



Capstone Proposal:

Appending Virial Star formation Algorithms to Cosmological Simulations



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Numerical Galaxy Simulations



- N-body simulations containing different particles representing gas, stars, and matter interact and evolve
- Observing their evolution over time till $t = 13.6$ Gyr using supercomputers
- NIHAO - Cosmological “zoom-in” simulations



Motivation

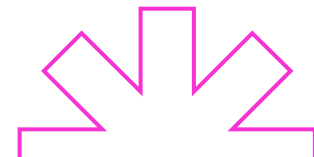
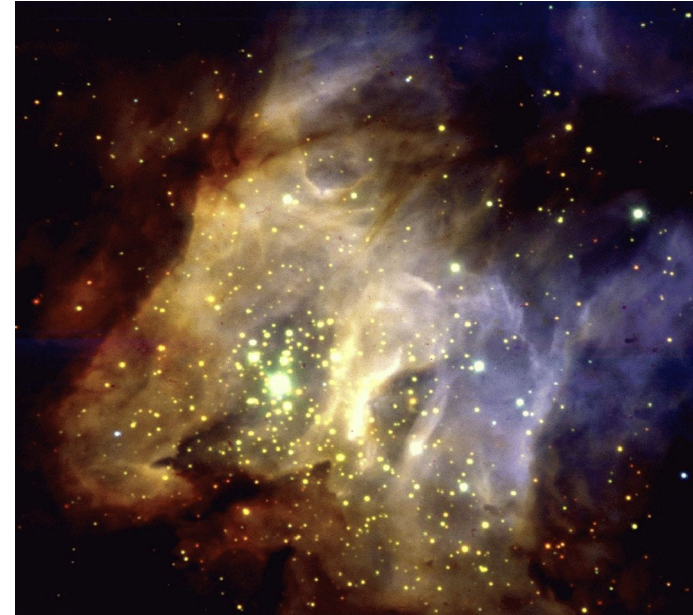
Star Formation in Giant Molecular Clouds (GMCs)

Average $n_H \sim 100 \text{ particles cm}^{-3}$

Max $n_H \sim 10^4 \text{ particles cm}^{-3}$

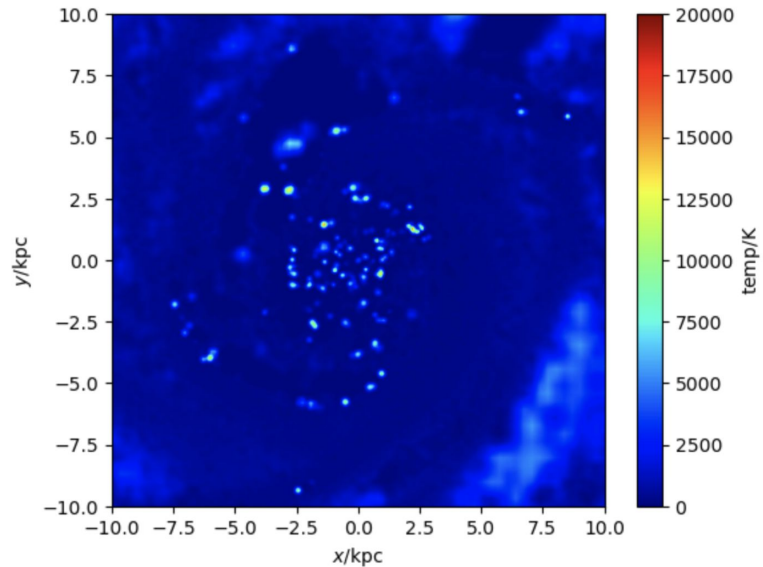
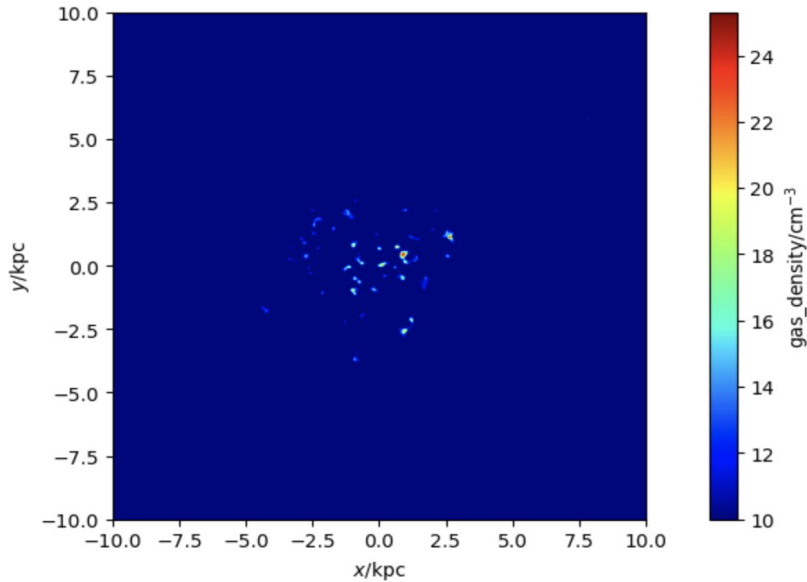
Very challenging to implement these in Simulations

- —> **Virial Theorem** to describe the Star
- Formation



Current Star Formation Criteria in NIHAO :

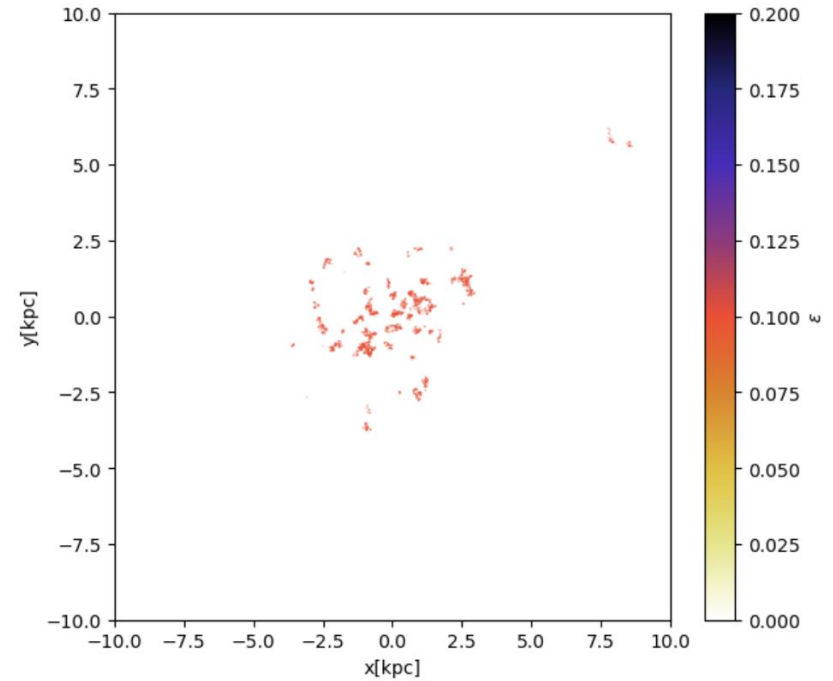
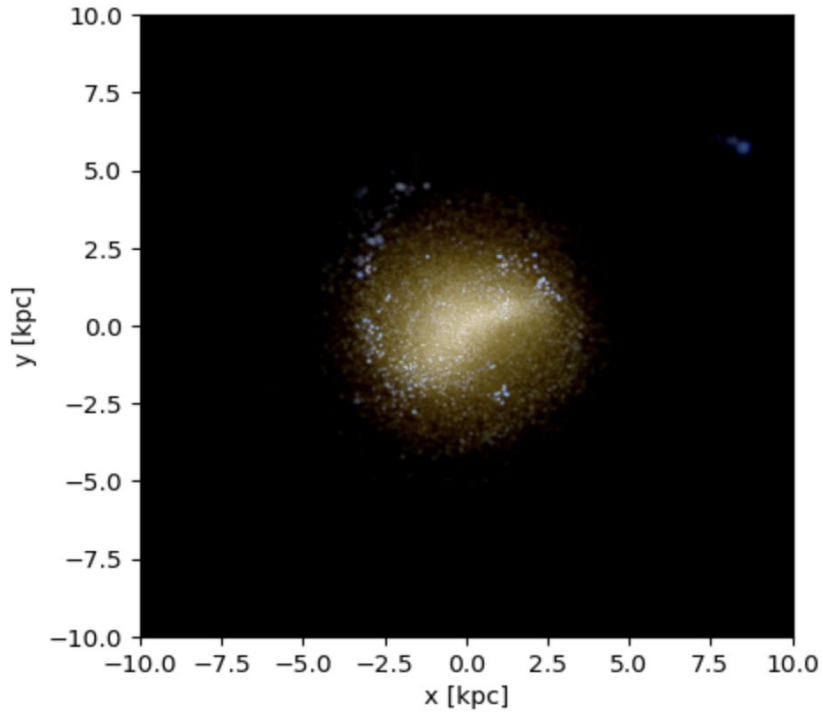
Density and Temperature Thresholds: $n_{\text{H}} > 10.3 \text{ cm}^{-3}$ and $T < 15000\text{K}$



Snapshot of galaxy '8.26e11' from NIHAO classic



Star Formation Efficiency





Virial Star Formation Models

- Physically Motivated Models

- Goal : Make sure they reproduce good attributes of Threshold model but improves the simulation

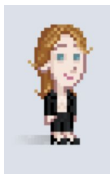


Virial Star Formation Model Candidates

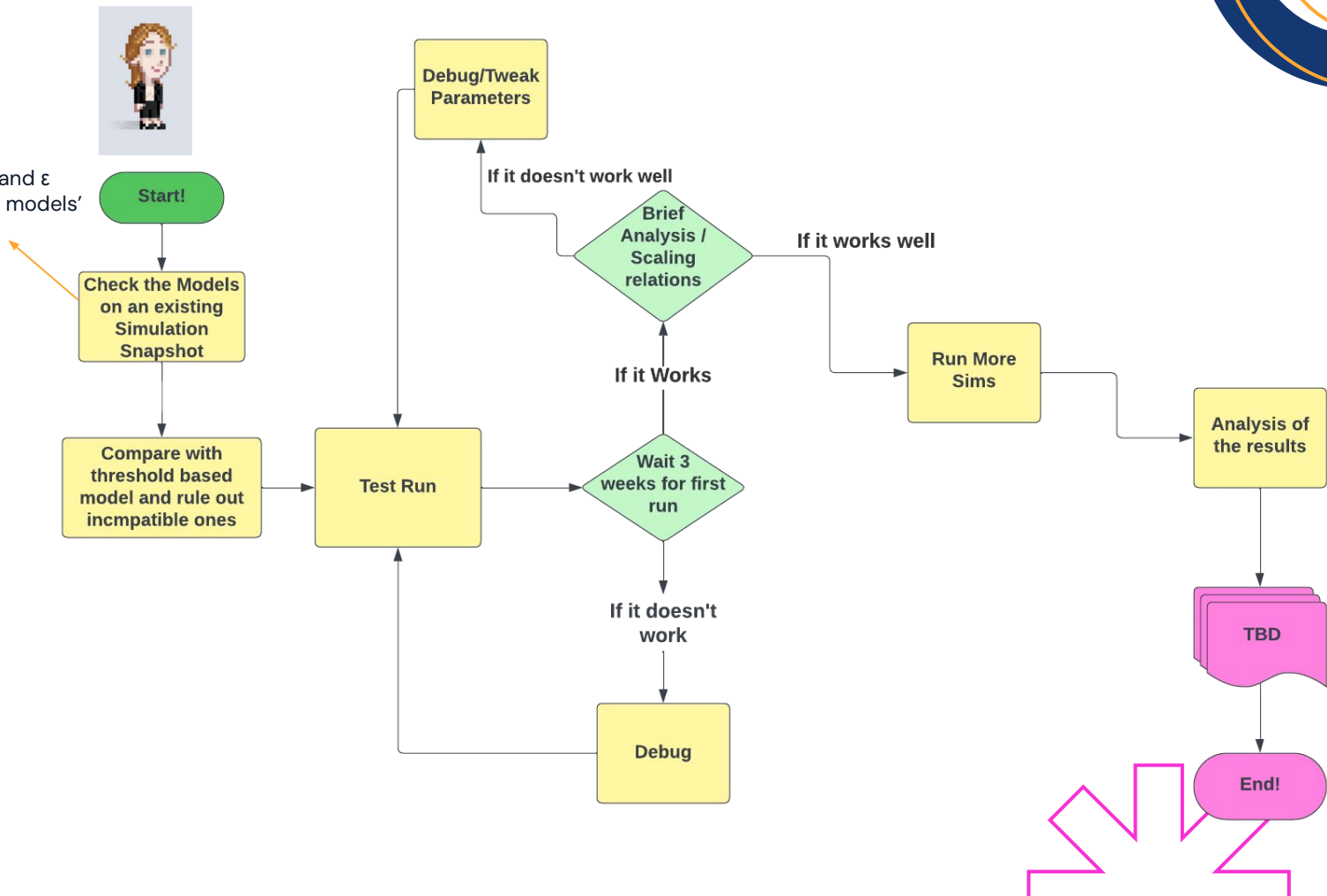


$$2\langle T \rangle = -\langle V \rangle$$

	Virial Parameter	Star Formation Efficiency
Evans et al. (2022)	$\alpha = \frac{5\sigma^2 r}{3GM}$	$\epsilon_{ff} = e^{-b\sqrt{\alpha_{vir}}}$
Padoan et al. (2012)	$\alpha_{vir} \approx 1.35 \left(\frac{t_{ff}}{t_{dyn}} \right)^2$	$\epsilon_{ff} = \epsilon_w e^{-1.6 \frac{t_{ff}}{t_{dyn}}}, \epsilon_w = 0.5$
Semenov et al. (2016)	$t_{dyn} = \frac{\Delta}{2\sqrt{\sigma^2 + c_s^2}}$	$\epsilon_{ff} = \epsilon_w e^{-1.6 \frac{t_{ff}}{t_{dyn}}}, \epsilon_w = 0.9$
Hopkins et al. (2013)	$\alpha = \frac{\beta}{2} \frac{ \nabla \times v ^2 + \nabla \cdot v ^2}{G\rho}$	$\epsilon = \begin{cases} 1 & \text{if } \alpha < 1 \\ 0 & \text{otherwise} \end{cases}$



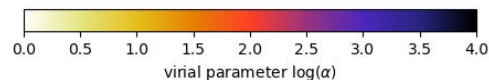
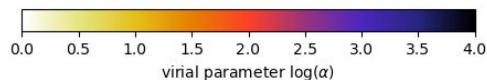
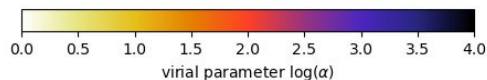
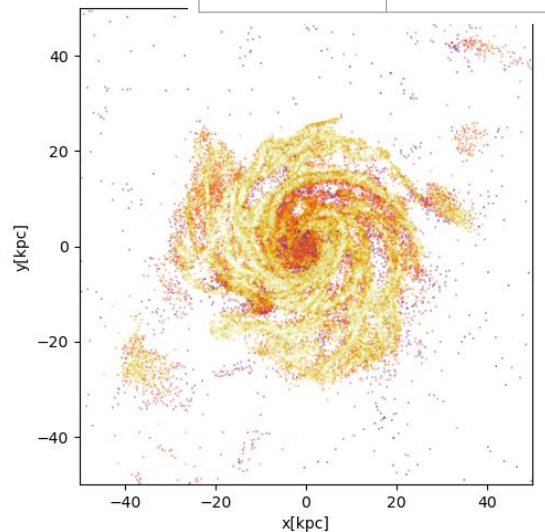
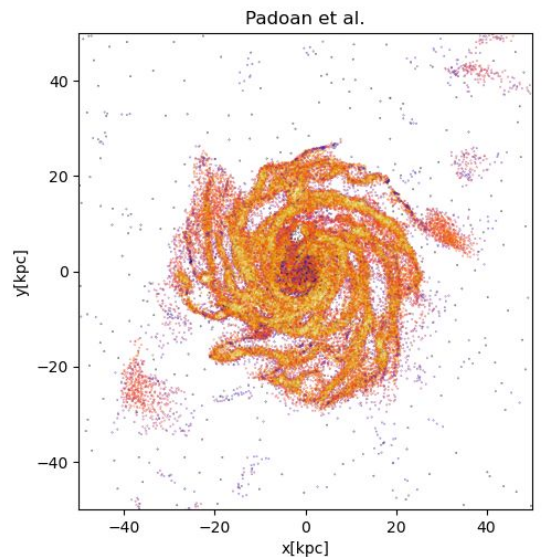
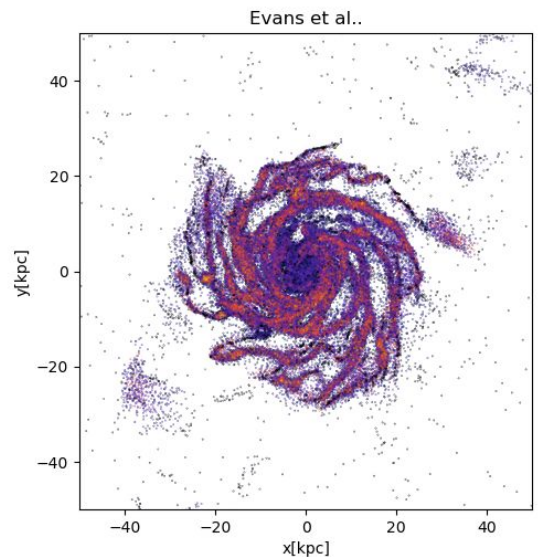
'calculate the α and ϵ proposed in the models'



NIHAO Classic 8.26.e11 at $z = 0$

Virial Parameter in Different Models

Evans et al. (2022)	$\alpha = \frac{5\sigma^2 r}{3GM}$	
Padoan et al. (2012)	$\alpha_{vir} \approx 1.35 \left(\frac{t_{ff}}{t_{dyn}} \right)^2$	$t_{ff} =$
Semenov et al. (2016)		$t_{dyn} =$
Hopkins et al. (2013)	$\alpha = \frac{\beta}{2} \frac{ \nabla \times v ^2 + \nabla \cdot v ^2}{G\rho}$	

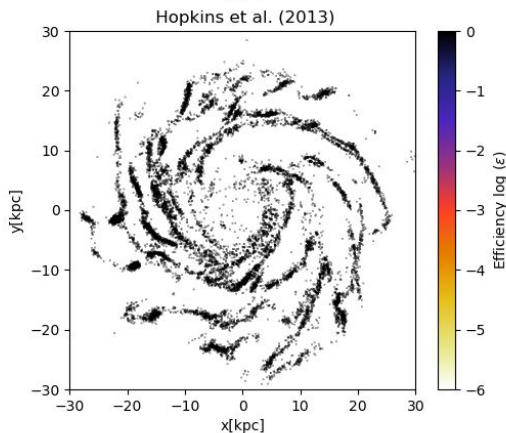
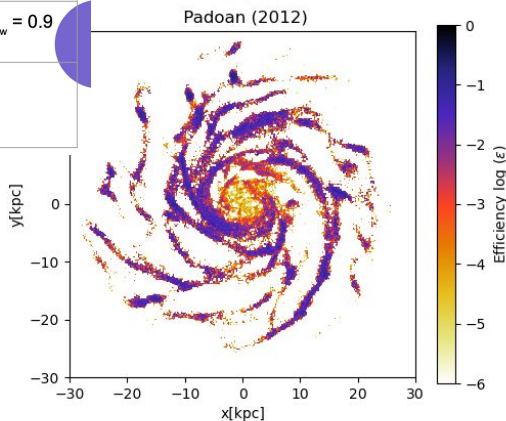
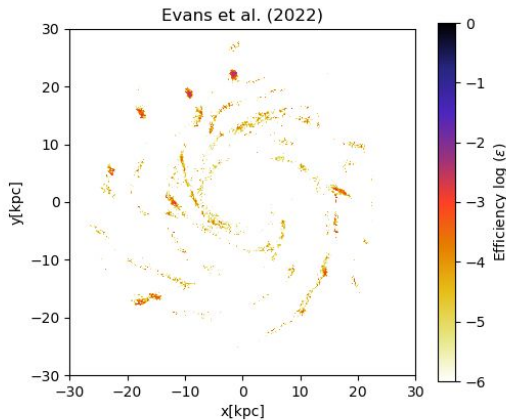
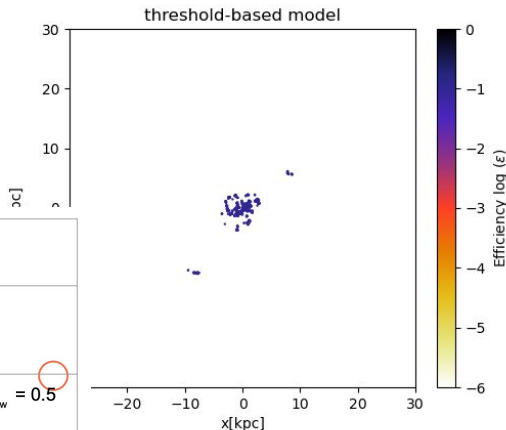


Star Formation Efficiency in Different Models

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	Virial Parameter	Star Formation Efficiency
Evans et al. (2022)	$\alpha = \frac{5\sigma^2 r}{3GM}$	$\epsilon_{ff} = e^{-b\sqrt{\alpha}_{vir}}$
Padoan et al. (2012)	$\alpha_{vir} \approx 1.35 \left(\frac{t_{ff}}{t_{dyn}} \right)^2$ $t_{ff} = \sqrt{\frac{2\pi}{32G\rho}}$ $t_{dyn} = \frac{\Delta}{2\sqrt{\sigma^2 + c_s^2}}$	$\epsilon_{ff} = -\epsilon_w e^{-1.6 \frac{t_{ff}}{t_{dyn}}}$, $\epsilon_w = 0.5$
Semenov et al. (2016)		$\epsilon_w = 0.9$
Hopkins et al. (2013)	$\alpha = \frac{\beta \nabla \times v ^2 + \nabla \cdot v ^2}{2 G\rho}$	$\epsilon = \begin{cases} 1 & \text{if } \alpha < 1 \\ 0 & \text{otherwise} \end{cases}$

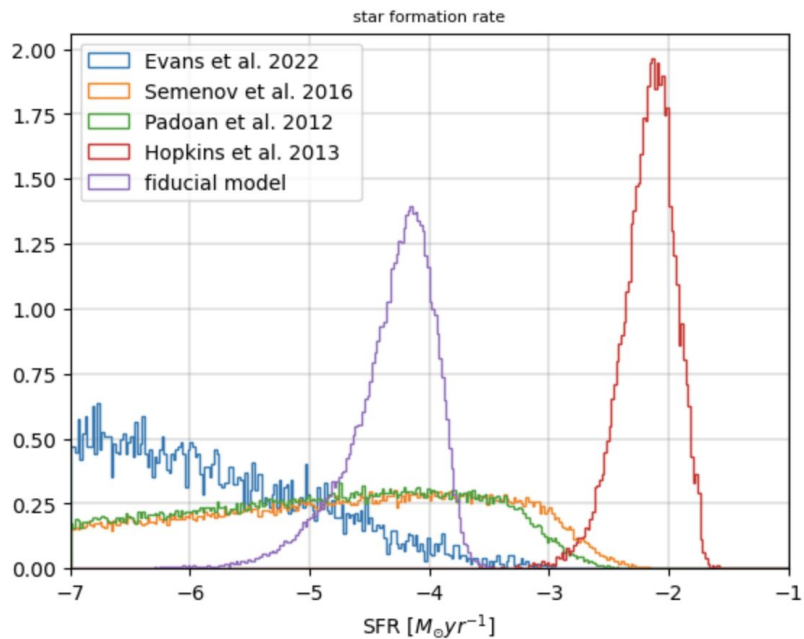
x [kpc]



Galaxy Image for Reference

Star Formation Rate

$$SFR_{\text{ff}} = \frac{M_{\text{mol,tot}} \cdot \epsilon_{\text{ff}}}{t_{\text{ff}}}$$



Model	Log ($M_{\text{gas}} \cdot \epsilon$)
Threshold Based	7.38
Padoan et al.	8.46
Semenov et al.	8.72
Hopkins et al.	9.65
Evans et al.	6.35

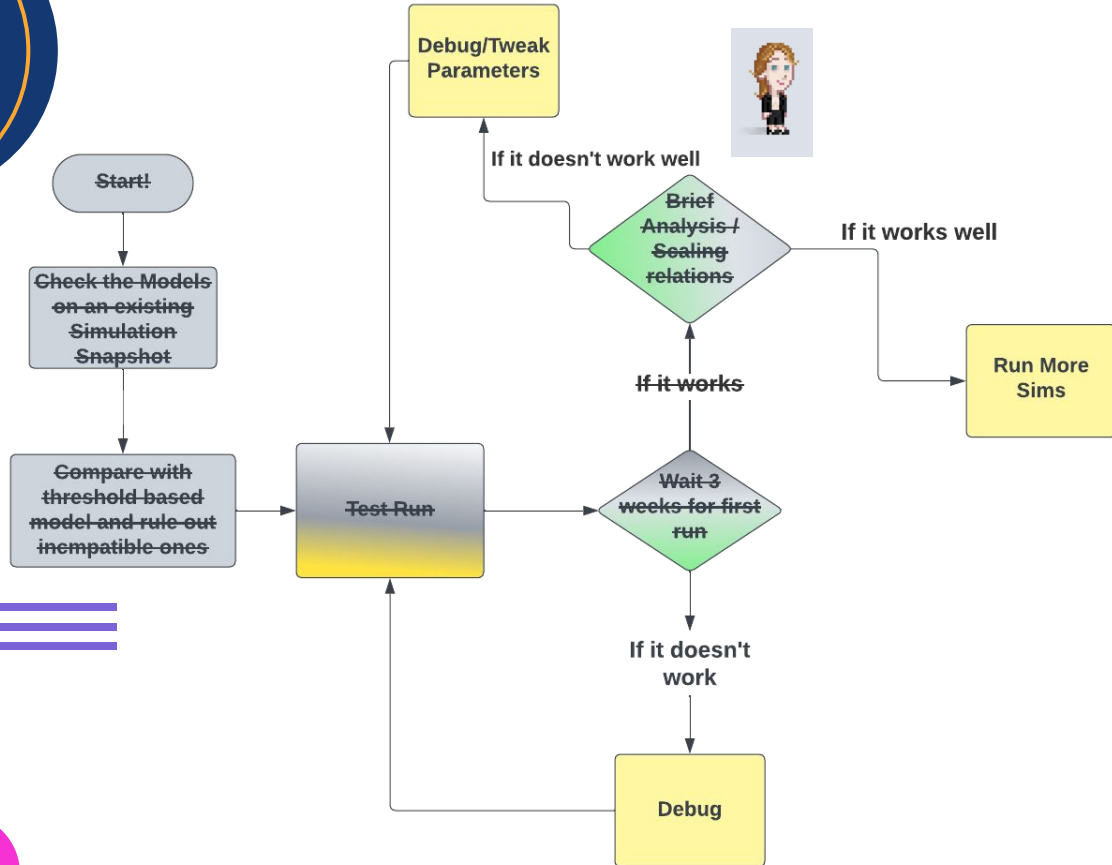
Running the new Simulation code

- Starting from the beginning, including feedback
- Ran the code appended with **Padoan model** (already tested on an isolated galaxy)

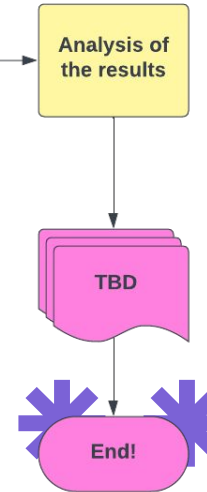
■ ■ ■ ■ ■ Test running this on a cosmological run

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g8.26e11.00448.OxMassFrac
g8.26e11.00448.alpha
g8.26e11.00448.alphaform
g8.26e11.00448.coolontime
g8.26e11.00448.effform
g8.26e11.00448.igasorder
g8.26e11.00448.iord
g8.26e11.00448.massform
g8.26e11.00448.timeform
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Junior Spring (in NY)

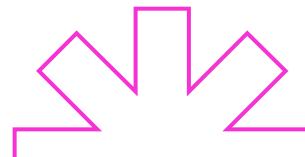


Senior Year



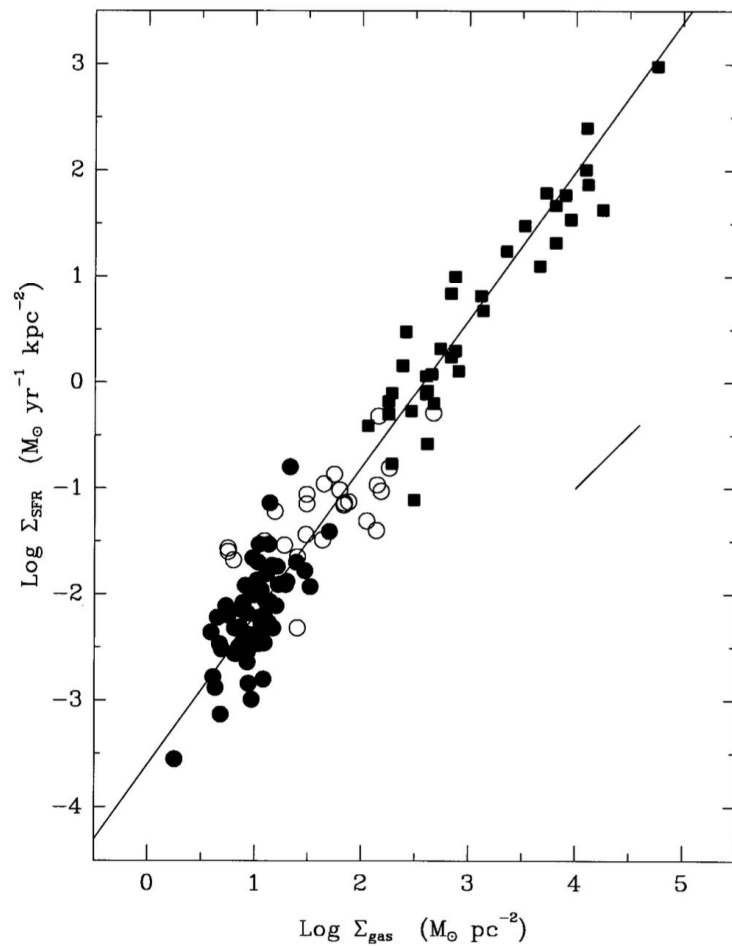
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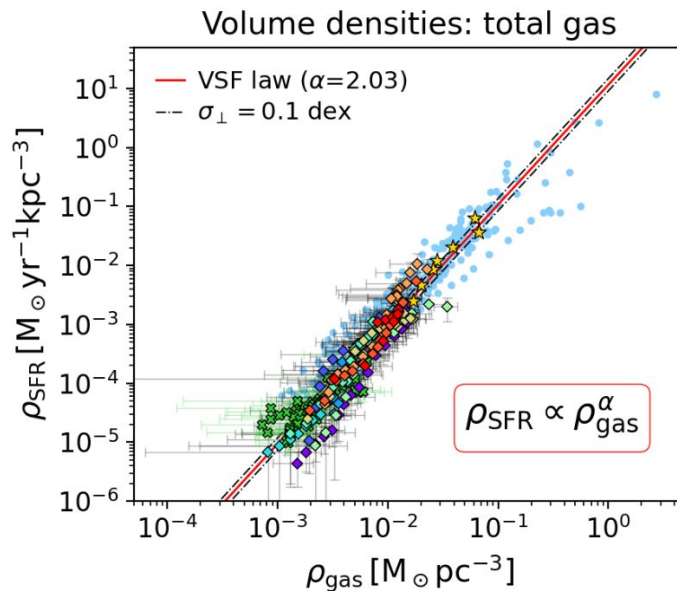
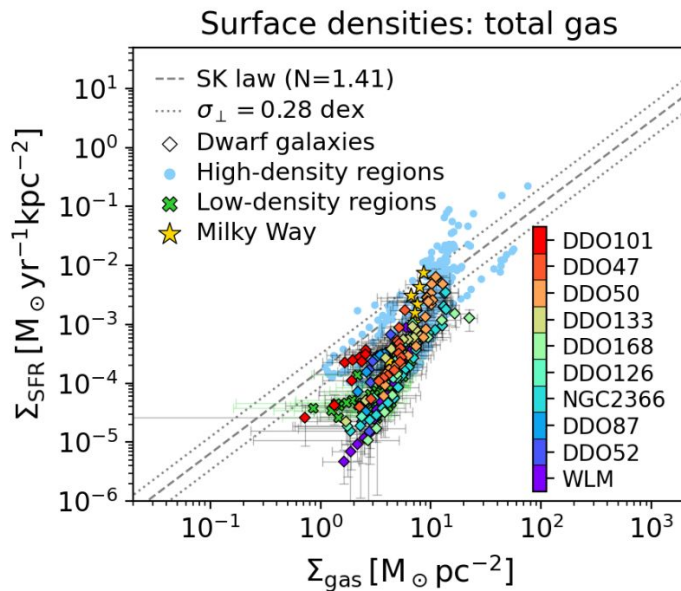


Kennicutt-Schmidt Relation

Kennicutt, (1989)

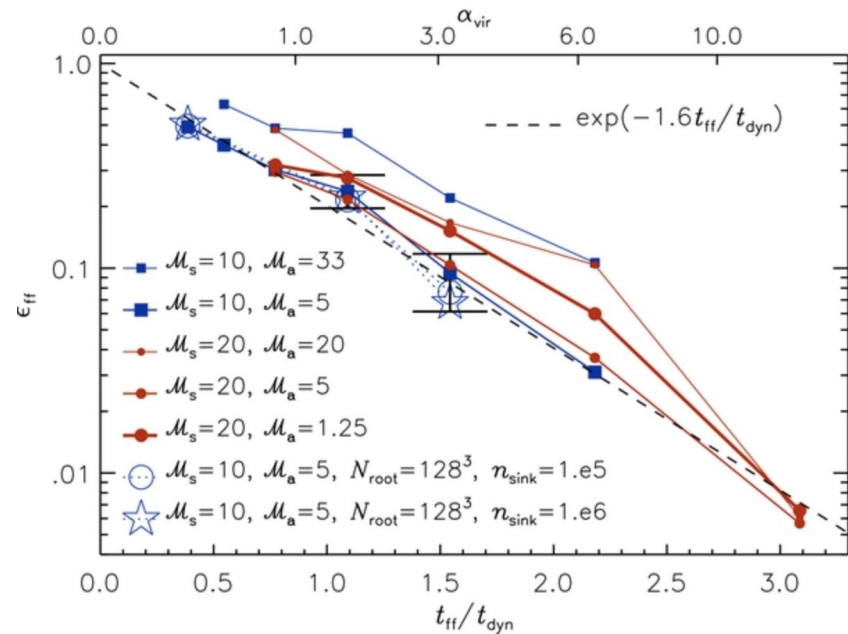
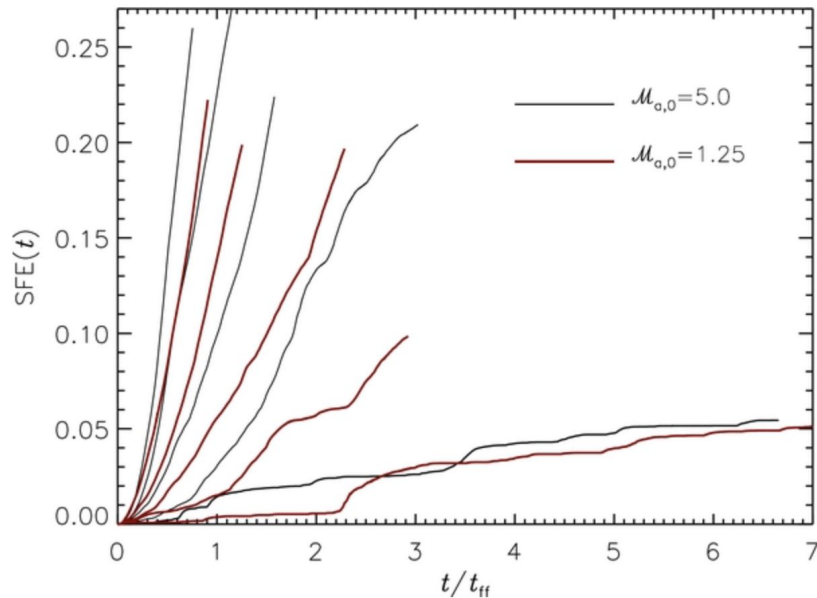


SFR and Volume Density



(Bacchini et al., 2022)

SFE Dependency on $t_{\text{ff}}/t_{\text{dyn}}$ and MHD turbulence



Padoan et al.




Hopkins et al. (2013)



$$\sigma_{\text{eff}}^2 + c_s^2 < \beta GM / \delta r.$$

$$\sigma_{\text{eff}}^2 = \beta (|\nabla \cdot \mathbf{v}|^2 + |\nabla \times \mathbf{v}|^2) \delta r^2$$


$$\alpha = \frac{\beta}{2} \frac{|\nabla \times v|^2 + |\nabla \cdot v|^2}{G\rho}$$
