Non-universal star formation efficiency in turbulent ISM

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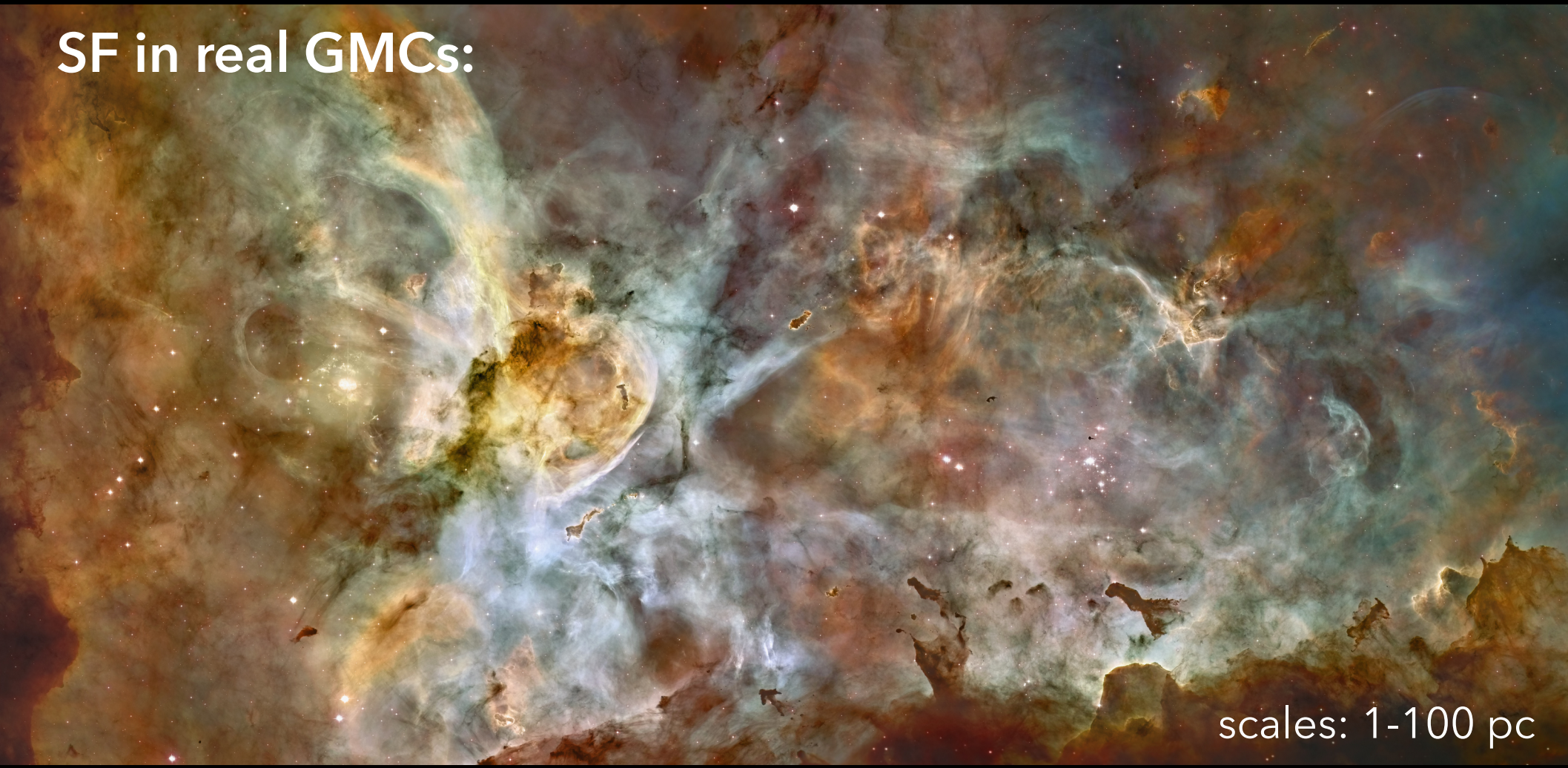
(ApJ accepted)

SF in simulations:

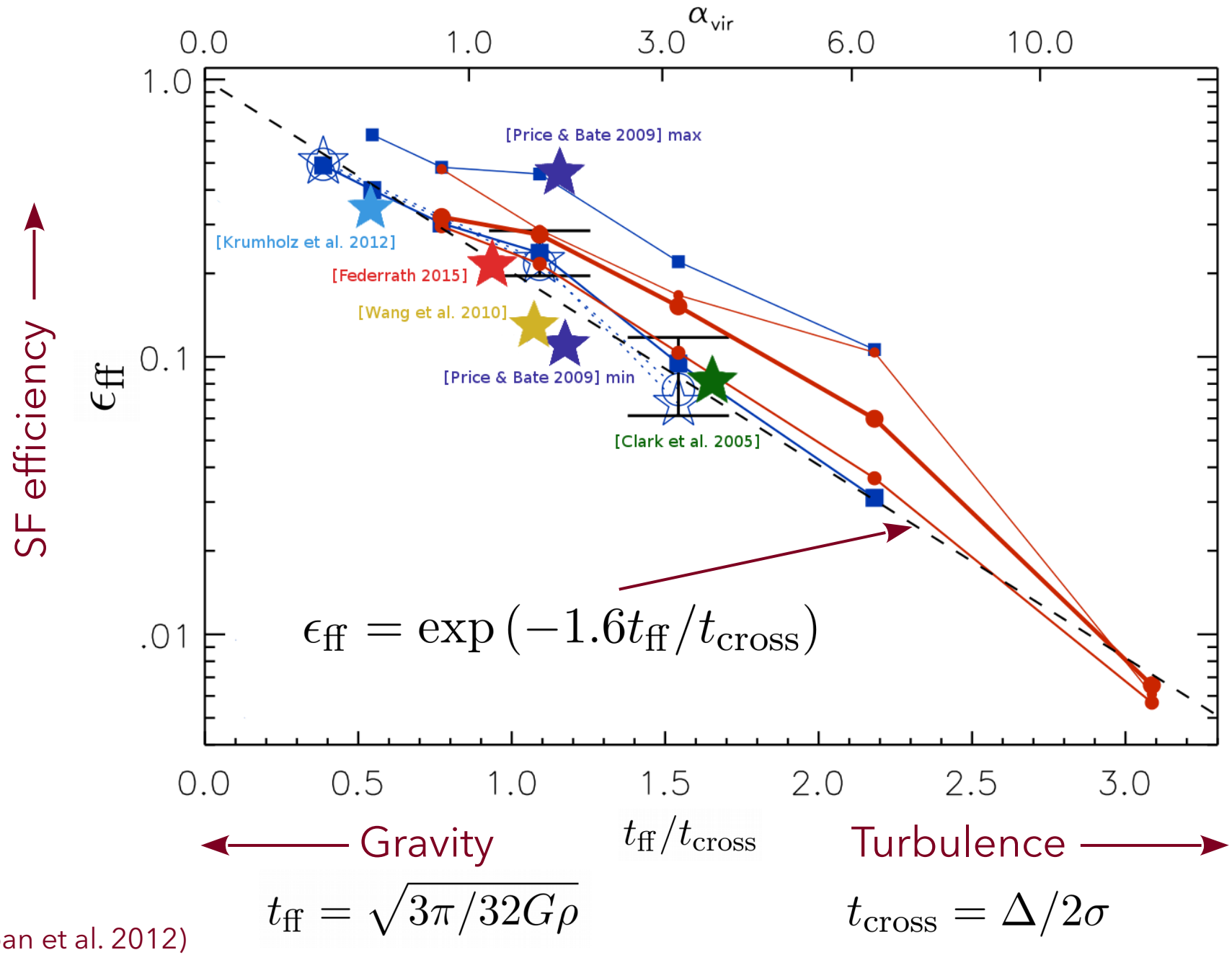
$$\dot{\rho}_\star = \epsilon_{\rm ff} \frac{\rho_{\rm g}}{t_{\rm ff}}$$

- **Universal** star formation efficiency (1-100%)
- **Artificial thresholds** ($T < T_{cr}$ $\rho > \rho_{cr}$ …)

SF in real GMCs:

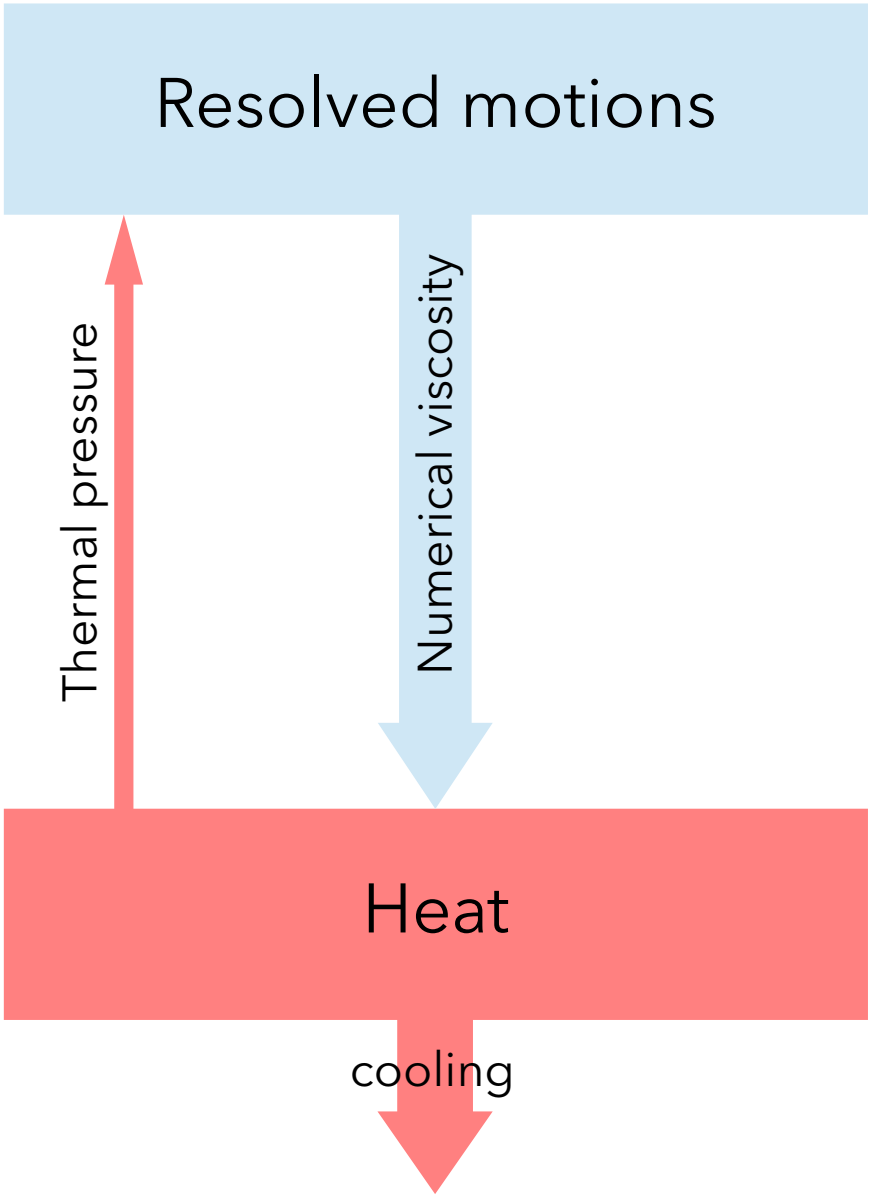


Results of GMCs simulations



(Padoan et al. 2012)

Model outline



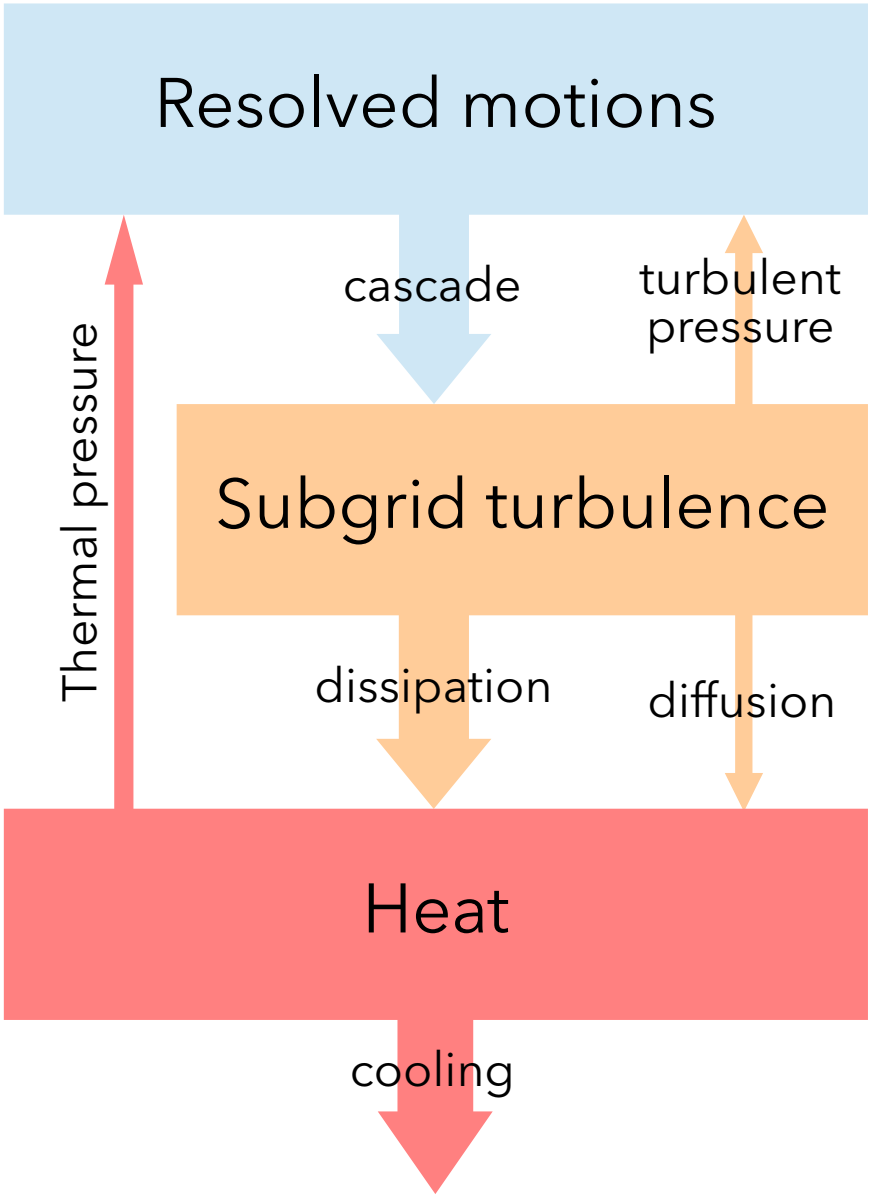
$$\frac{\partial}{\partial t}\rho + \nabla_k v_k \rho = 0$$

$$\frac{\partial}{\partial t}\rho v_i + \nabla_k v_k \rho v_i = -\rho \nabla_i \phi - \nabla_i P$$

$$\frac{\partial}{\partial t}E + \nabla_k v_k E = -\rho v_k \nabla_k \phi - \nabla_k v_k P - \Lambda_{\rm net}$$

$$\frac{\partial}{\partial t}e + \nabla_k v_k e = -\Lambda_{\rm net} - P \nabla_k v_k$$

Model outline: **subgrid turbulence**



$$\frac{\partial}{\partial t}\rho + \nabla_k v_k \rho = 0$$

$$\frac{\partial}{\partial t}\rho v_i + \nabla_k v_k \rho v_i = -\rho\nabla_i\phi - \nabla_i\left(P + \frac{2}{3}K\right) + \nabla_k \tau_{ki}$$

$$\frac{\partial}{\partial t}E + \nabla_k v_k E = -\rho v_k \nabla_k \phi - \nabla_k v_k \left(P + \frac{2}{3}K\right) - \Lambda_{\rm net} + \nabla_k v_i \tau_{ki} + \nabla_k\left(\mathfrak{F}_k^{(K)} + \mathfrak{F}_k^{(e)}\right)$$

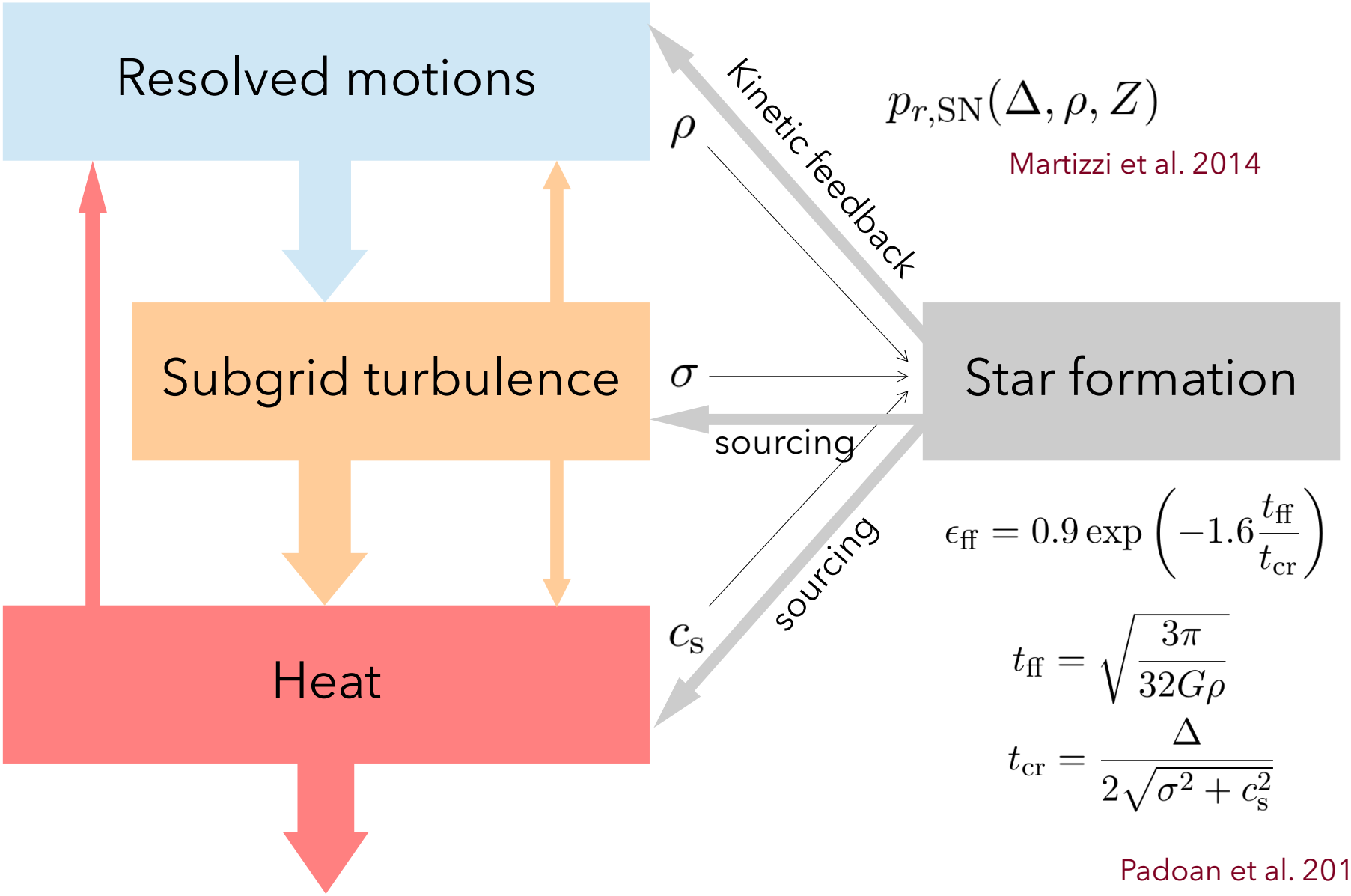
$$\frac{\partial}{\partial t}K + \nabla_k v_k K = \tau_{ki}\nabla_k v_i - \epsilon - \frac{2}{3}K\nabla_k v_k + \nabla_k \mathfrak{F}_k^{(K)}$$

$$\sigma = \sqrt{\frac{2K}{\rho}}$$ - subgrid turbulent velocity

$$\frac{\partial}{\partial t}e + \nabla_k v_k e = \epsilon - \Lambda_{\rm net} - P\nabla_k v_k + \nabla_k \mathfrak{F}_k^{(e)}$$

Schmidt et al. 2014

Model outline: **SF prescription**



Milky Way-sized isolated disk

The ART code

+ subgrid turbulence
+ turbulent star formation

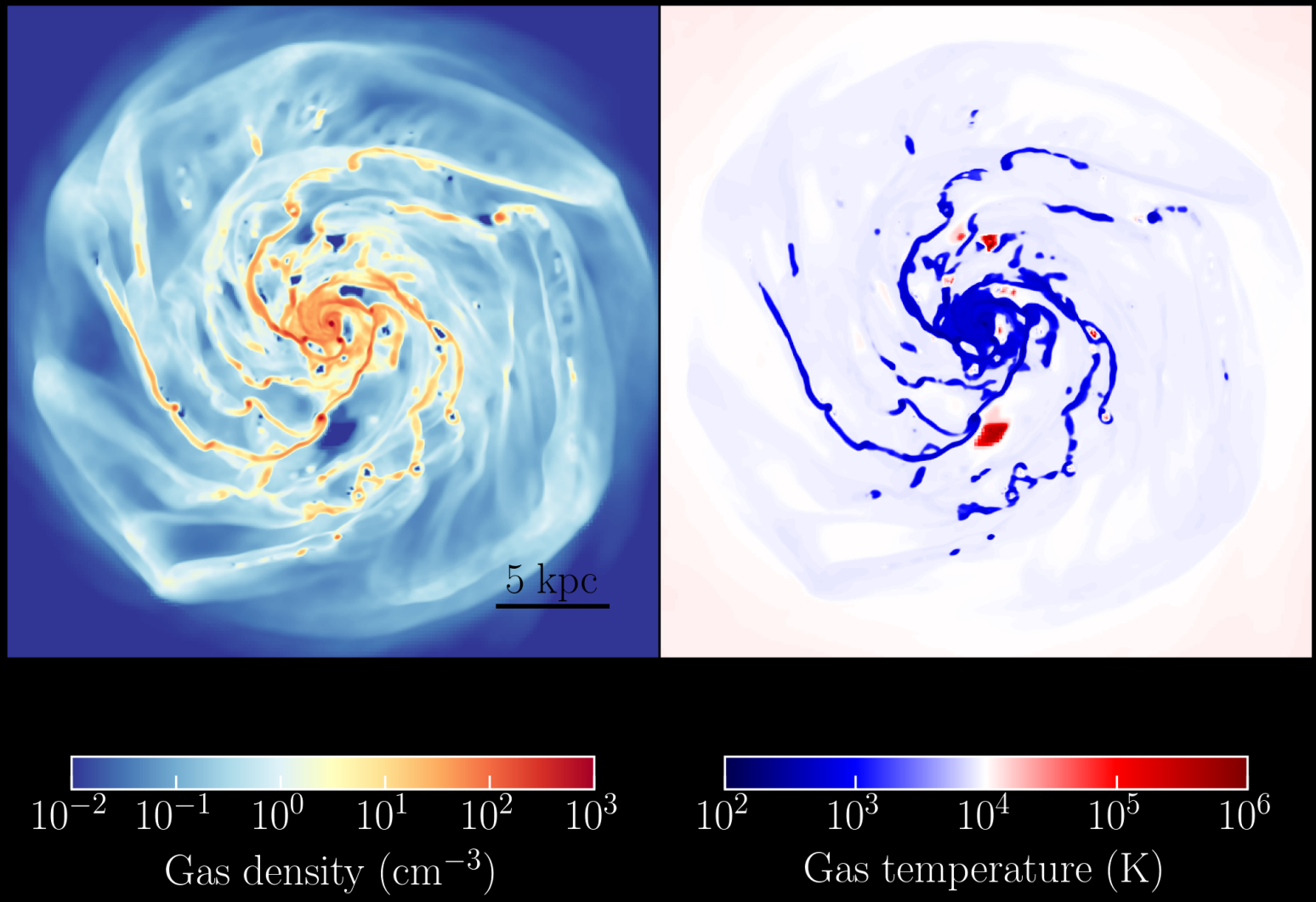
AGORA initial conditions

$M_{disk} \sim 4.3 \times 10^{10} M_{sun}$

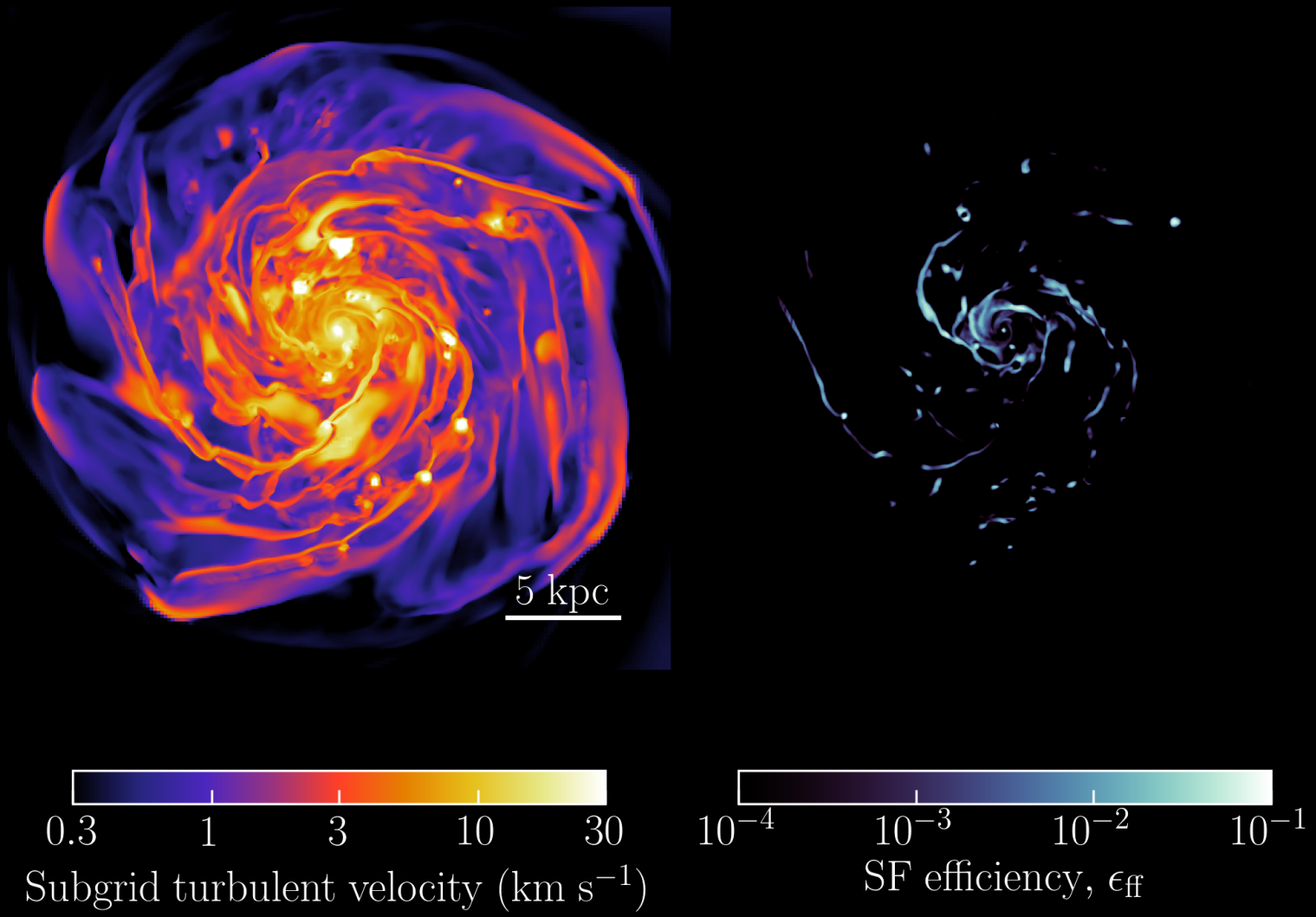
$f_{gas} = 0.2$

$\Delta = 40$ pc

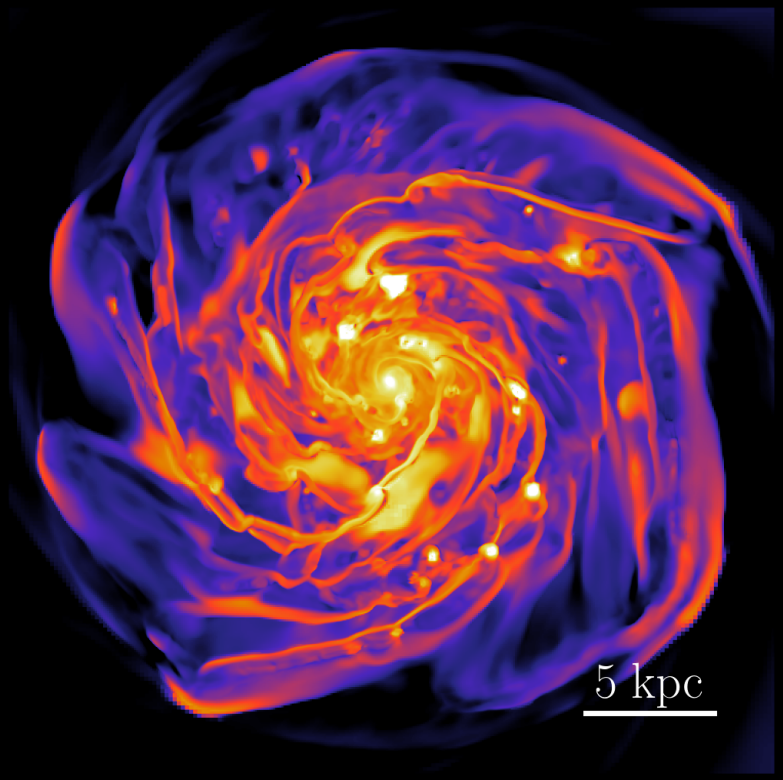
Milky Way-sized isolated disk

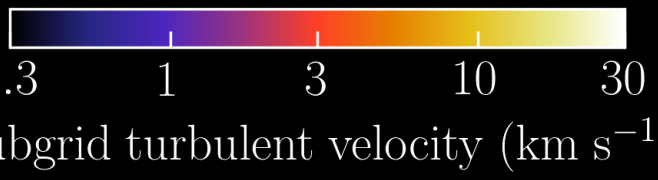


Milky Way-sized isolated disk



Milky Way-sized isolated disk





Non-universal SF efficiency

$$\epsilon_{\rm ff} = 0.9 \exp\left(-1.6 \frac{t_{\rm ff}}{t_{\rm cr}}\right)$$

$$t_{\rm ff} = \sqrt{\frac{3\pi}{32 G \rho}}$$

$$t_{\rm cr} = \frac{\Delta}{2\sqrt{\sigma^2 + c_{\rm s}^2}}$$

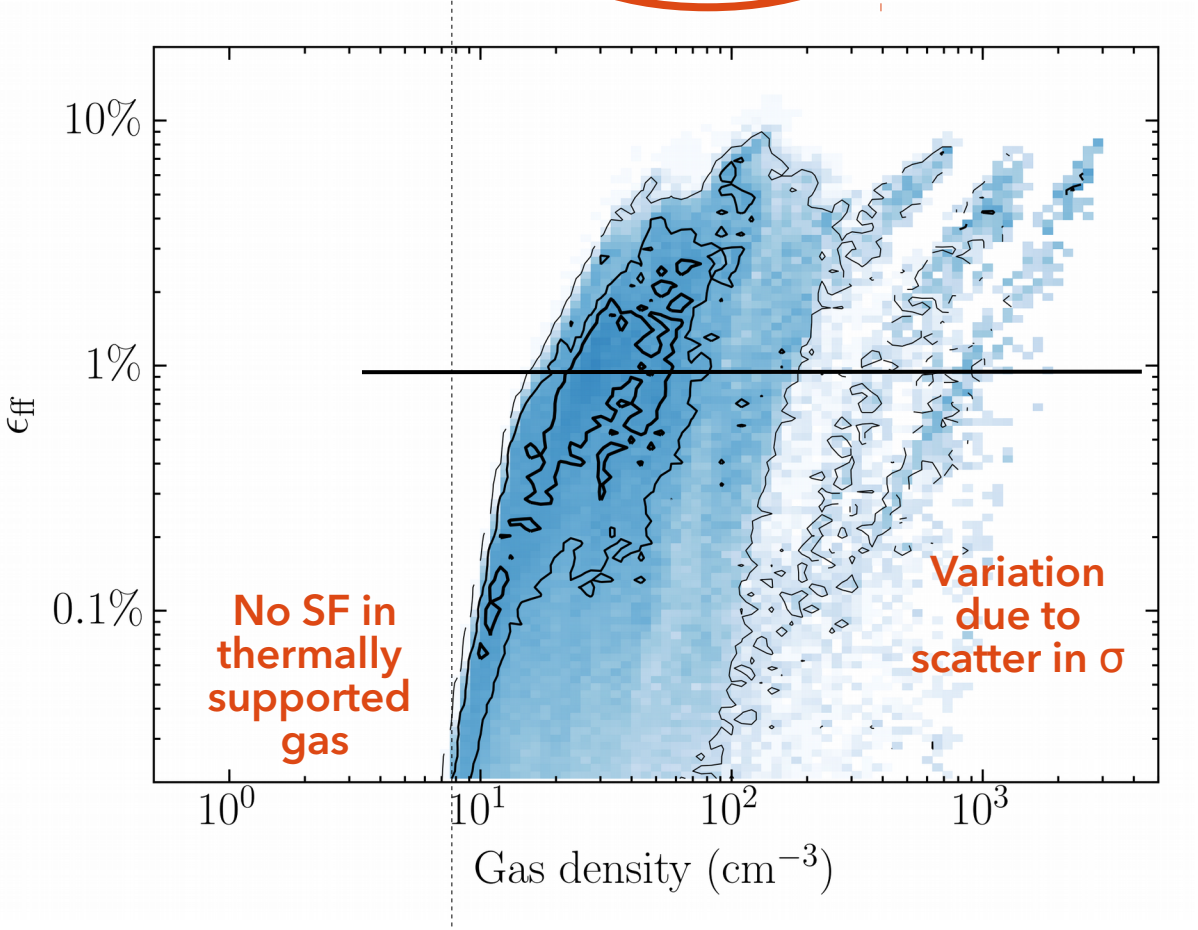
- Density threshold
- Average SFE ~ 1%
- Wide variation

Subsonic

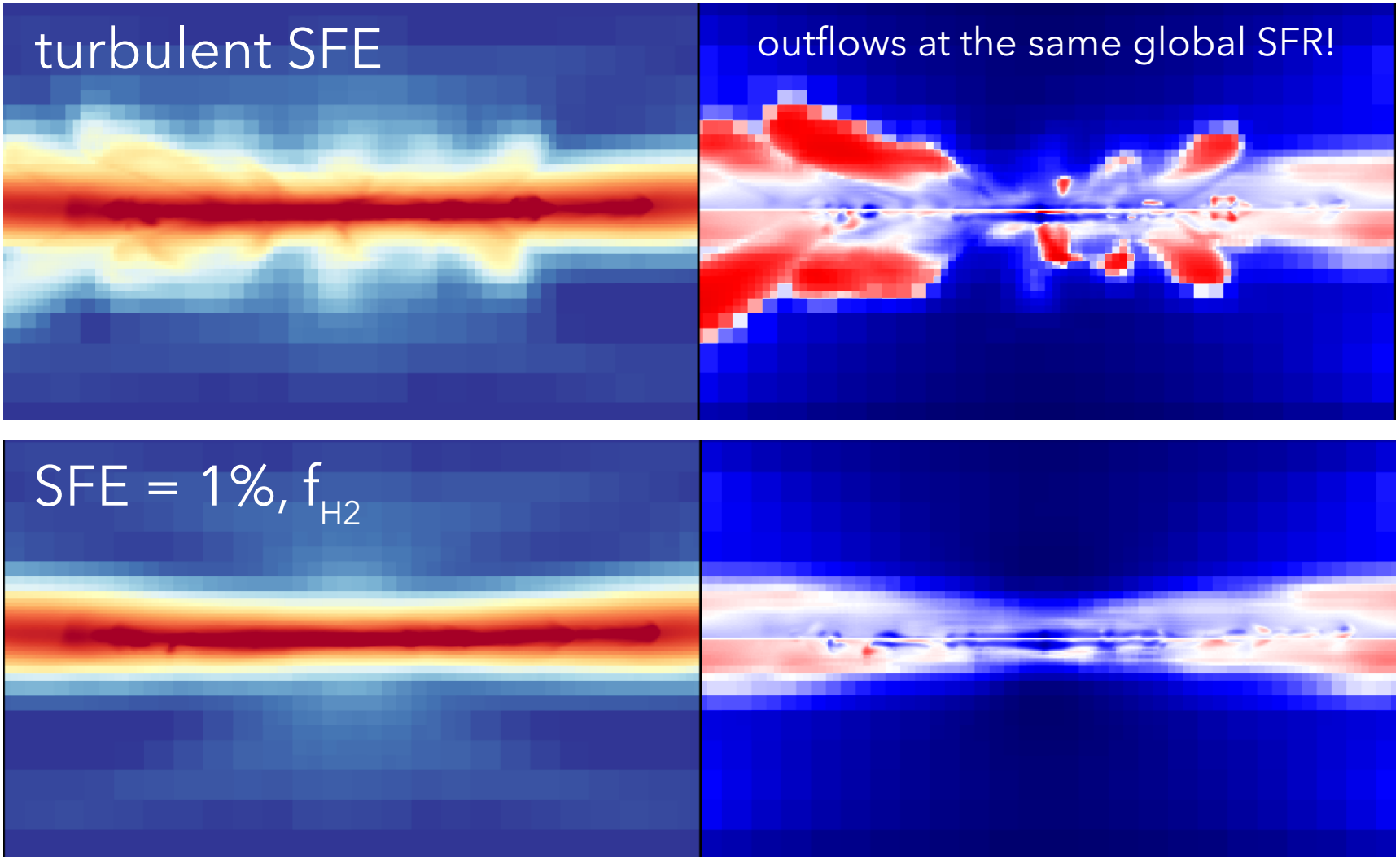
$t_{\rm cr} \approx \Delta / 2 c_{\rm s}$

Supersonic

$t_{\rm cr} \approx \Delta / 2\sigma$

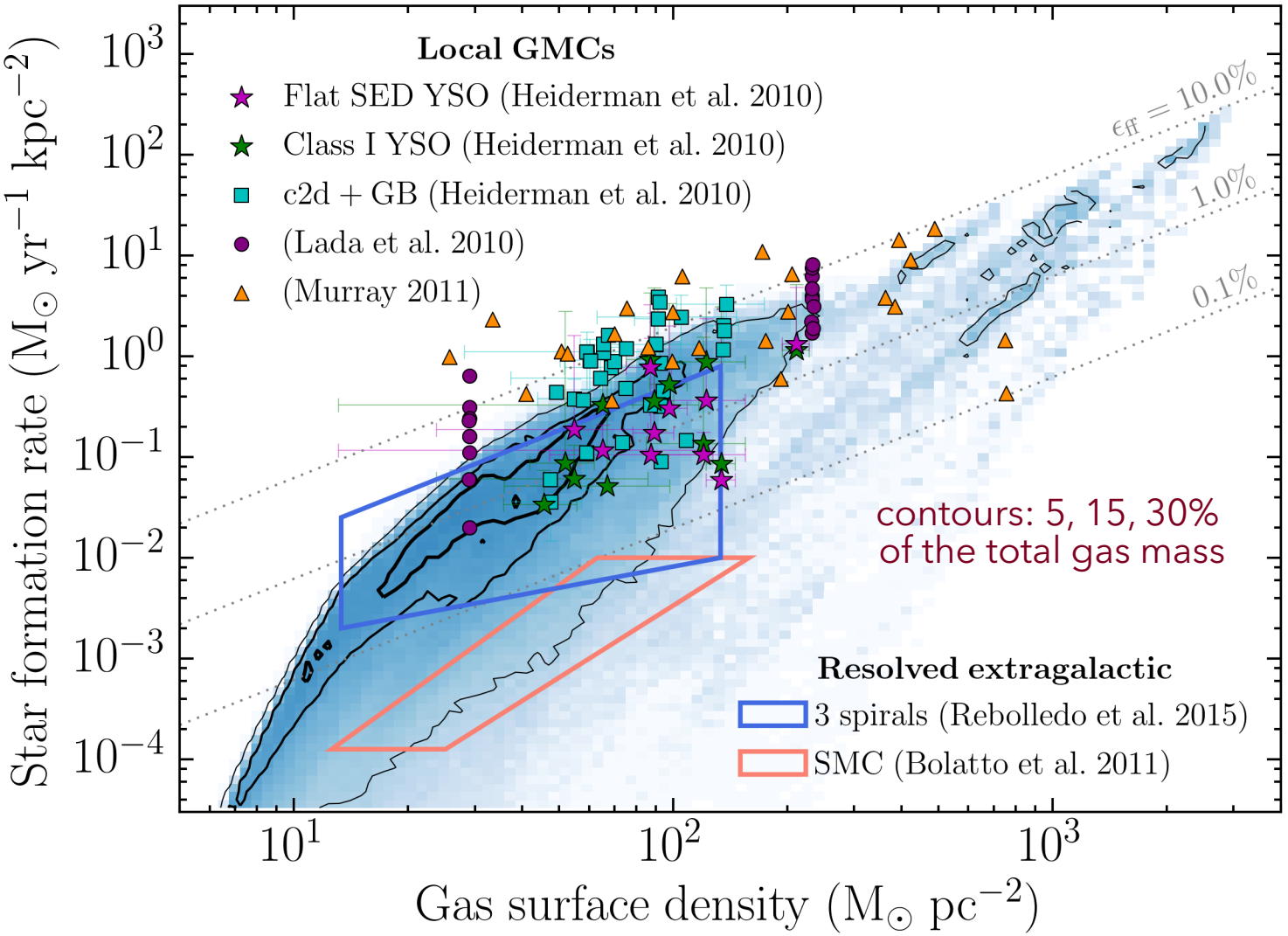


Why SFE variation matters



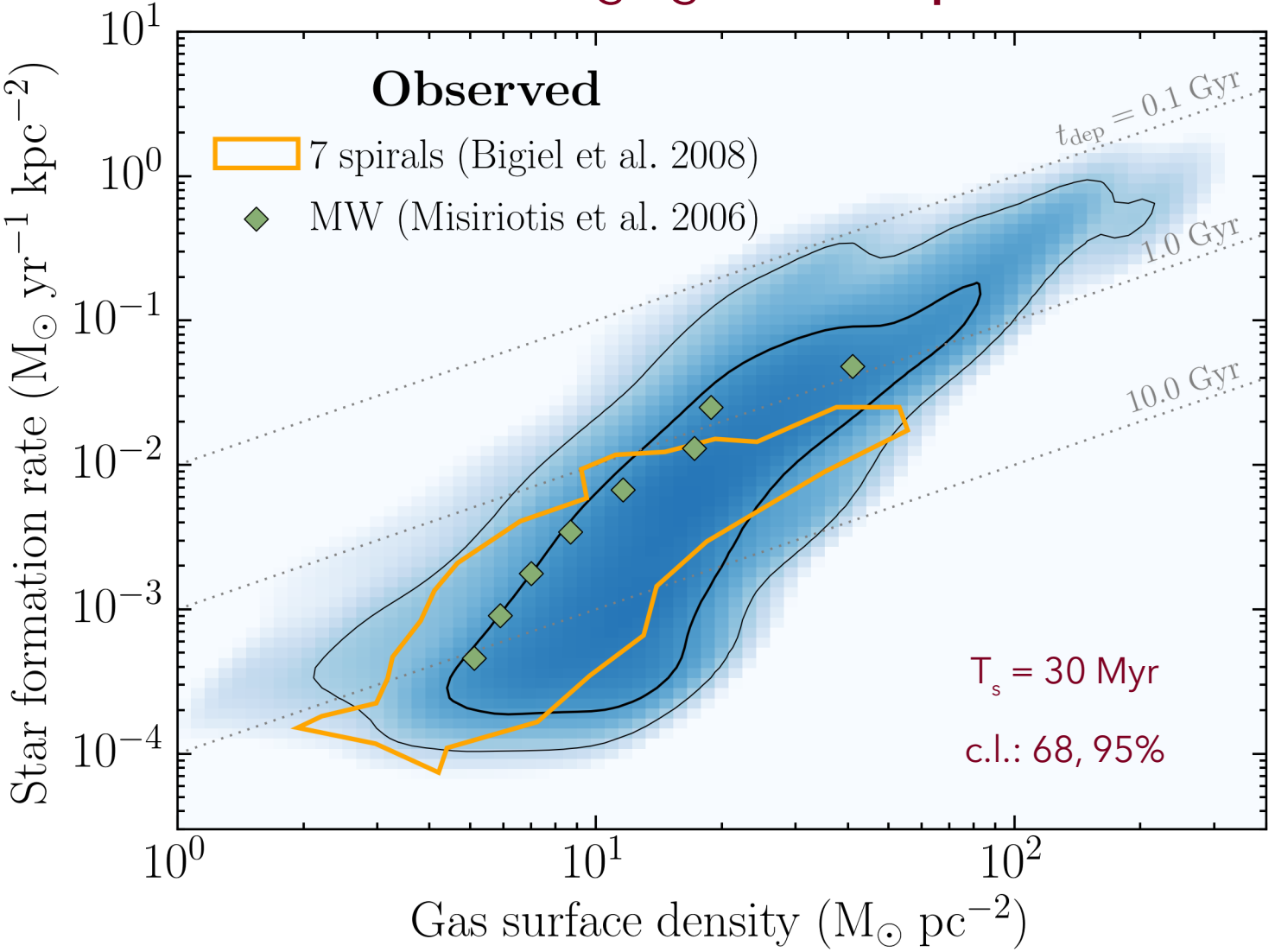
Star formation on GMC scale

Averaging scale: **40 pc**



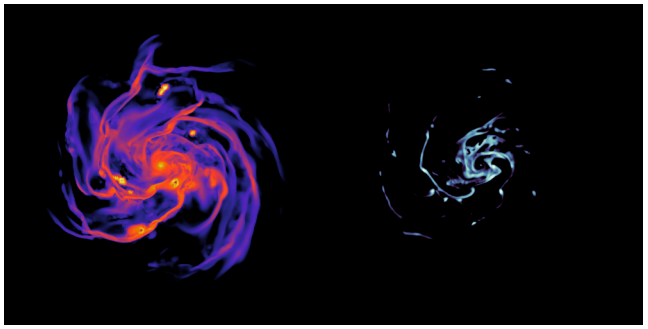
Kennicutt-Schmidt relation

Averaging scale: **1 kpc**

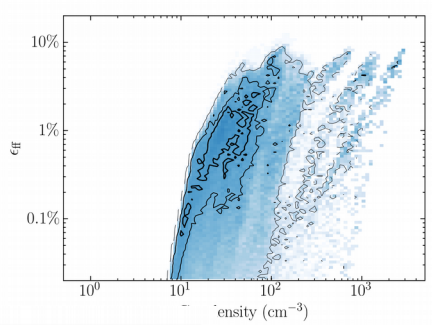


Summary

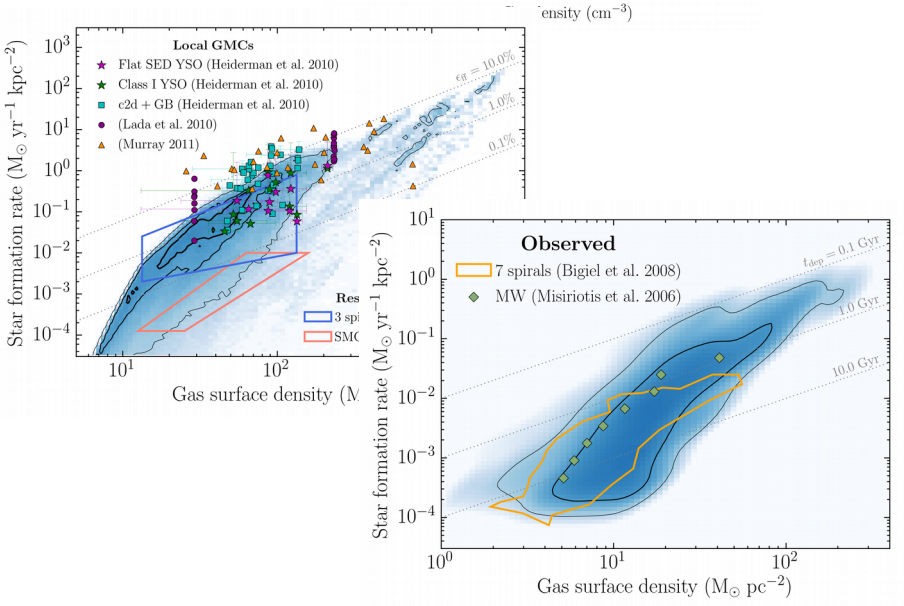
arXiv: 1512.03101



Turbulent star formation model predicts wide spatial and temporal **variation of SFE**



SF in cold gas **without artificial thresholds**



Distribution of SFE agrees with observed SF in local GMCs as well as with extragalactic SFR maps