Stellar Explosions in High Surface-Density Galaxies

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with

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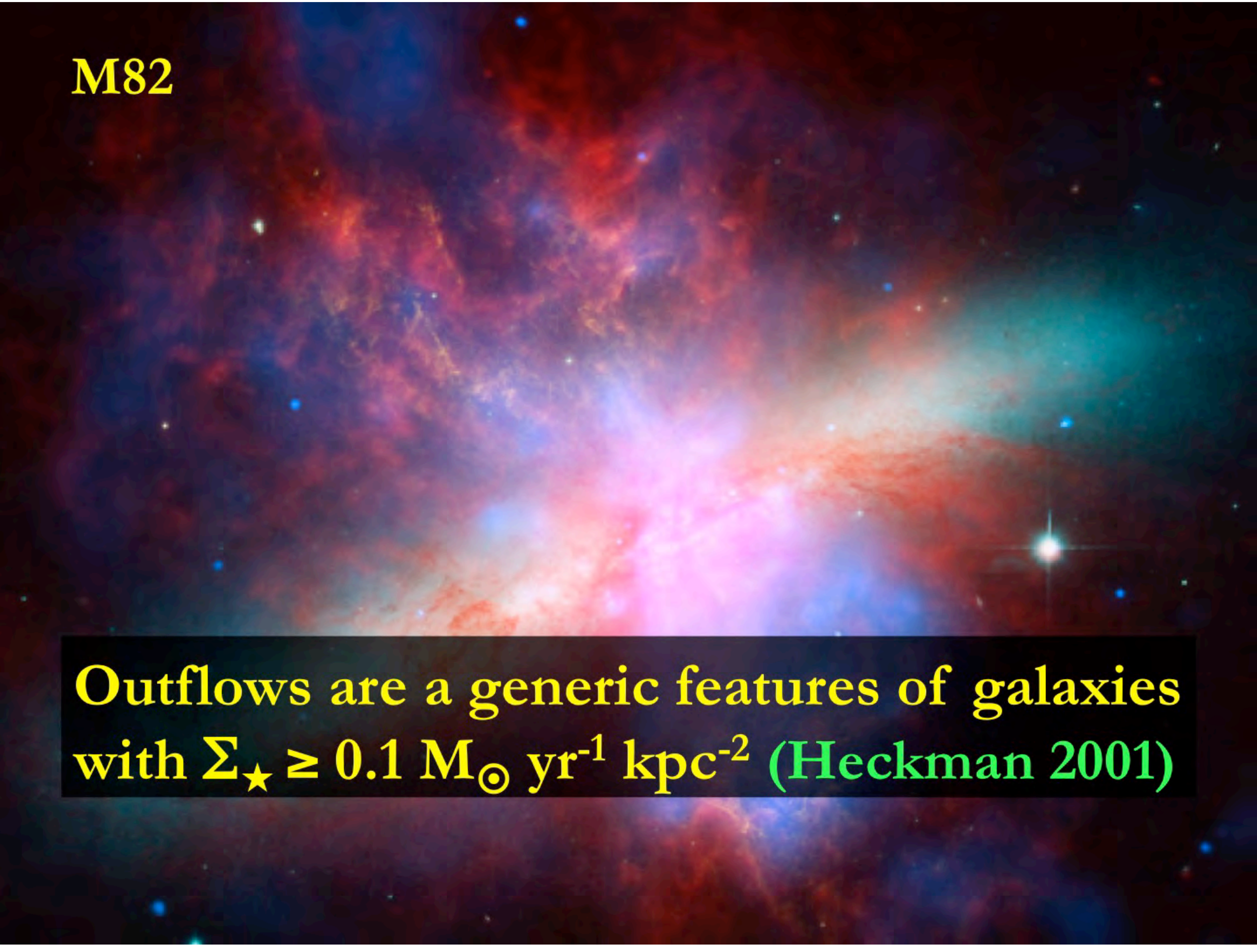
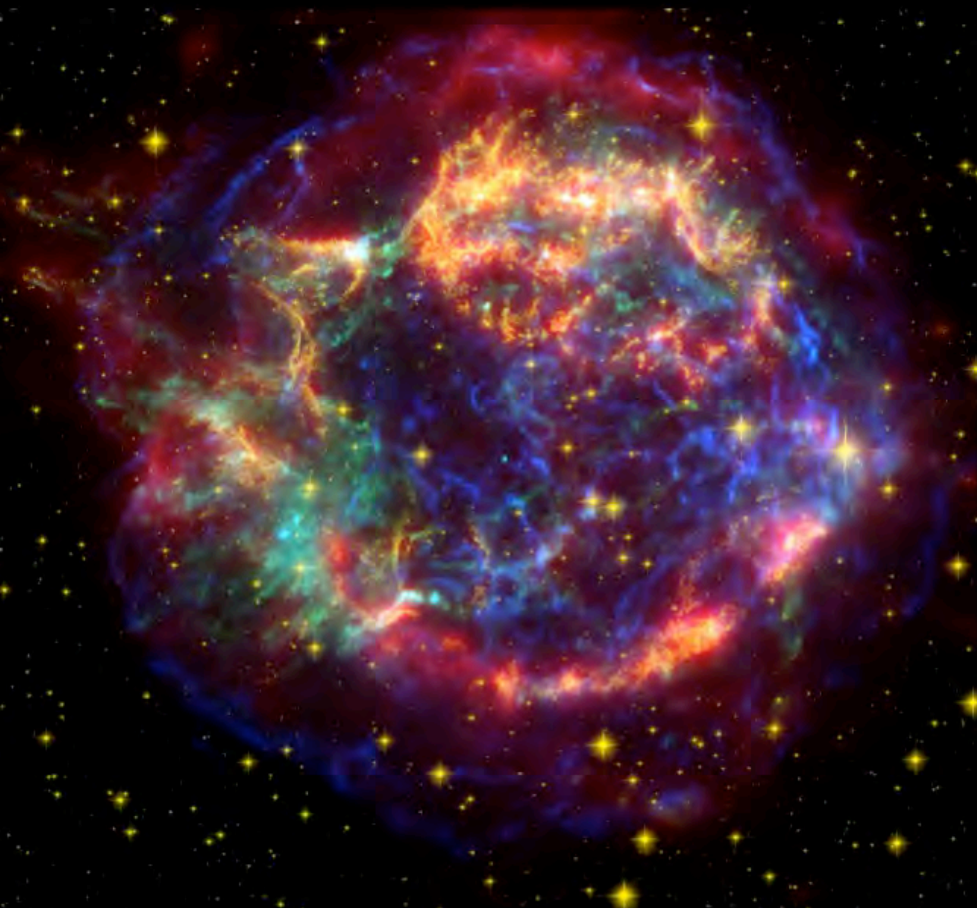


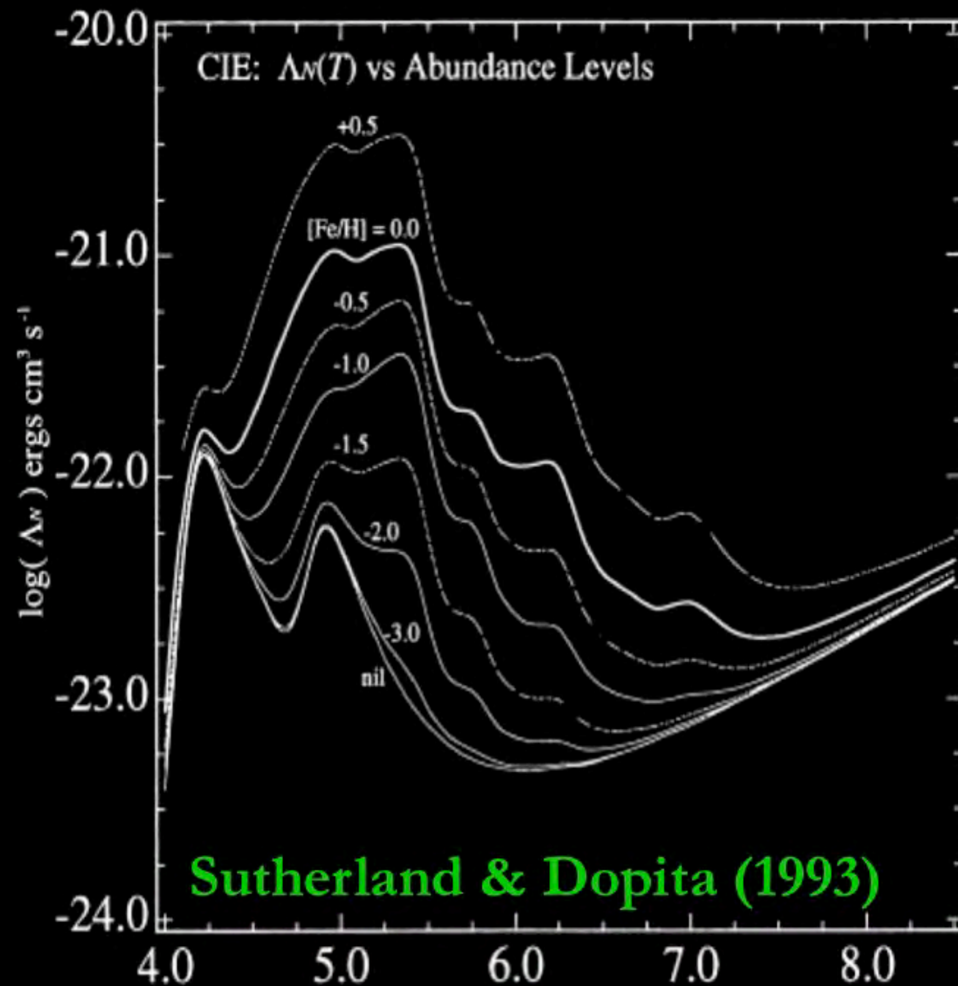
M82

Outflows are a generic features of galaxies with $\Sigma_{\star} \geq 0.1\ M_{\odot}\ yr^{-1}\ kpc^{-2}$ (Heckman 2001)

Supernovae & Cooling



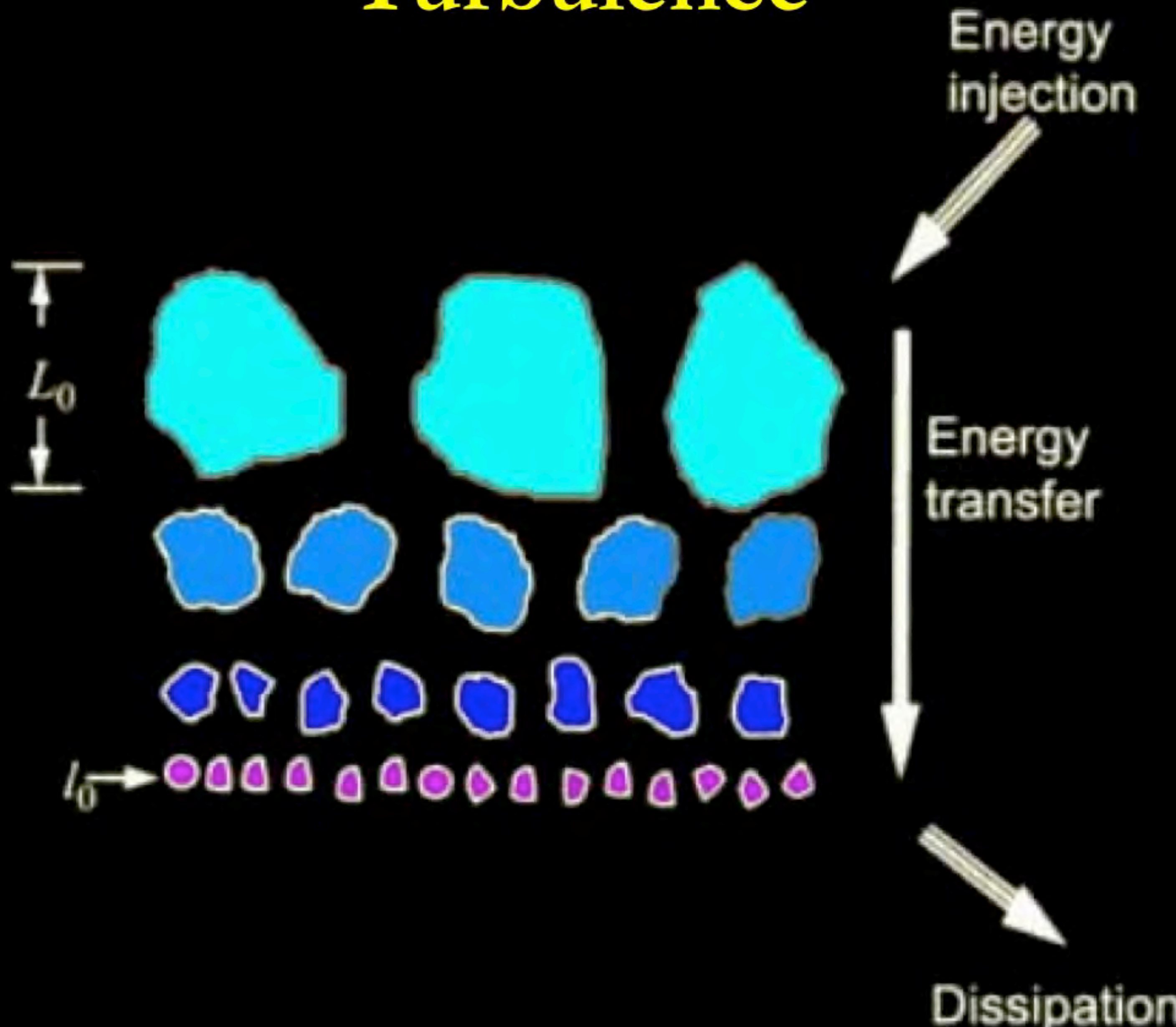
~3 pc



Log T

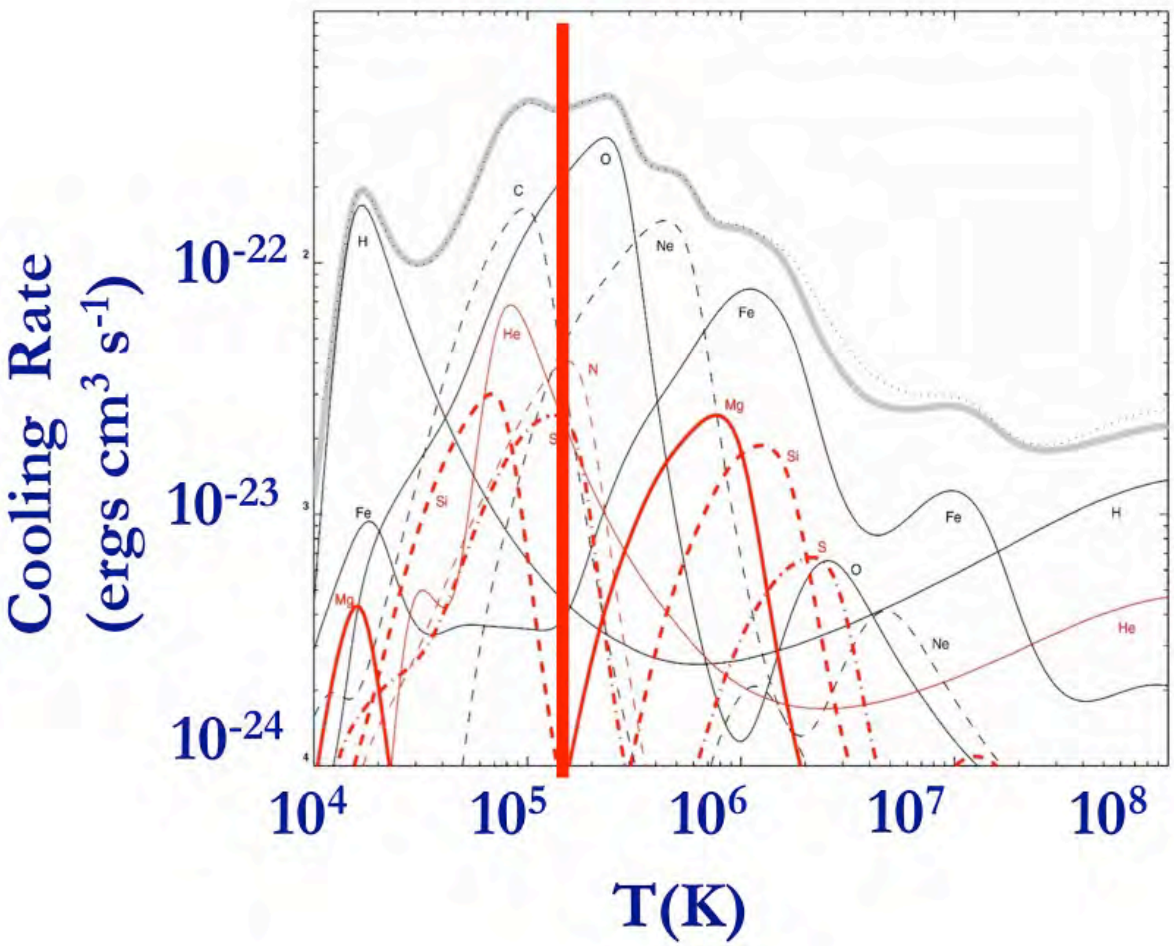
Cooling times ~ 3000 years

Turbulence



Kolmogorov (1941)

Cooling Instability



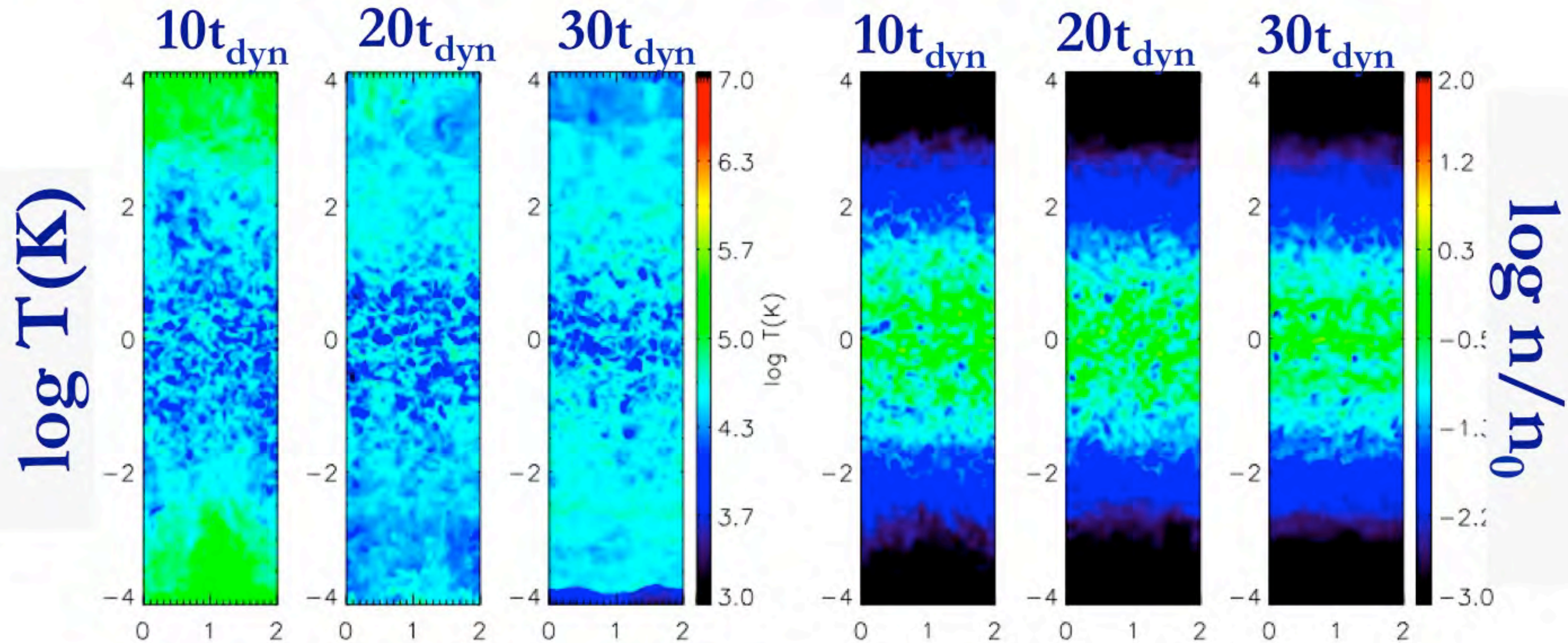
$$\left(1 - \frac{\partial \ln \Lambda}{\partial \ln T}\right) > 0$$

Field (1965)
McCourt et al. (2011)

Gnat & Ferland (2012)

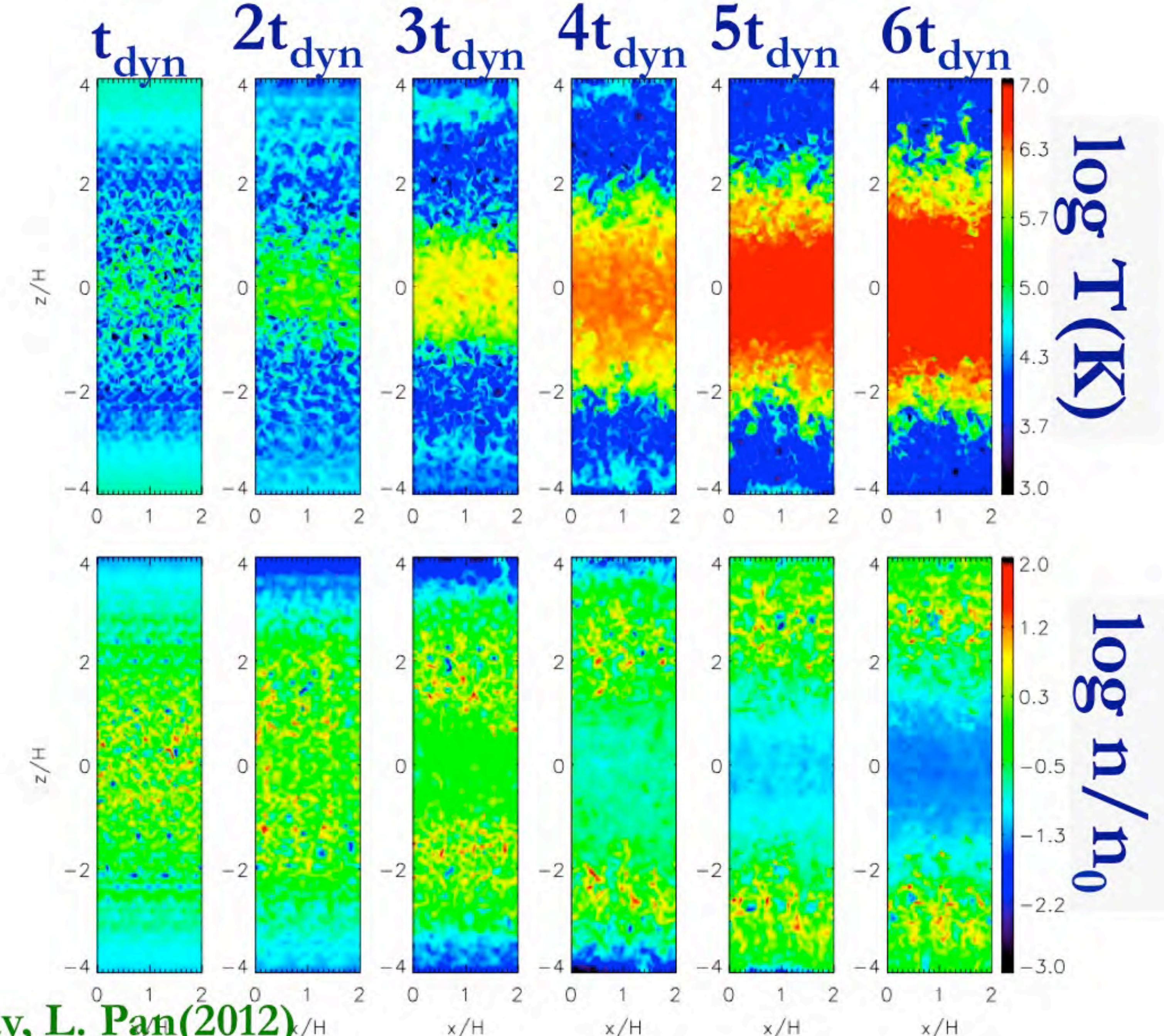
σ_{1D}=20 km/s

Simulation with turbulent stirring from stellar explosions, but no supernovae directly added



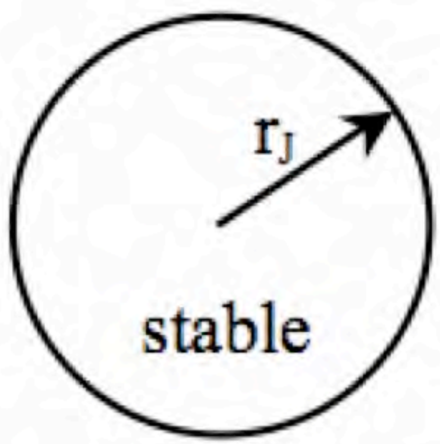
ES, W. Gray, L. Pan(2012)

σ_{1D}=34 km/s

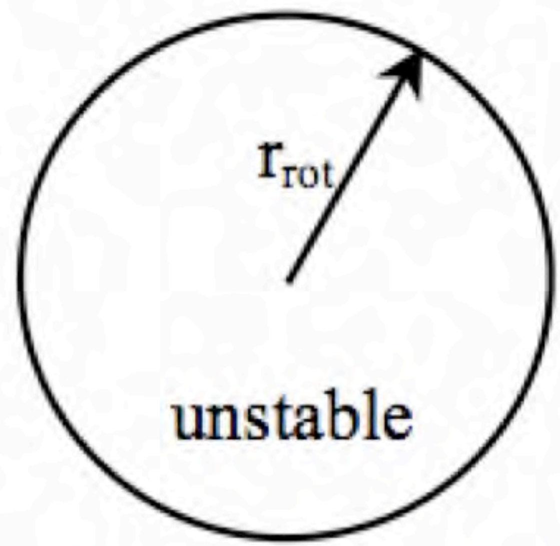


ES, W. Gray, L. Pan(2012)

Can we relate σ_{1D} to other galaxy Properties?



Pressure support vs Gravity



Rotational support vs Gravity

Disk Stability Analysis

$$Q_{\rm gas+stars} = \frac{\sigma_{\rm 1D,gas}\,\kappa}{f^{1/2}\pi G \Sigma_{\rm gas+stars}} \approx 1$$

Toomre Q

Epicyclic Freq.

Fraction of "pressure" from turbulence

Surface Density

ES (2013)

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Epicyclic Freq.

Fraction of "pressure" from turbulence

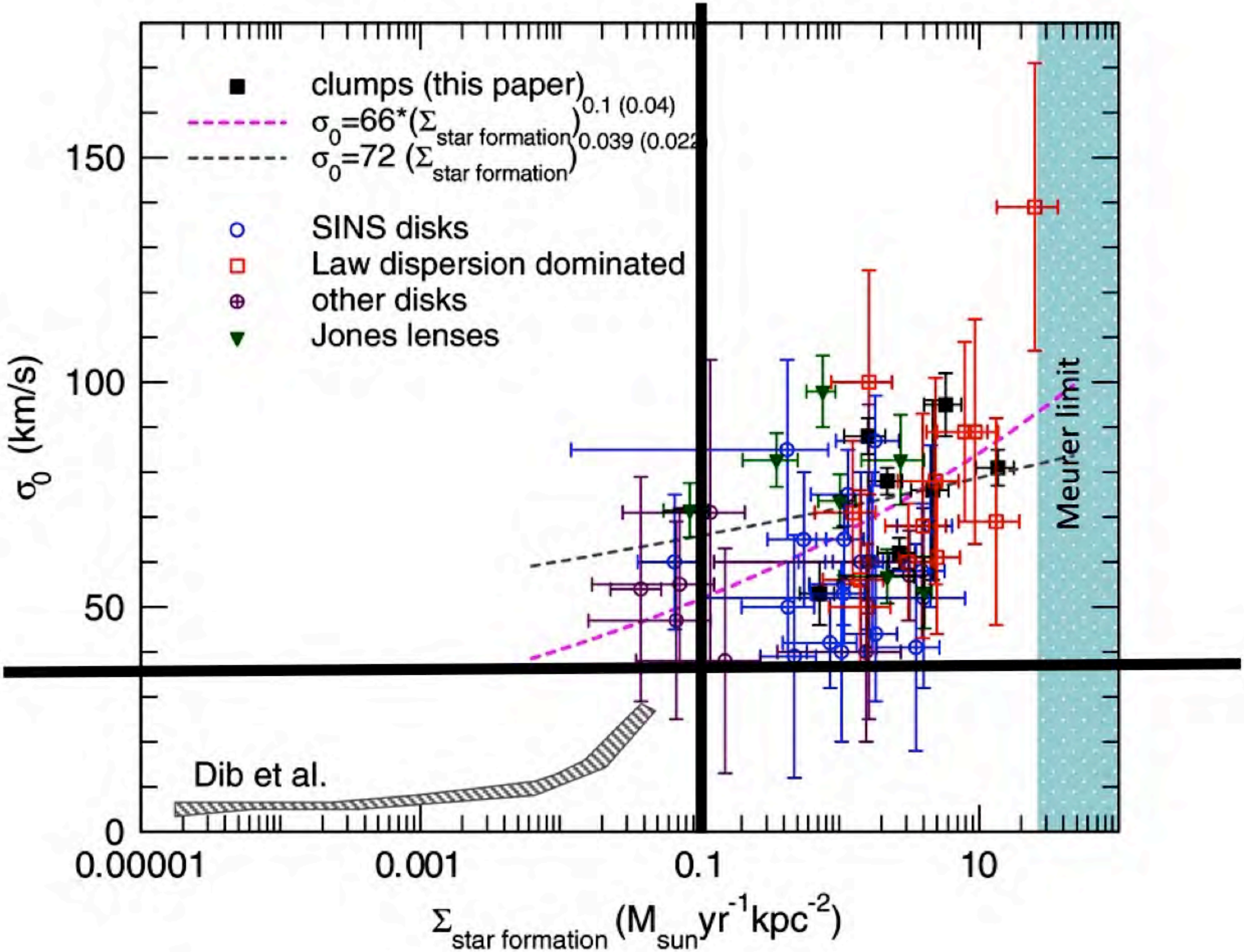
Surface Density

If $\kappa \approx$ 1/30 Myrs and $f \approx$ 1/2

$\sigma_{\rm 1D,gas} \approx$ 35 km/s, corresponds to

$\Sigma_{\rm gas+stars} \approx 150\, M_\odot {\rm pc}^{-2}$ and $\dot{\Sigma}_\star \approx 0.1\ \frac{M_\odot}{{\rm kpc}^2\,{\rm yr}}$

ES (2013)



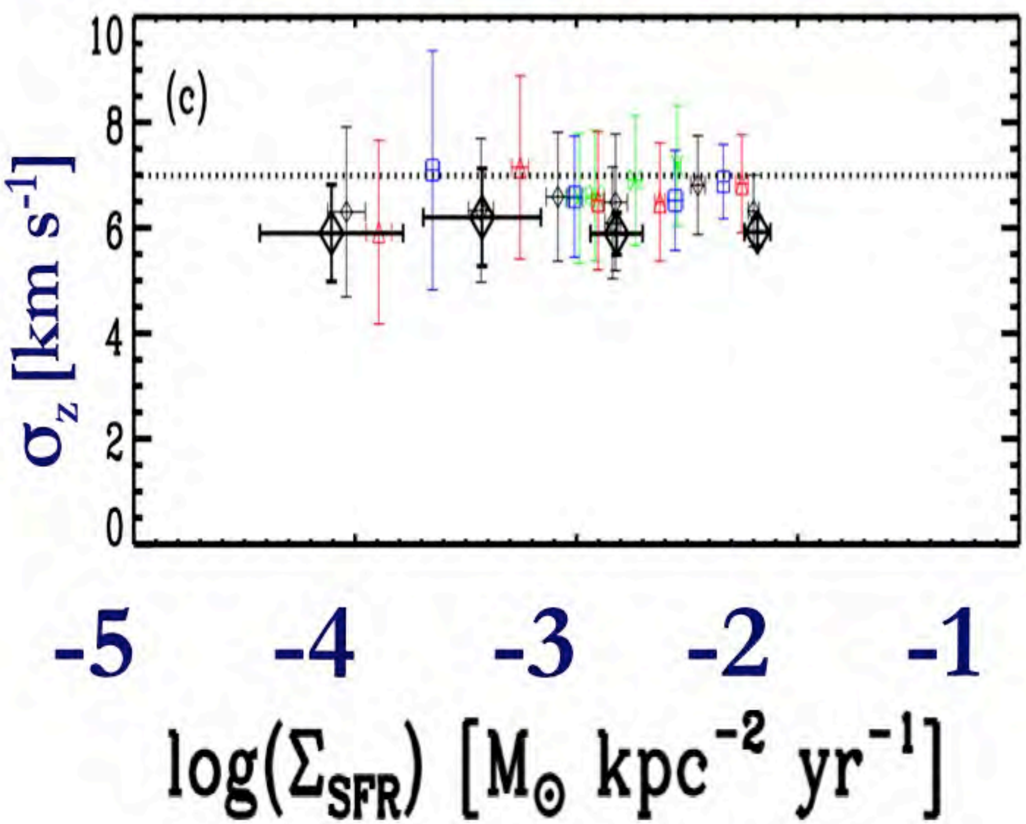
Genzel et al (2011)

Getting High σ_z is Hard

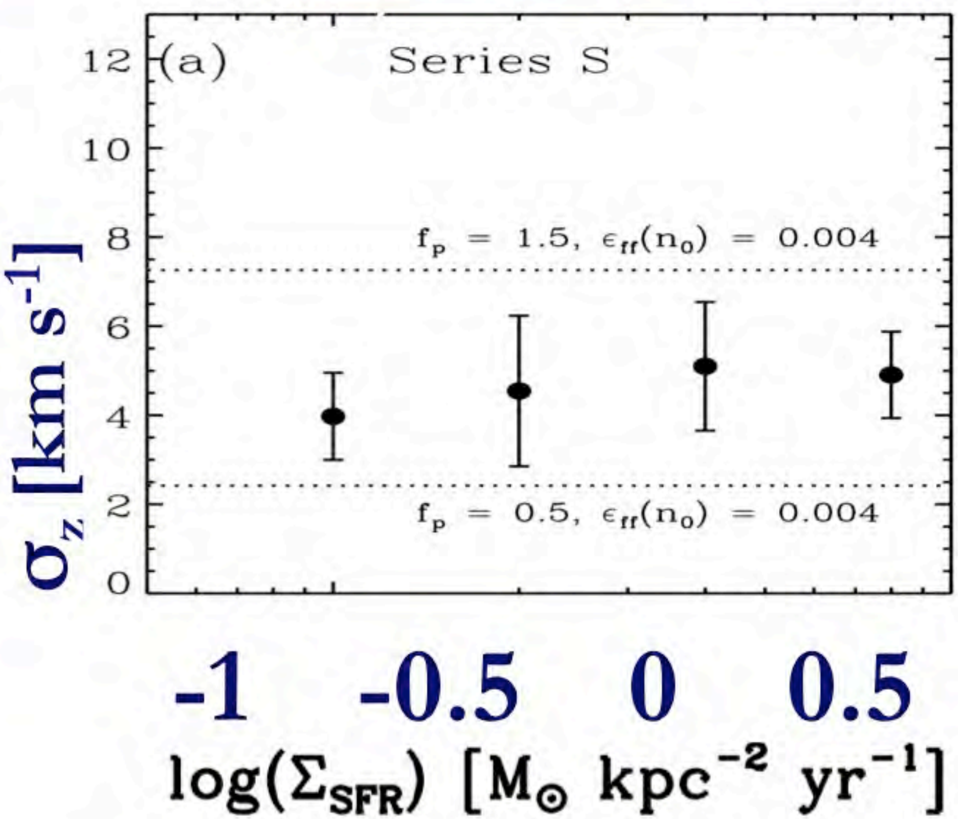
SFR per Free-fall time

$$\sigma_v = 5.5\,\mathrm{km\,s^{-1}}\; f_p \left(\frac{\epsilon_{\rm ff}(n_0)}{0.005}\right)\left(\frac{p_*/m_*}{3000\,\mathrm{km\,s^{-1}}}\right)$$

Momentum Input per SN

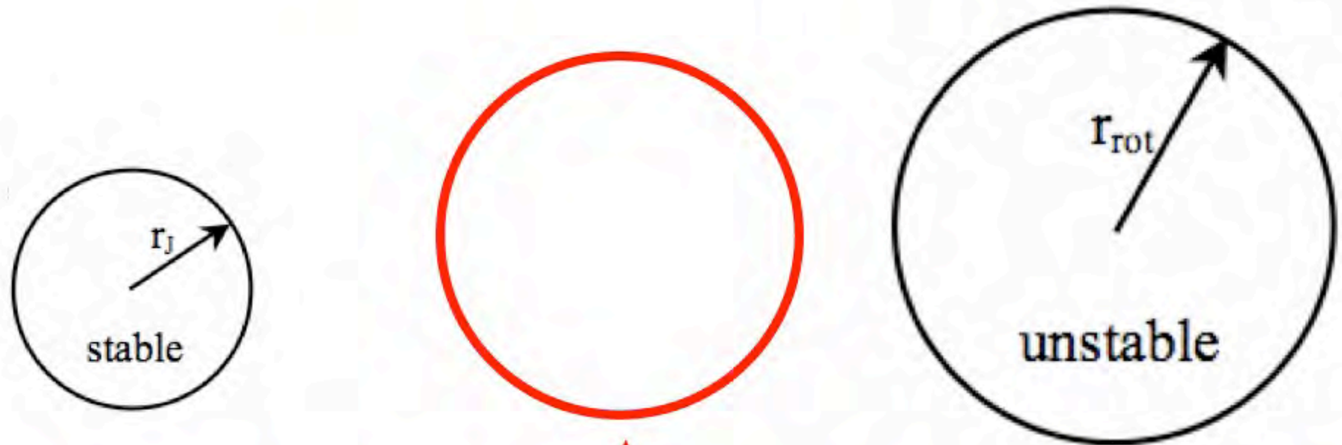


Shetty & Ostriker (2012)



Kim, Ostriker, & Kim (2013)

What if Q is not ≈ 1?



Pressure support vs Gravity **Rotational support vs Gravity**

Intermediate Scale modes will collapse (horizontally) with velocities comparable to σ_{1D} in the stable case.

Pure Horizontal Driving

$$\frac{D\rho}{Dt} = 0,$$

$$\frac{D\rho u_i}{Dt} + \frac{\partial P}{\partial x_i} = \rho g_i + \rho \boxed{f_i}$$

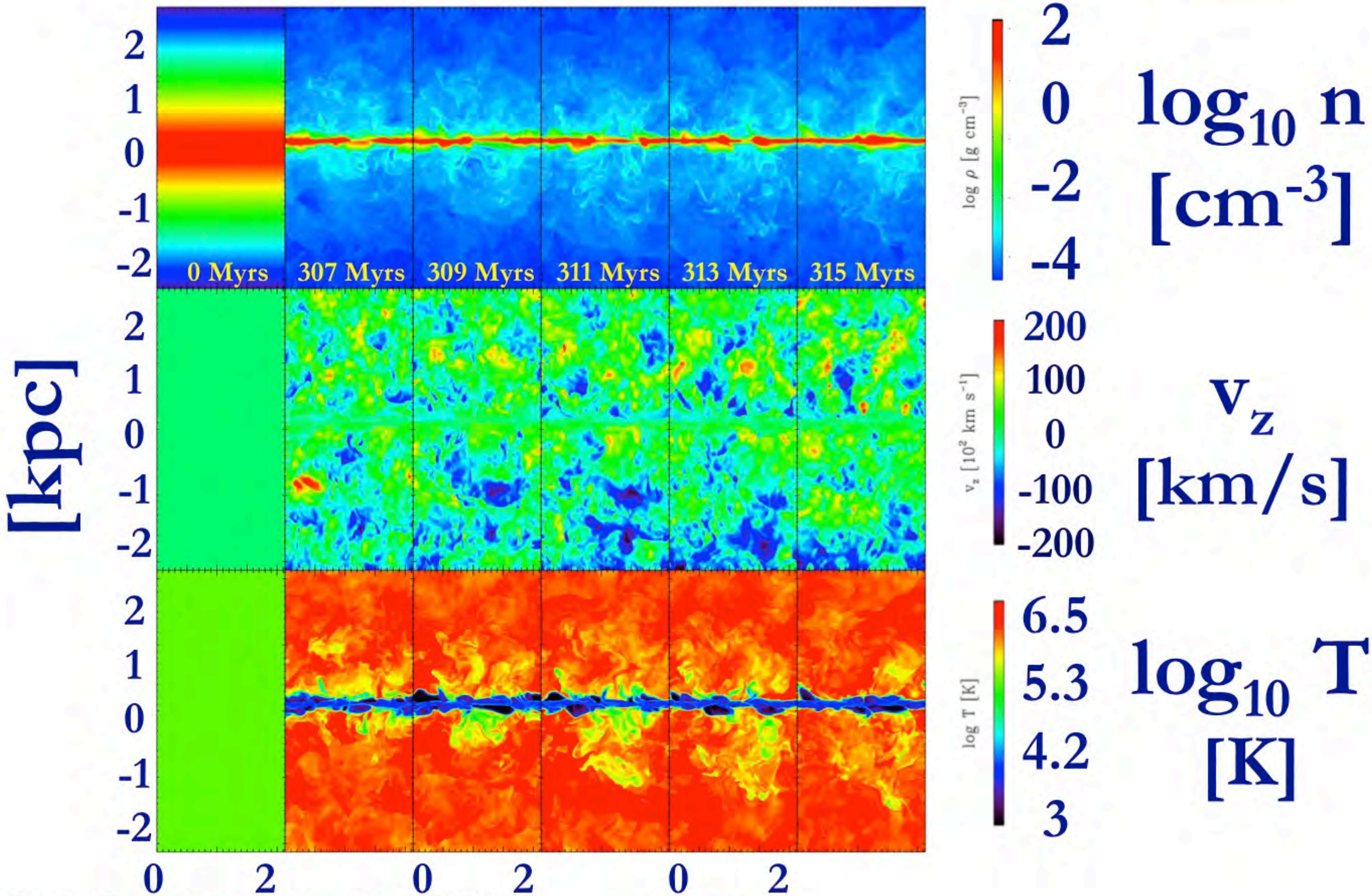
$$\frac{D\rho E}{Dt} + \frac{\partial P u_j}{\partial x_j} = \rho \dot{E}_{\mathrm{cool}}$$

512×256^2 Boxes

No Supernovae At all (Sorry)!

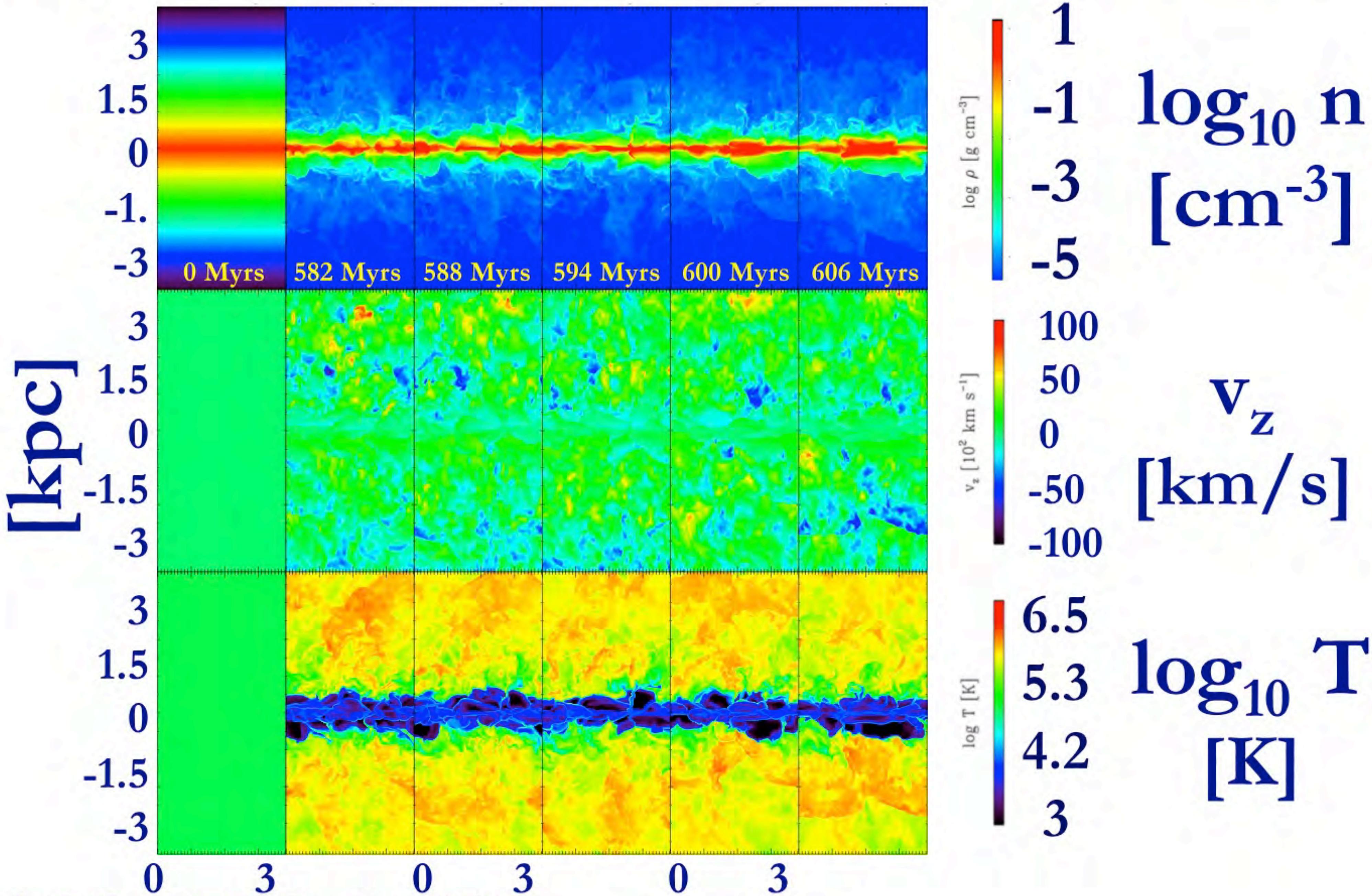
ES, S. Sur, & E. Ostriker (2015)

Σ_g=250 $M_\odot$ pc^{-2}, κ^{-1}=10 Myr, σ_{1D}= 50 km/s



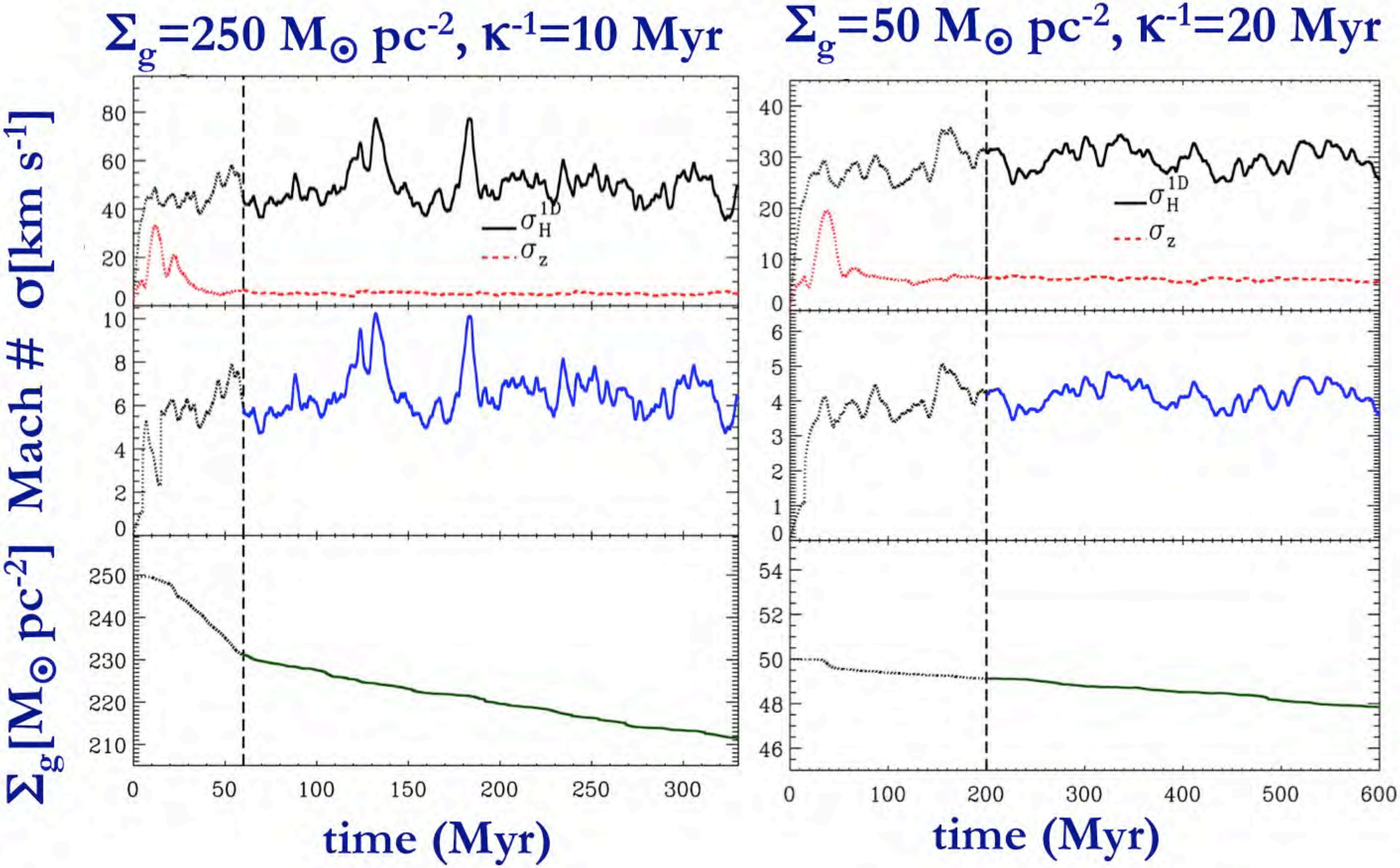
ES, S. Sur, & E. Ostriker (2015)

Σ_g=50 $M_\odot$ pc^{-2}, κ^{-1}=20 Myr, σ_{1D}= 20 km/s



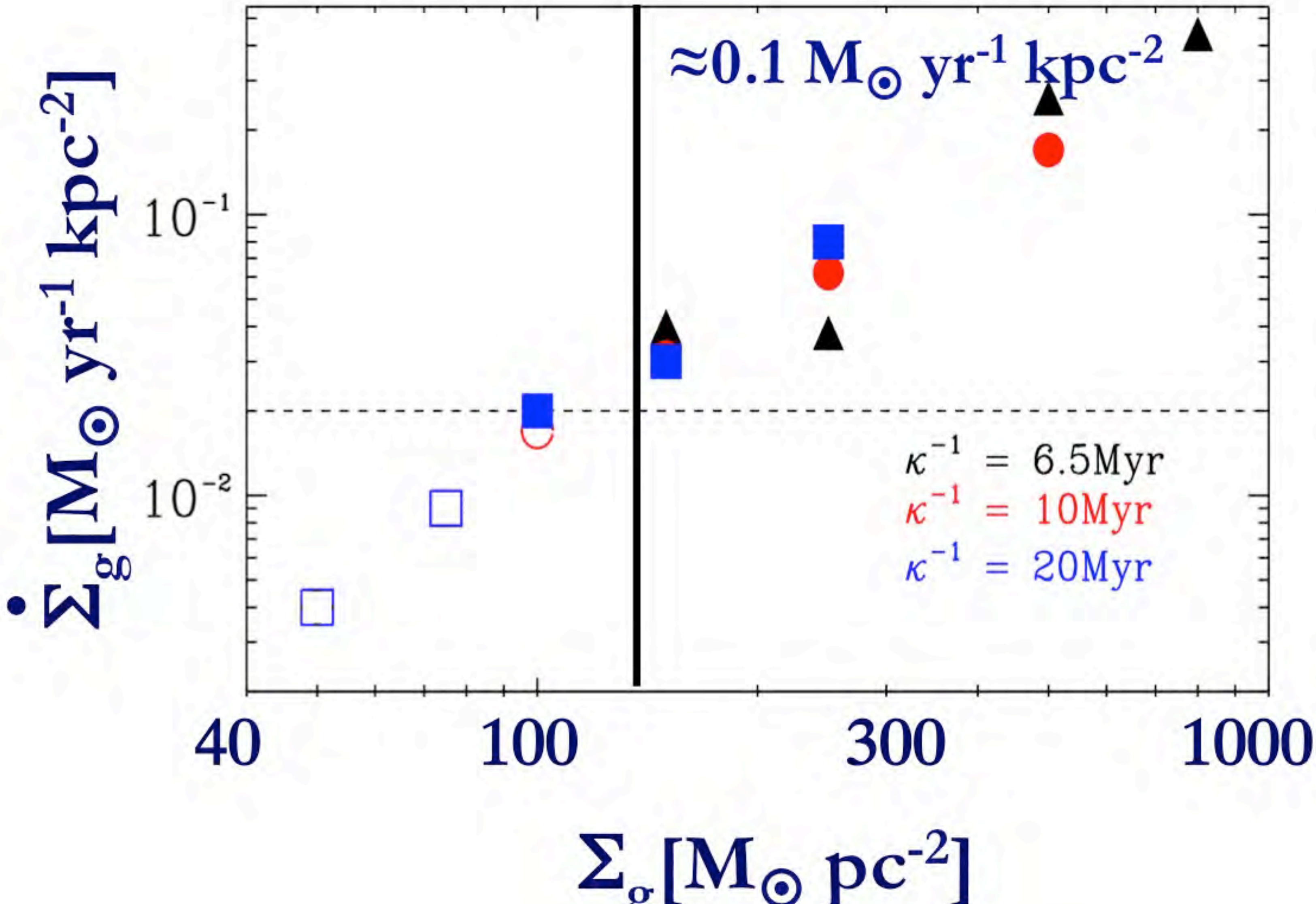
ES, S. Sur, & E. Ostriker (2015)

Evolution

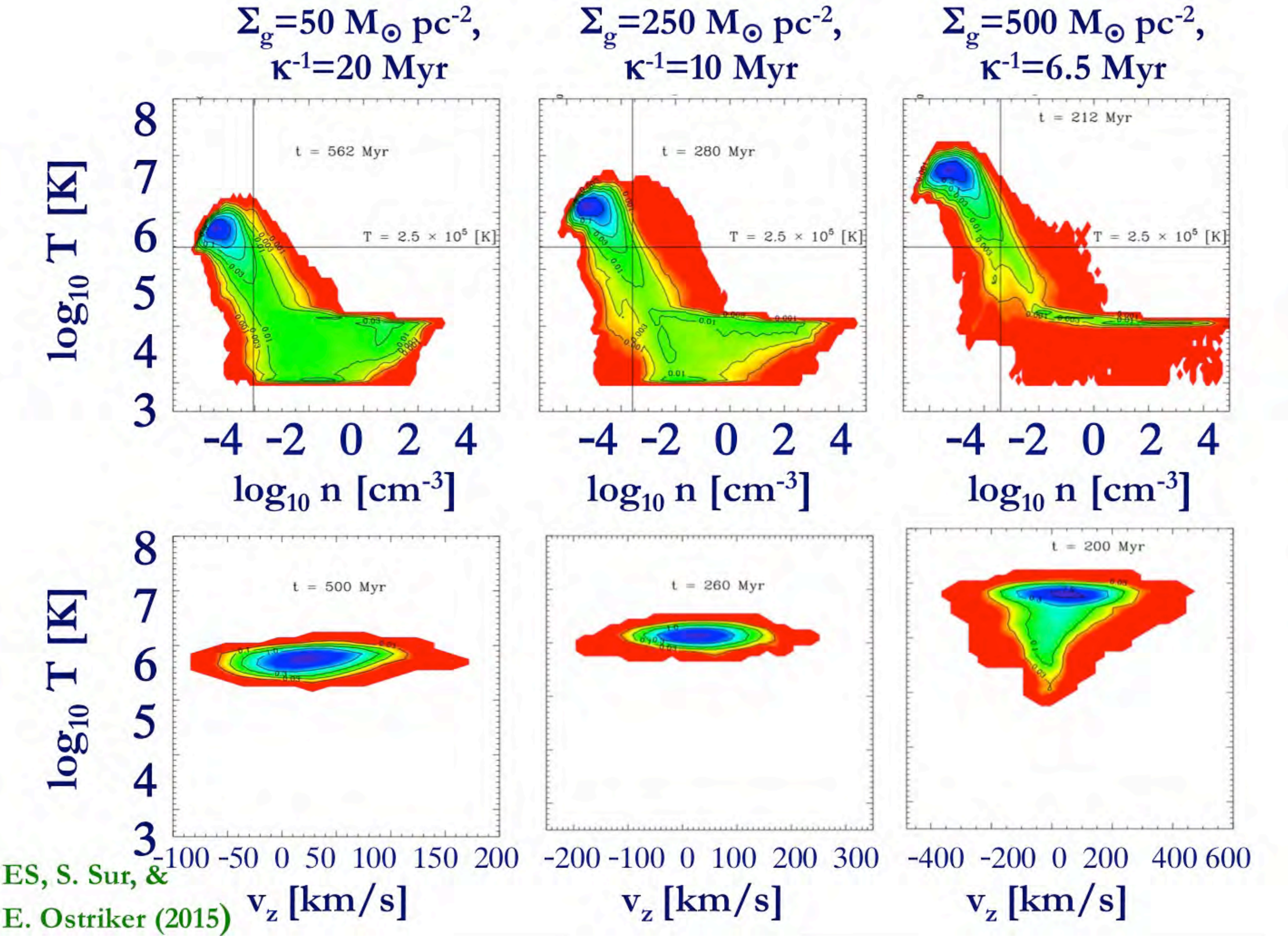


ES, S. Sur, & E. Ostriker (2015)

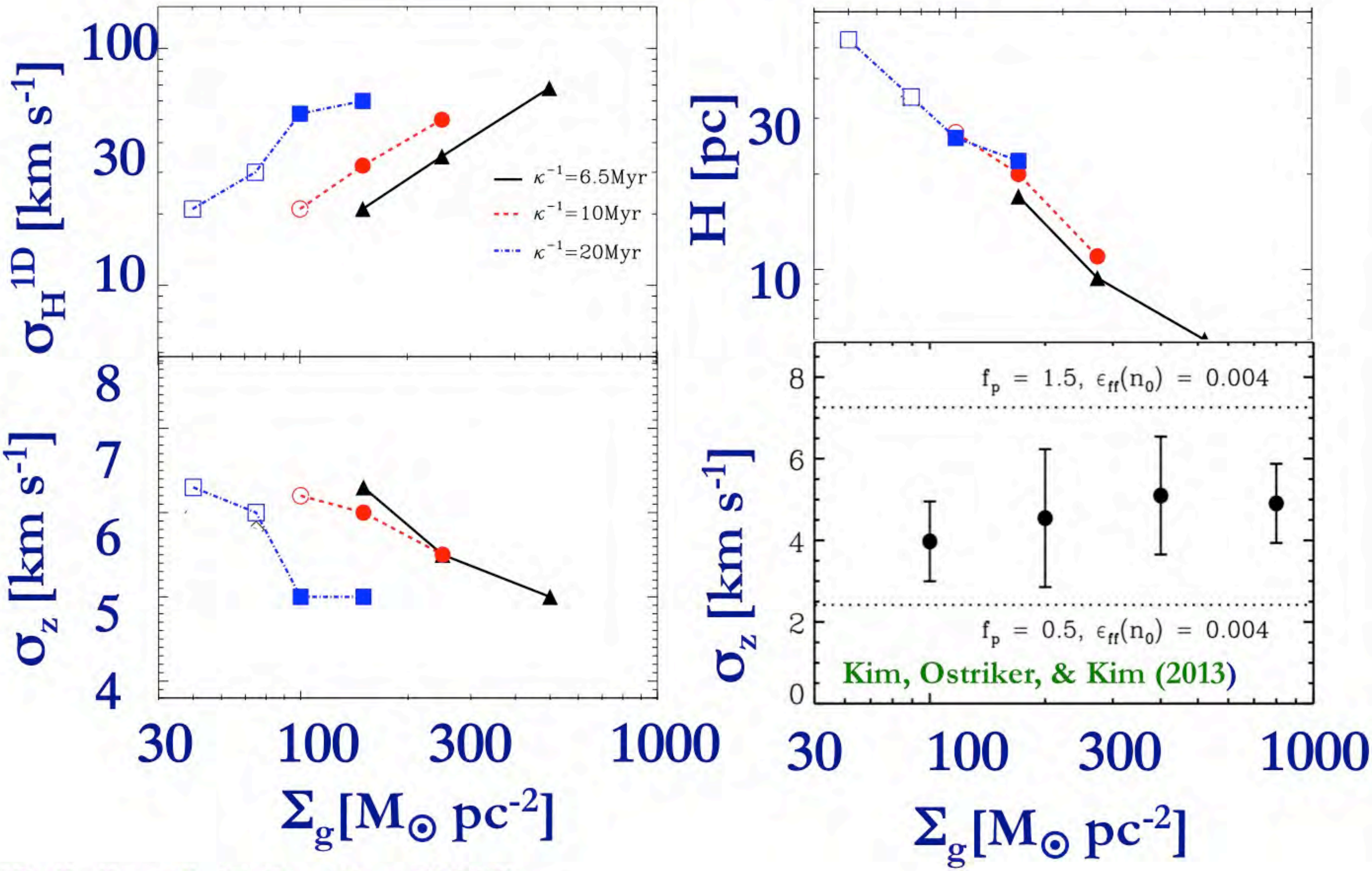
Mass Loss Rate



ES, S. Sur, & E. Ostriker (2015)


Σ_g=50 $M_\odot$ pc^{-2}, κ^{-1}=20 Myr
Σ_g=250 $M_\odot$ pc^{-2}, κ^{-1}=10 Myr
Σ_g=500 $M_\odot$ pc^{-2}, κ^{-1}=6.5 Myr
$\log_{10}$ T [K]
t = 562 Myr
t = 280 Myr
t = 212 Myr
T = 2.5 × 10^5 [K]
$\log_{10}$ n [cm^{-3}]
t = 500 Myr
t = 260 Myr
t = 200 Myr
v_z [km/s]
ES, S. Sur, &
E. Ostriker (2015)

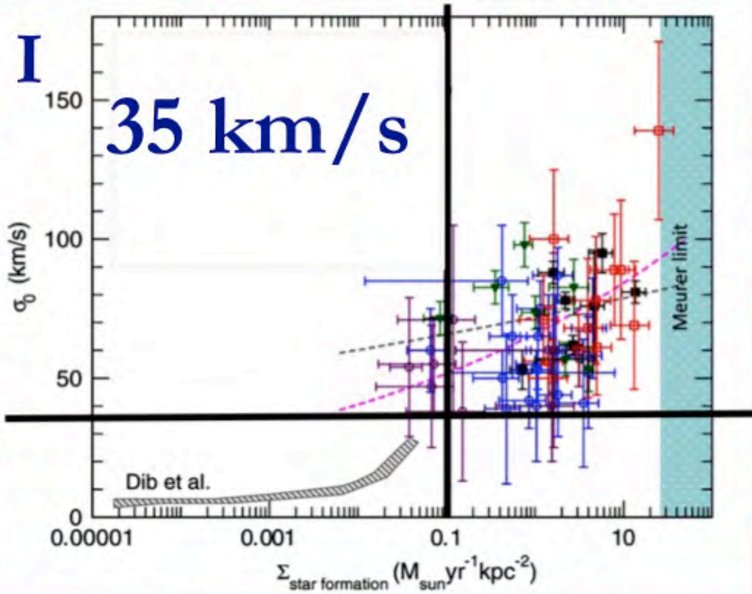
Disk Thickness / σ_z Stay Small!



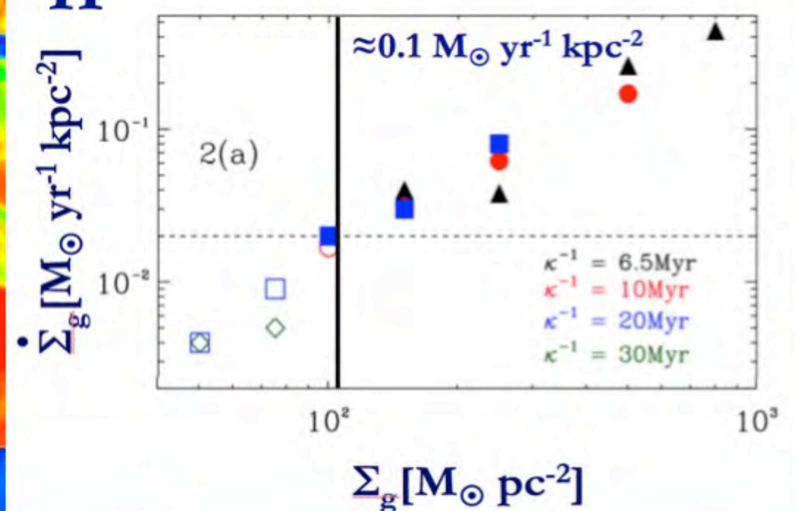
ES, S. Sur, & E.Ostriker (2015)

Conclusions

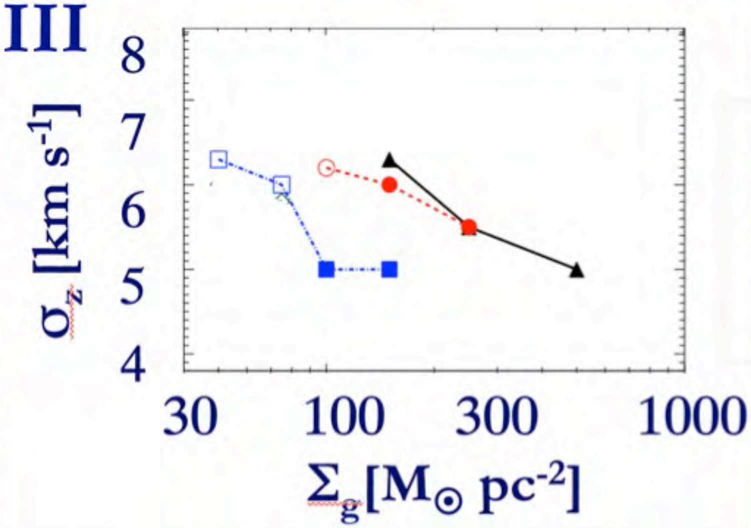
I



II



III



IV

Mind where you put your supernovae!