RAMSES USER MEETING 2016

TURBULENT STAR FORMATION (& INITIAL CONDITIONS)

VALENTIN PERRET

R. TEYSSIER, J. DEVRIENDT, A. SLYZ

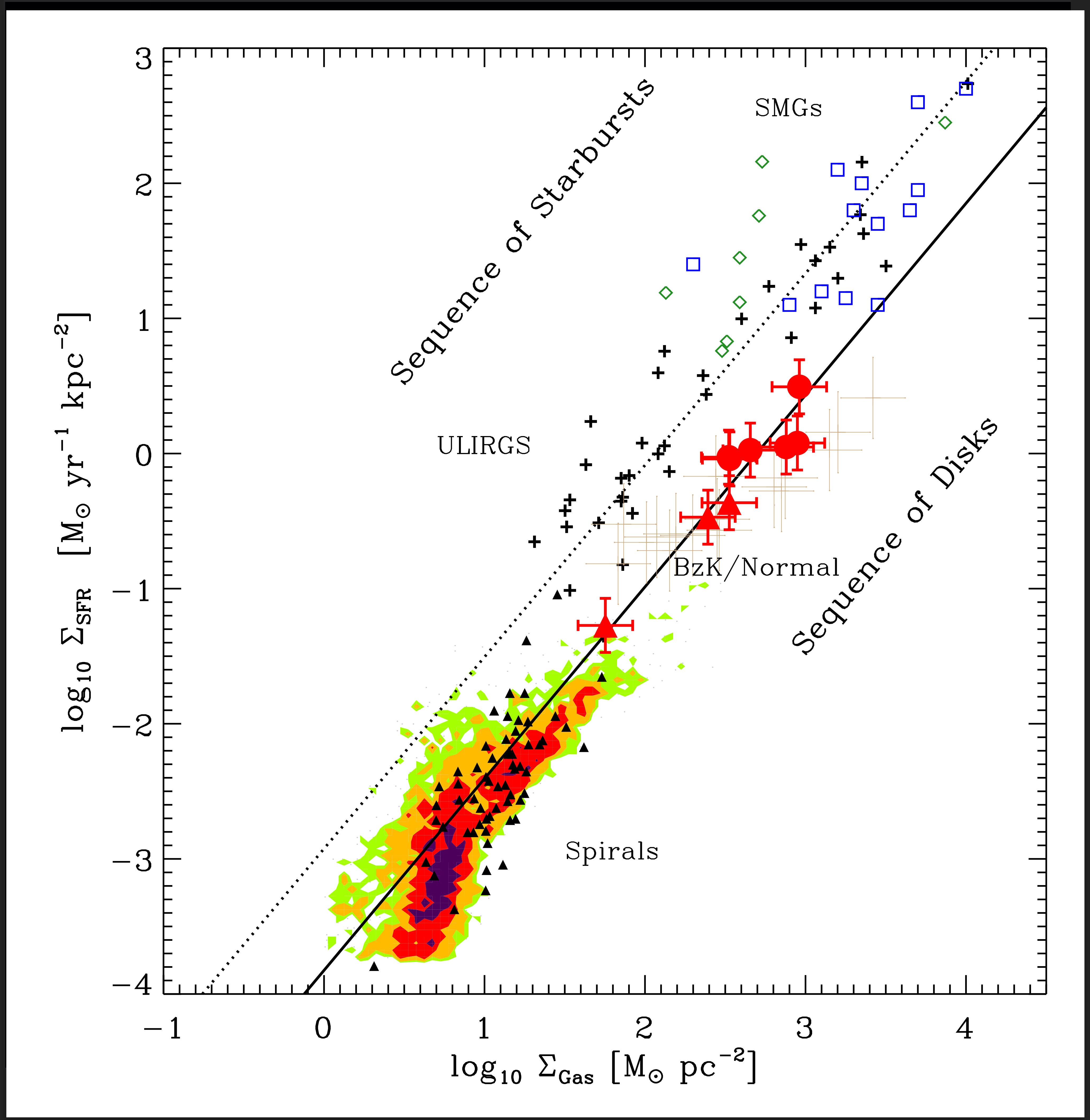
University of Zurich[UZH]

DIVERSITY OF SCALES

Dubois+2014

"CLASSICAL" STAR FORMATION CRITERION

- Local Schmidt law: $t_{ff} \propto 1/\sqrt{G\rho}$ $\dot{\rho}_\star \propto \rho/t_{ff} \propto \rho^{1.5}$
- 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:
  - ε~1%
  - ρ_0~100 cm^{-3} (resolution dependent)



Daddi et al. 2010

"VIRIAL" STAR FORMATION CRITERION

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

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

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

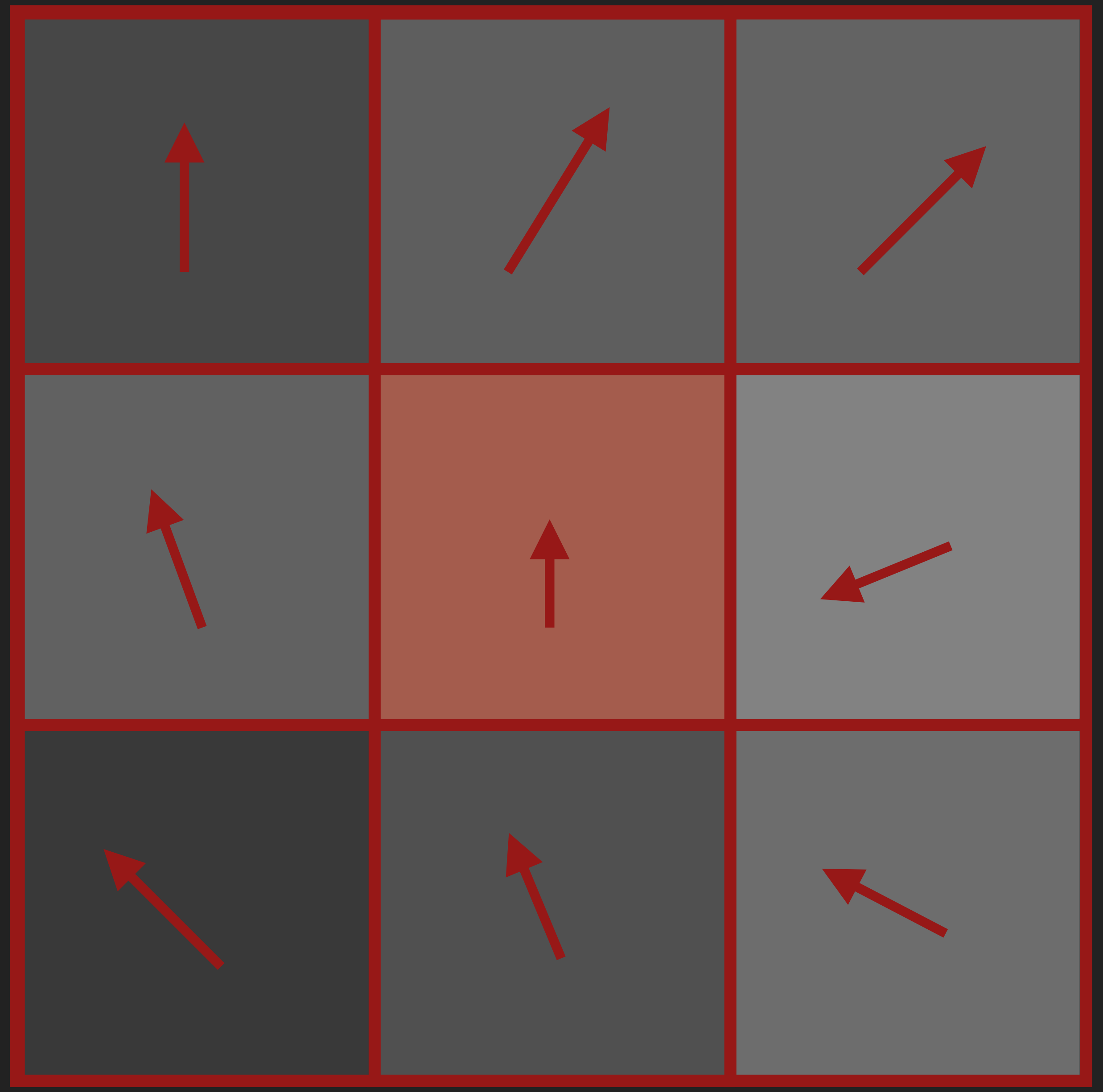
$$\alpha = \frac{-c_s^2 \Delta\rho/\rho + \sigma^2}{4\pi\rho G}$$

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

- 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

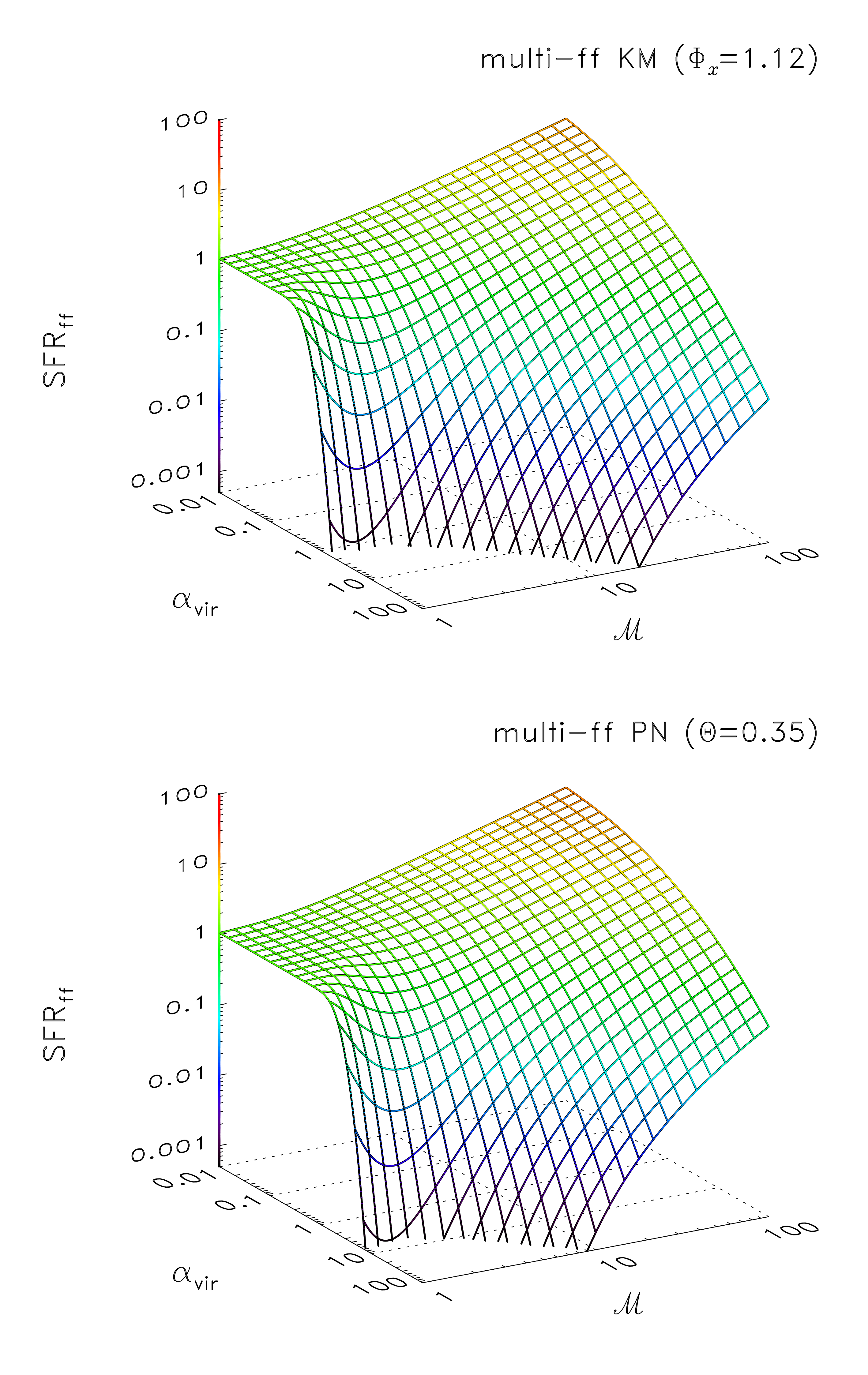


Density criterion
Virial criterion

$\nabla . v \quad \nabla \times v$

STAR_FORMATION.F90 (PULL REQUEST #200)

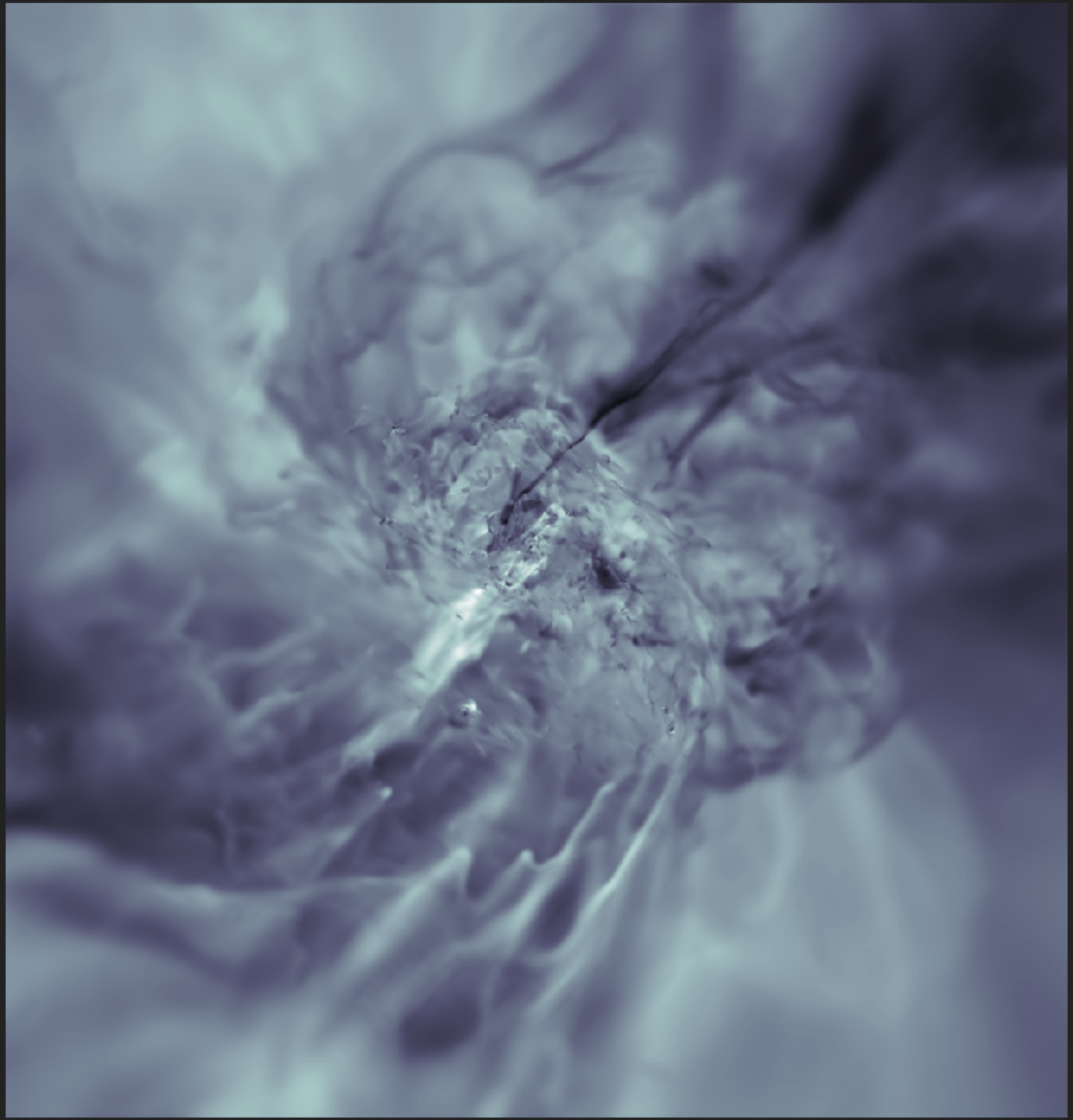
- sf_virial=.true. activates local Virial analysis
- 5 turbulent SF models available sf_model=
  - 1 : Multi-ff KM (Krumholz & McKee 2005)
  - 2 : Multi-ff PN (Padoan & Nordlund 2011)
  - 3 : Classical Virial parameter (ε=cste)
  - 4 : Padoan 2012 simple law ($\varepsilon \sim \exp(-1.6 t_{ff}/t_{dyn})$)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



Federrath & Klessen 2012

SIMULATION SETUP

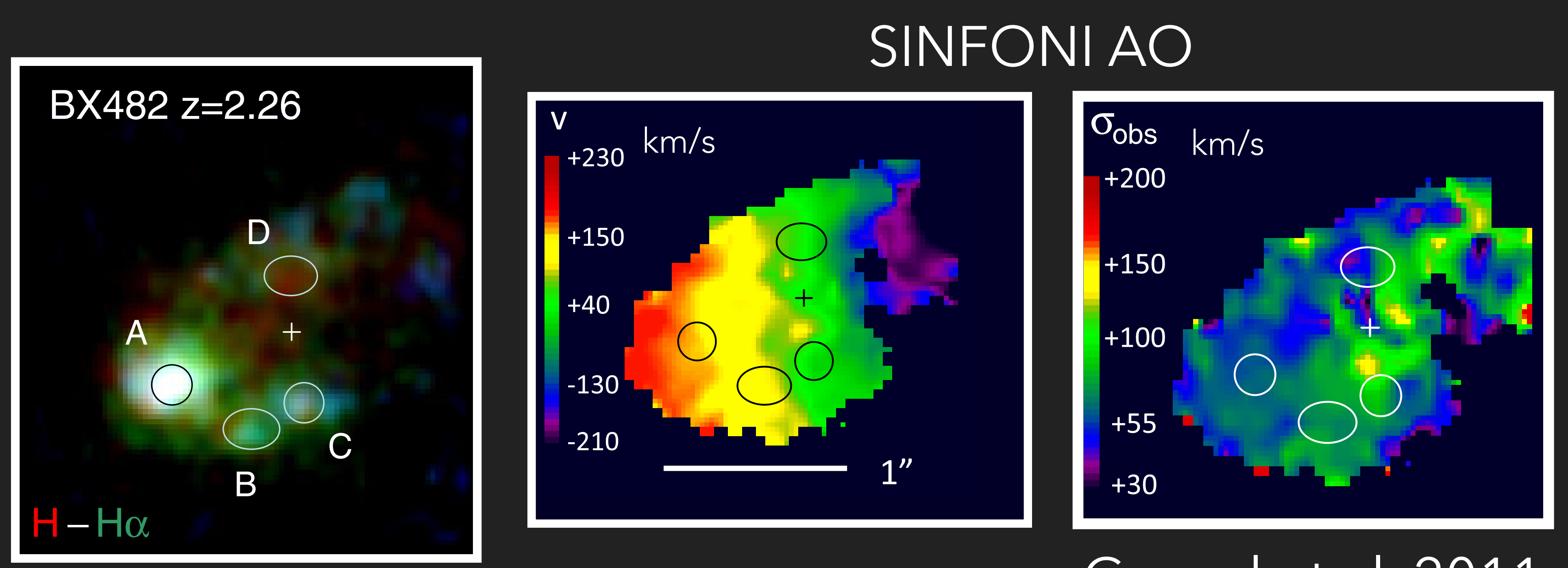
- RAMSES main parameters:
  - AMR box size = 150 kpc
  - Quasi-Lagrangian refinement scheme
    - Finest cells = 18 pc
  - Supernovae thermal feedback: $2{\times}10^{51}$ ergs / 10M⊙ → Turbulence modelled with a cooling switch t_{dissip}=20 Myr (Teyssier et al. 2013)
  - Metal cooling & metals advection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



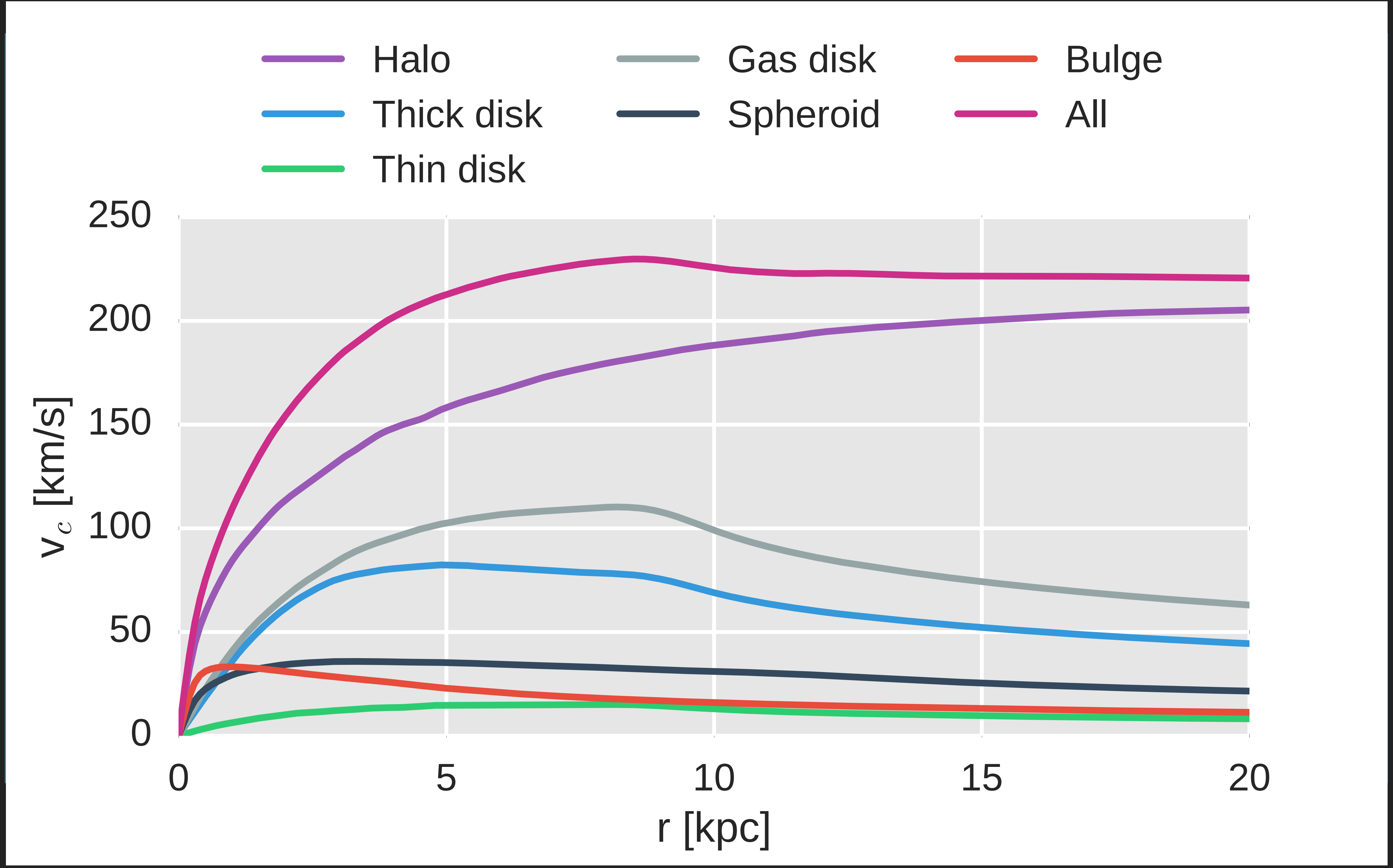
HIGH REDSHIFT DISK SETUP

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

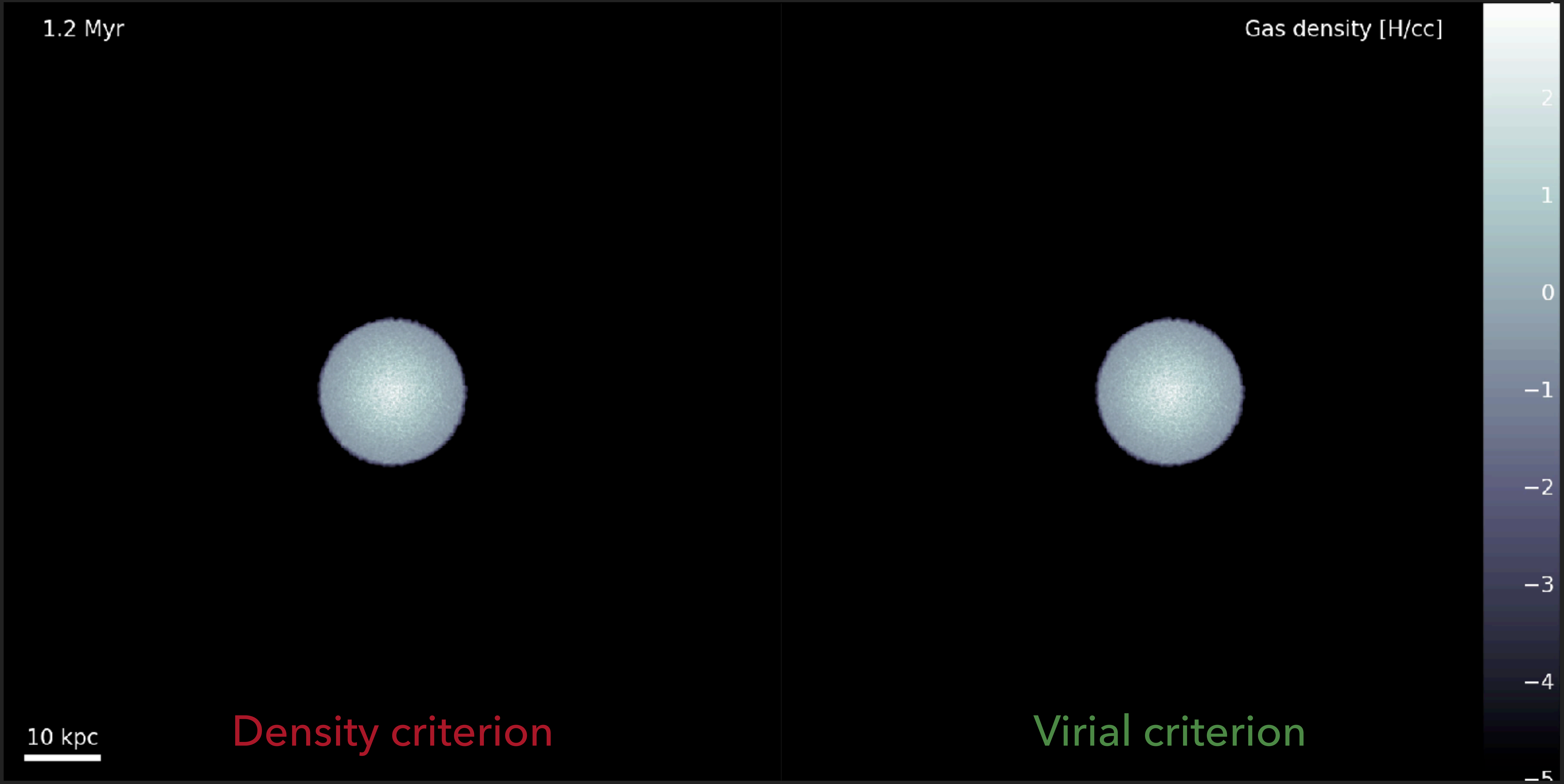
V_{200}	$M_{200,z=3}$	$R_{200,z=3}$	C_{NFW}	f_{gas}	B/D	$m_{part,DM}$	$m_{part,star}$	$m_{tot,star}$
200 km/s	5.9e11M⊙	63 kpc	5	61%	5%	1.5e5M⊙	5e3M⊙	1.1e10M⊙



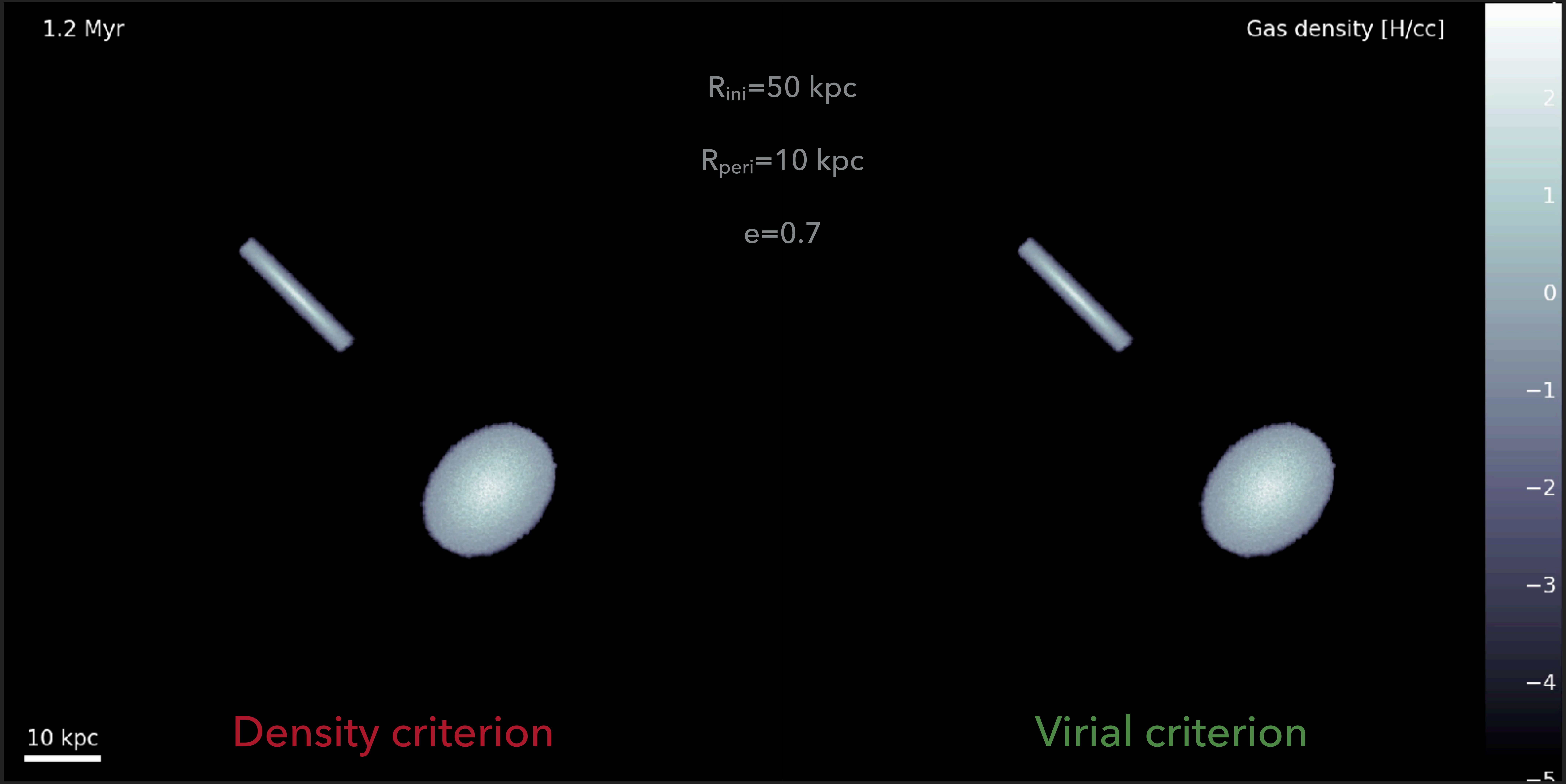
Genzel et al. 2011



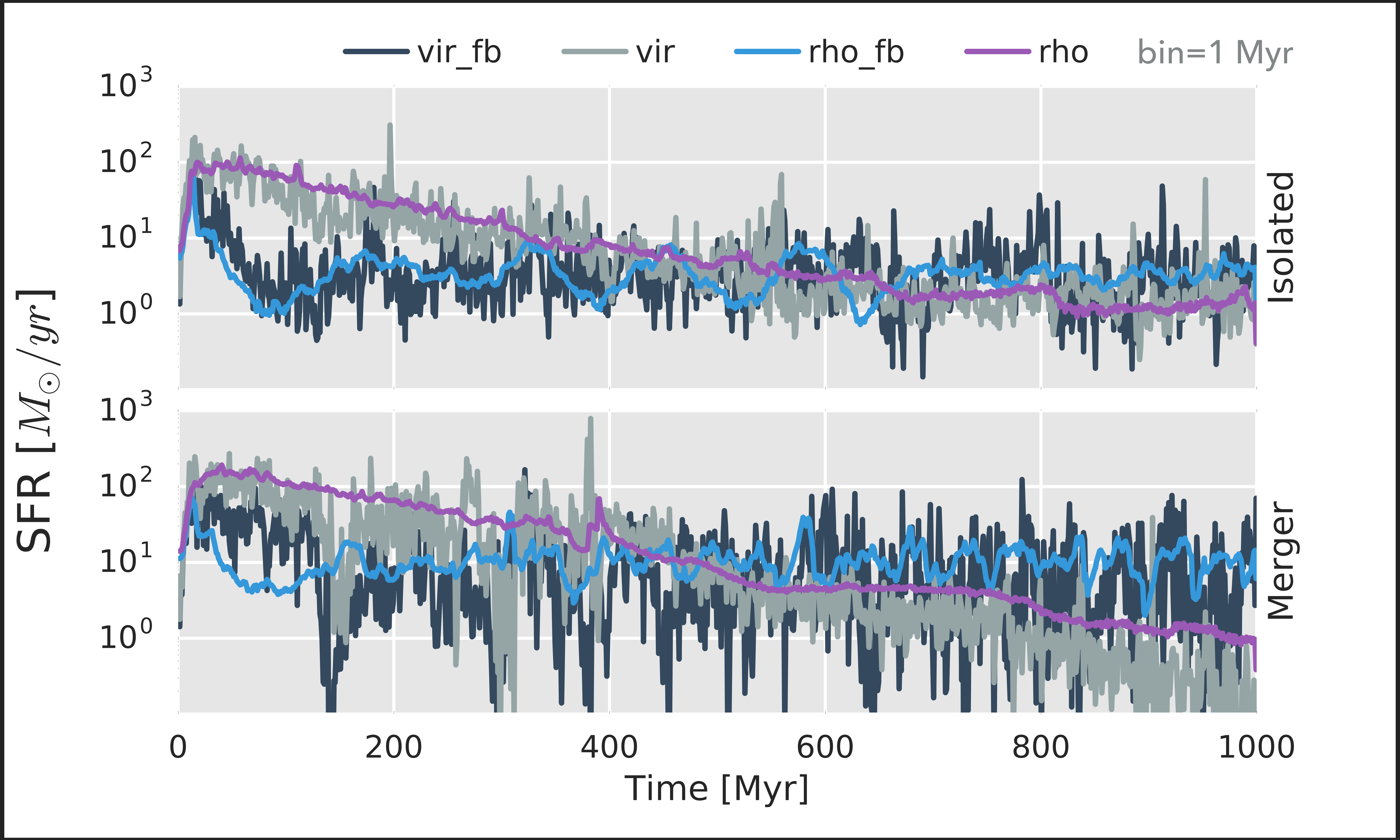
STELLAR FEEDBACK SIMULATIONS



MERGER STELLAR FEEDBACK SIMULATION



STAR FORMATION HISTORY



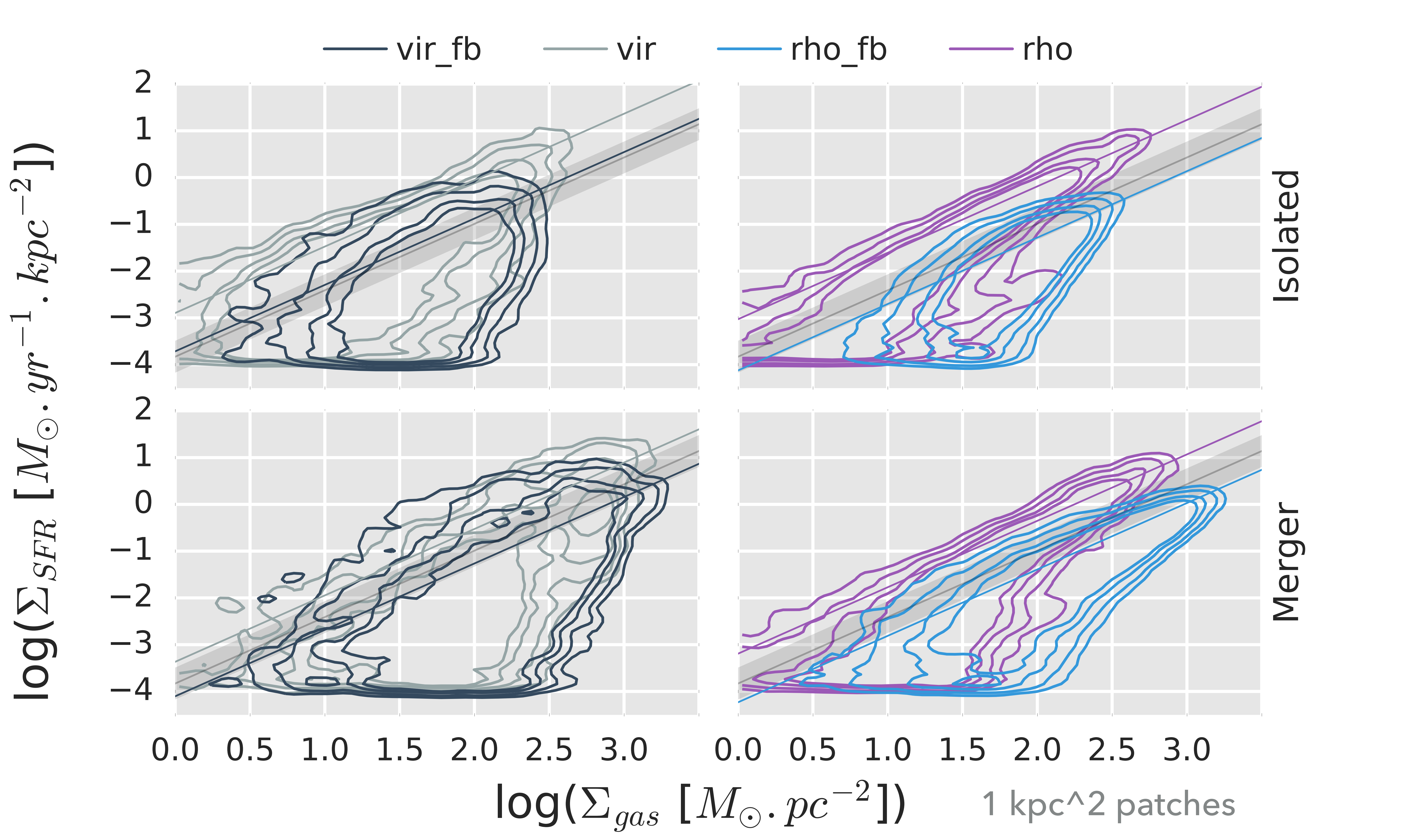
σ=0.09

σ=0.53

σ=0.13

σ=0.66

KENNICUTT-SCHMIDT RELATION

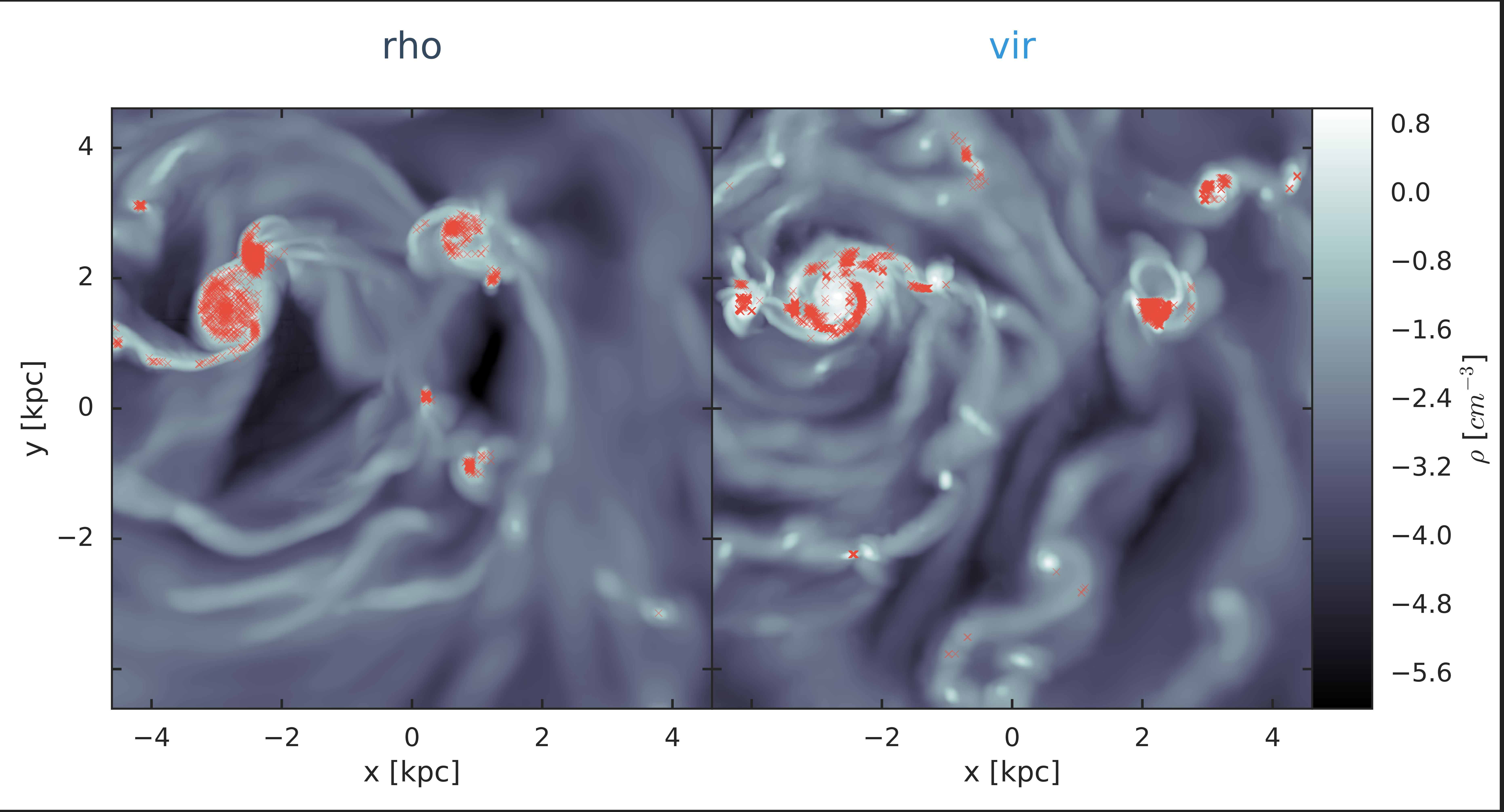


$\sigma_{\Sigma SFR}$=0.21
$\sigma_{\Sigma SFR}$=0.33
$\sigma_{\Sigma SFR}$=0.32
$\sigma_{\Sigma SFR}$=0.51

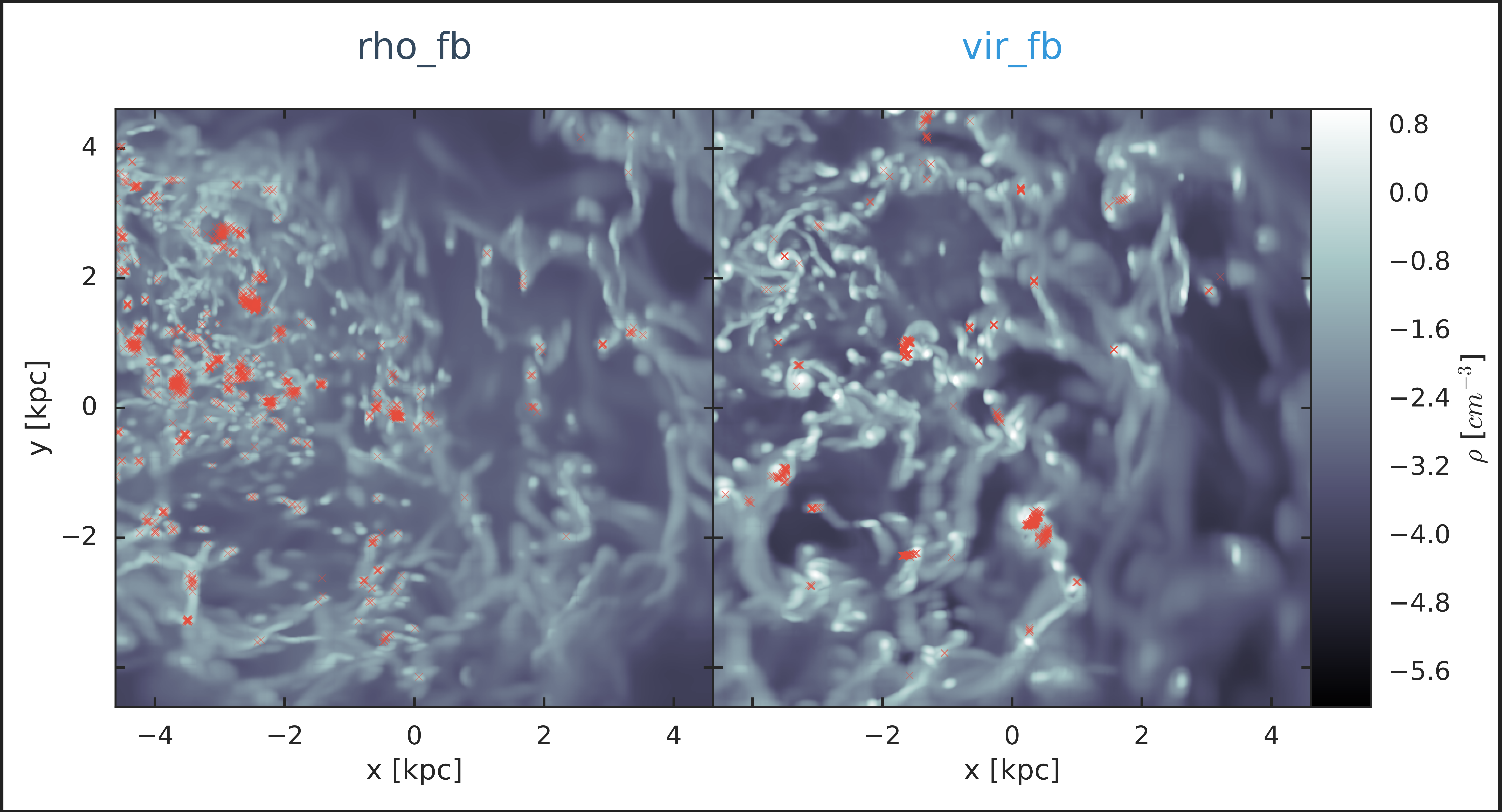
$\sigma_{\Sigma SFR}$=0.22
$\sigma_{\Sigma SFR}$=0.50
$\sigma_{\Sigma SFR}$=0.30
$\sigma_{\Sigma SFR}$=0.64

See the talk of Jeremy Fensch later!

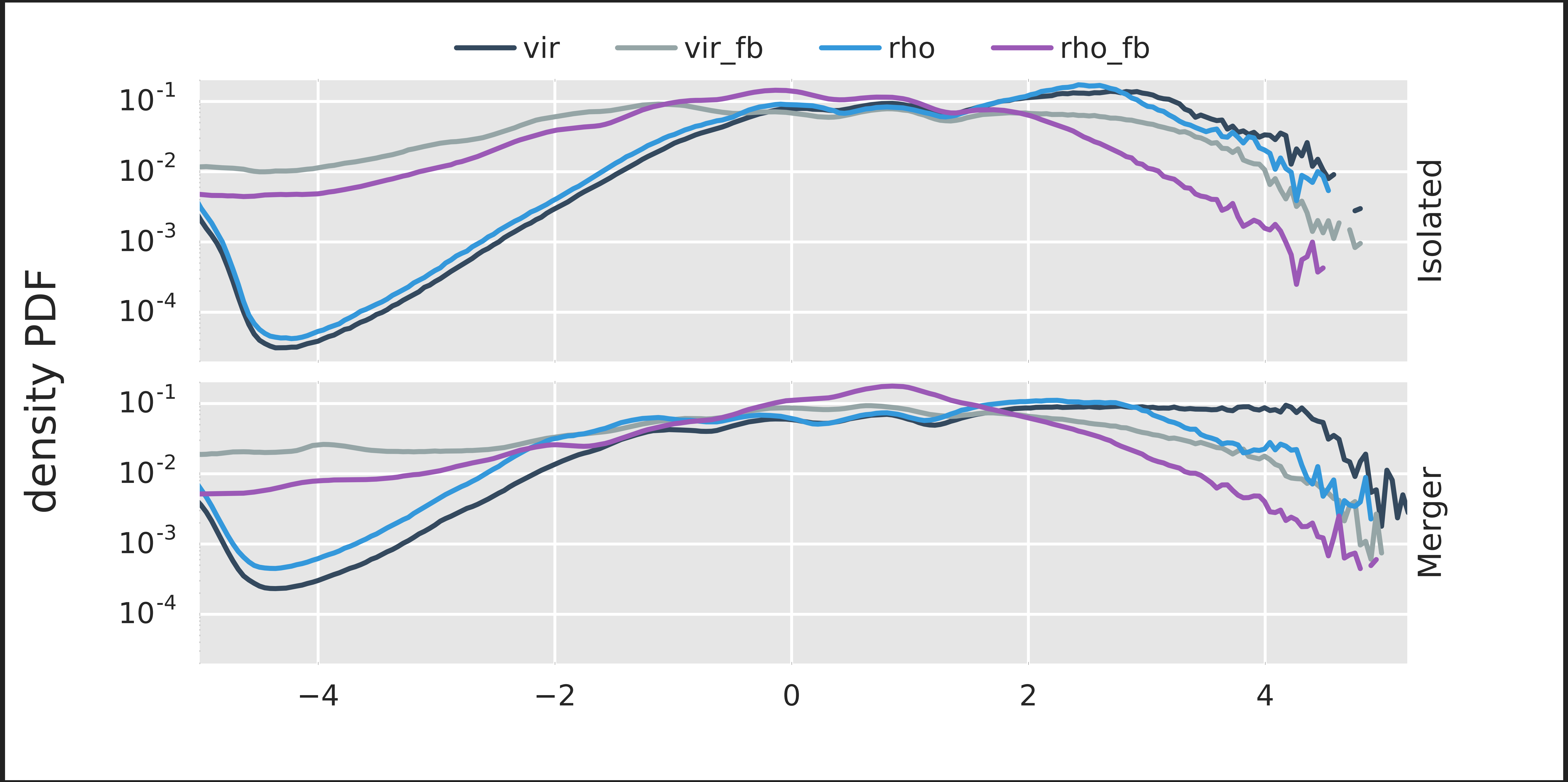
WHERE ARE BORN THE STARS?



WHERE ARE BORN THE STARS?



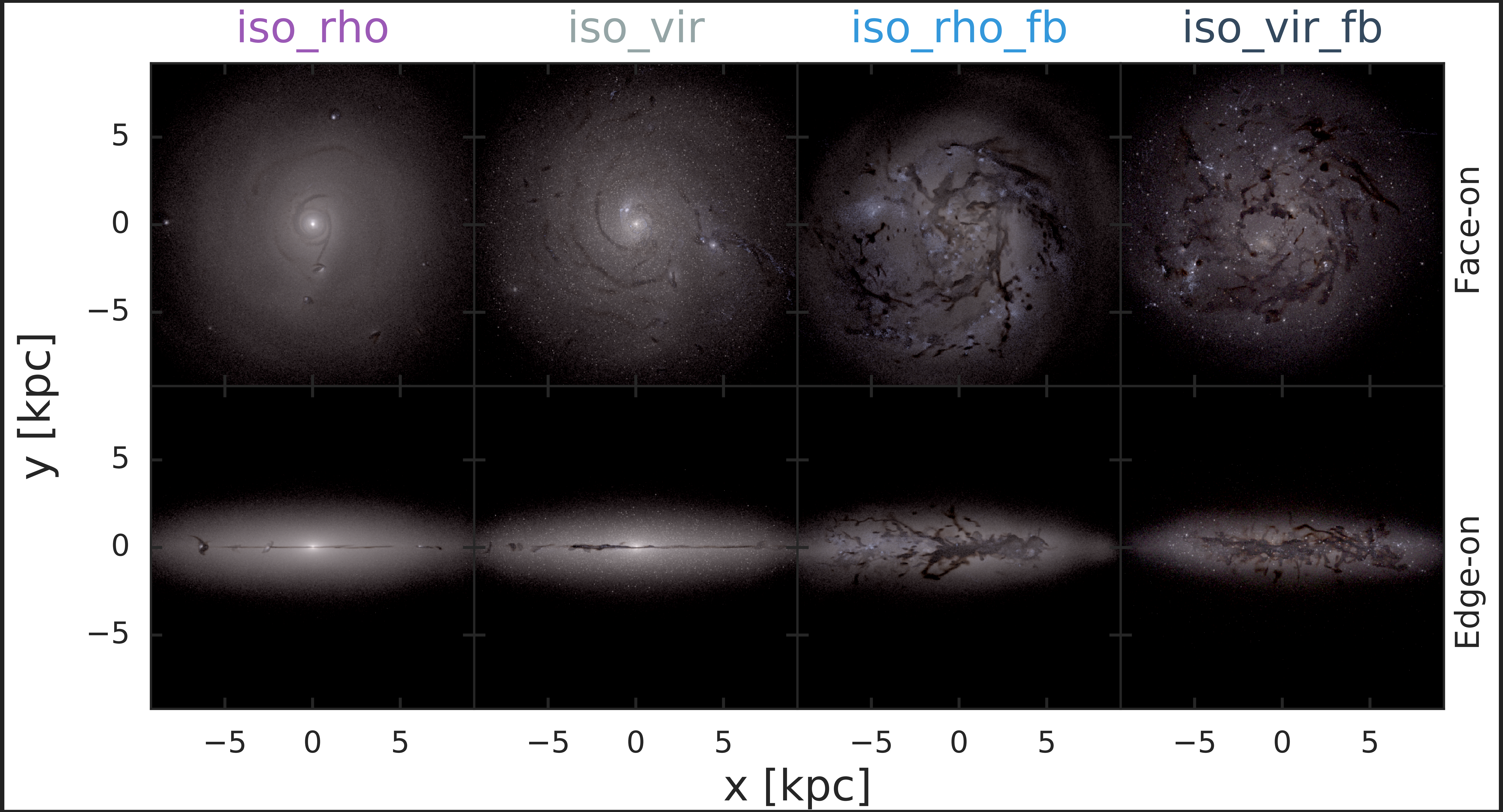
IMPACT ON GAS PDF



Average gas PDF 400<t<500 Myr

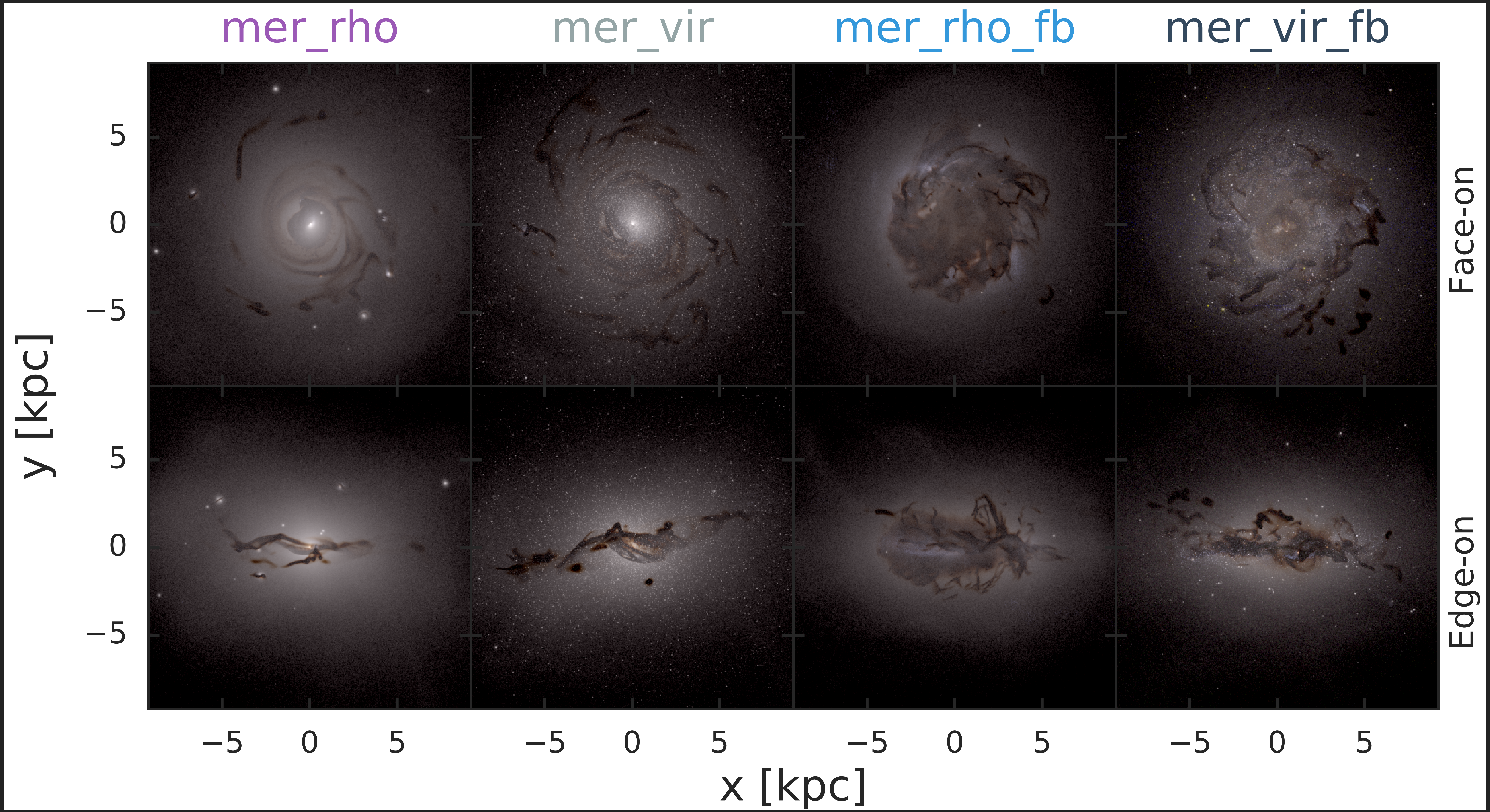
CLUSTERING OF SF FROM RESOLVED TURBULENCE

Mock SDSS ugr @ t=1 Gyr

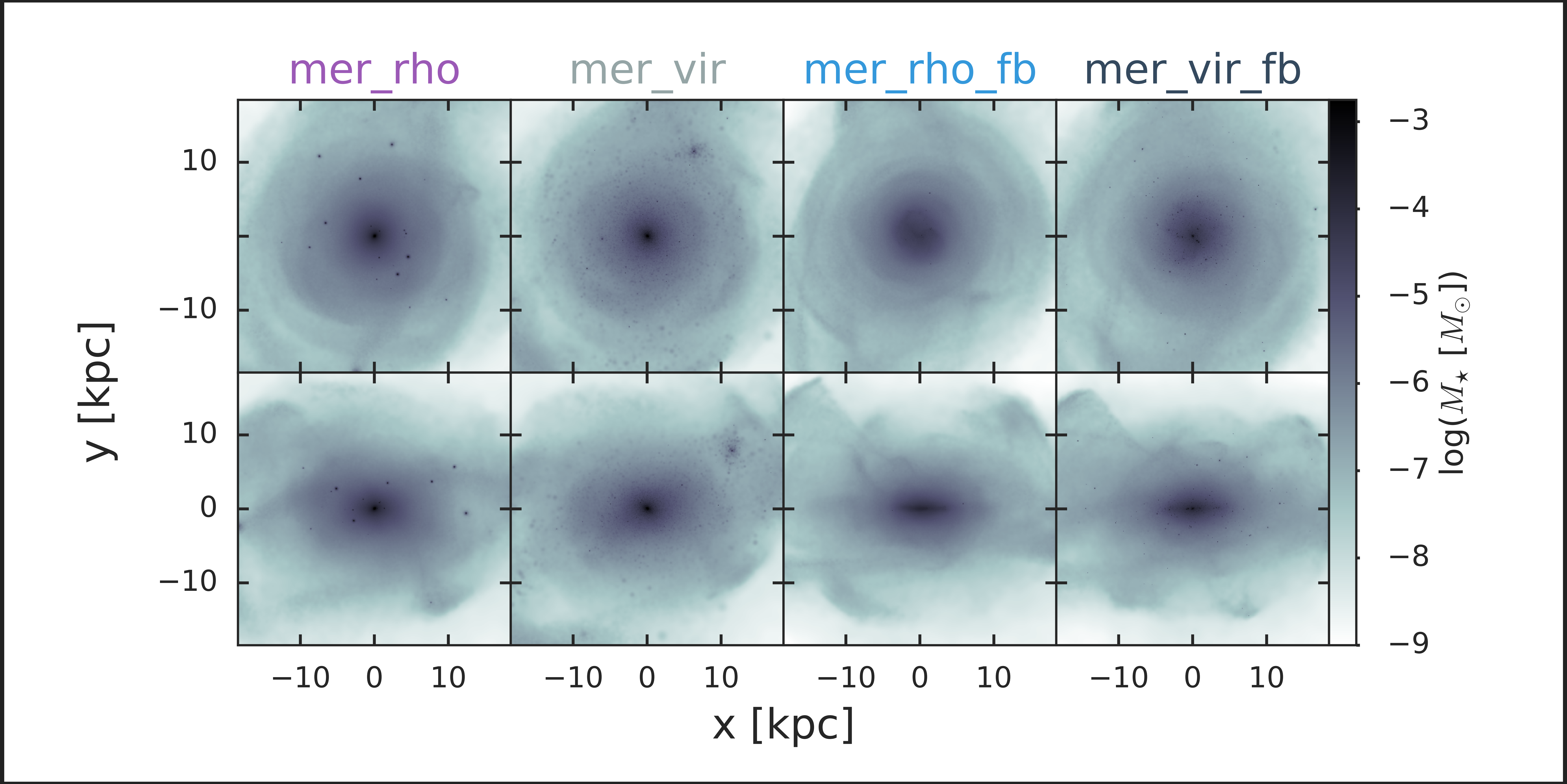


CLUSTERING OF SF FROM RESOLVED TURBULENCE

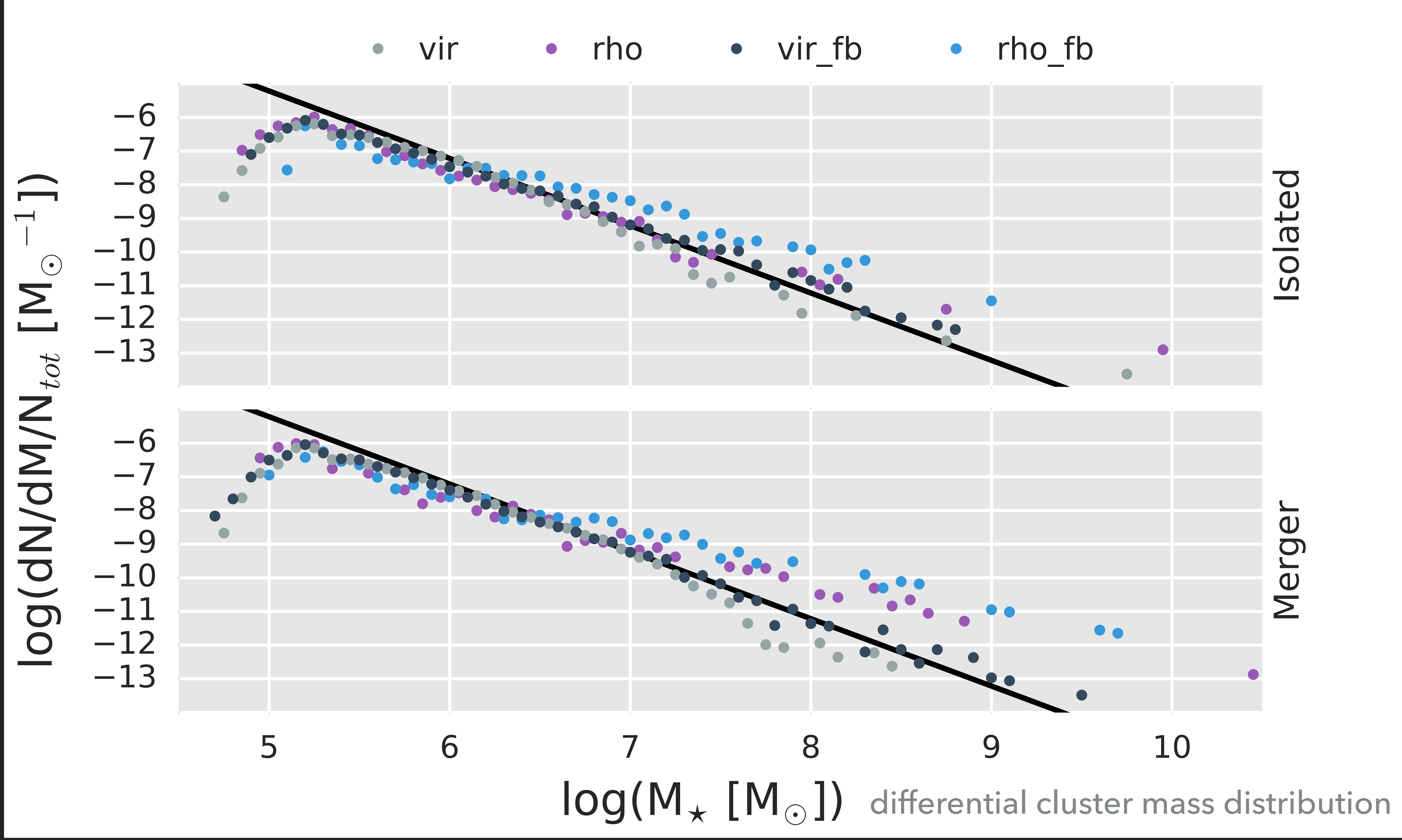
Mock SDSS ugr @ t=1 Gyr



CLUSTERING OF SF FROM RESOLVED TURBULENCE

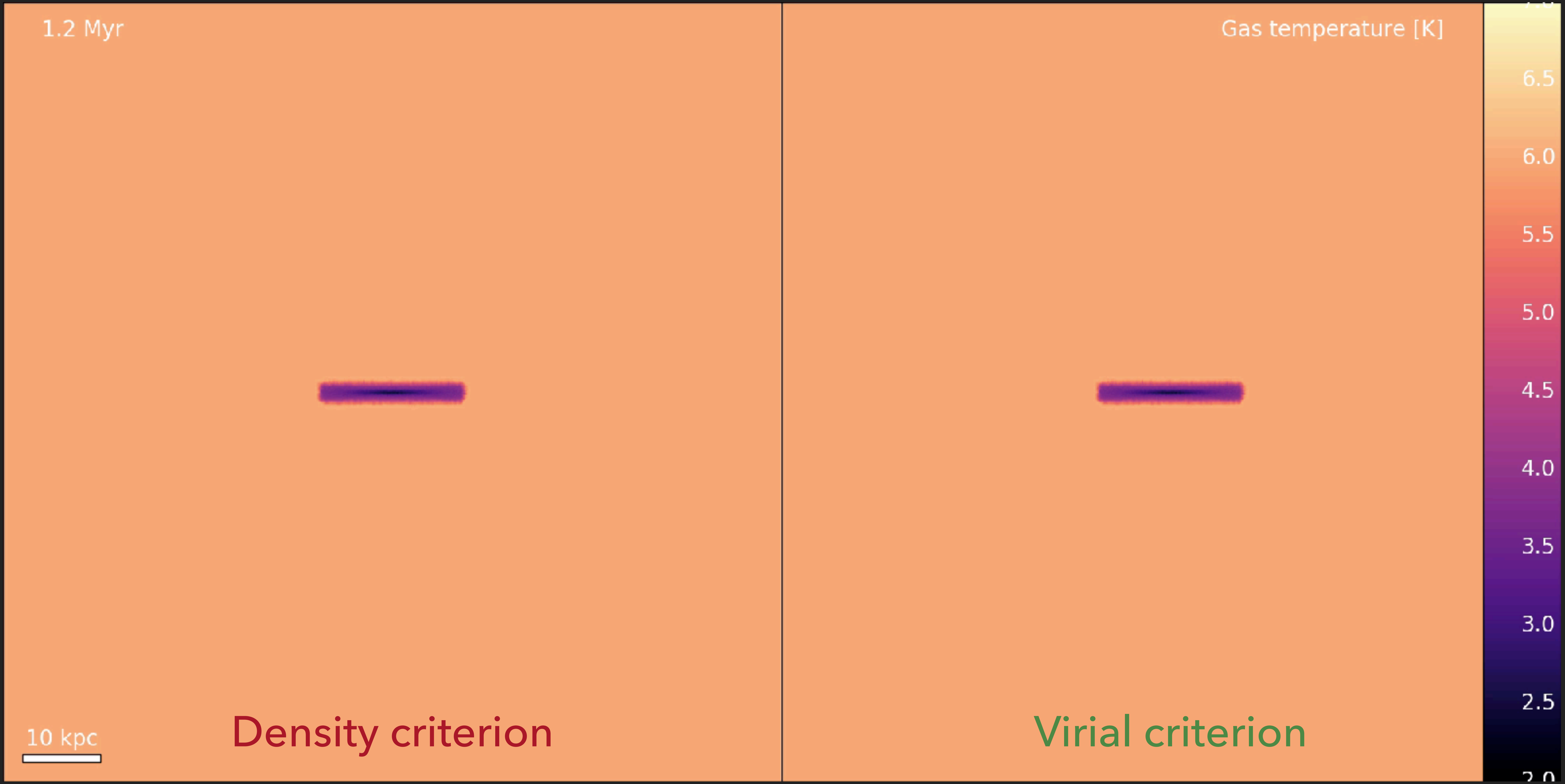


STAR CLUSTERS POPULATION

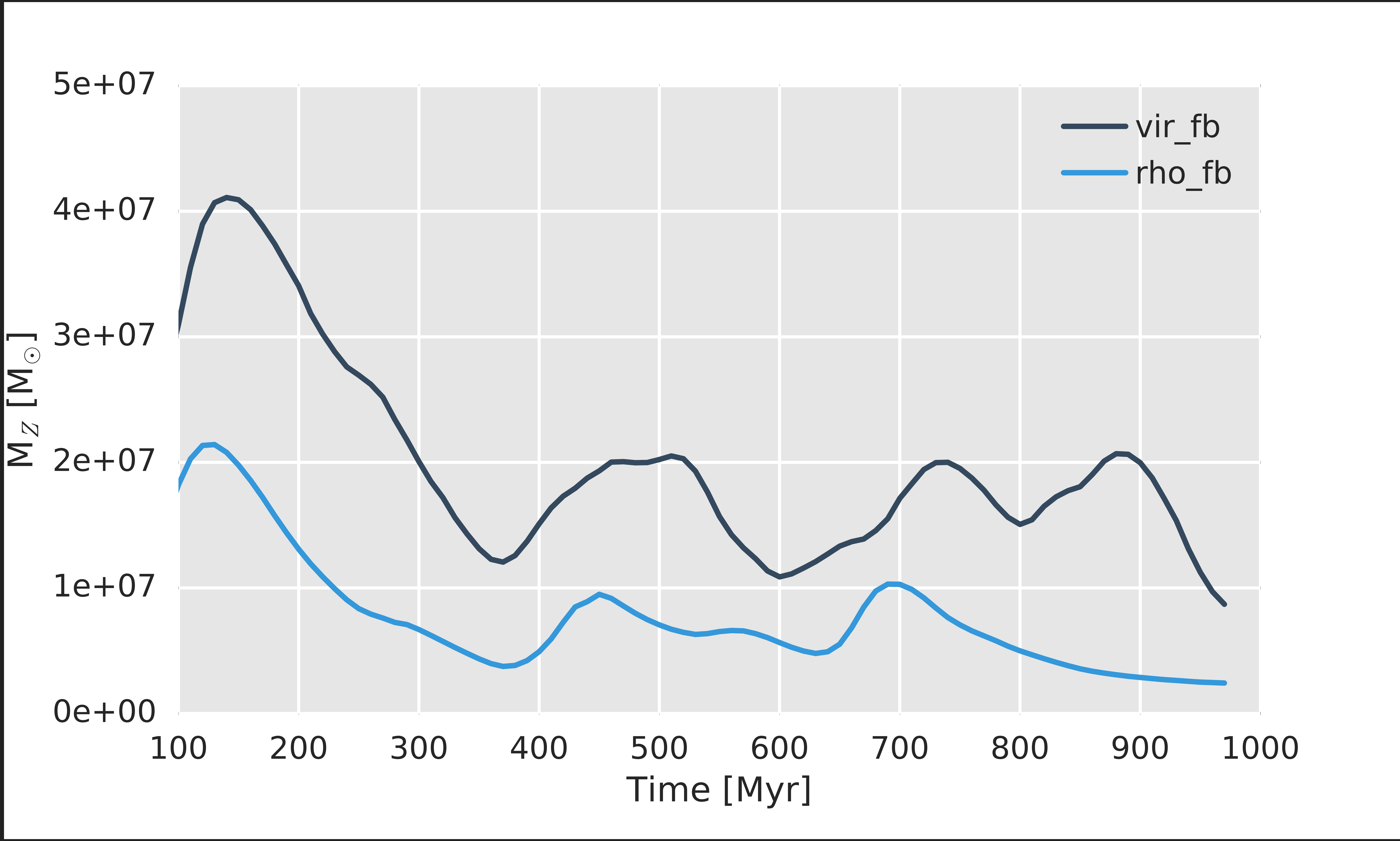


differential cluster mass distribution

OUTFLOWS

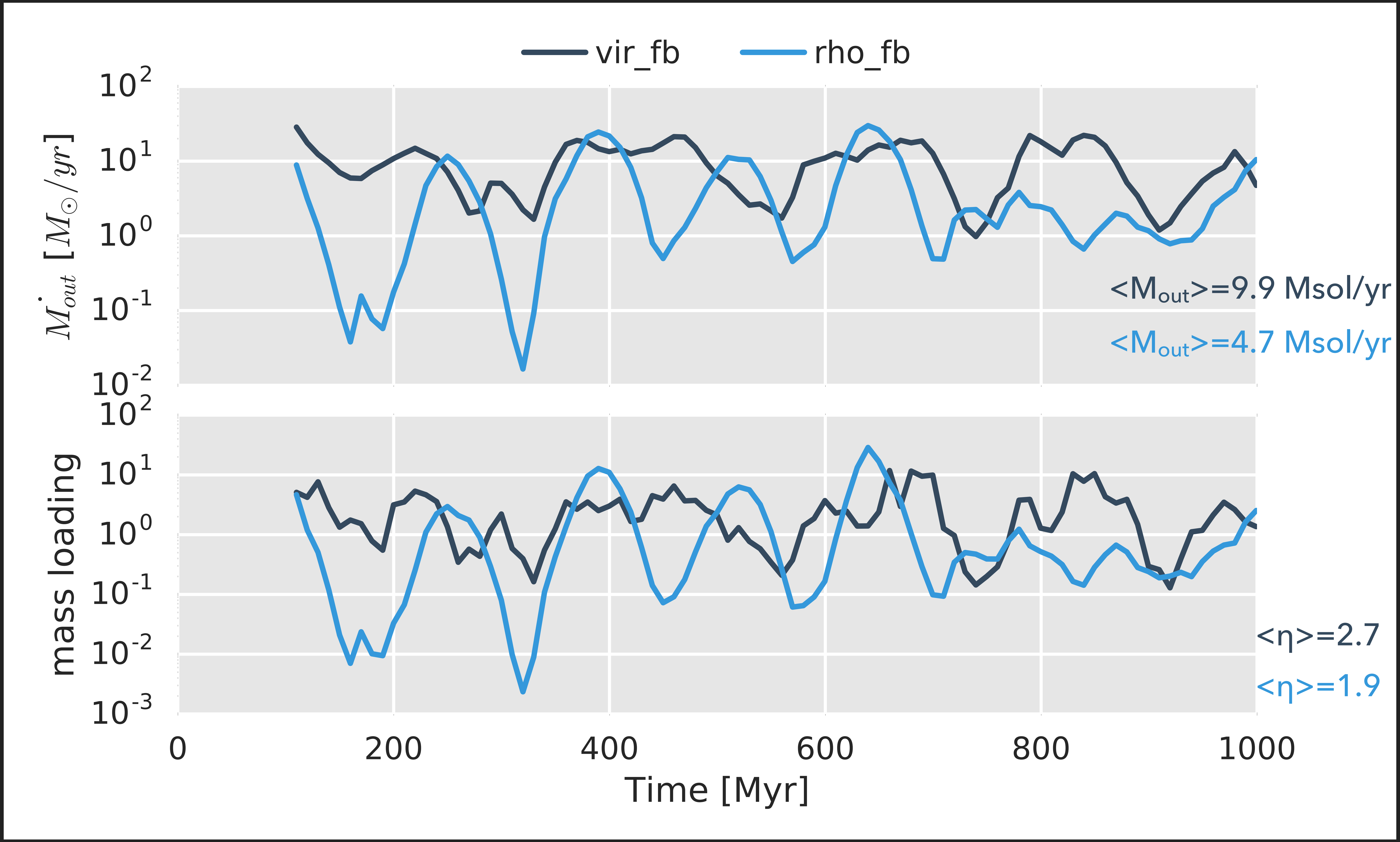

1.2 Myr
Gas temperature [K]
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
10 kpc
Density criterion
Virial criterion

A MORE EFFICIENT CGM METAL ENRICHMENT



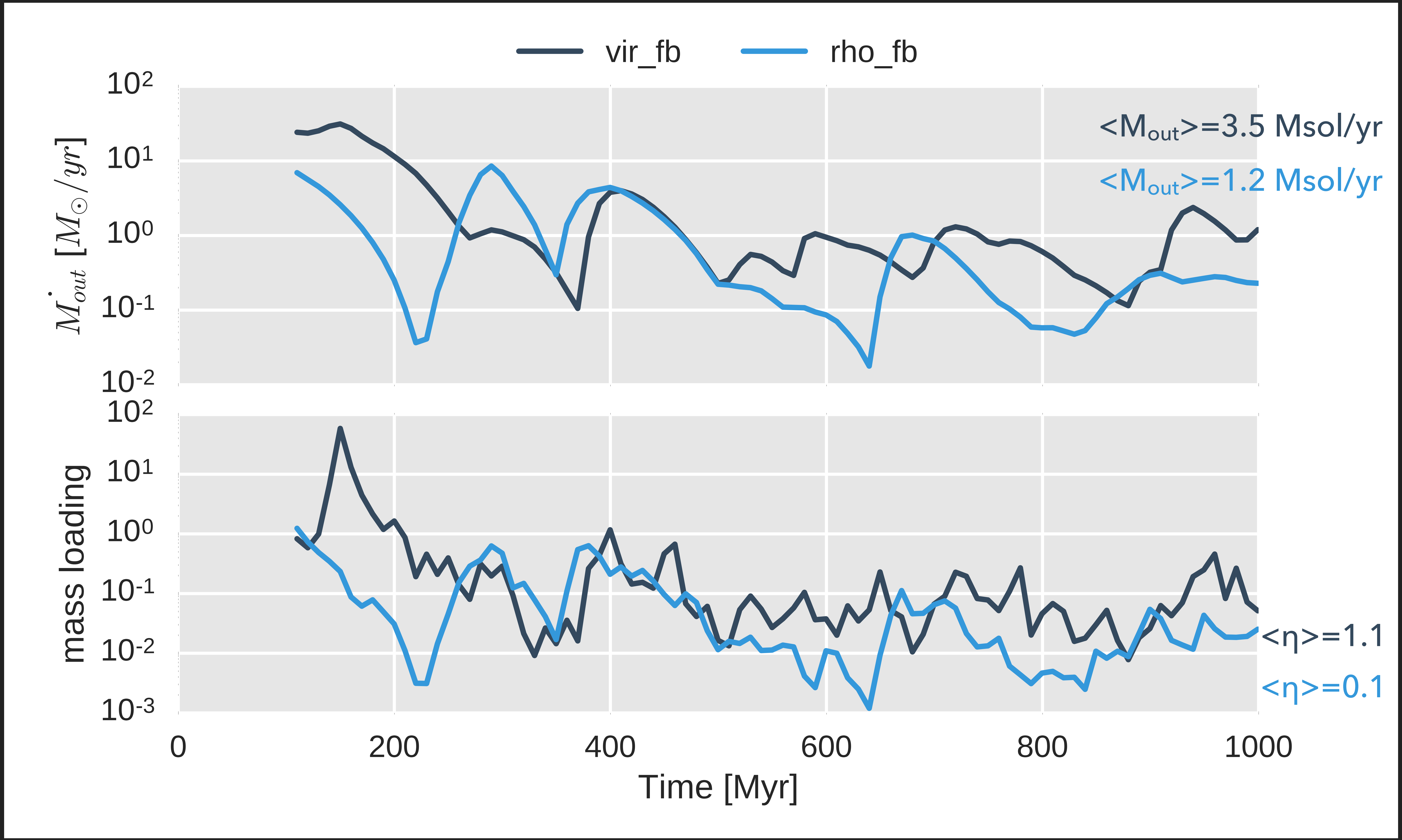
CONSEQUENCES FOR OUTFLOWS – ISOLATED

outflow rate @ r=0.2*r_{virial}



CONSEQUENCES FOR OUTFLOWS - MERGER

outflow rate @ $r=0.2*r_{virial}$

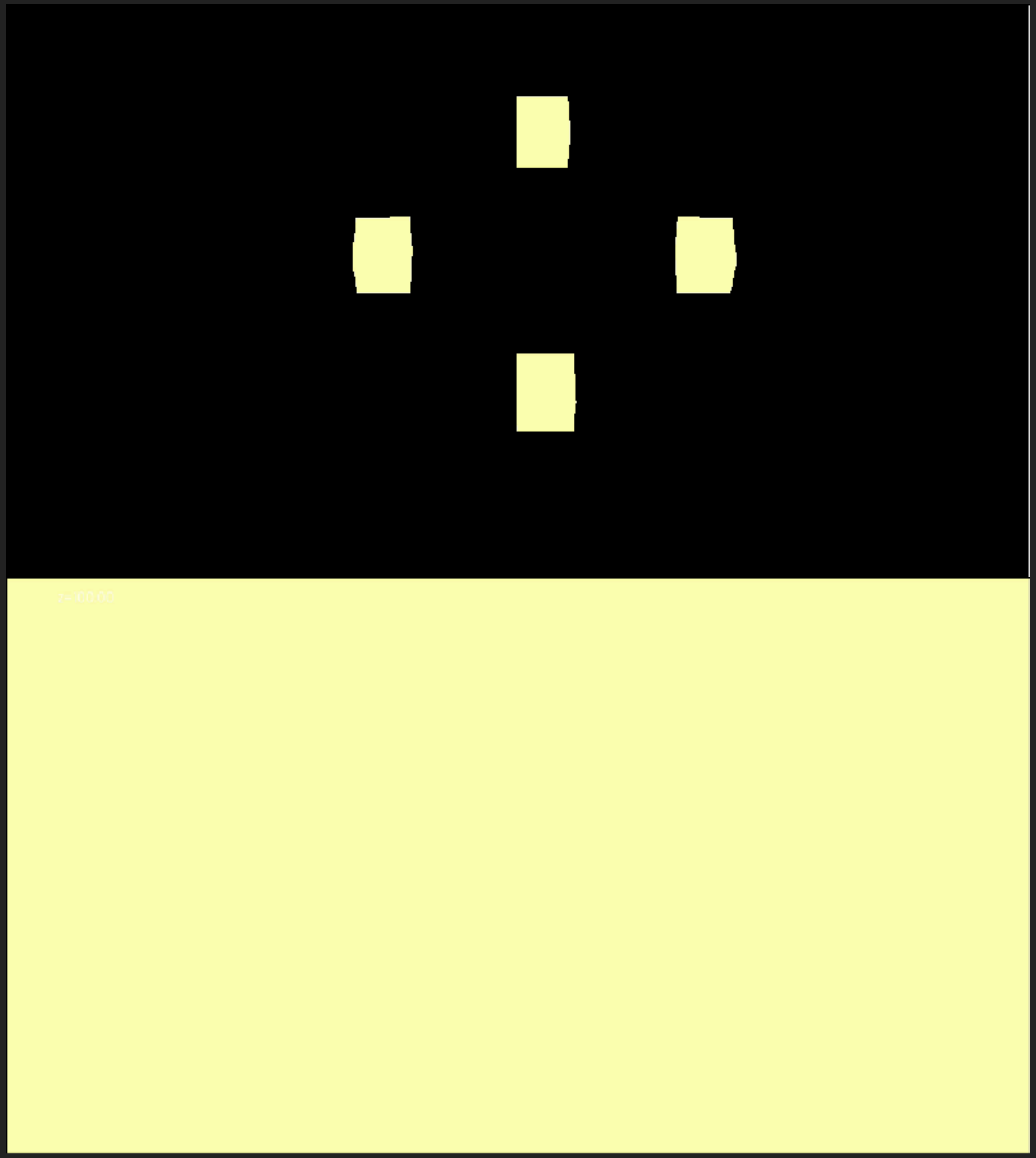


TAKE HOME MESSAGES - CONSEQUENCES OF A TURBULENT SF CRITERION

- 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

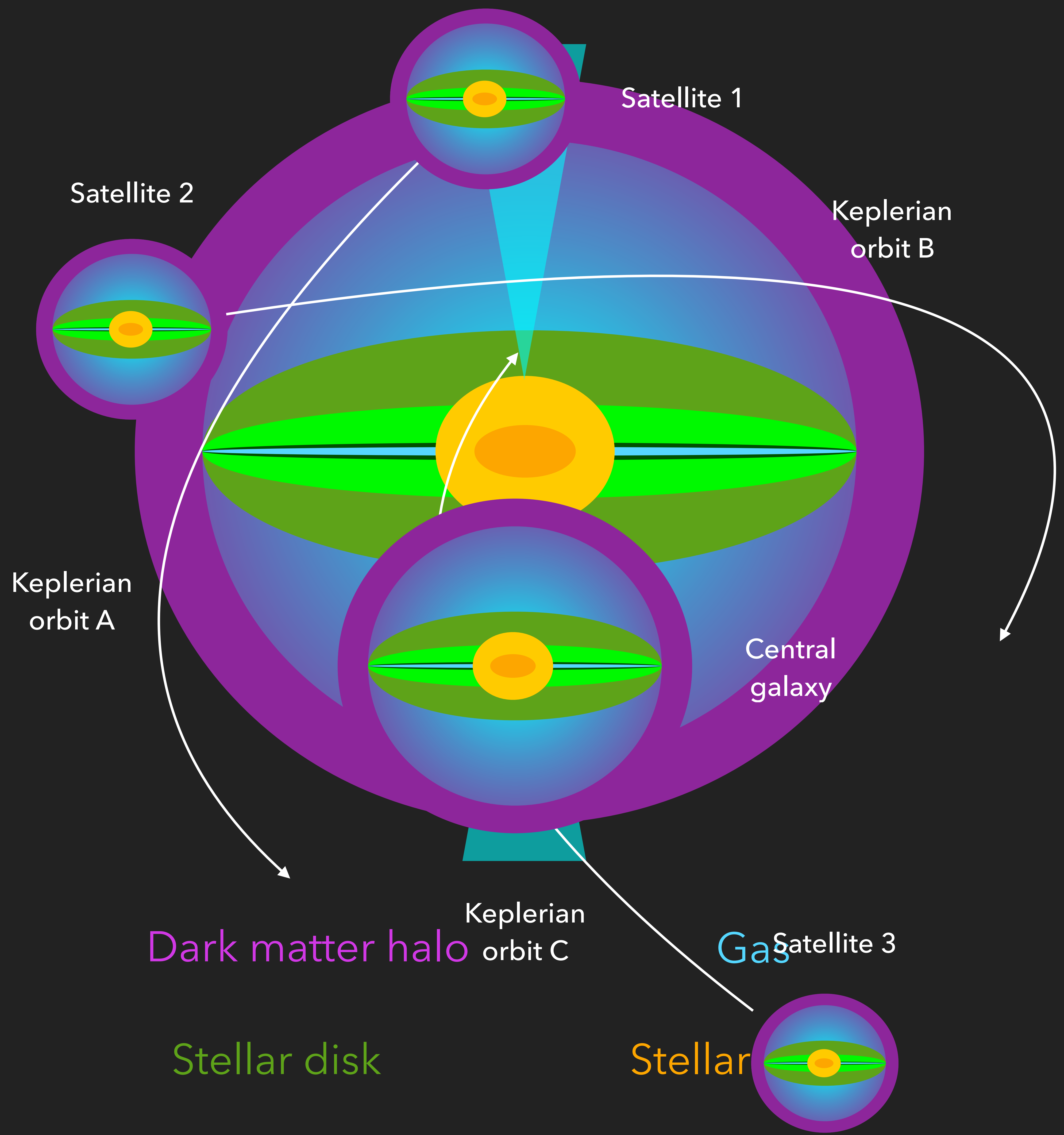
MOVIE.F90

- 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)

IDEALIS

SO WI