

RAMSES USER MEETING 2016

TURBULENT STAR FORMATION (& INITIAL CONDITIONS)

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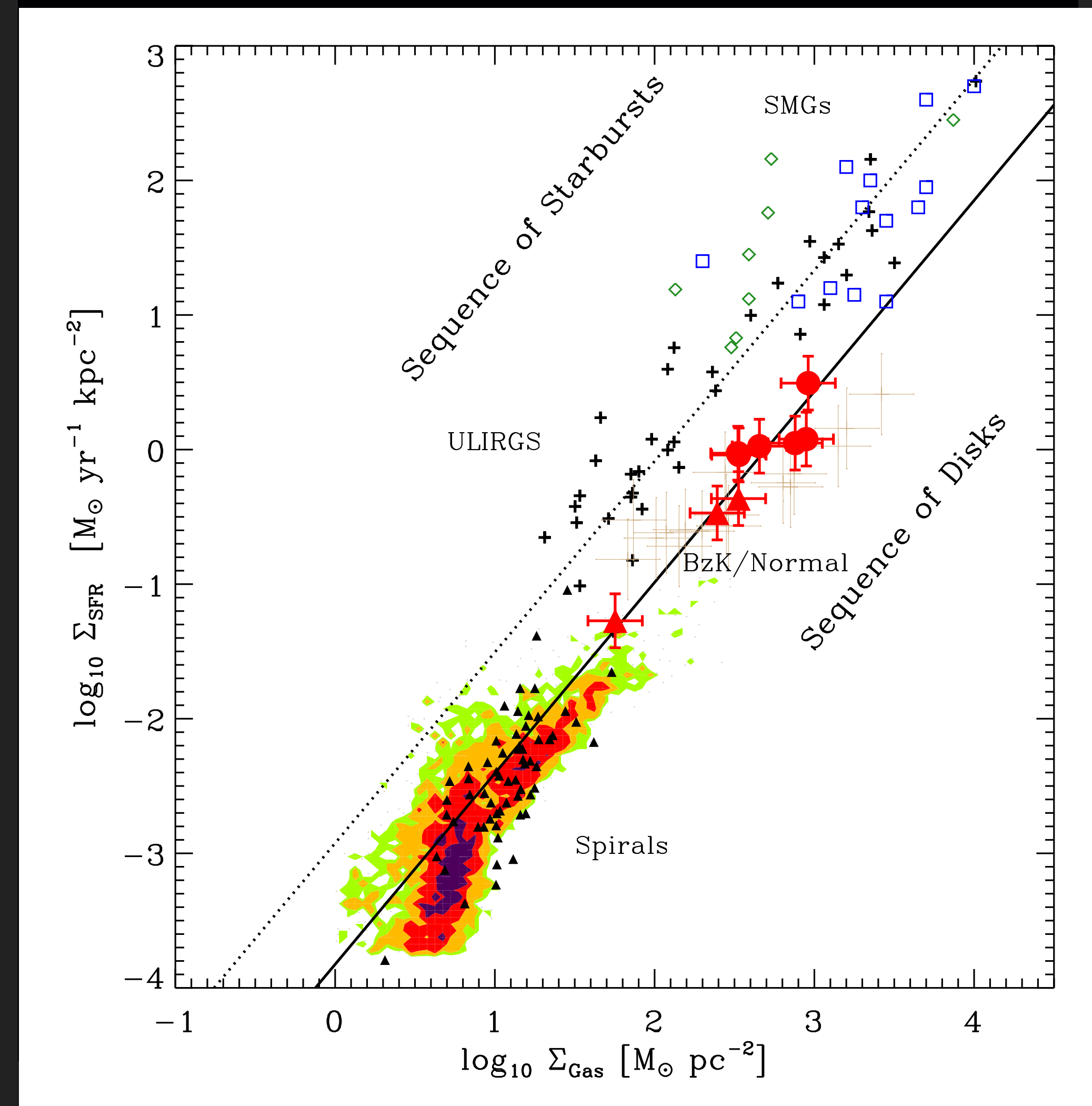
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Zurich^{UZH}

DIVERSITY OF SCALES



“CLASSICAL” STAR FORMATION CRITERION

- ▶ Local Schmidt law: $t_{ff} \propto 1/\sqrt{G\rho}$ $\dot{\rho}_* \propto \rho/t_{ff} \propto \rho^{1.5}$
- ▶ Density trigger $\rho > \rho_0$ and efficiency are free parameters
- ▶ $[\rho_0, \epsilon]$ are fine tuned to match the KS relation
- ▶ In high resolution hydro simulations, common values are:
 - ▶ $\epsilon \sim 1\%$
 - ▶ $\rho_0 \sim 100 \text{ cm}^{-3}$ (resolution dependent)



“VIRIAL” STAR FORMATION CRITERION

- ▶ Local derivation of the virial theorem for any geometry and an arbitrary volume element

$$4\pi\rho G > -\Delta P/\rho + \sigma^2$$

$$\sigma^2 = \sum_i \sum_j G_{i,j}^2 \quad P = \rho c_s^2 \quad \text{with G velocity gradient tensor}$$

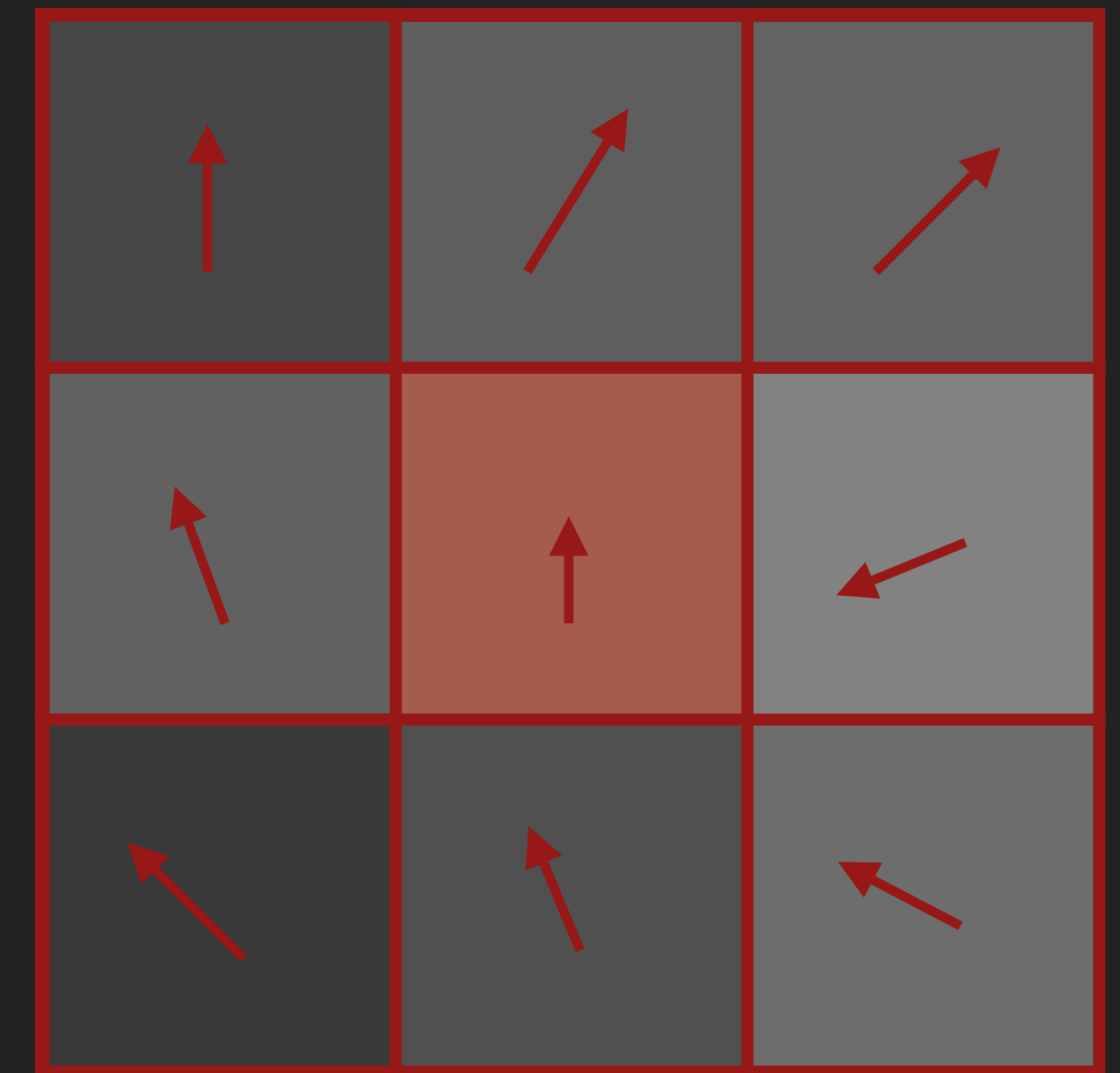
$$\alpha = \frac{-c_s^2 \Delta\rho/\rho + \sigma^2}{4\pi\rho G}$$

$$\Delta\rho < 0, \alpha < 1 \rightarrow \dot{\rho}_\star = \frac{\epsilon}{t_{ff}} \quad \epsilon = 1$$

- ▶ Benefit: this formulation does not depend on free parameters!
- ▶ Only depends on the ability to resolve the turbulent cascade

IMPLEMENTATION OF THE VIRIAL CRITERION

- ▶ Looping on each gas cell:
 - ▶ **Density criterion**
Check the density of the cell
 - ▶ **Virial criterion**
Gather velocity information of the 27 neighbours

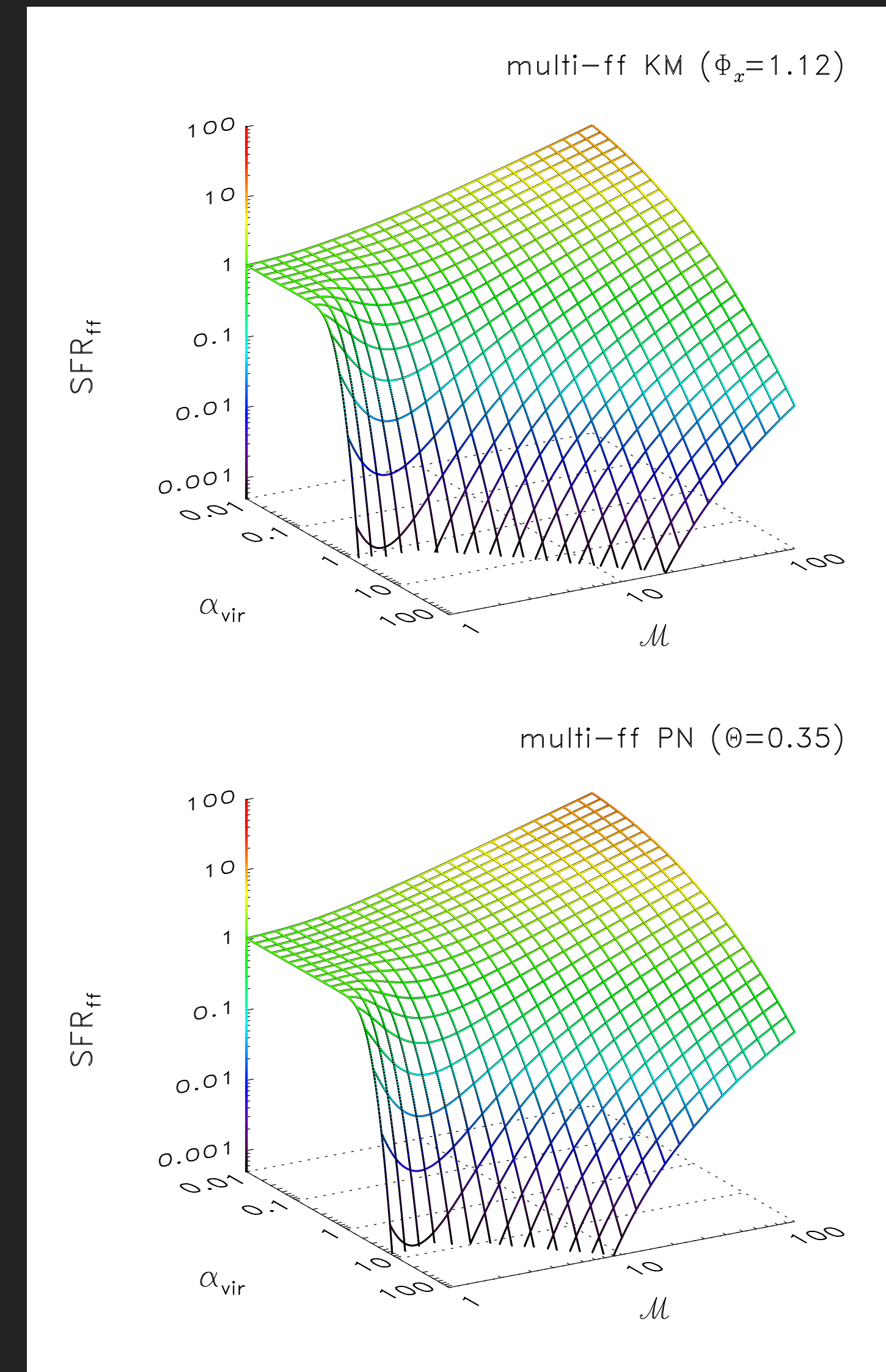


Density criterion

$$\nabla \cdot v \quad \nabla \times v$$

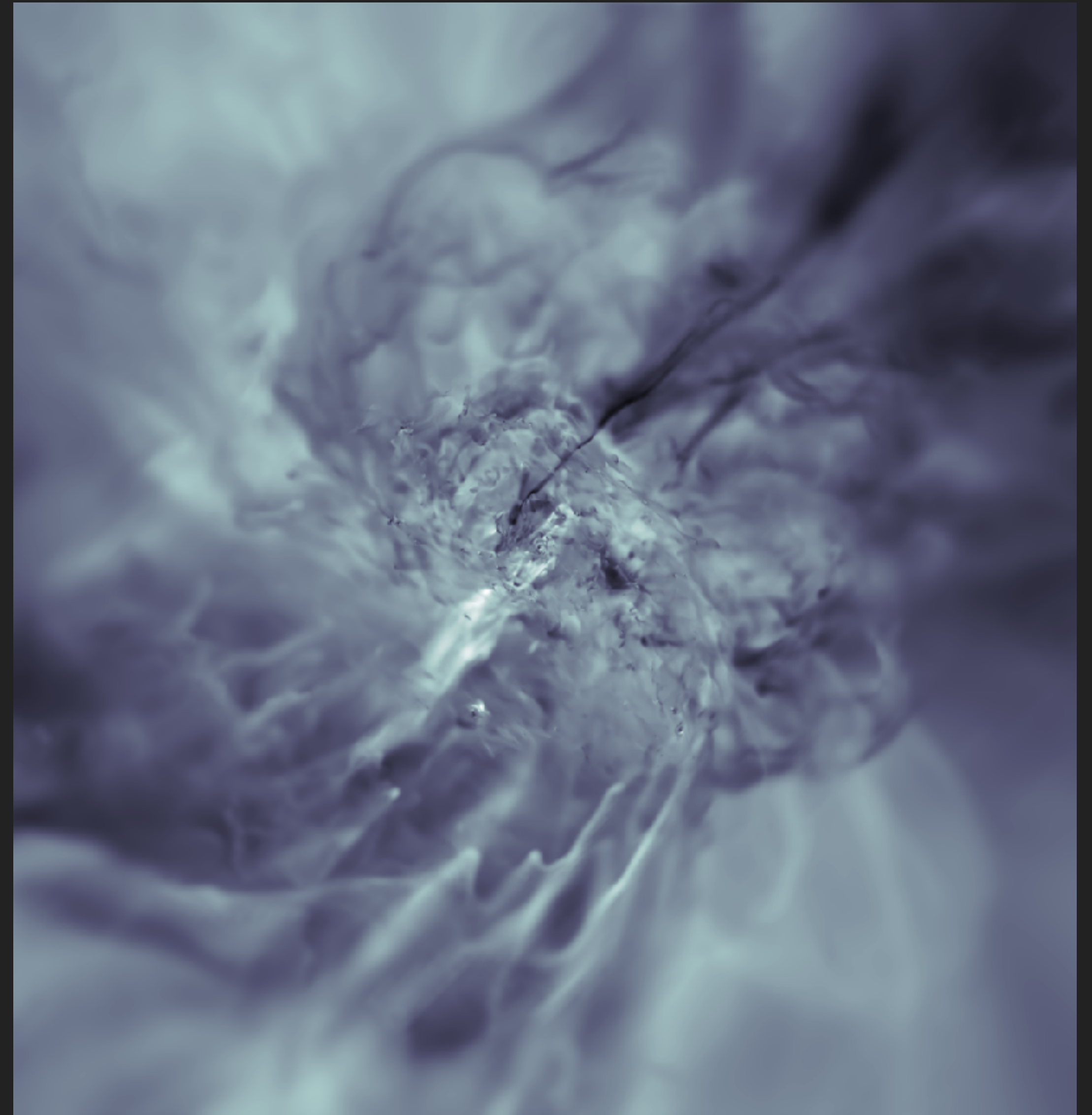
STAR_FORMATION.F90 (PULL REQUEST #200)

- ▶ `sf_virial=.true.` activates local Virial analysis
- ▶ 5 turbulent SF models available `sf_model=`
 - ▶ 1 : Multi-ff KM (Krumholz & McKee 2005)
 - ▶ 2 : Multi-ff PN (Padoan & Nordlund 2011)
 - ▶ 3 : Classical Virial parameter ($\epsilon=cste$)
 - ▶ 4 : Padoan 2012 simple law ($\epsilon \sim \exp(-1.6t_{ff}/t_{dyn})$)
 - ▶ 5 : Hopkins 2013 turbulent SF law ($\epsilon=cste$)
- ▶ `sf_birth_properties=.true.` saves star gas local properties at birth



SIMULATION SETUP

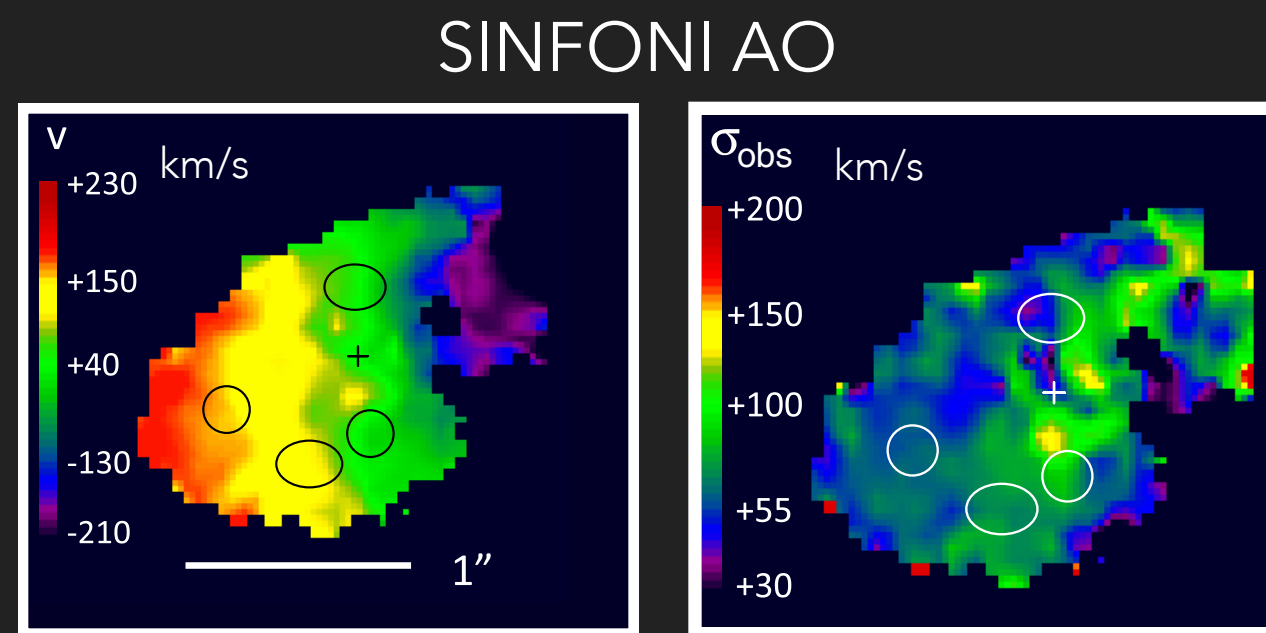
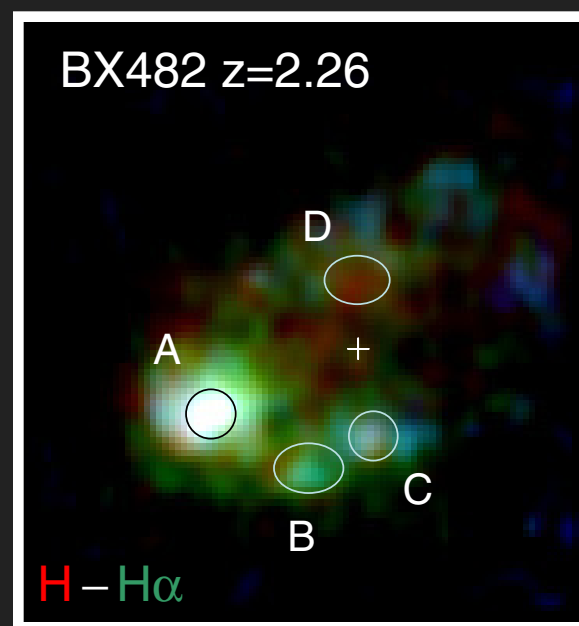
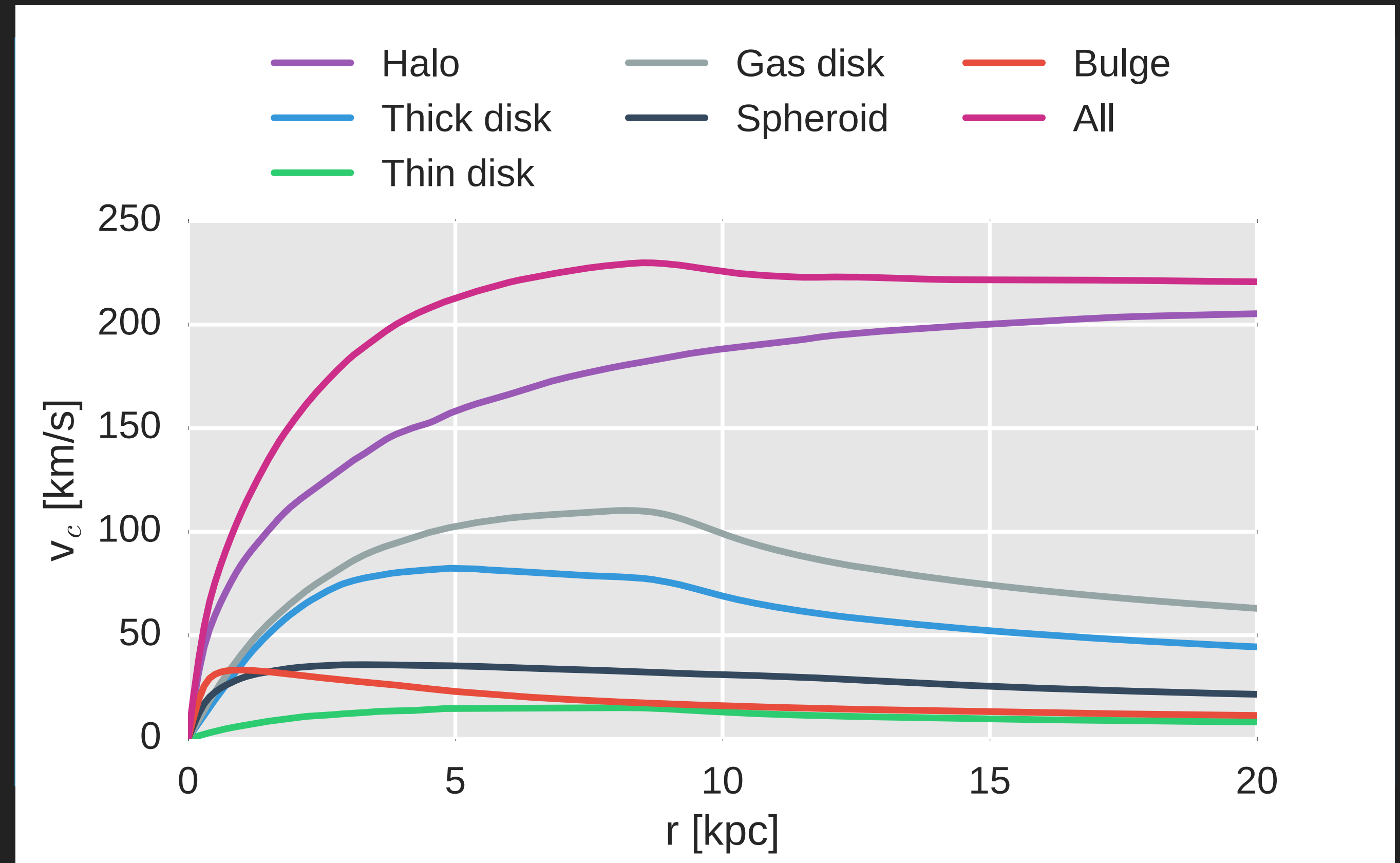
- ▶ RAMSES main parameters:
 - ▶ AMR box size = 150 kpc
 - ▶ Quasi-Lagrangian refinement scheme
 - ▶ Finest cells = 18 pc
 - ▶ Supernovae thermal feedback:
 2×10^{51} ergs / $10 M_{\odot}$
→ Turbulence modelled with a cooling switch
 $t_{\text{dissip}} = 20$ Myr (Teyssier et al. 2013)
 - ▶ Metal cooling & metals advection
 - ▶ Isothermal temperature floor = 100 K (no polytrope)



HIGH REDSHIFT DISK SETUP

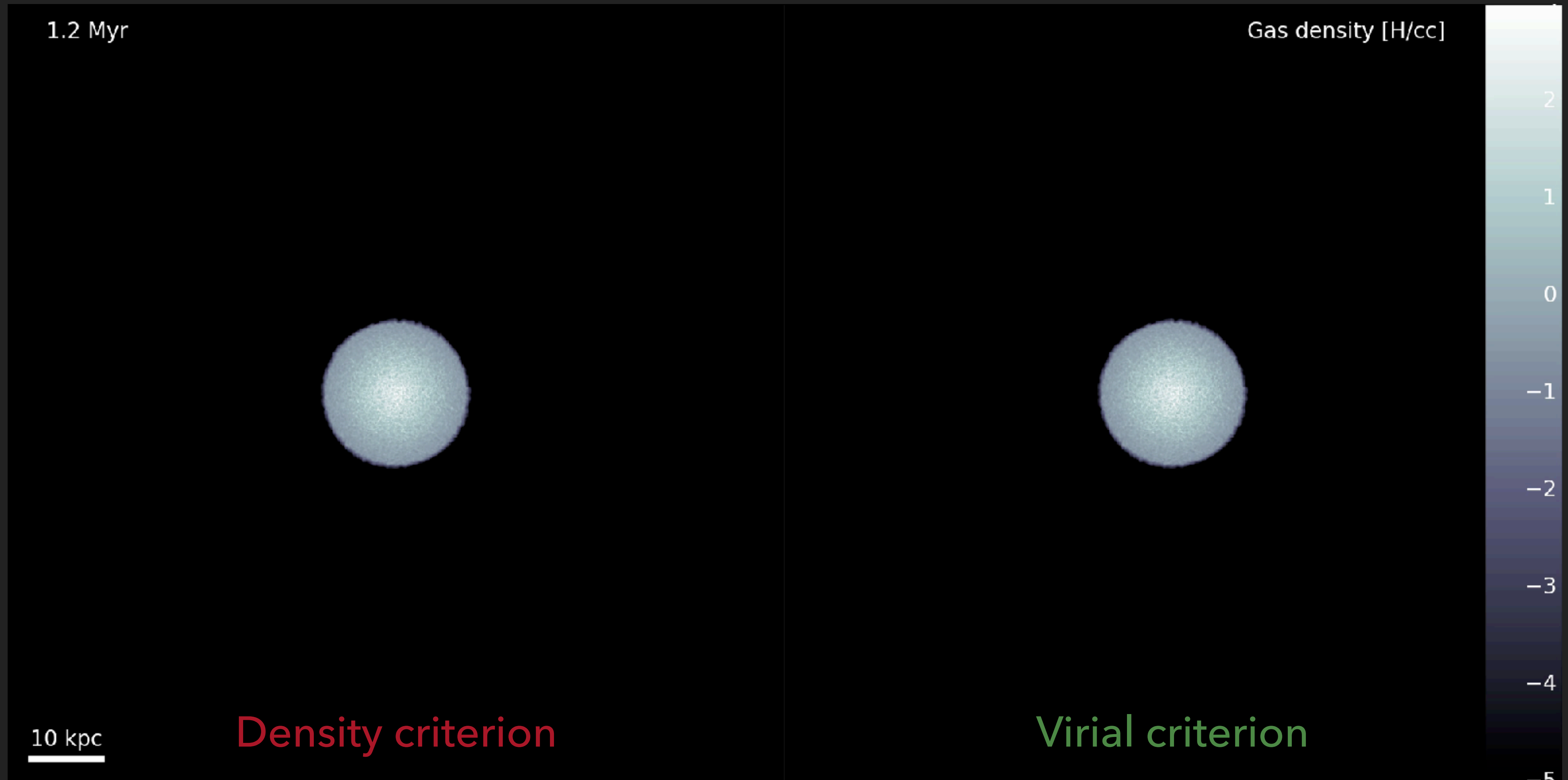
- ▶ Idealised initial conditions of a massive gas rich disk at $z \sim 3$
- ▶ Easier to resolve the turbulence injection scale (disk scale height)

V_{200}	$M_{200,z=3}$	$R_{200,z=3}$	C_{NFW}	f_{gas}	B/D	$m_{\text{part,DM}}$	$m_{\text{part,star}}$	$m_{\text{tot,star}}$
200 km/s	$5.9e11 M_{\odot}$	63 kpc	5	61%	5%	$1.5e5 M_{\odot}$	$5e3 M_{\odot}$	$1.1e10 M_{\odot}$

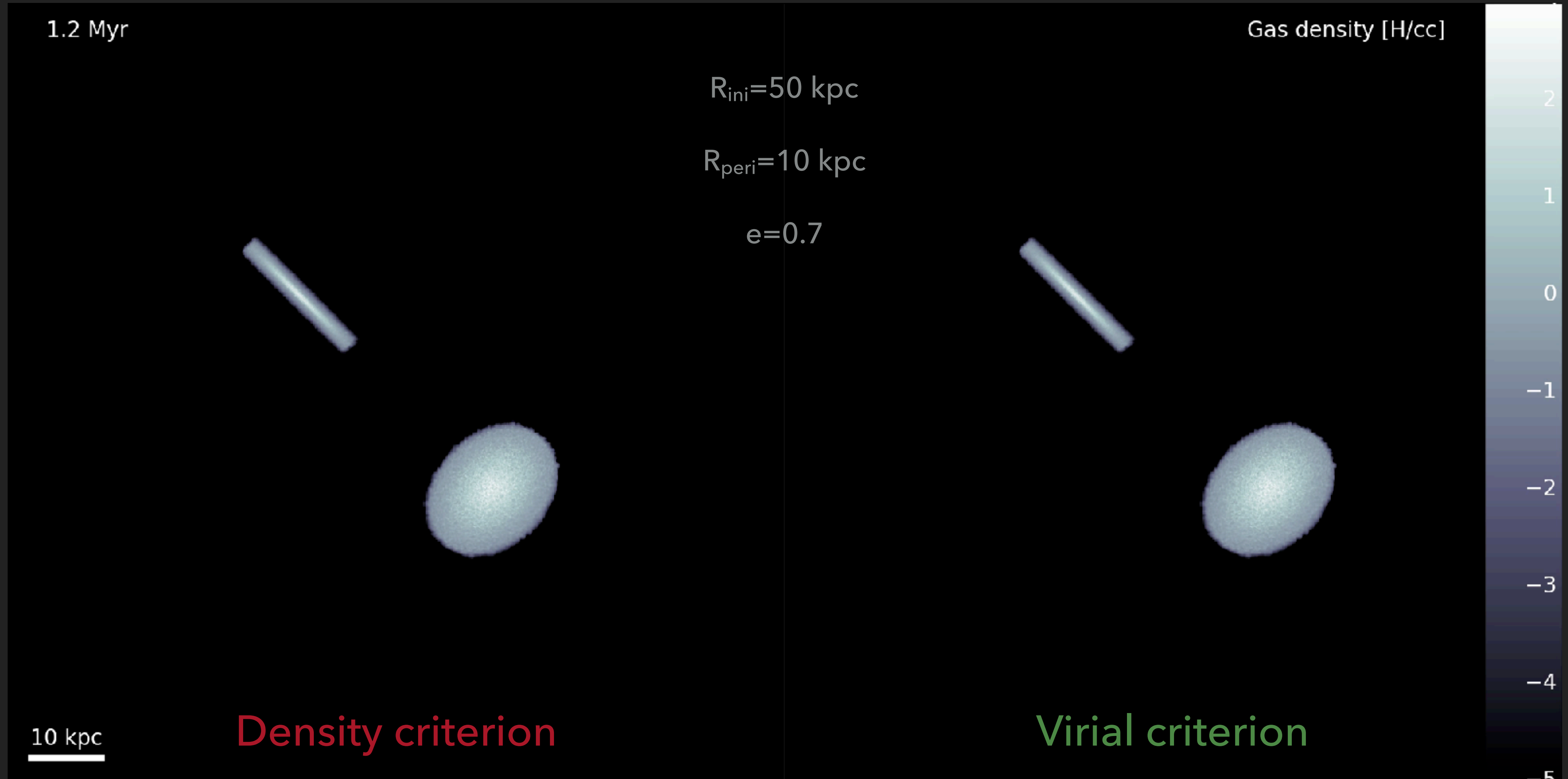


Genzel et al. 2011

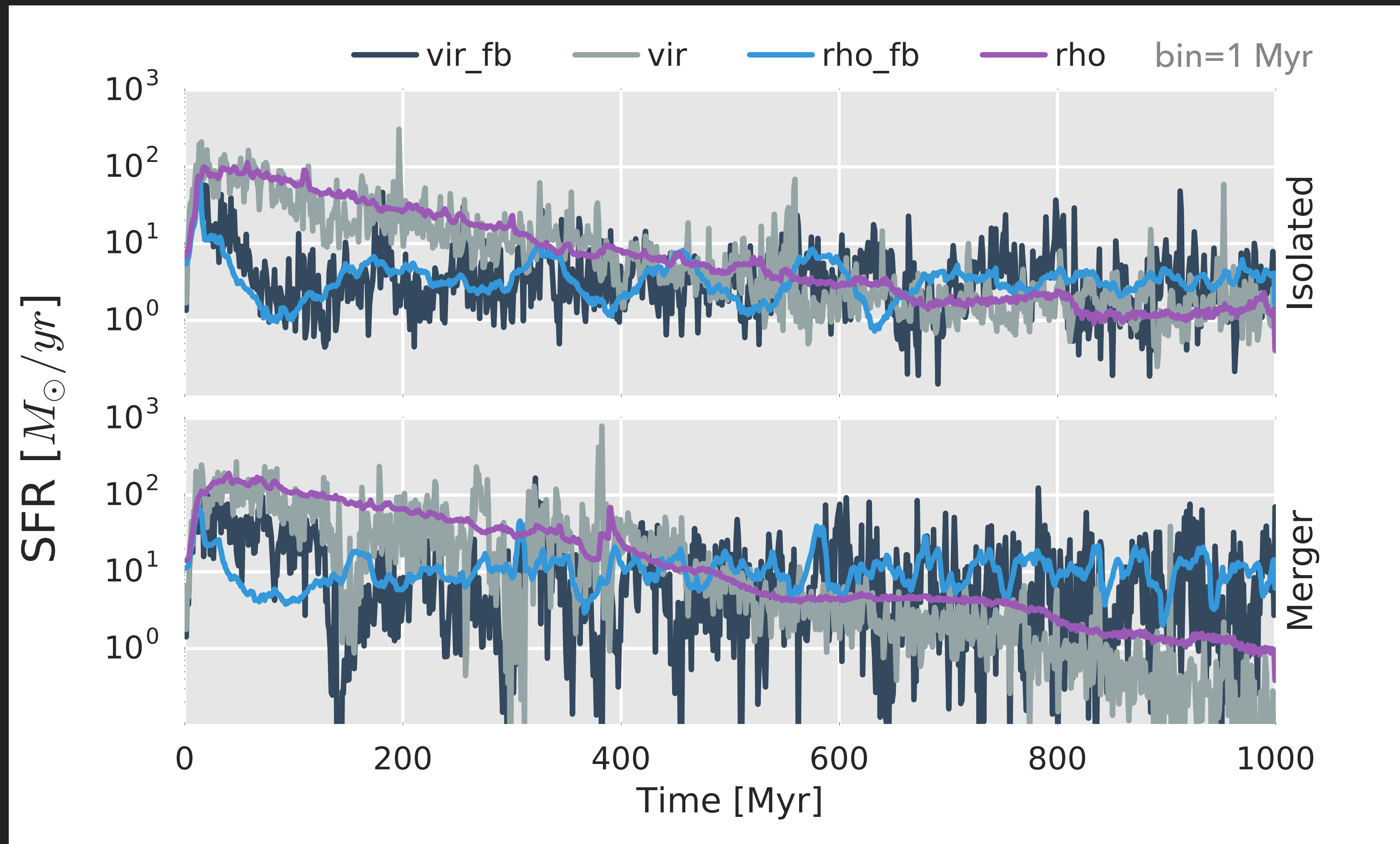
STELLAR FEEDBACK SIMULATIONS



MERGER STELLAR FEEDBACK SIMULATION



STAR FORMATION HISTORY



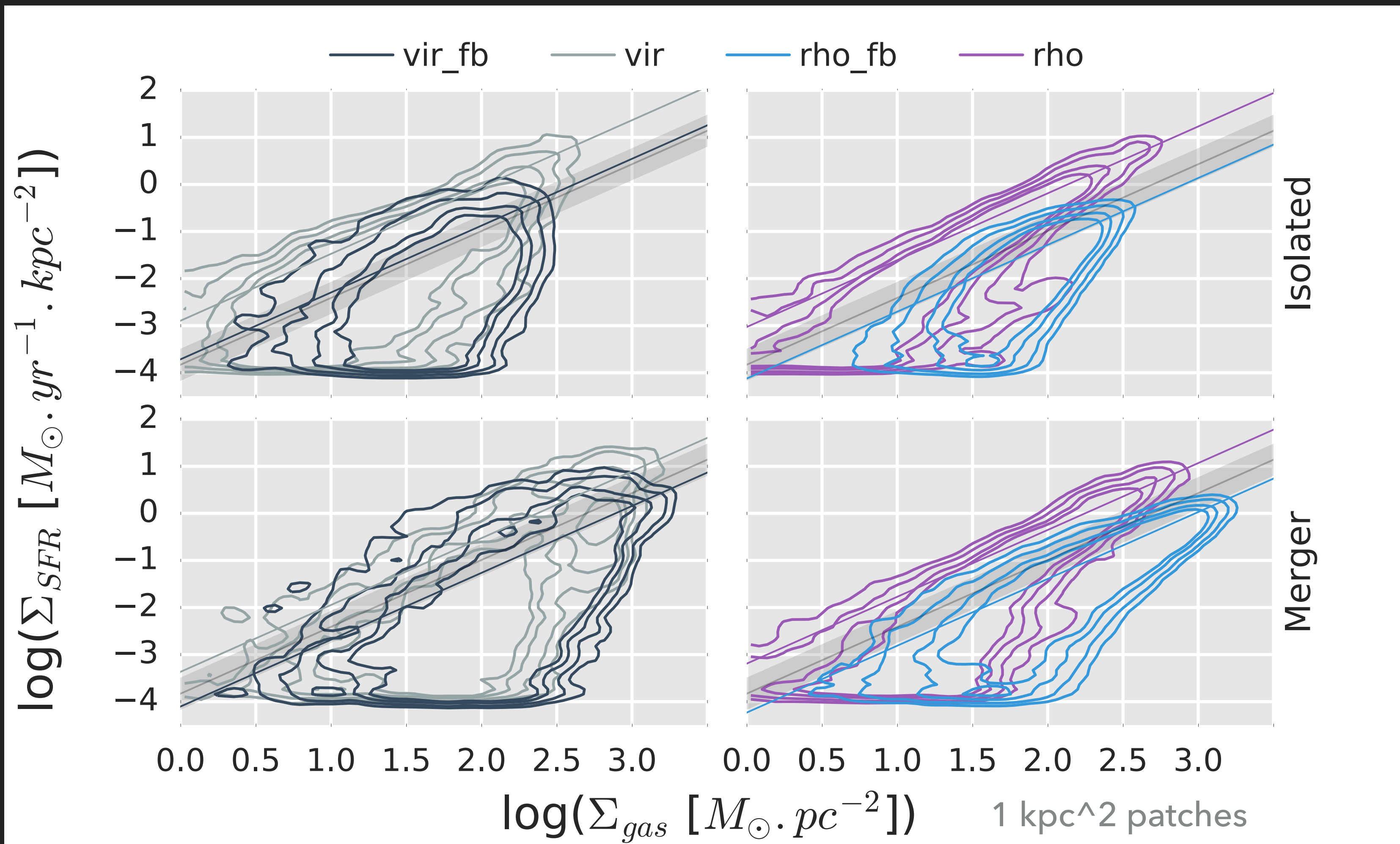
$\sigma=0.09$

$\sigma=0.53$

$\sigma=0.13$

$\sigma=0.66$

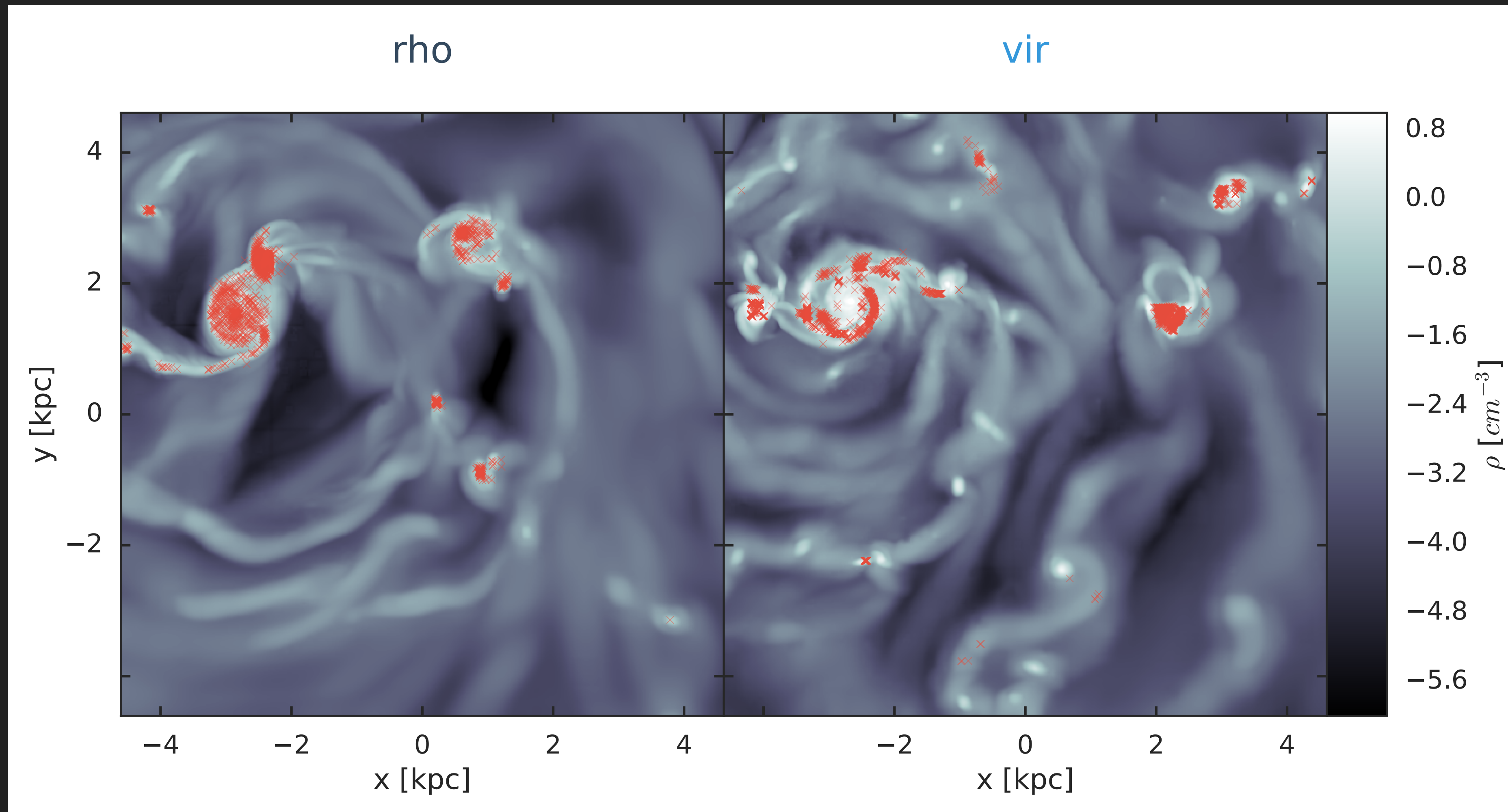
KENNICUTT-SCHMIDT RELATION



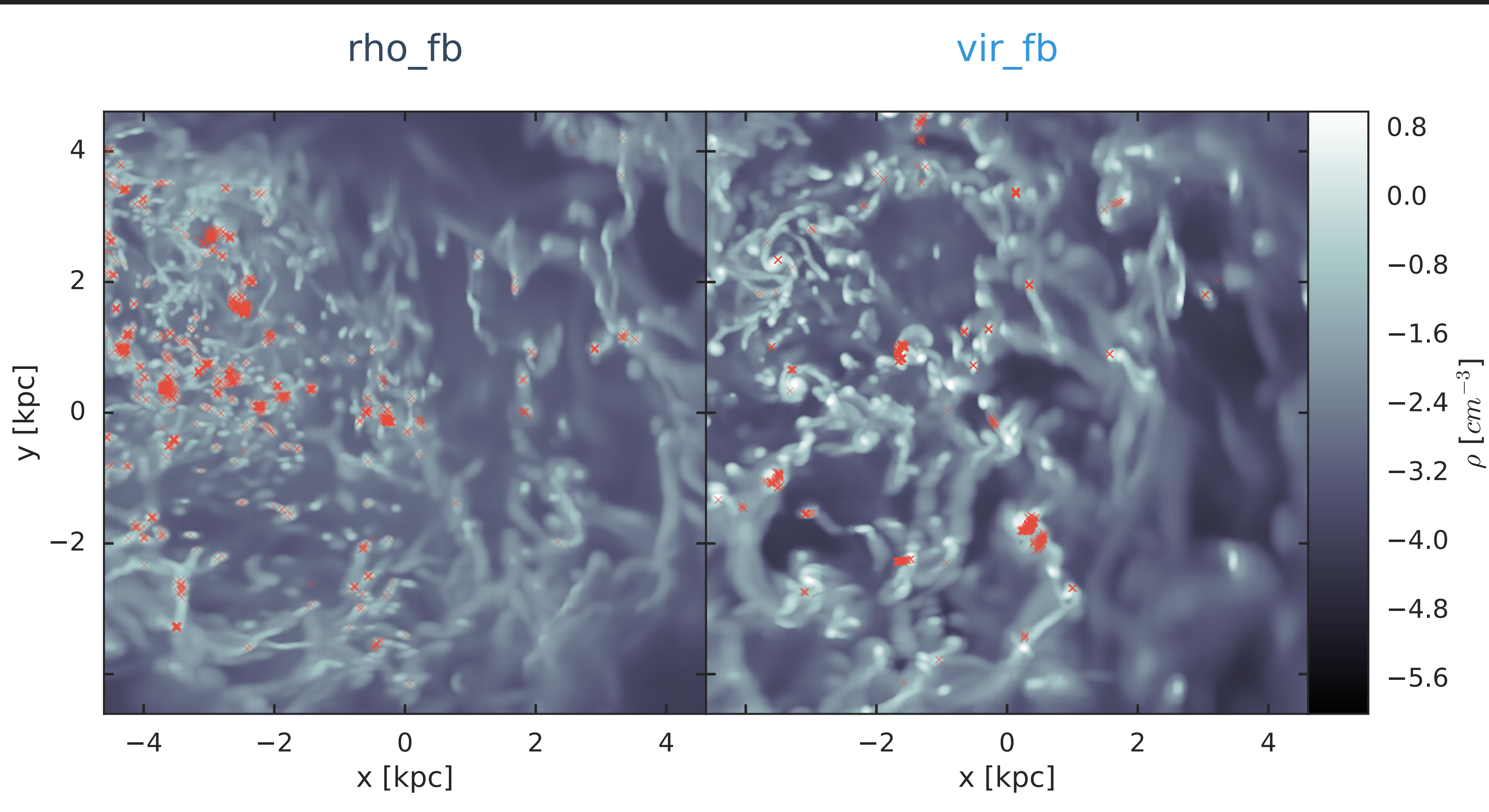
$\sigma_{\Sigma_{SFR}}=0.21$
 $\sigma_{\Sigma_{SFR}}=0.33$
 $\sigma_{\Sigma_{SFR}}=0.32$
 $\sigma_{\Sigma_{SFR}}=0.51$

$\sigma_{\Sigma_{SFR}}=0.22$
 $\sigma_{\Sigma_{SFR}}=0.50$
 $\sigma_{\Sigma_{SFR}}=0.30$
 $\sigma_{\Sigma_{SFR}}=0.64$

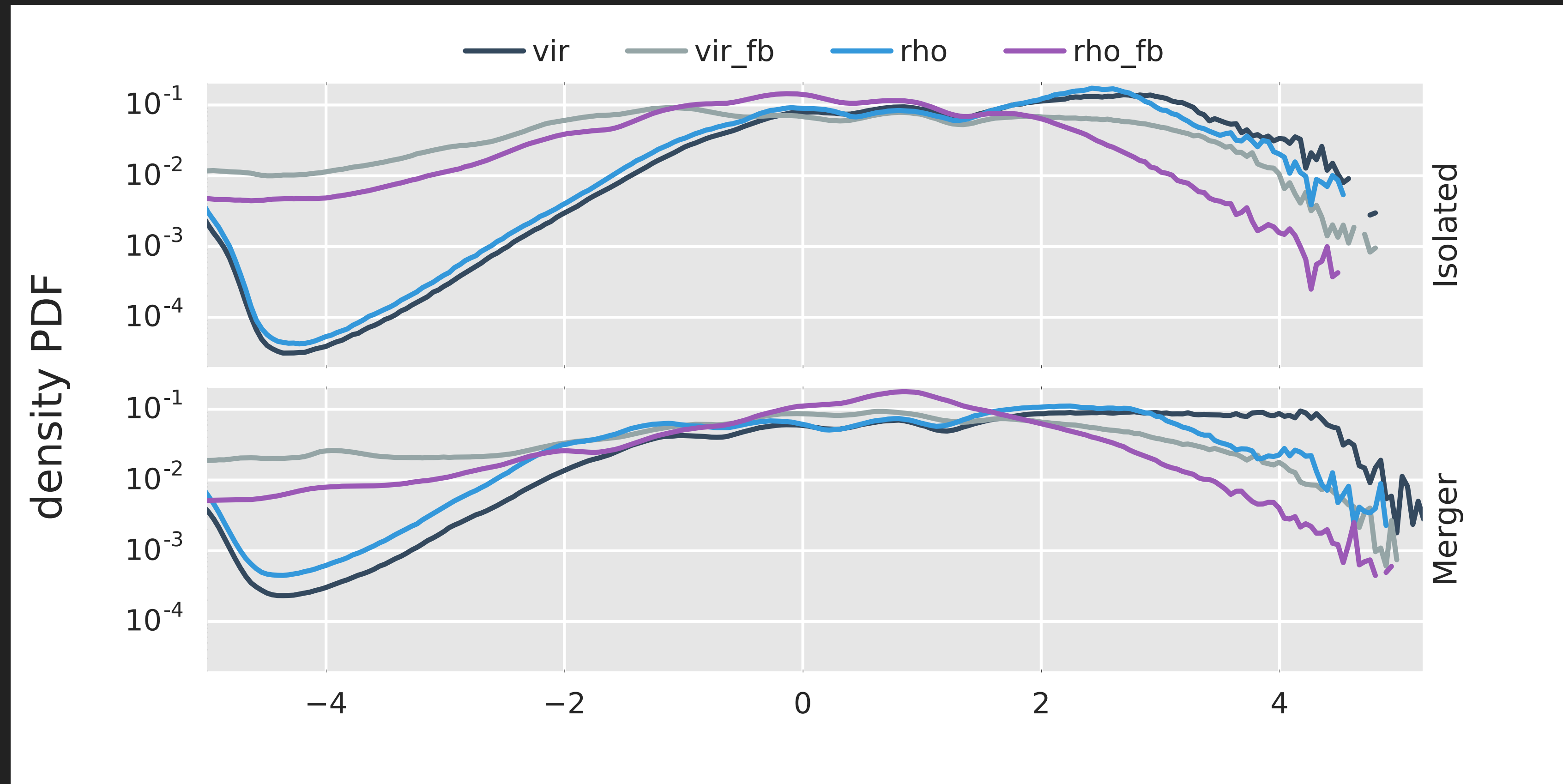
WHERE ARE BORN THE STARS?



WHERE ARE BORN THE STARS?



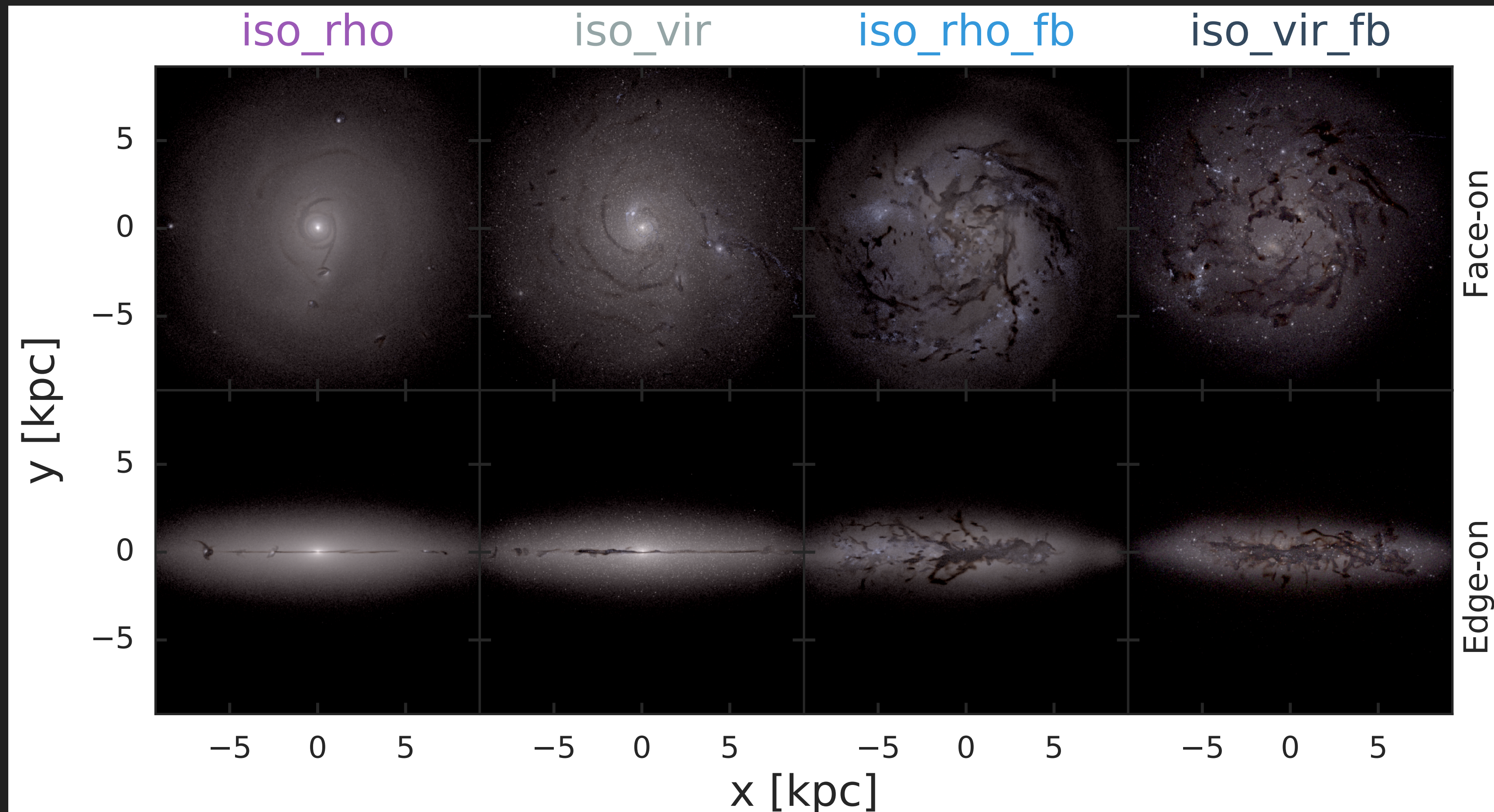
IMPACT ON GAS PDF



Average gas PDF $400 < t < 500$ Myr

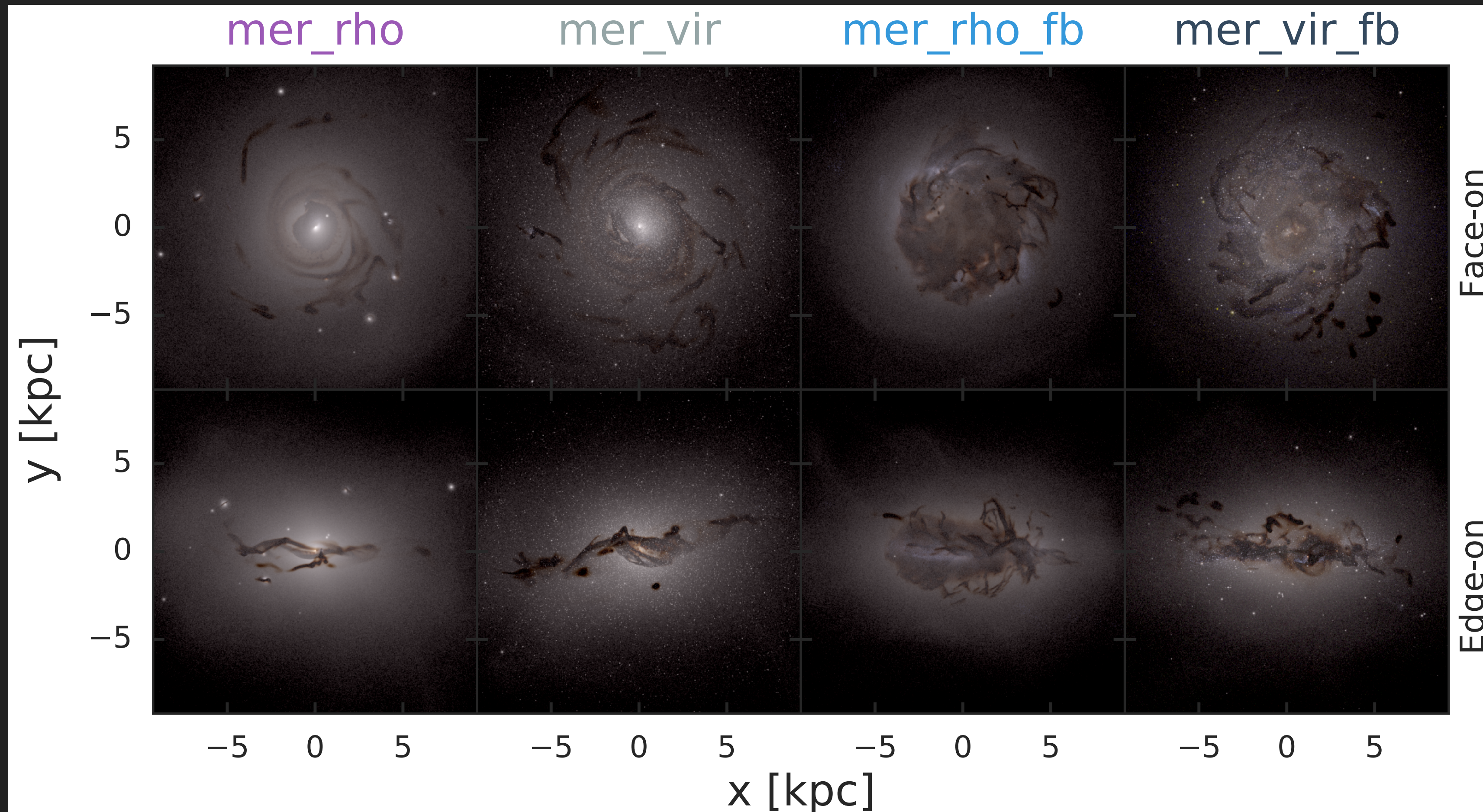
CLUSTERING OF SF FROM RESOLVED TURBULENCE

Mock SDSS ugr @ t=1 Gyr

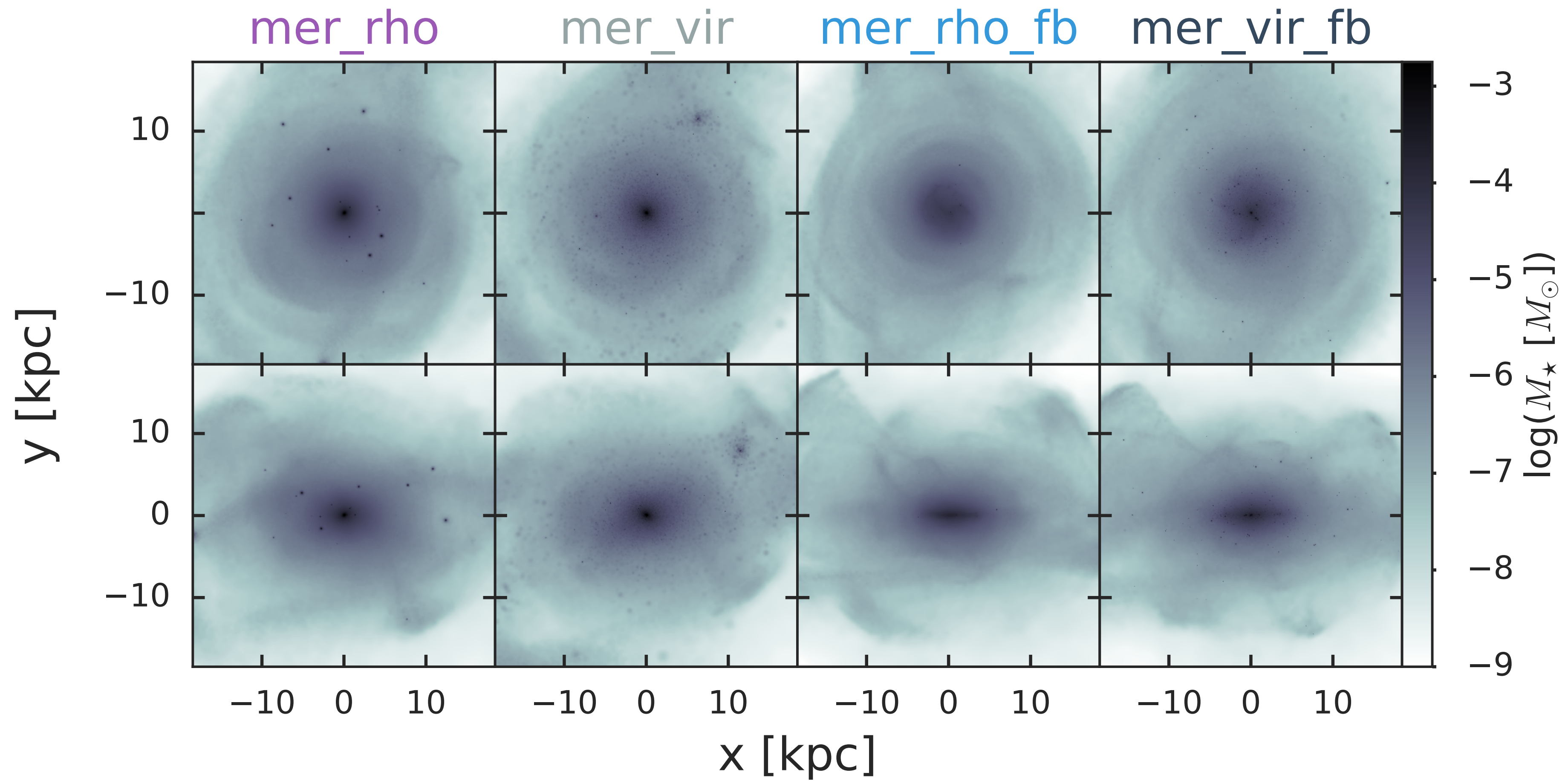


CLUSTERING OF SF FROM RESOLVED TURBULENCE

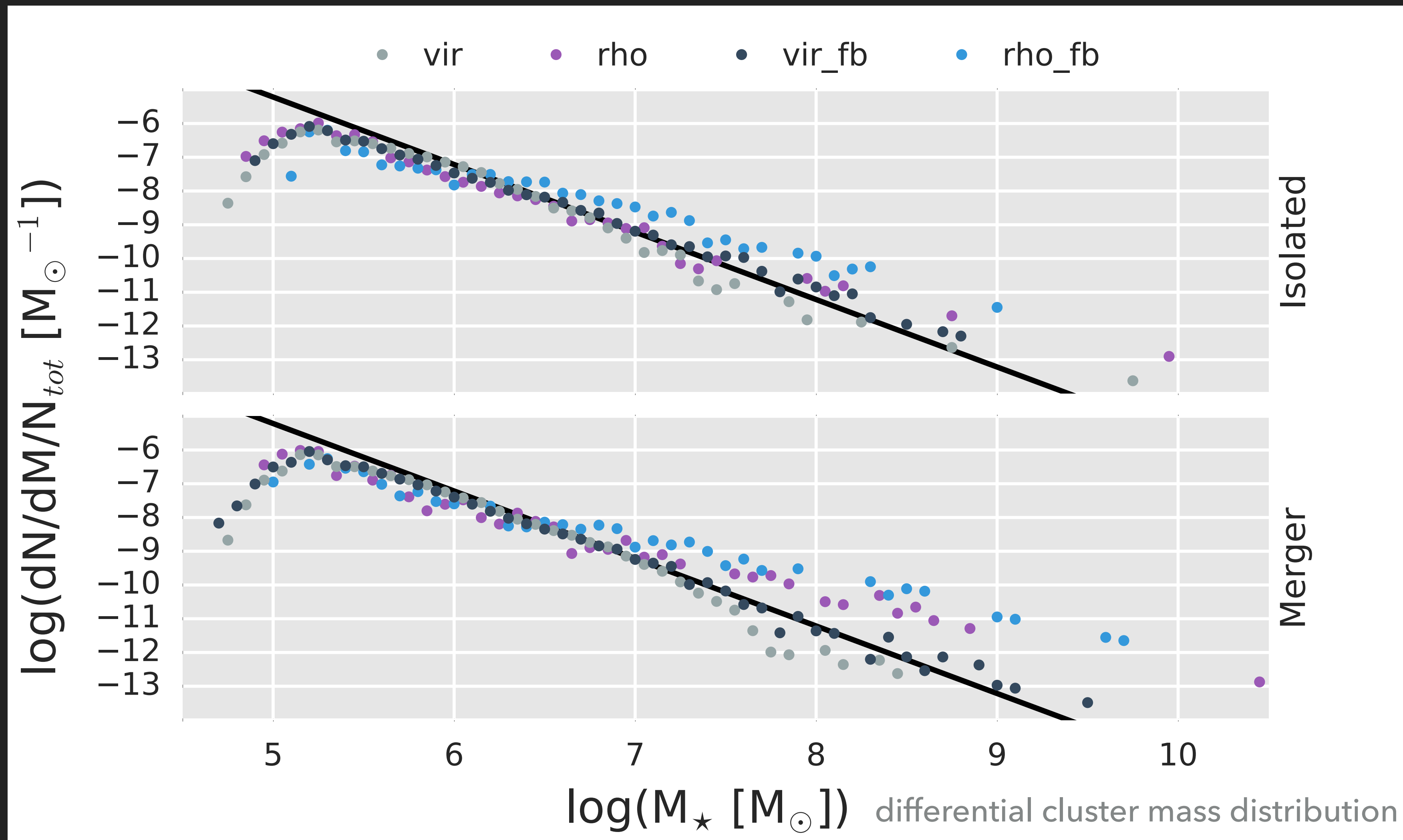
Mock SDSS ugr @ t=1 Gyr



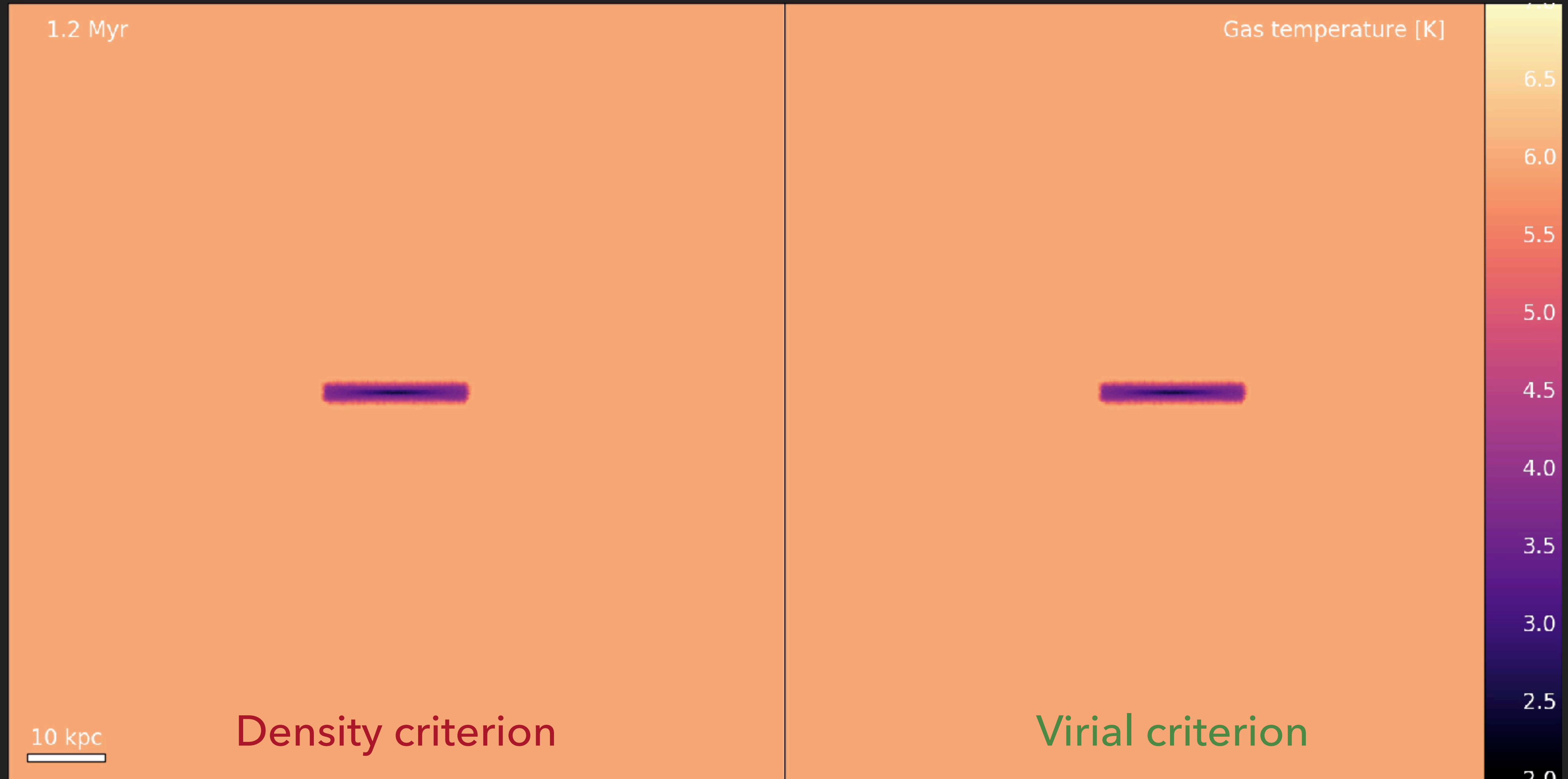
CLUSTERING OF SF FROM RESOLVED TURBULENCE



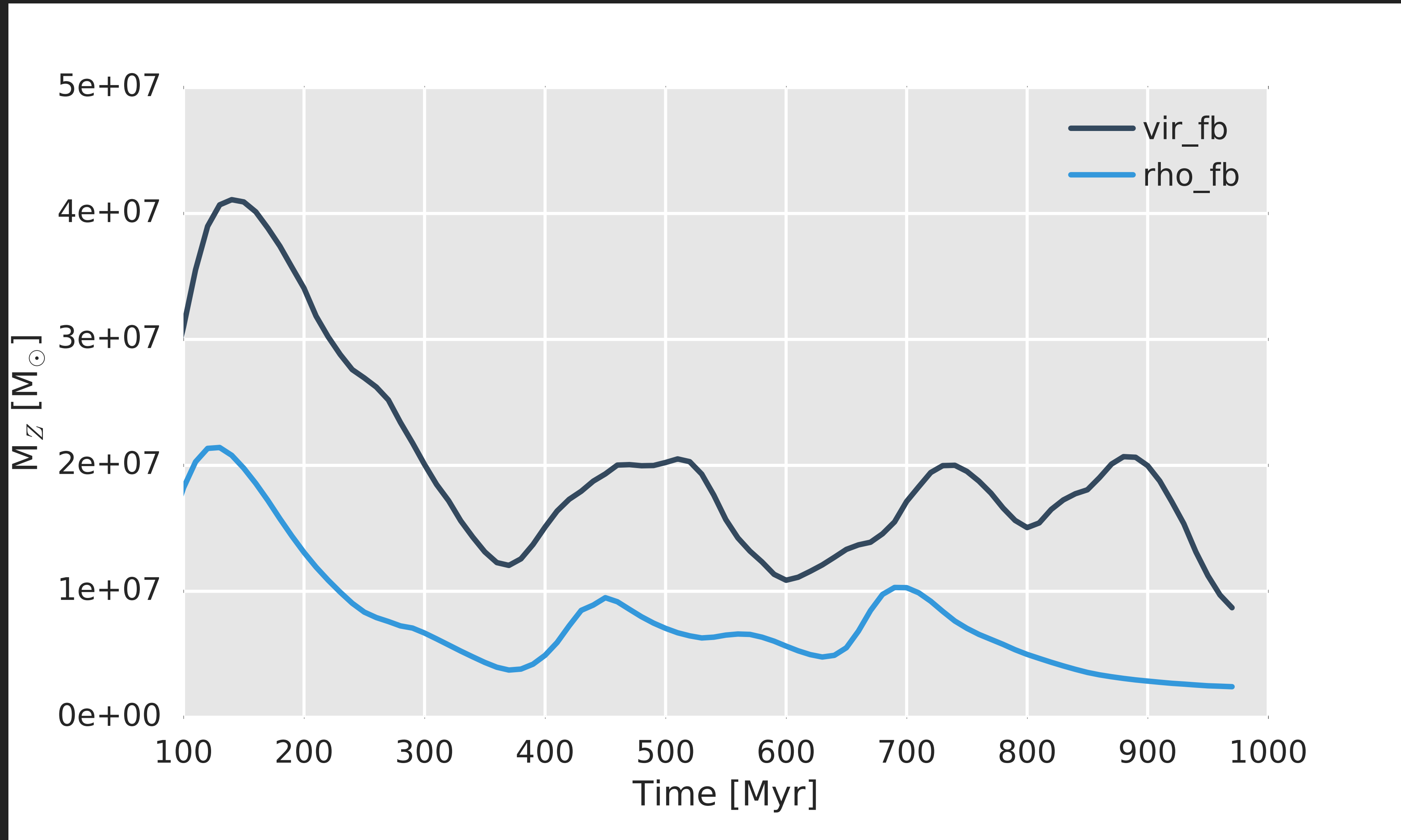
STAR CLUSTERS POPULATION



OUTFLOWS

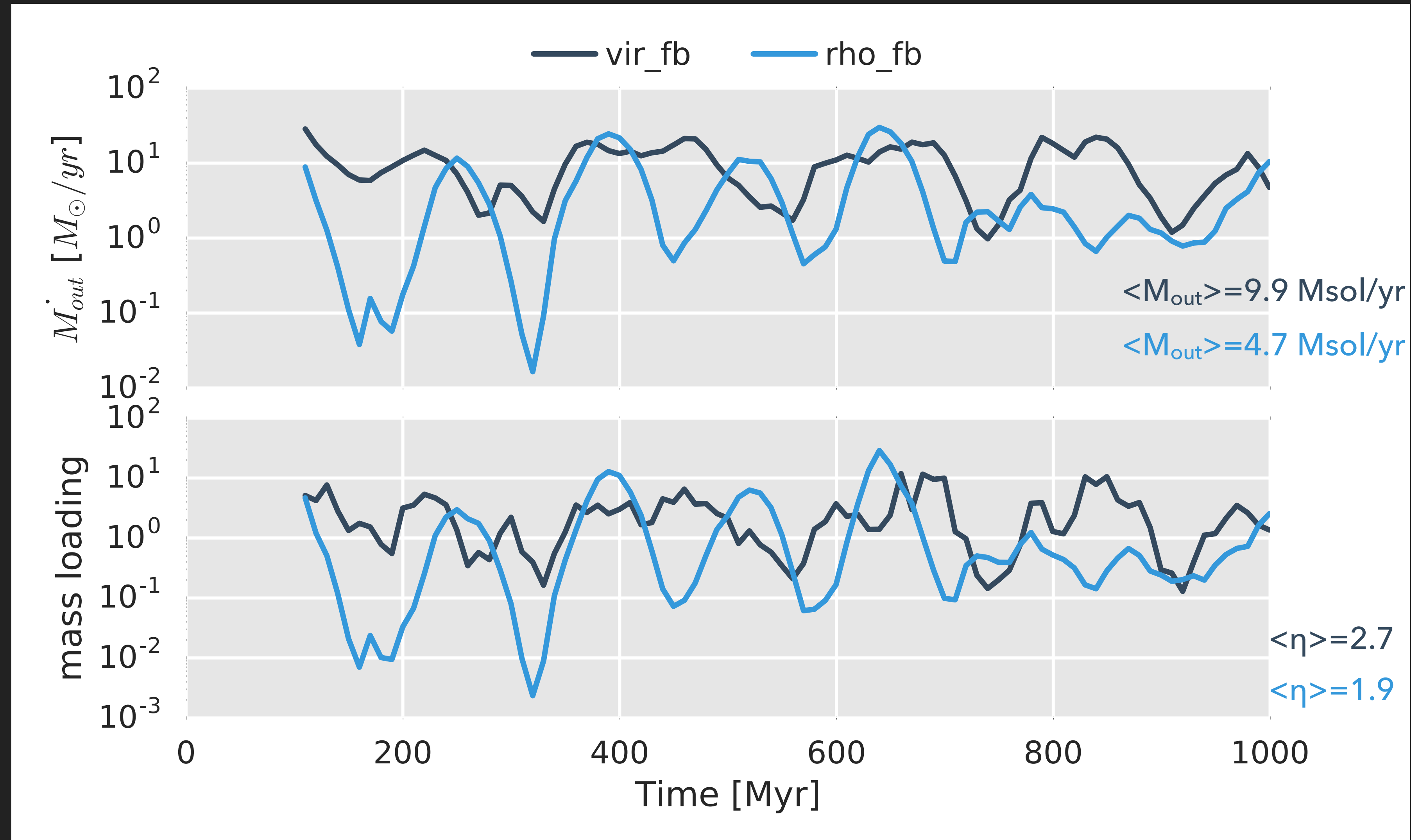


A MORE EFFICIENT CGM METAL ENRICHMENT



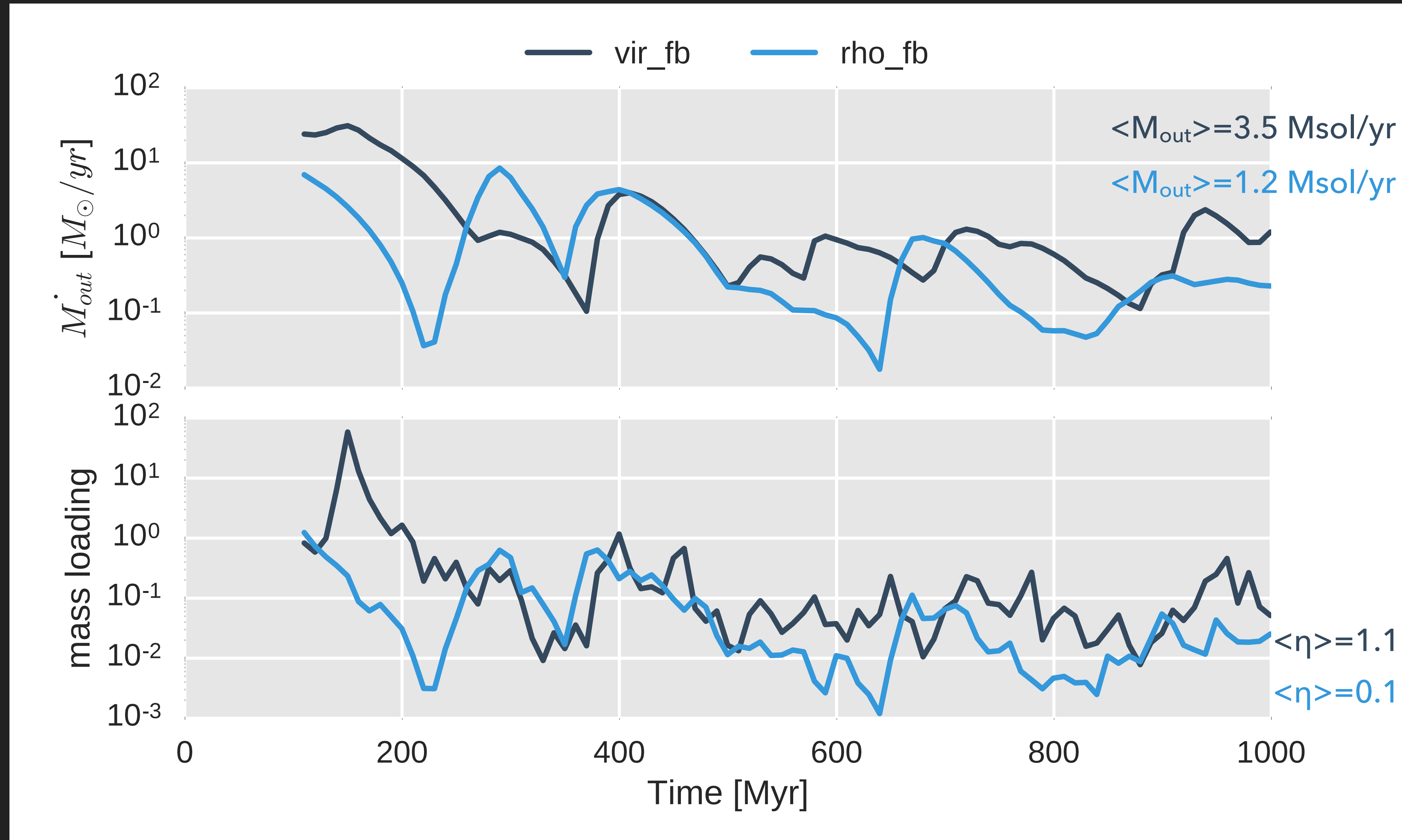
CONSEQUENCES FOR OUTFLOWS - ISOLATED

outflow rate @ $r=0.2 \cdot r_{\text{virial}}$



CONSEQUENCES FOR OUTFLOWS - MERGER

outflow rate @ $r=0.2 \cdot r_{\text{virial}}$

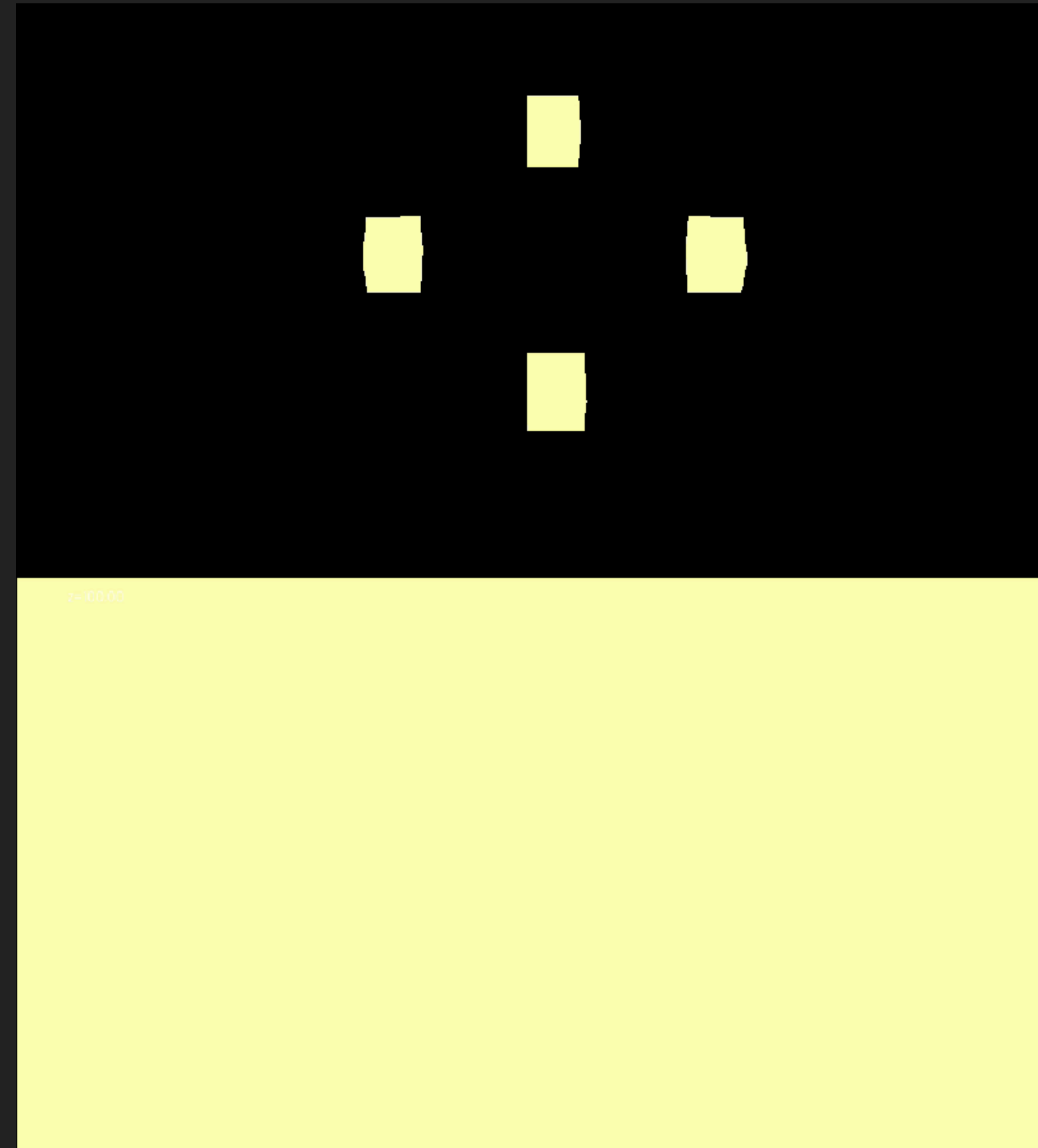


TAKE HOME MESSAGES – CONSEQUENCES OF A TURBULENT SF CRITERION

- ▶ Reproduces the KS without any tuning
- ▶ Increased SFH dispersion by a factor 5
- ▶ Creates a population of bound star clusters
- ▶ SF events are more rare hence more energetic
- ▶ Outflows mass loading 0.5 times higher in isolated disks
- ▶ Outflows mass loading 10 times higher in mergers
- ▶ CGM metal enrichment is ~ 2 times more efficient in isolated disks

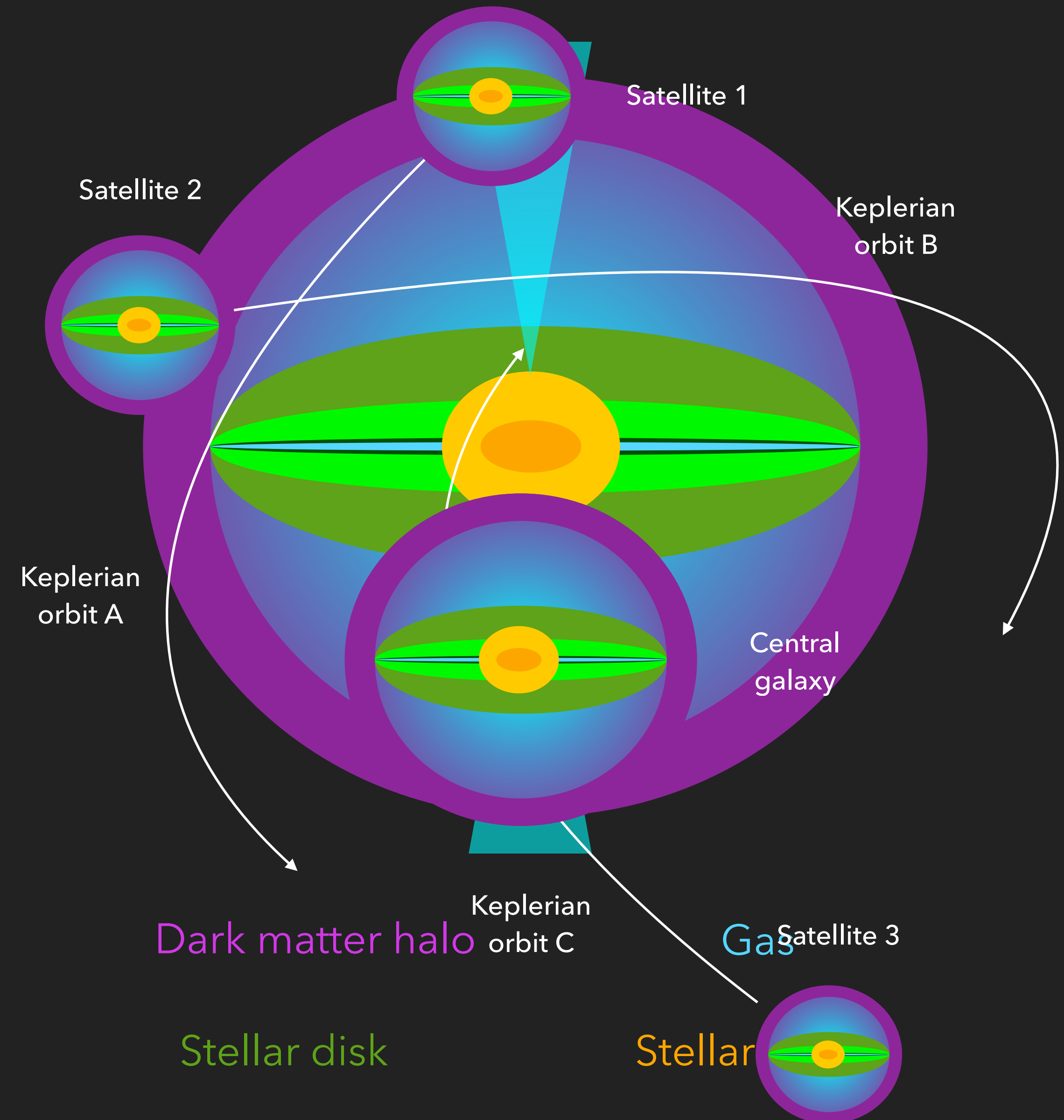
MOVIE.F90

- ▶ Some advanced camera parameters in Ramses!
- ▶ What's new:
 - ▶ Camera rotation
 - ▶ Perspective projection
 - ▶ Cubic shader
 - ▶ Focal plane



SIMULATION SETUP

- ▶ Why using an idealised environment?
 - ▶ Controlled experiments
 - ▶ High numerical resolution
 - ▶ Parameter space exploration
- ▶ **DICE 4.0** : multi-component/multi-galaxy approach
 - ▶ Complex & stable galaxy models
 - ▶ Merger / Galaxy group / Cluster
 - ▶ Rotating thermalised gas halos (cooling haloes)
 - ▶ Cold free falling streams



DICE – KEY FEATURES

- ▶ ~100 parameters (to tweak) per component to reach physical & numerical stability
- ▶ Solve numerically Jeans equations in either 1D, 2D, 3D on an adaptive grid
- ▶ Spherical/Vertical hydrostatic equilibrium for a polytropic gas $P=K(r)*\rho^\Gamma$ with any potential shape
- ▶ Thermal equilibrium for any rotating gas distribution
- ▶ Initial turbulent velocity field in the gas
- ▶ Multiple galaxies on relative Keplerian orbits
- ▶ Warped/spiral/inclined disks
- ▶ Magnetised toroidal/constant disks (dice patch thanks to M. Rieder)

Atlassian, Inc.

Bitbucket Teams Projects Repositories Snippets

Find a repository...

Valentin Perret / DICE

Overview

SSH git@bitbucket.org:vperret/dice.git
Share

Last updated	2016-09-30	3	0
Language	C	Branches	Tags
Access level	Admin	0	8
		Forks	Watchers

[Send invitation](#)

Recent activity

- 1 commit**
Pushed to vperret/dice
76068c3 Correct component rotation
Valentin Perret · 4 days ago
- 1 commit**
Pushed to vperret/dice
9908385 Bug hunting
Valentin Perret · 2016-09-28
- be18460**
Commit commented on in vperret/dice
Valentin Perret · 2016-09-28
- 2 commits**
Pushed to vperret/dice
8be0a9e Merge branch 'master' of ssh://bit...
be18460 Bug hunting
Valentin Perret · 2016-09-28
- 1 commit**
Pushed to vperret/dice
69bad95 dice_init.c edited online with Bitbu...
Valentin Perret · 2016-09-28

[Edit README](#)

This is the DICE bitbucket repository.

DICE is an open source code modelling initial conditions of idealised galaxies to study their secular evolution, or to study more complex interactions such as mergers or compact groups using N-Body/hydro codes. The particularity of this code is its ability to setup a large number of components modelling distinct parts of the galaxy. The code creates 3D distributions of particles using a N-try MCMC algorithm which does not require a prior knowledge of the distribution function. The gravitational potential is then computed on a multi-level cartesian mesh by solving the poisson equation in the Fourier space. Finally, the dynamical equilibrium of each component is computed by integrating the Jeans equations for each particles. Several galaxies can be generated in a row and be placed on Keplerian orbits to model interactions. DICE writes the initial conditions in the **Gadget1** or **Gadget2** format and is fully compatible with [Ramses](#) thanks to a [patch](#) included in the public ramses distribution.

The user's guide is accessible [here](#).

Download the code by cloning the git repository using

```
$ git clone https://bitbucket.org/vperret/dice
```

Please register also to the [DICE google group](#).