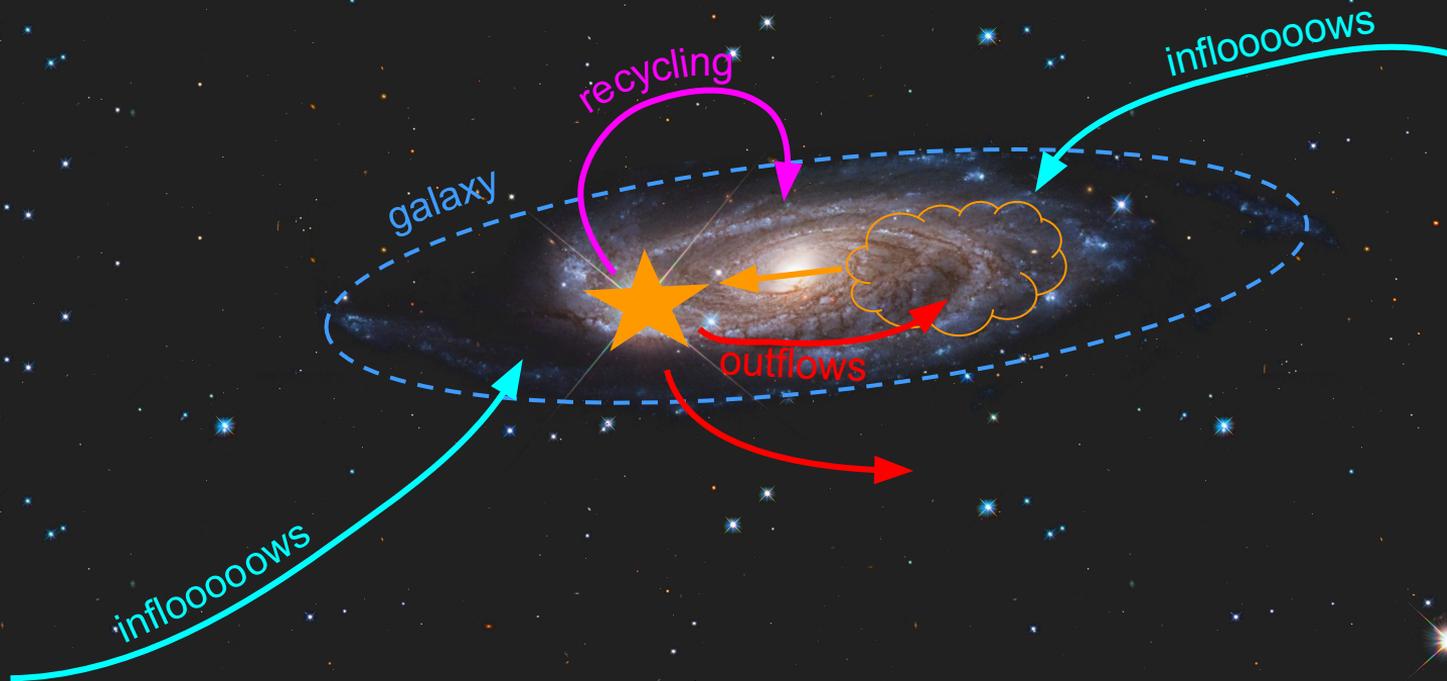
The background of the slide is a dark, black space filled with various celestial objects. There are several bright, multi-colored star clusters or nebulae scattered across the field. A prominent, larger star cluster is visible in the center, showing a dense core of stars and surrounding diffuse gas. Other smaller, more distant galaxies or star-forming regions are visible in the periphery, some appearing as faint, glowing clouds. The overall aesthetic is that of a deep-space astronomical image.

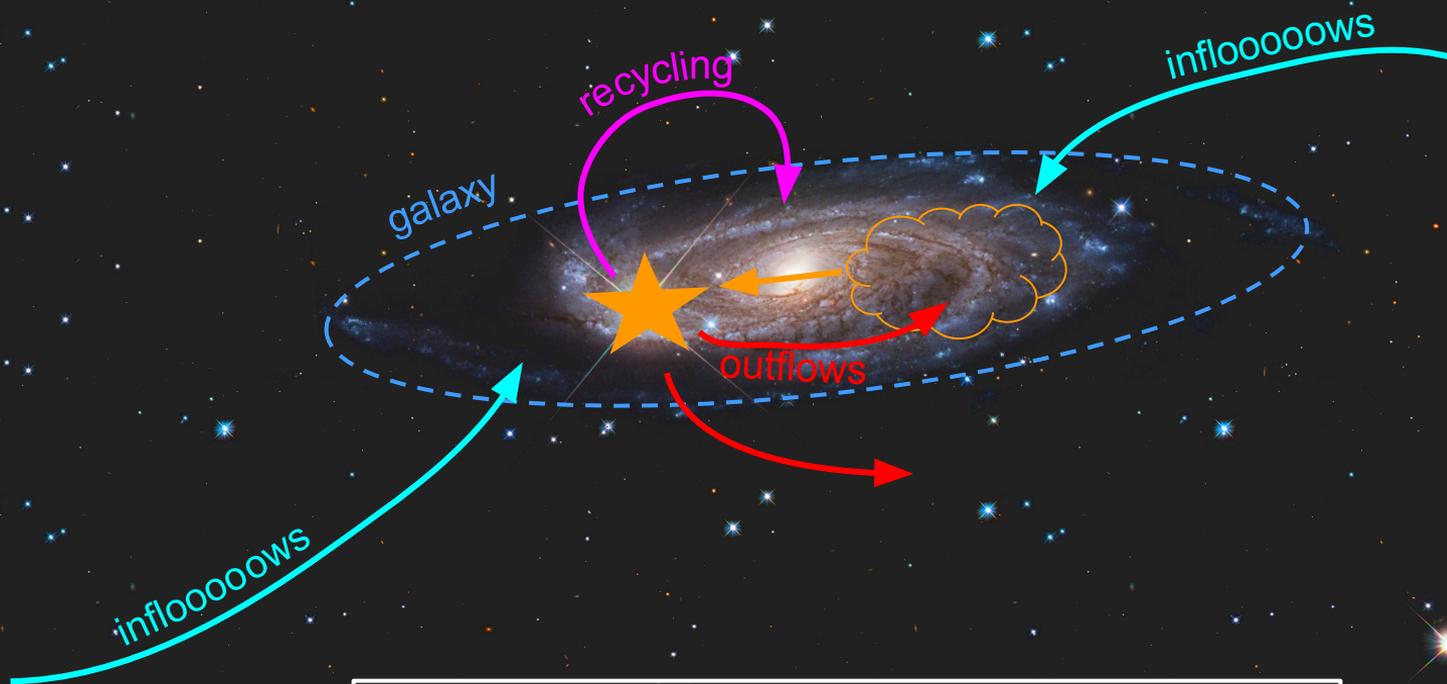
Maxime Rey

The CGM as a constraint for star formation and feedback subgrid models

Supervised by Jérémy Blaizot

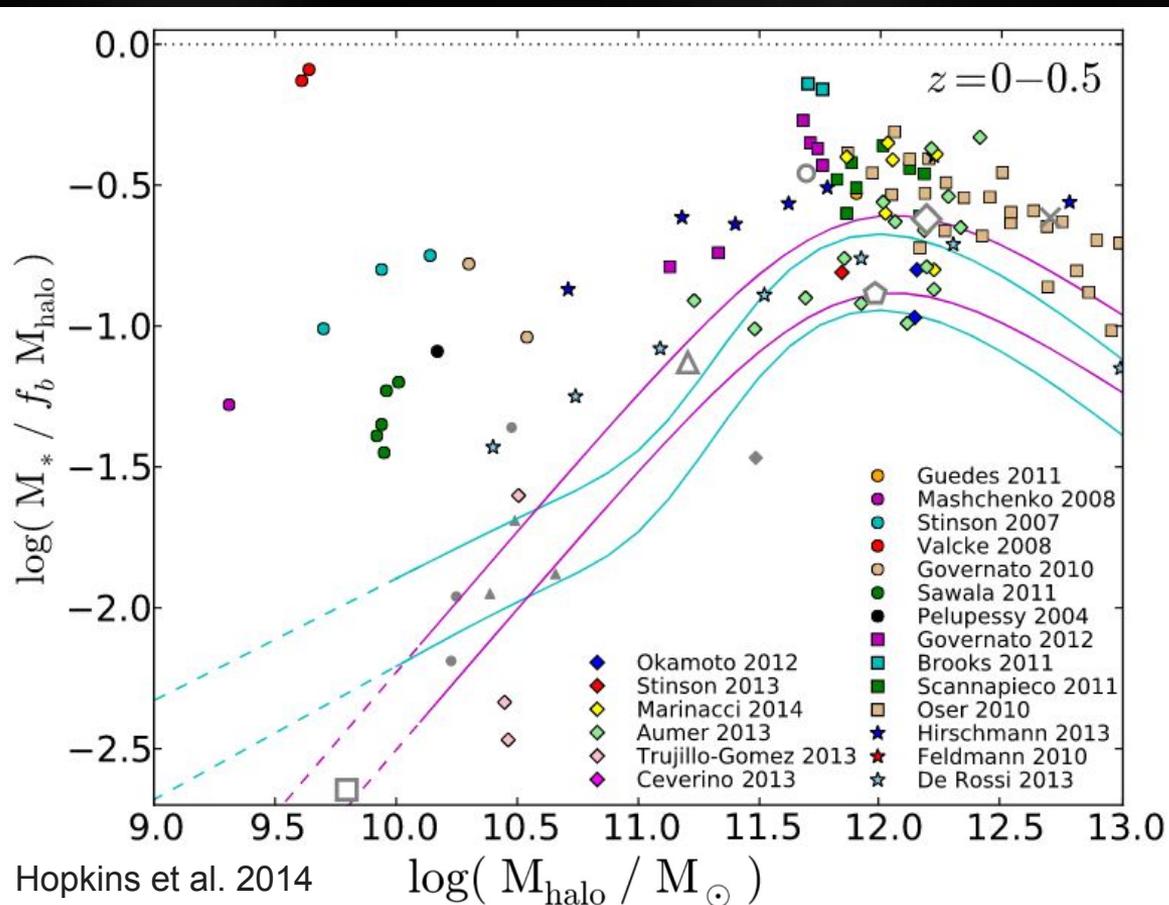


An intricate medium !



Star formation and feedback are unresolved in galaxy simulations, **we need subgrid models !**

$M_{\text{star}} - M_{\text{halo}}$ relation for calibration



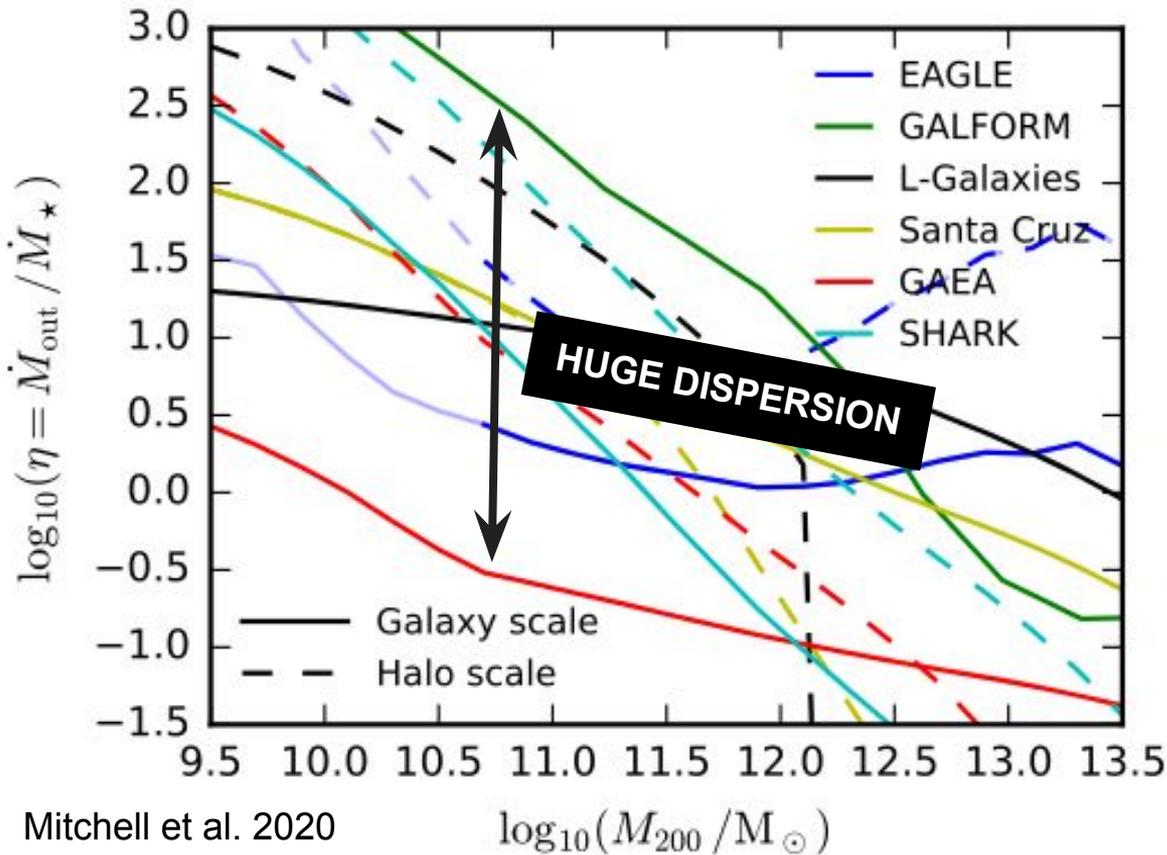
Simulations with

- different physics
- different subgrid models
- different resolutions

YET

the same stellar mass ?

$M_{\text{star}} - M_{\text{halo}}$ relation for calibration



Mitchell et al. 2020

Simulations with

- different physics
- different subgrid models
- different resolutions

YET

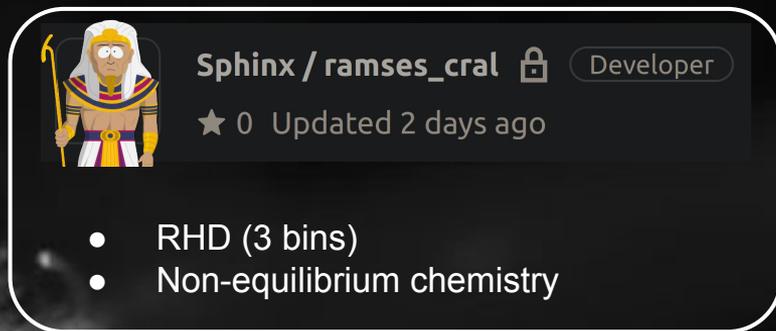
the same stellar mass ?

Different mass loading factor.

Can we constrain them through the CGM ?

Strategy

- Same galaxy
 - Same code
 - Same initial conditions
 - Same refinement scheme
- Different subgrid models for
 - Star formation
 - Feedback
- Calibration on M_{star}
- Try to distinguish them through their CGM.



A screenshot of a GitHub repository page for 'Sphinx / ramses_cral'. The repository is locked and has a 'Developer' badge. It shows 0 stars and was updated 2 days ago. The repository features two main items:

- RHD (3 bins)
- Non-equilibrium chemistry

A white arrow points from the 'Same code' bullet point in the text to the repository screenshot.

The different models

Kimm et al. 2015

➤ Local turbulence approximation for star formation.

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

$$P_{\text{SN}} = \begin{cases} P_{\text{SN}, \text{ad}} & (\chi < \chi_{\text{tr}}) \\ P_{\text{SN}, \text{snow}} & (\chi \geq \chi_{\text{tr}}) \end{cases} \longrightarrow \text{Neighbouring cells}$$

Kimm et al. 2015

+ Andersson et al. 2020

➤ same + runaway stars
(uniform kick < 50 km s⁻¹)

Kretschmer et Teyssier 2020

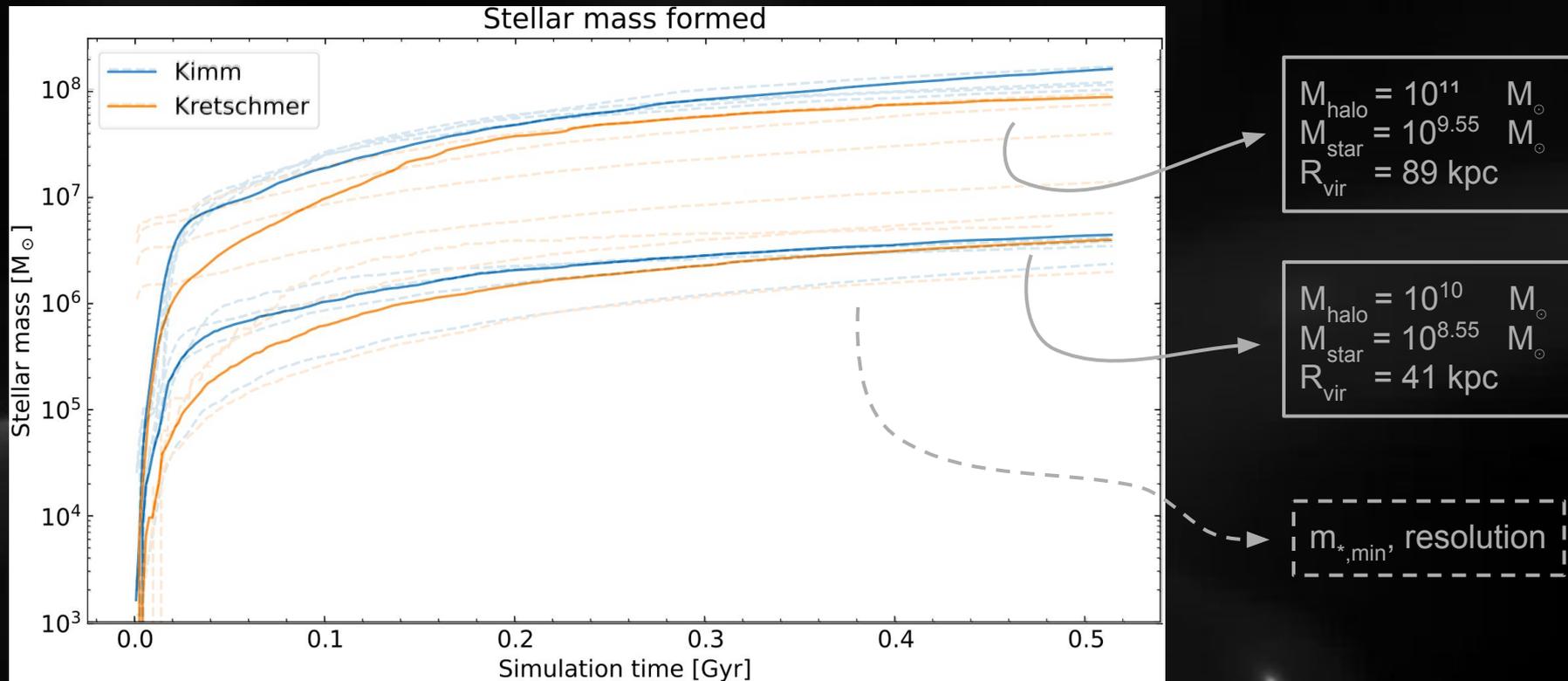
➤ Subgrid turbulence model for star formation.

➤ $E_{\text{th}} \ \& \ \Delta x < R_{\text{cool}} = 6.3 \text{ pc} \left(\frac{Z}{Z_{\odot}} \right)^{-0.05} \left(\frac{n_{\text{H}}}{100 \text{ cm}^{-3}} \right)^{-0.42}$

$$P_{\text{SN}} \longrightarrow \text{Euler conservation equations}$$

$$\frac{\partial}{\partial t}(\rho v_i) + \frac{\partial}{\partial x_j}(\rho v_i v_j) + \frac{\partial}{\partial x_i}(P + P_{\star}) = -\rho \frac{\partial \phi}{\partial x_i}$$

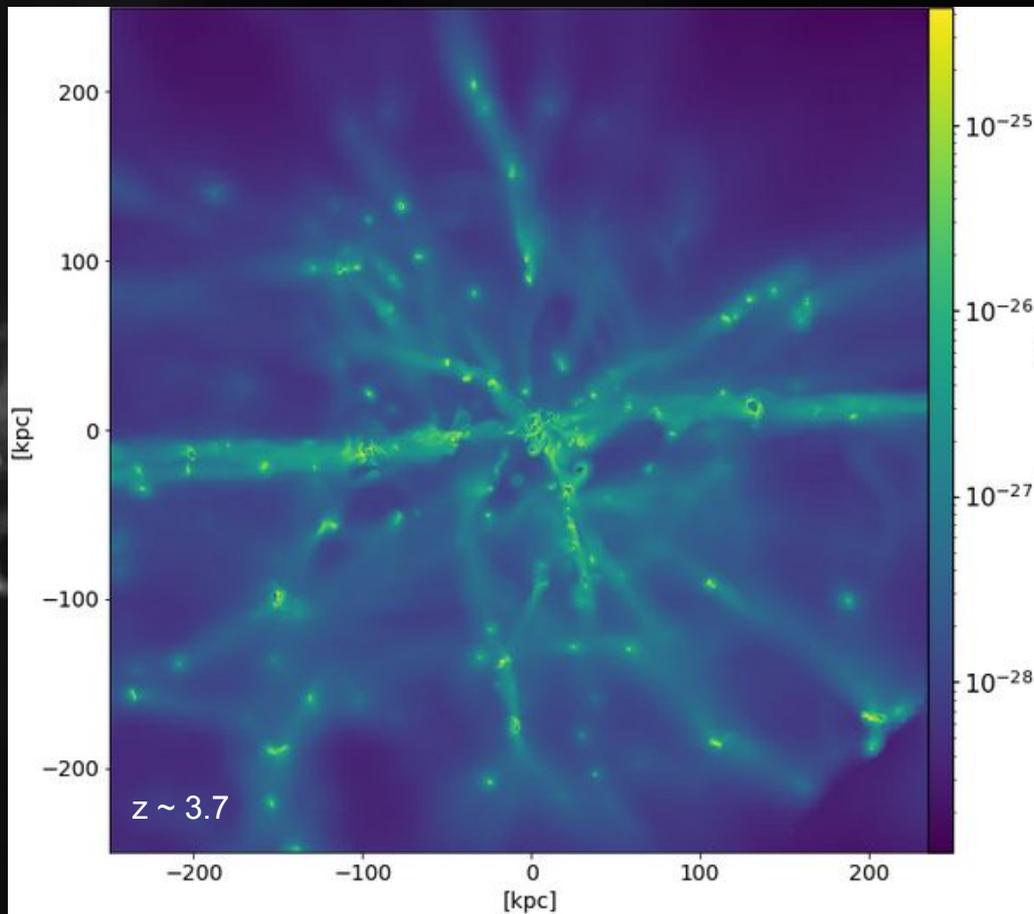
Tests of the models on idealised simulations



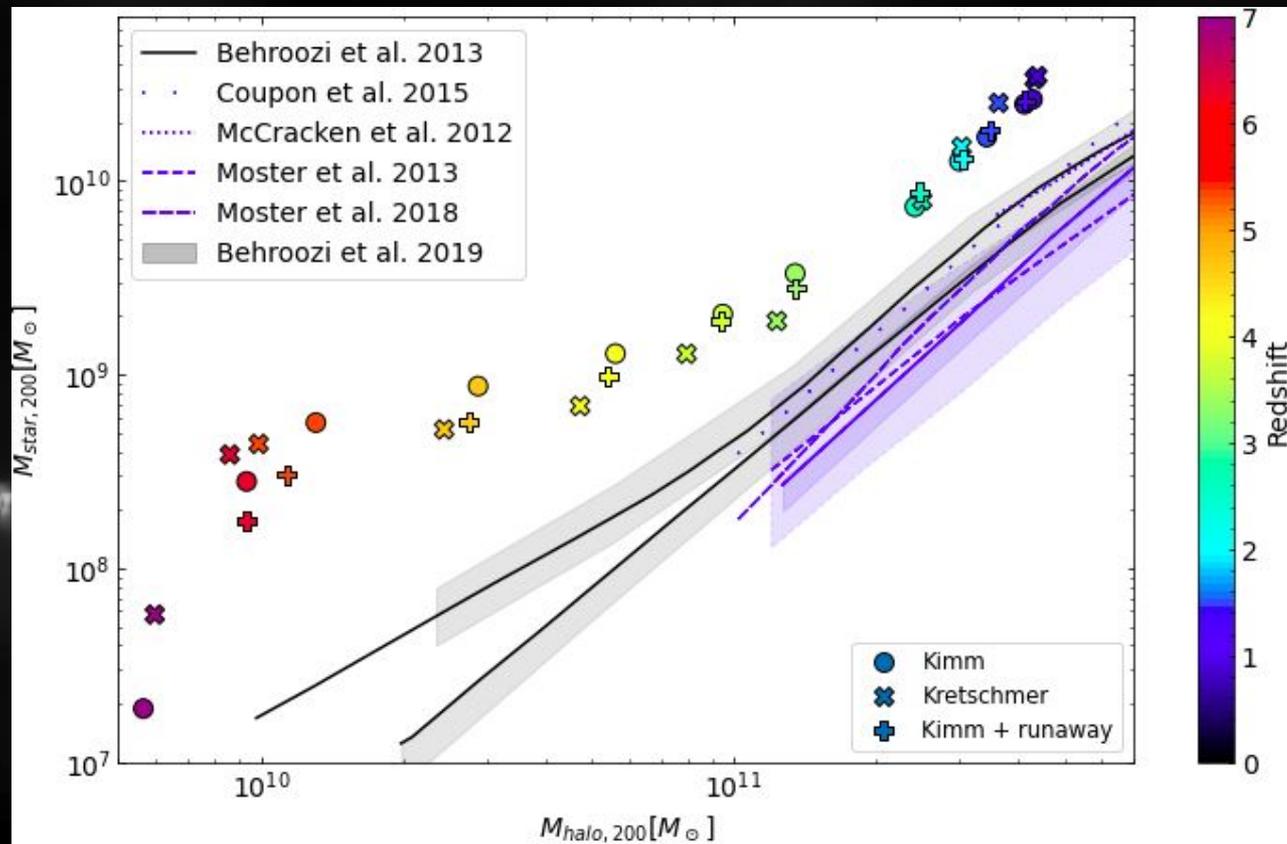
Different parameters were tested and the simulations calibrated in stellar mass.

Cosmological zoom-in simulation

Box size	30 cMpc/h
m_{DM}	$10^{5.55} M_{\odot}$
M_{halo}	$10^{11.6} M_{\odot}$
M_{star}	$10^{10.5} M_{\odot}$
R_{200}	103 kpc at $z = 1$
Zoom	$1 R_{\text{vir}}$
Res.	330 kpc to 20 pc

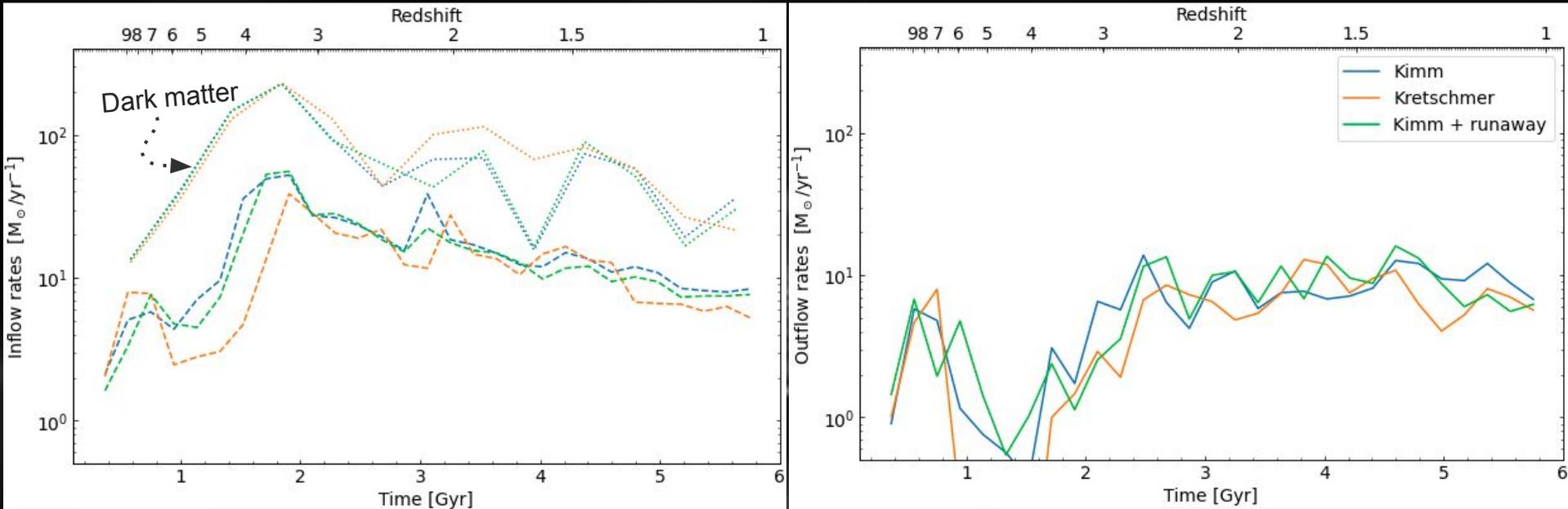


Zoom-in simulation



The stellar mass is too high compared to the $M_{\text{star}}-M_{\text{halo}}$ relation (possibly due to the lack of AGN ?) but the three models are still well converged ✓.

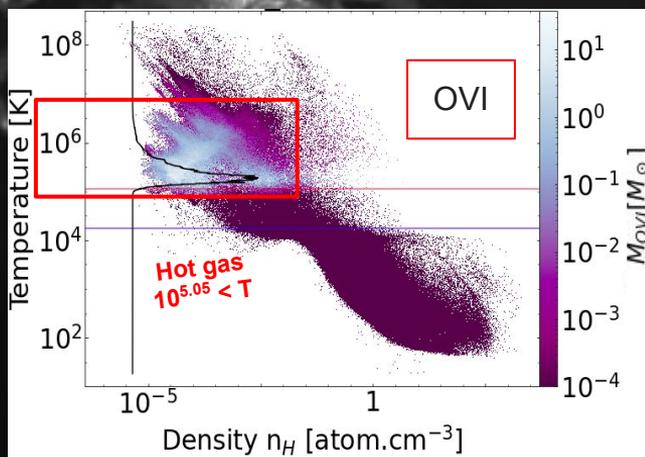
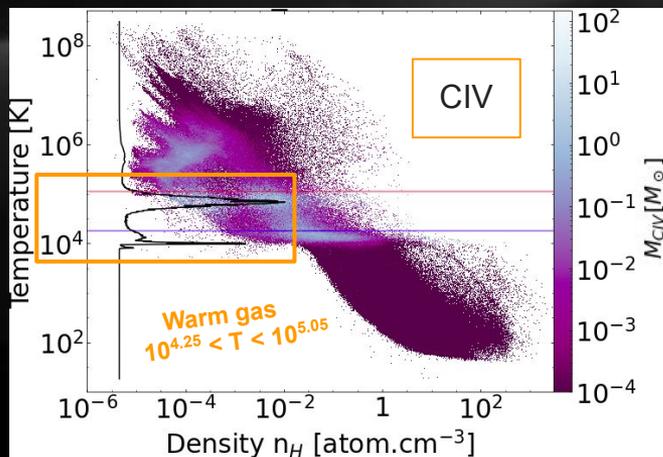
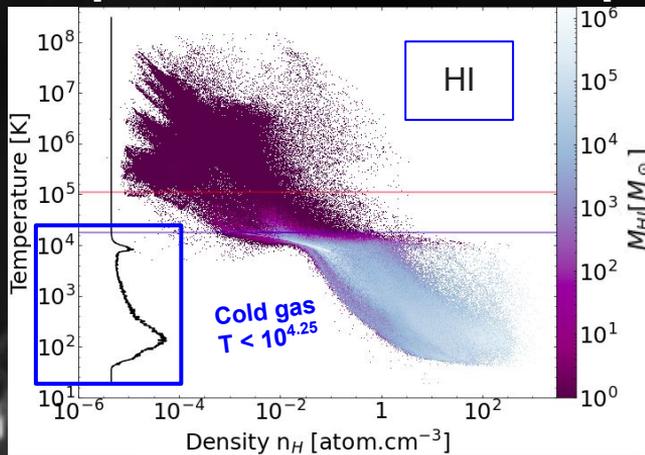
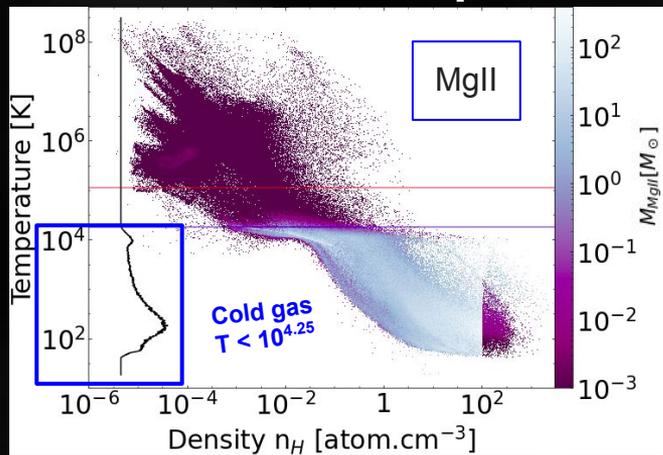
What about the CGM ?



The flow of mass through the CGM is very similar for the three models.

What about its gas content ?
How does it compares to observational constraints ?

Temperature split and ionic species



Post processing of the simulations made with KROME to compute the ionic fractions.

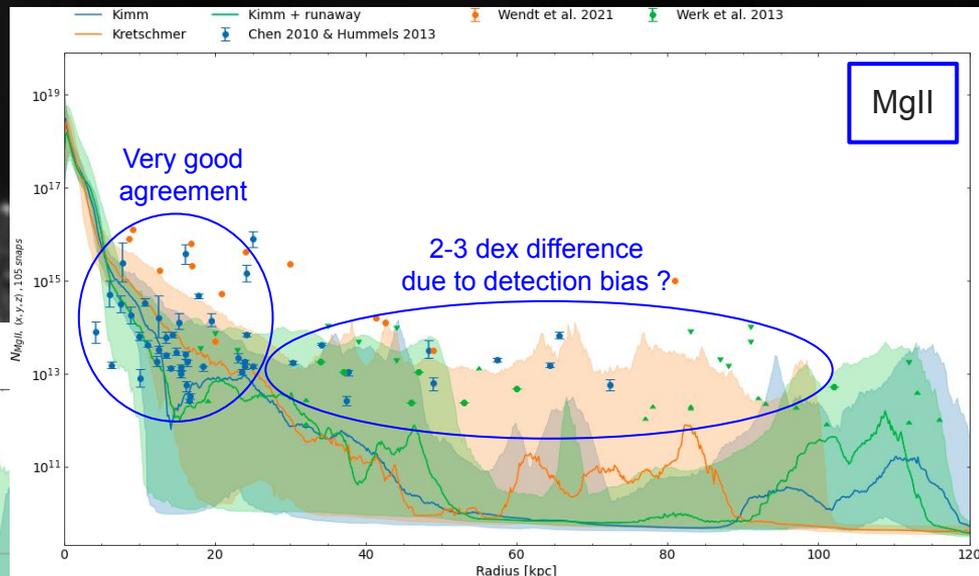
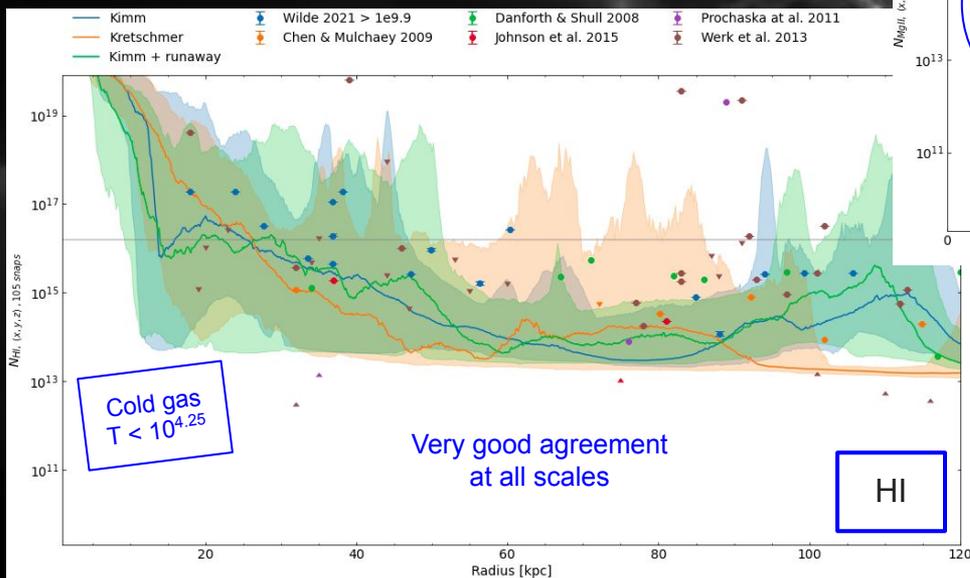


see Mauerhofer et al. 2021

Radial column density: cold tracers

Stack over 100 snapshots
 $z = 1.3$ to $z = 1.0$ (~ 1 Gyr)

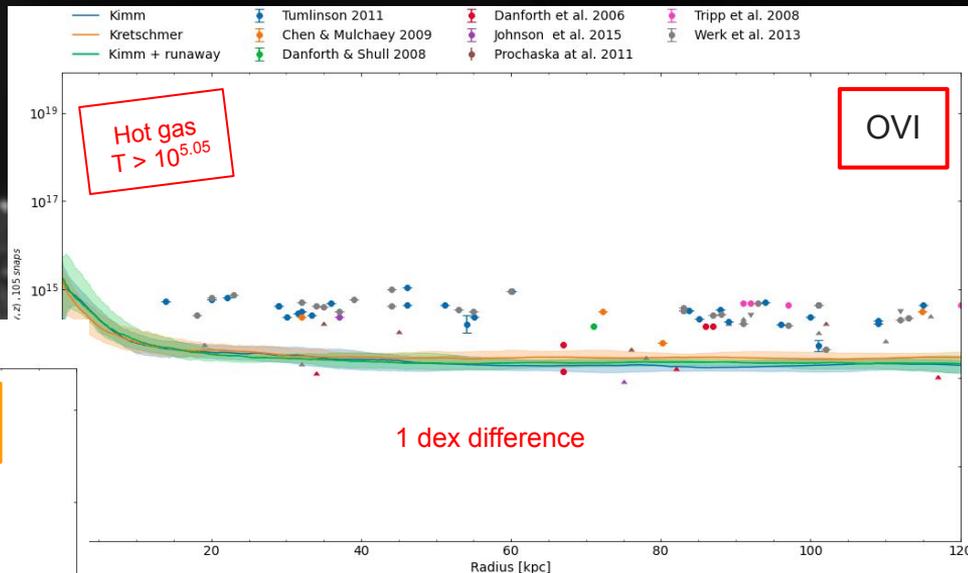
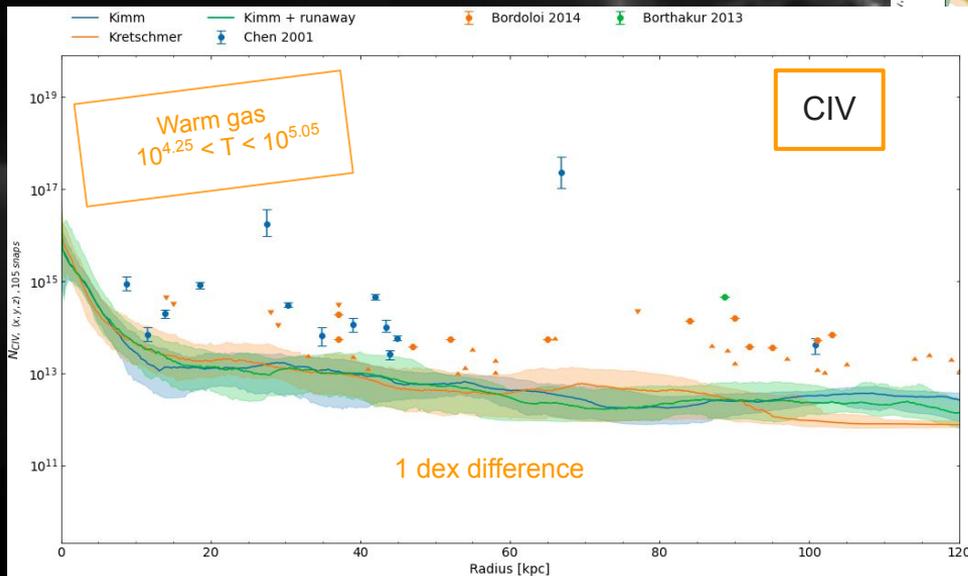
- The simulations remotely match the observations.
- The models are very similar \rightarrow the gas content is similar.



Radial column density: warm and hot tracers

Stack over 100 snapshots
 $z = 1.3$ to $z = 1.0$ (~ 1 Gyr)

- 1 dex difference with observation for warm and hot gas.
- The models are **very** similar \rightarrow the gas content is similar.



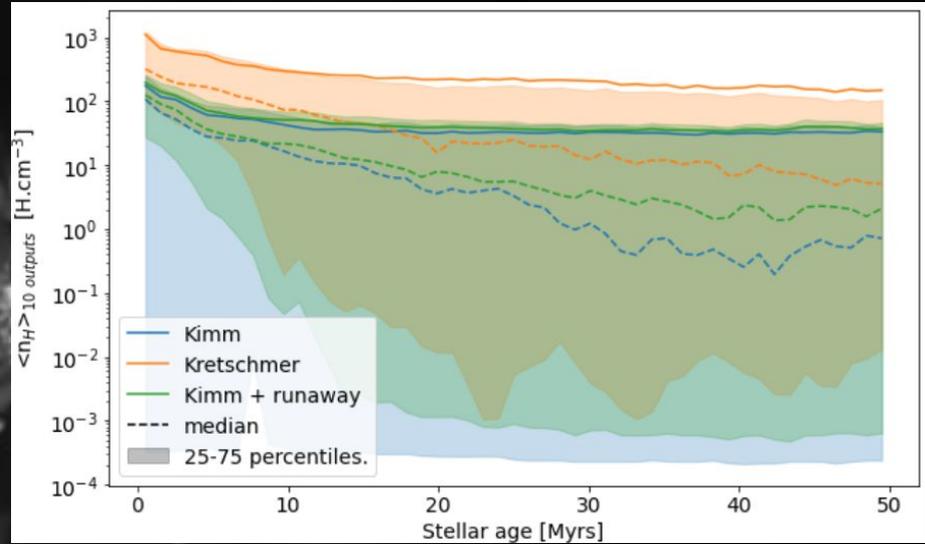
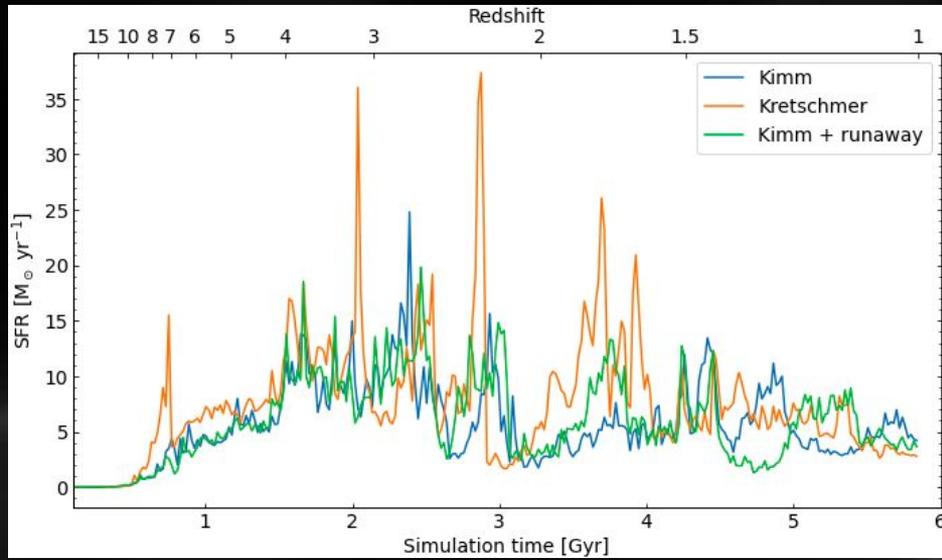
These models can't be distinguished through the CGM

The background of the slide is a dark, black space filled with faint, glowing celestial objects. In the center, there is a cluster of stars, some of which are brighter and more distinct than others. The overall appearance is that of a star field or a galaxy core. The text is overlaid on this background.

The models match in stellar mass, outflows, radial column density profiles, gas content *but*...

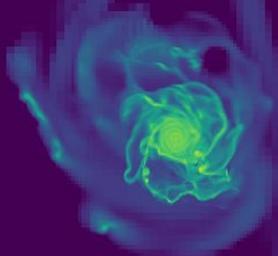
... differences still arise !

1st difference: the star formation history

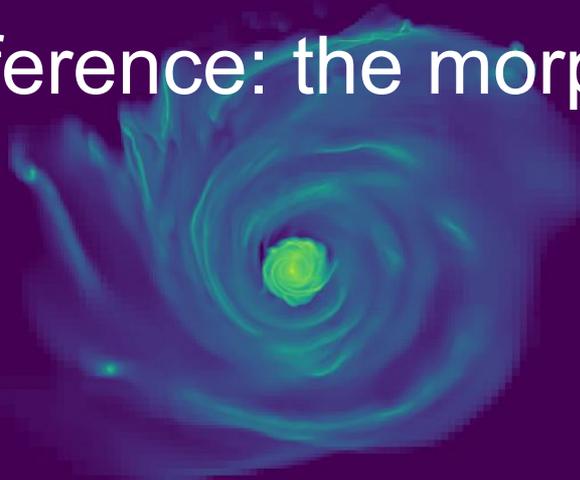


- Kretschmer's model indeed has an impact on how stars are formed but it does not show in the CGM.
- Runaway stars do not have much impact on the density of the cells where stars go supernovae.

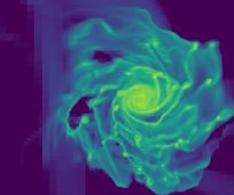
2nd difference: the morphology



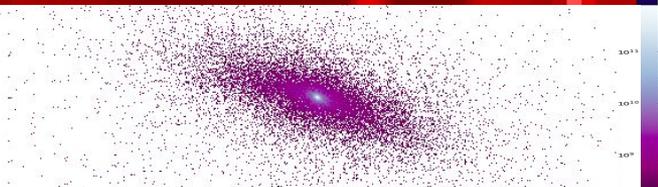
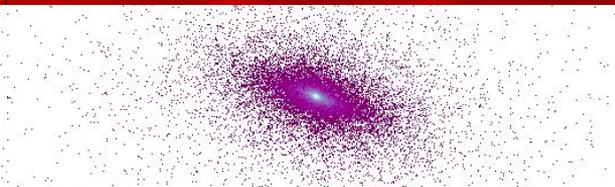
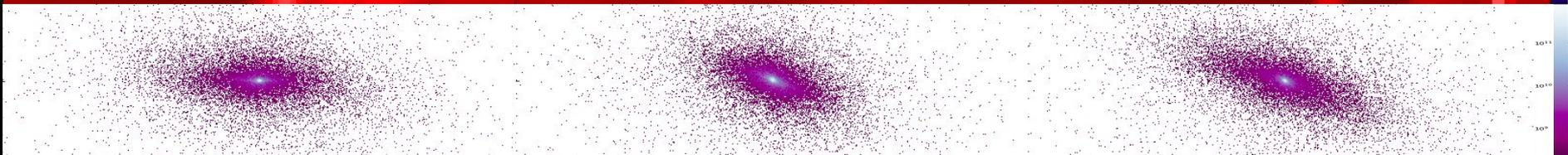
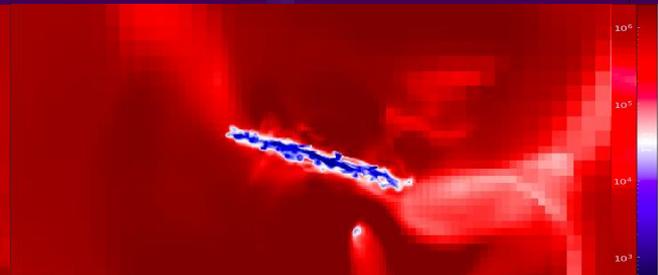
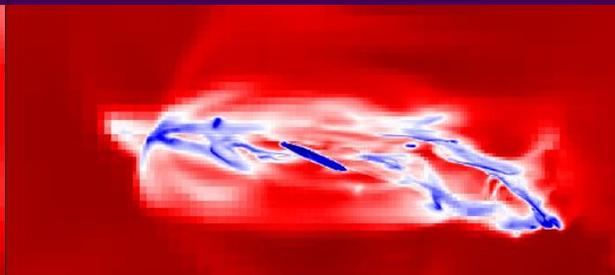
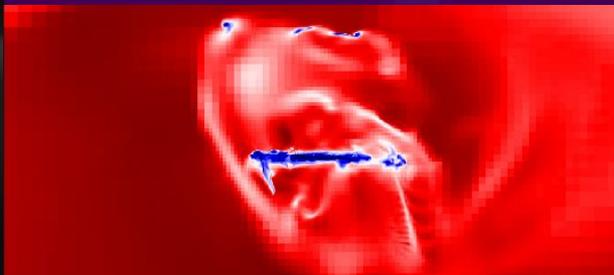
Kimm et al. 2015



Kretschmer & Teyssier 2020

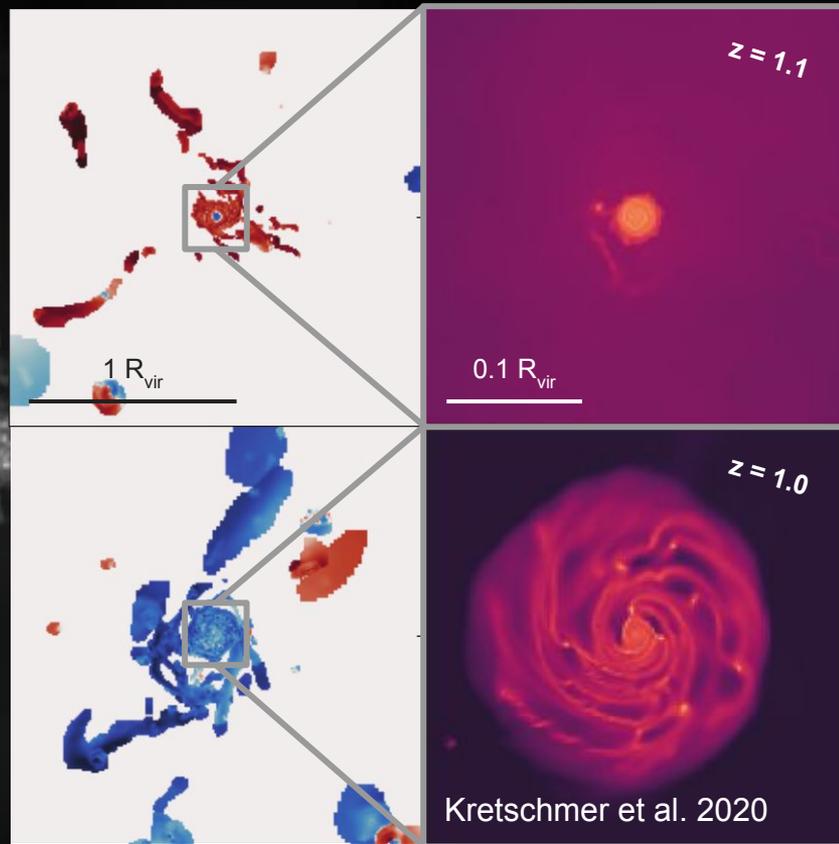
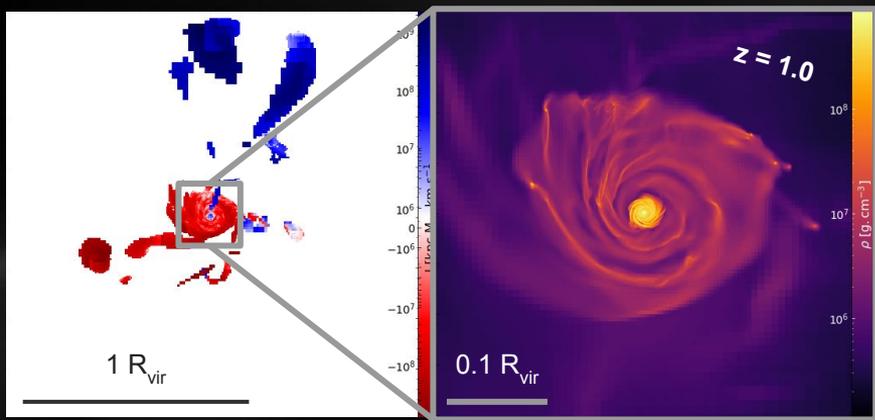


Kimm + runaway stars



Morphology: origin in additive accretion ?

mass-weighted cold gas
angular momentum

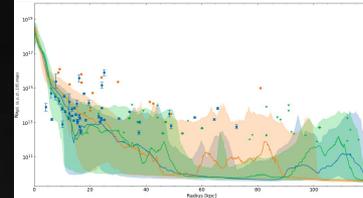


The extended disc does not seem to be caused by
the constructive or destructive accretion of gas.

Summary and future work.

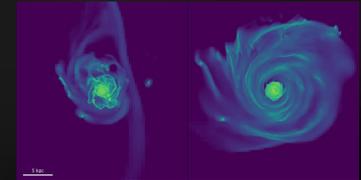
The differences in the models...

- The turbulence consideration in star formation
- The implementation of the momentum feedback in the surrounding cells or in the Euler equations
- Runaway stars

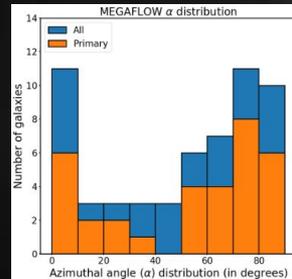


...could not be discriminated through the CGM flows or content.

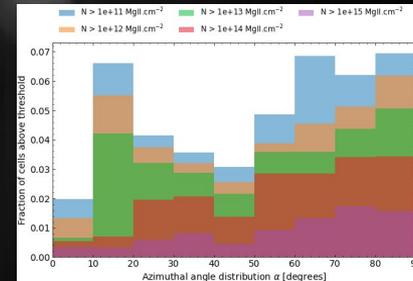
YET disparities are found following the different models.



A new
constraint ?



VS



Schroetter et al. 2019