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 ~ 100 particles cm^{-3}

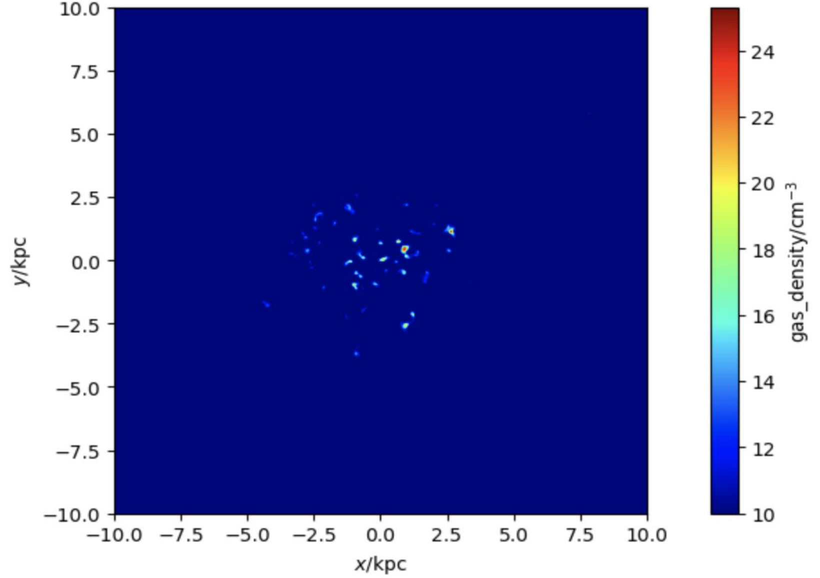
Max n_H ~ 10^4 particles cm^{-3}

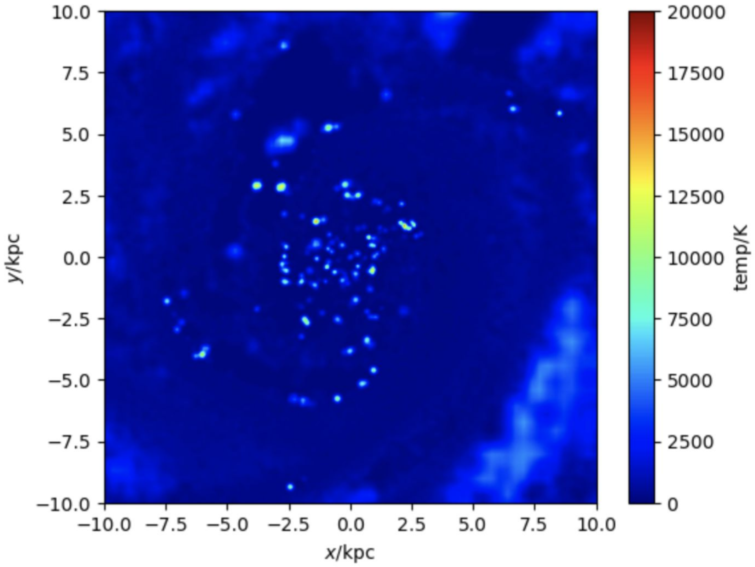
Very challenging to implement these in Simulations

⟶ **Virial Theorem** to describe the Star Formation

Current Star Formation Criteria in NIHAO :

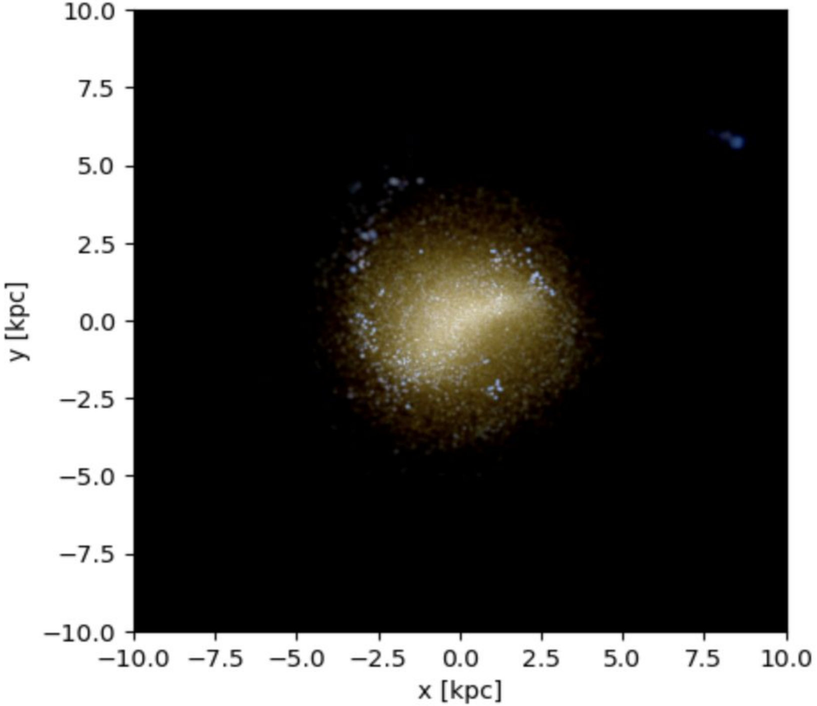
Density and Temperature Thresholds: $n_H > 10.3\ cm^{-3}$ and $T < 15000K$

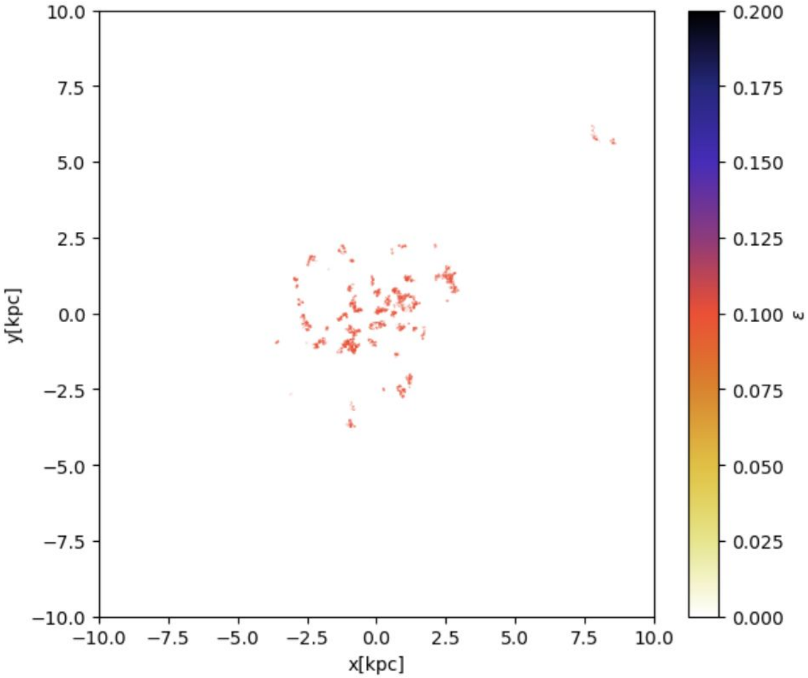




Snapshot of galaxy ‘8.26e11’ from NIHAO classic

Star Formation Efficiency





Virial Star Formation Models

- Physically Motivated Models

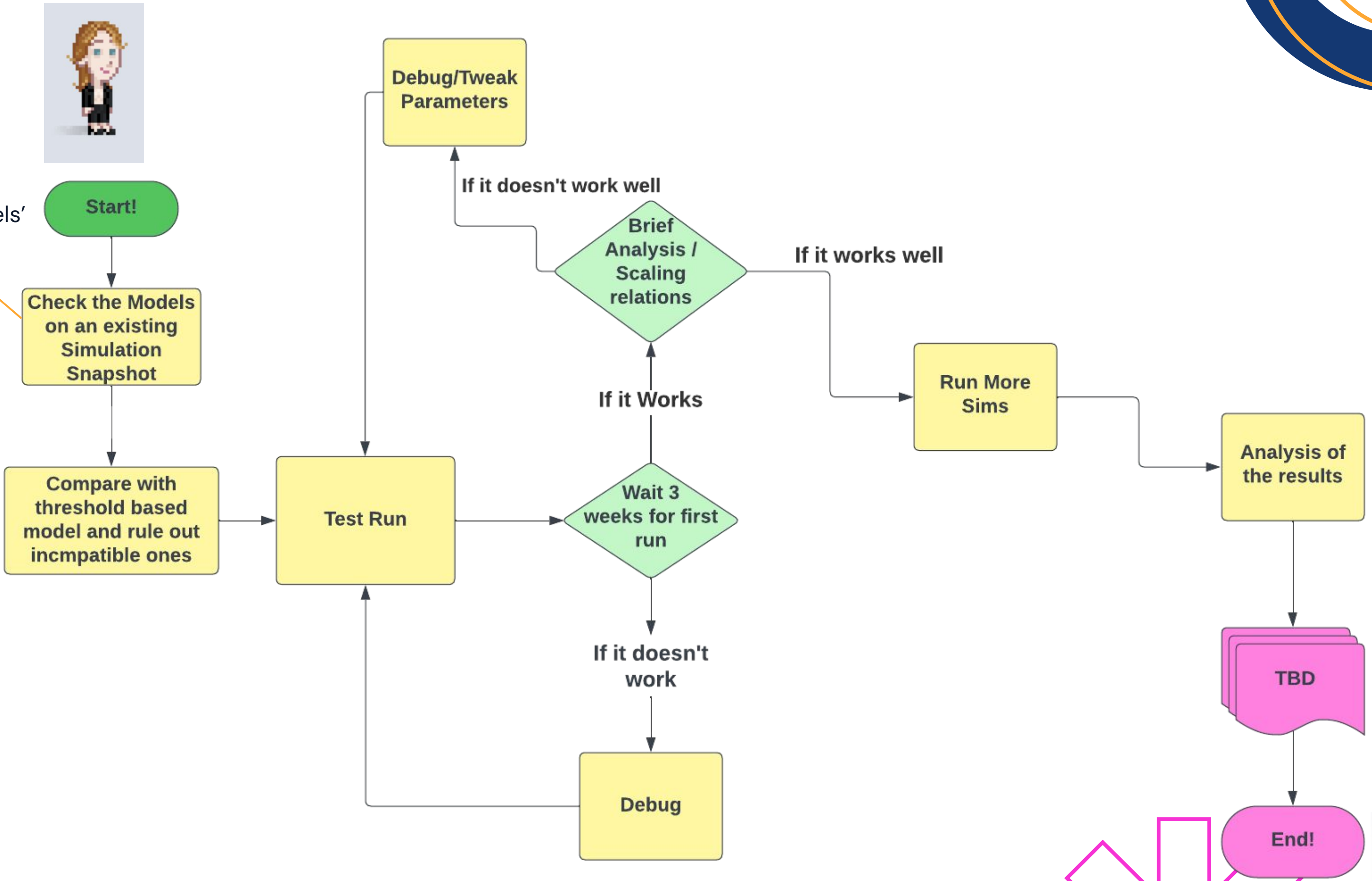
- **Goal** : Make sure they reproduce good attributes of Threshold model but improves the simulation

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)	$\alpha_{vir} \approx 1.35(\frac{t_{ff}}{t_{dyn}})^2$; $tff = \sqrt{\frac{2\pi}{32G\rho}}$	$\epsilon_{ff} = \epsilon_w e^{-1.6\frac{t_{ff}}{t_{dyn}}}$, $\epsilon_w = 0.5$
Semenov et al. (2016)	$t_{dyn} = \frac{\Delta}{2\sqrt{\sigma^2 + c_s}}$	, $\epsilon_w = 0.9$
Hopkins et al. (2013)	$\alpha = \frac{\beta}{2}\frac{\lvert\nabla \times v\rvert^2 + \lvert\nabla \cdot v\rvert^2}{G\rho}$	$\epsilon = \begin{cases} 1 & \text{if } \alpha < 1 \\ 0 & \text{otherwise} \end{cases}$

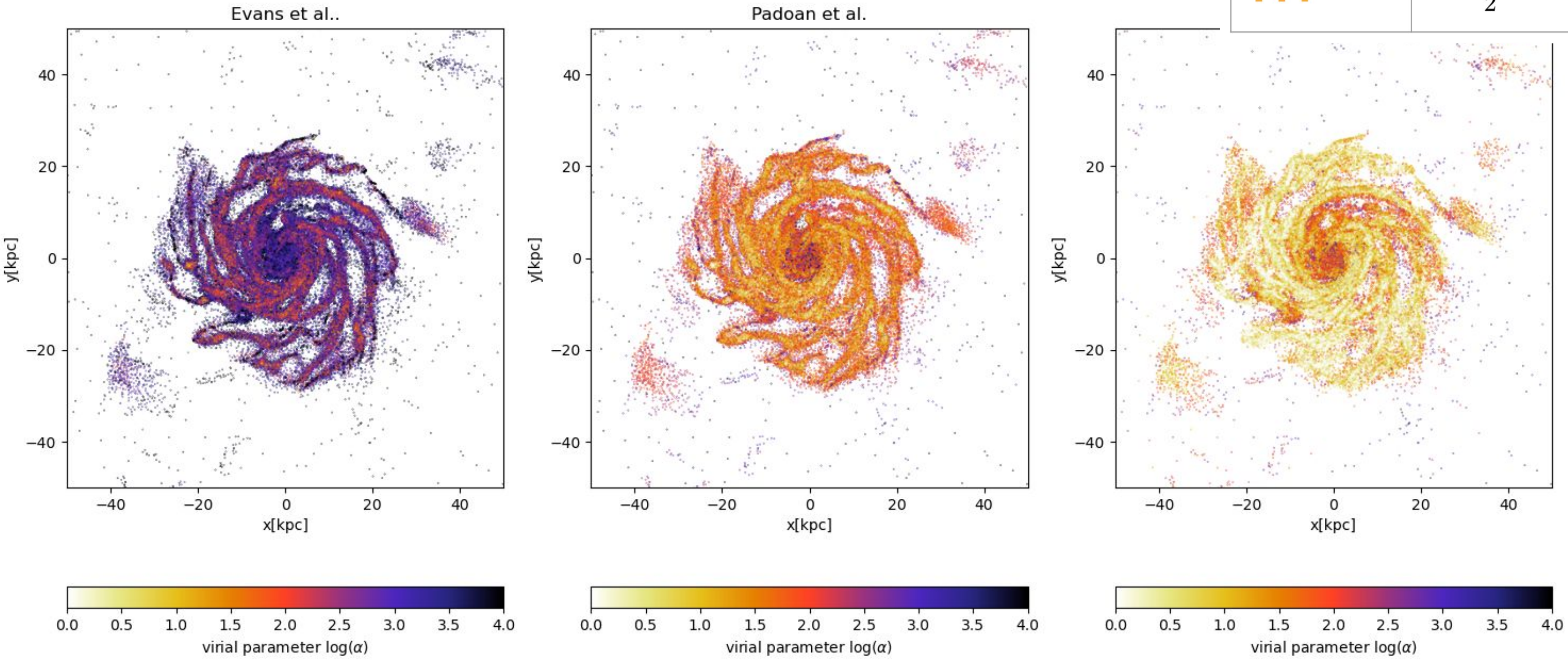
‘calculate the α and ε proposed in the models’



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)	$\alpha_{vir} \approx 1.35(\frac{t_{ff}}{t_{dyn}})^2$ — $t_{ff} =$ … $t_{dyn} =$ …
Semenov et al. (2016)	
Hopkins et al. (2013)	$\alpha = \frac{\beta}{2} \frac{\lvert\nabla \times v\rvert^2 + \lvert\nabla \cdot v\rvert^2}{G\rho}$



Star Formation Efficiency in Different Models

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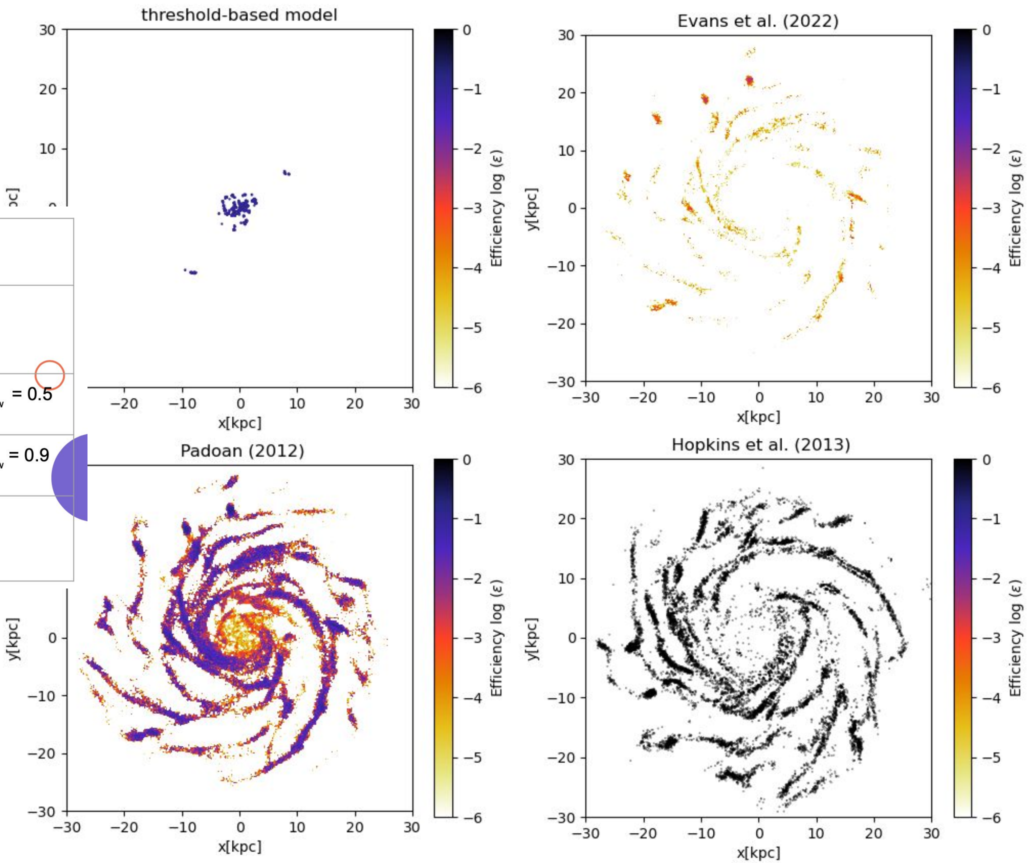
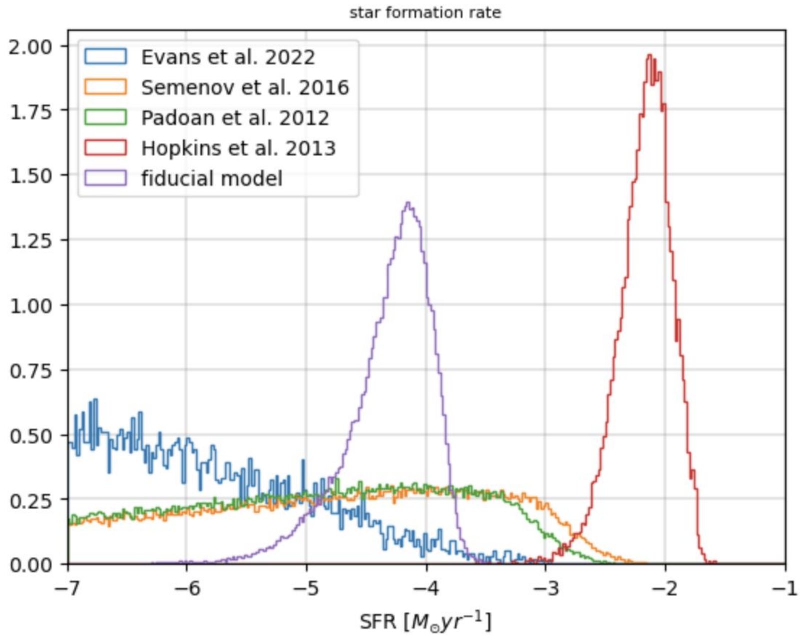


Galaxy Image for Reference

Star Formation Rate

$$SFR_{\mathrm{ff}} = \frac{M_{\mathrm{mol,tot}} \cdot \varepsilon_{\mathrm{ff}}}{t_{\mathrm{ff}}}$$



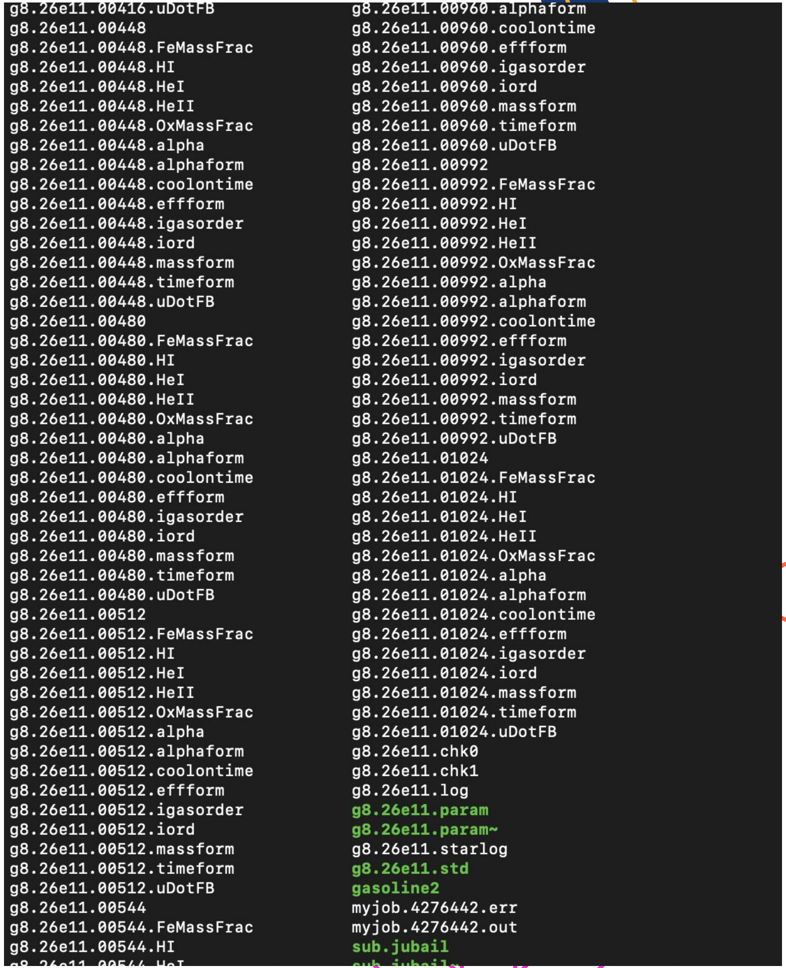
Model	Log (M_{gas}. ε)
Threshold Based	7.38
Padoan et al.	8.46
Semenov et al.	8.72
Hopkins et al.	9.65
Evans et al.	6.35

Running the new Simulation code

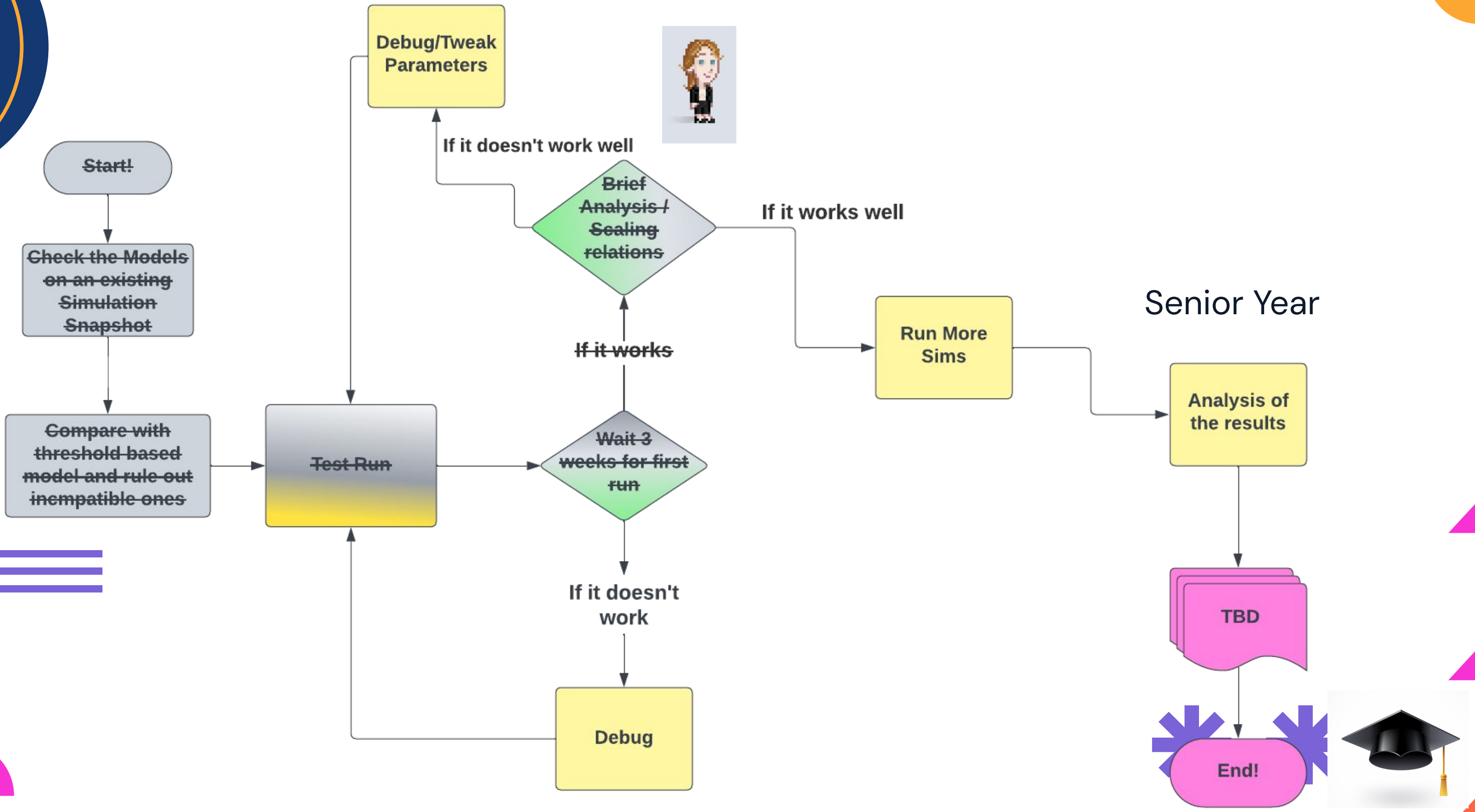
- Starting from the beginning, including feedback

- Ran the code appended with Padoan model (already tested on an isolated galaxy)

- Test running this on a cosmological run



Junior Spring (in NY)



References

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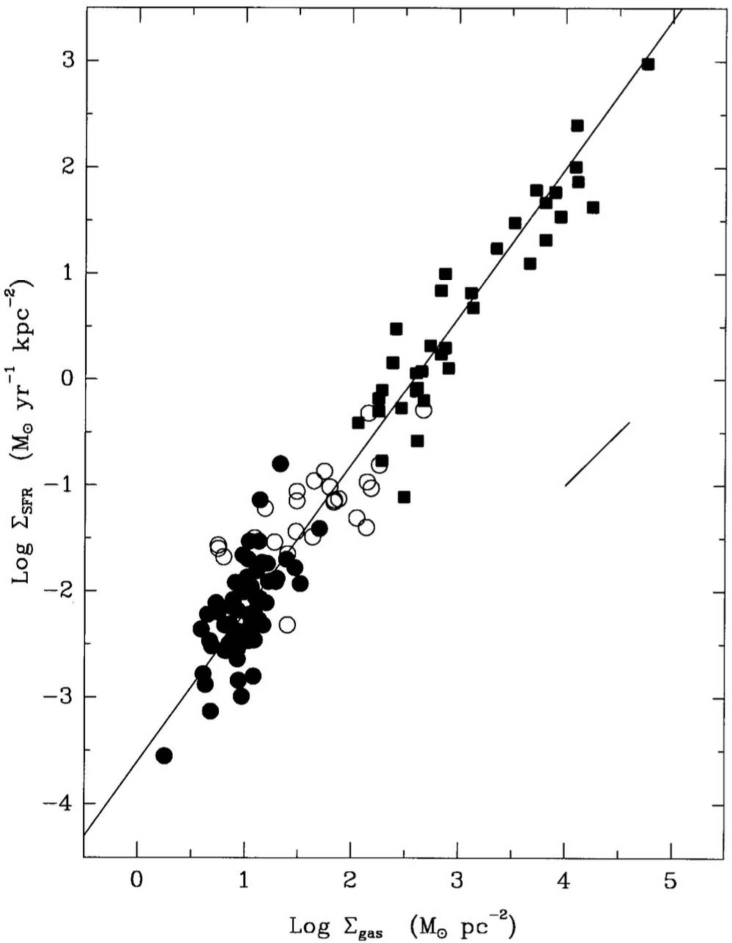
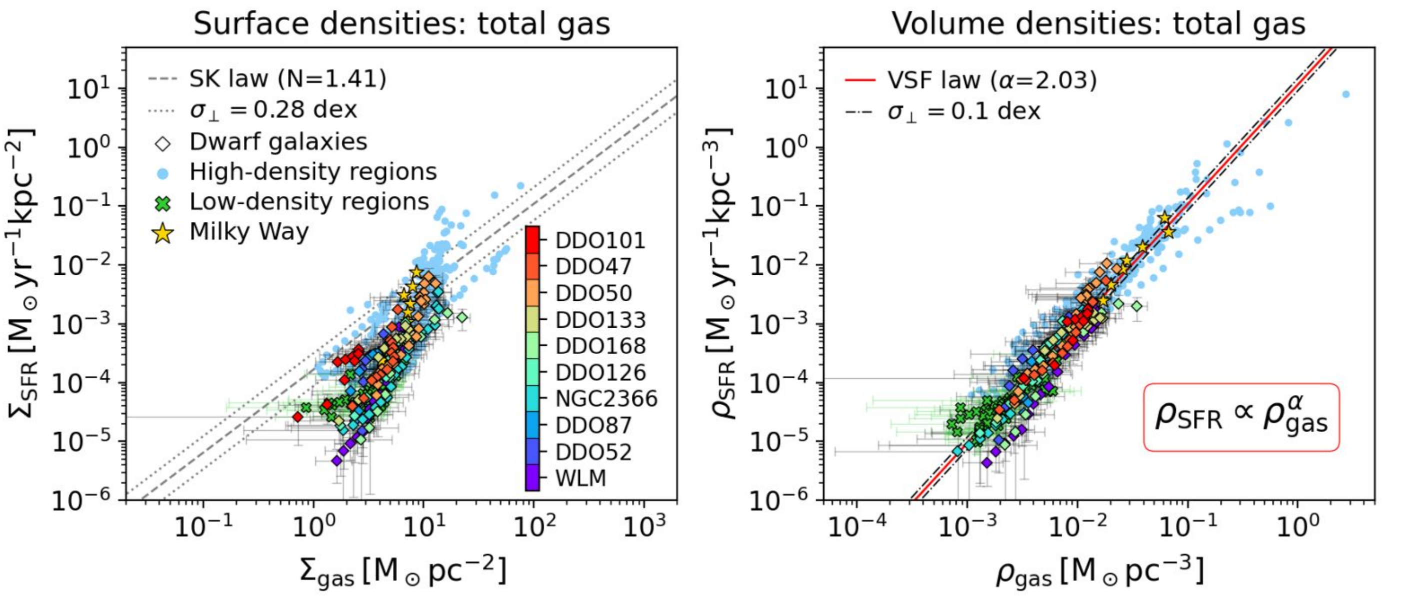
Kennicutt-Schmidt Relation



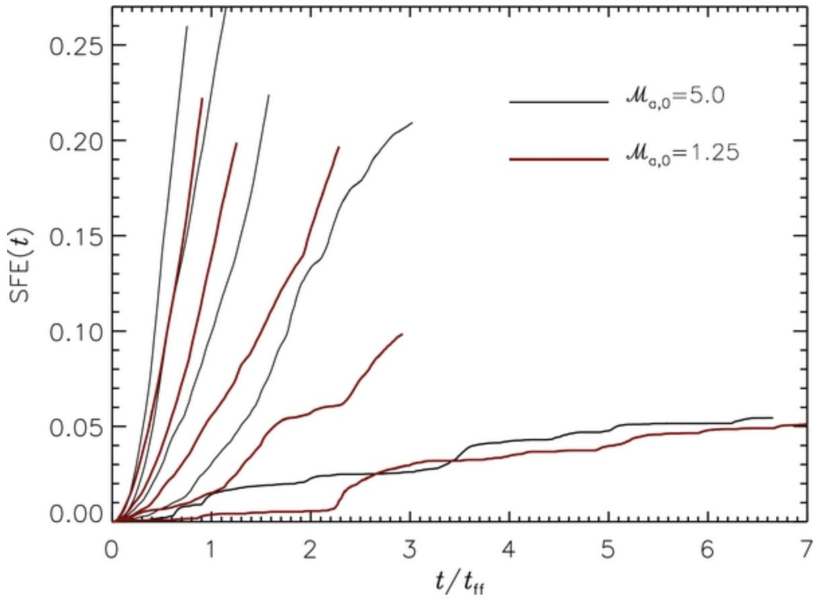
[Kennicutt, (1989)]

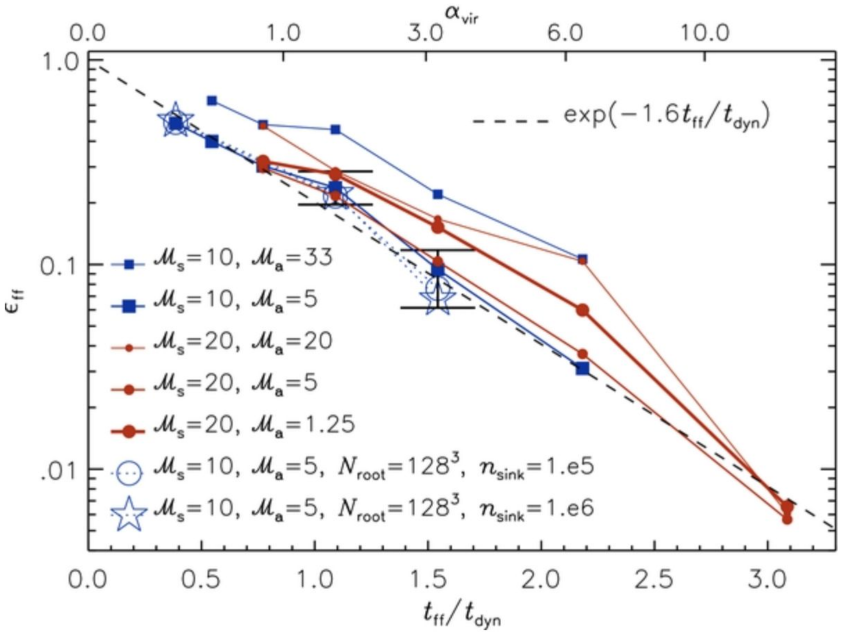
SFR and Volume Density



(Bacchini et al., 2022)

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





Padoan et al.

Hopkins et al. (2013)

$$\sigma_{\mathrm{eff}}^2 + c_s^2 < \beta G M / \delta r.$$

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

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