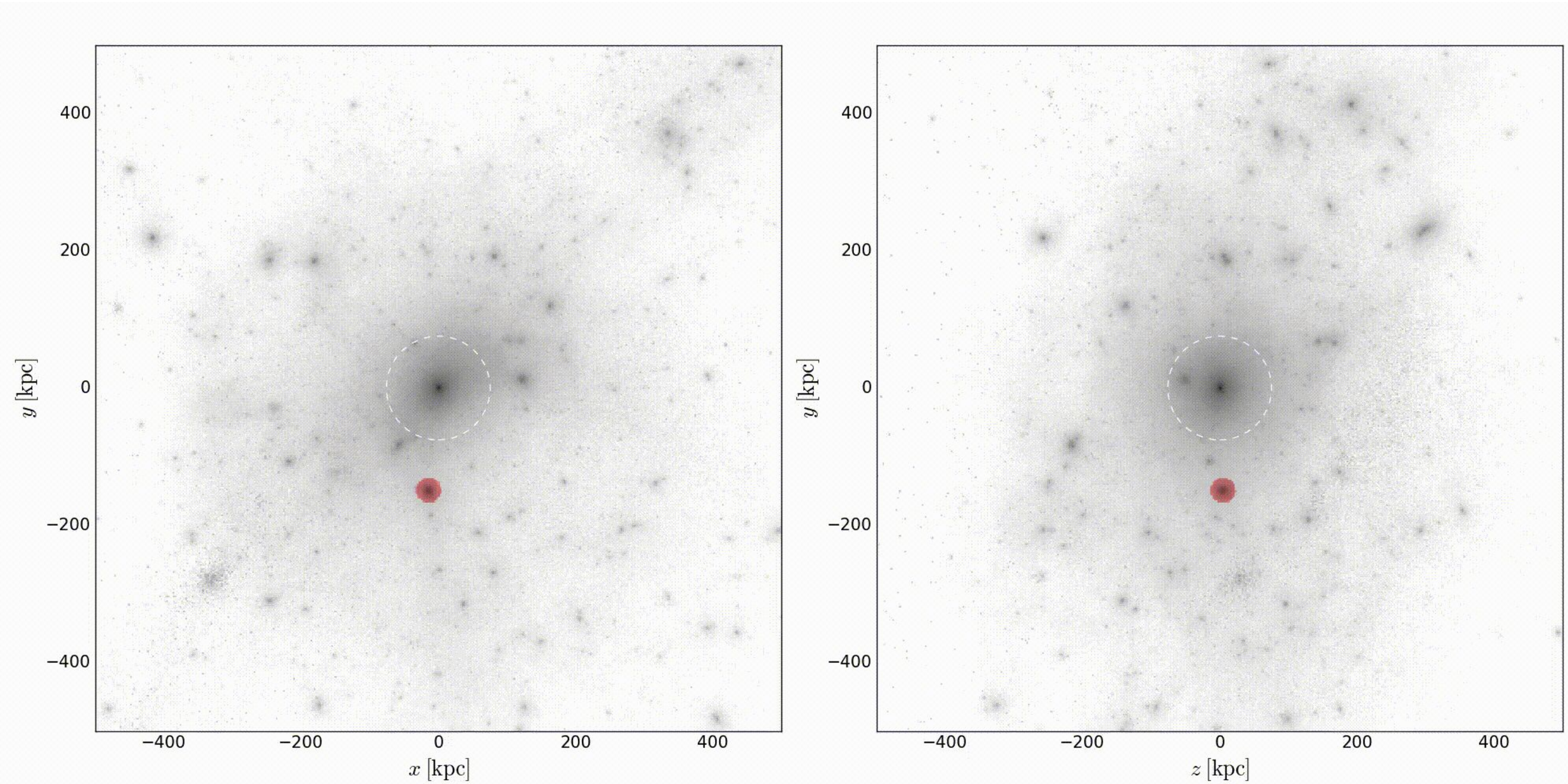




Star Formation history



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

Schmidt law for star formation:

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

Krumholz & Tan (2007). Governato et al (2007). Scannapieco et al (2009). Agertz et al (2011)

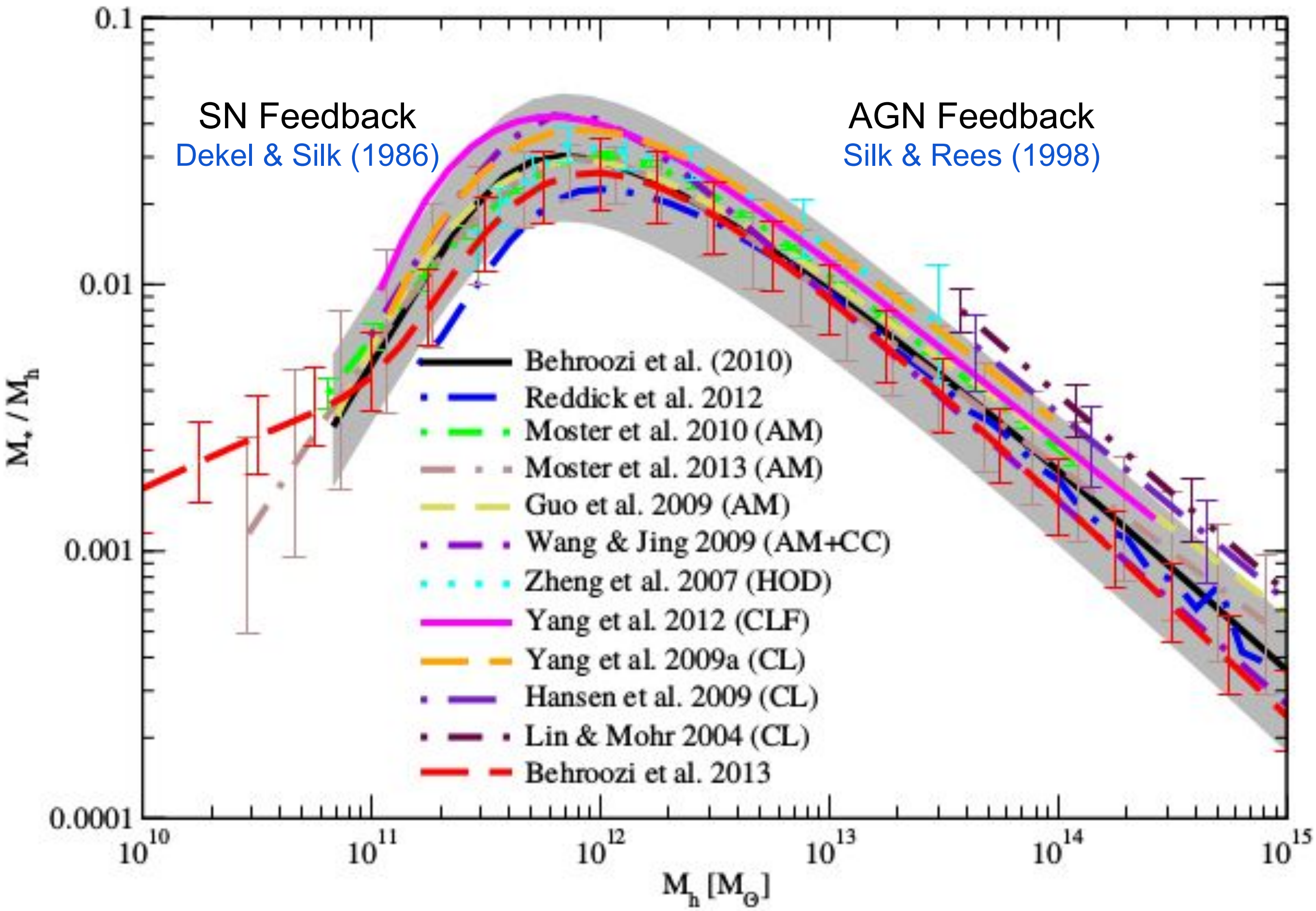
Option 1: constant efficiency

The aim is to **calibrate parameters** to reproduce Kennicutt (1998) relation:

$$\Sigma_{\rm SFR} = (2.5 \pm 0.7) \times 10^{-4} \left(\frac{\Sigma_{\rm gas}}{\rm M_\odot pc^{-2}} \right)^{1.4}$$

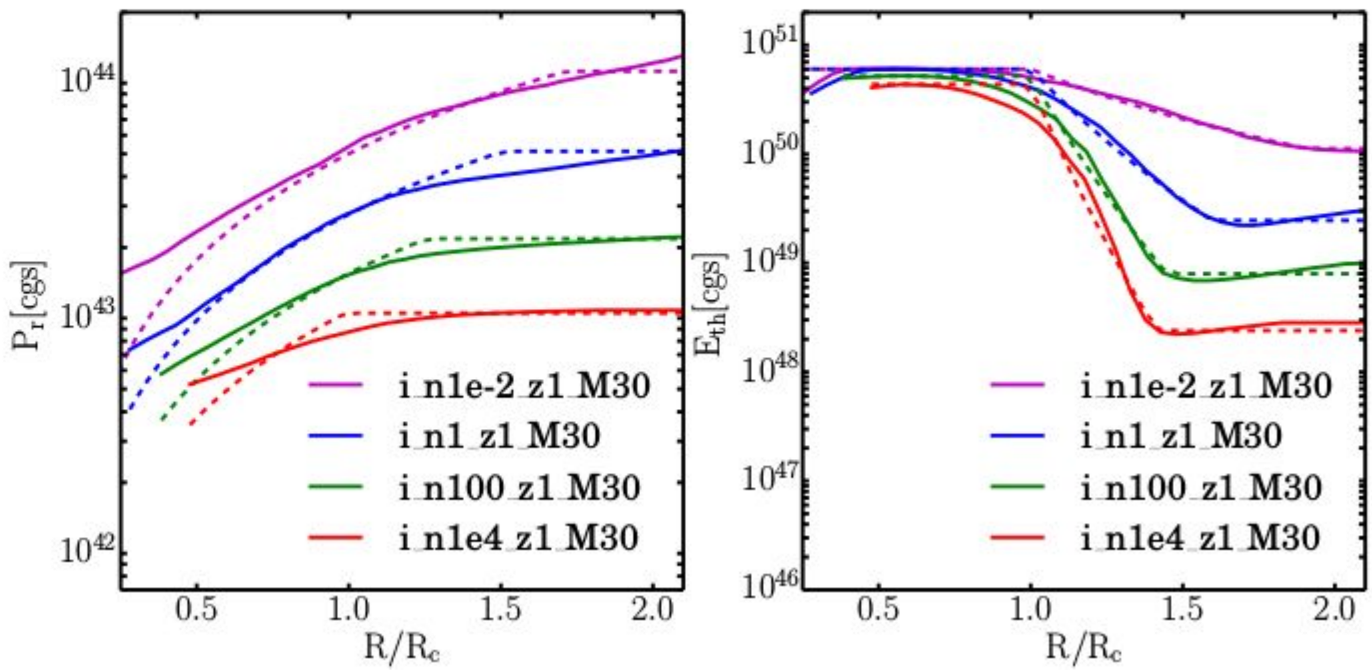
Daddi et al. (2010)

Feedback



Behroozi et al. (2013)

SN Feedback



At early time, energy-conserving Sedov phase.
At late time, momentum-conserving snow-plow phase.
cooling radius: $R_c \approx 3pc * (n\_h/(100\ H\ /cc\ ))^{-(1/5)}$
If cooling radius is not resolved, inject terminal radial momentum

Cosmological Simulations