Thermal and Turbulent Feedback in Simulations of Isolated Disk Galaxies

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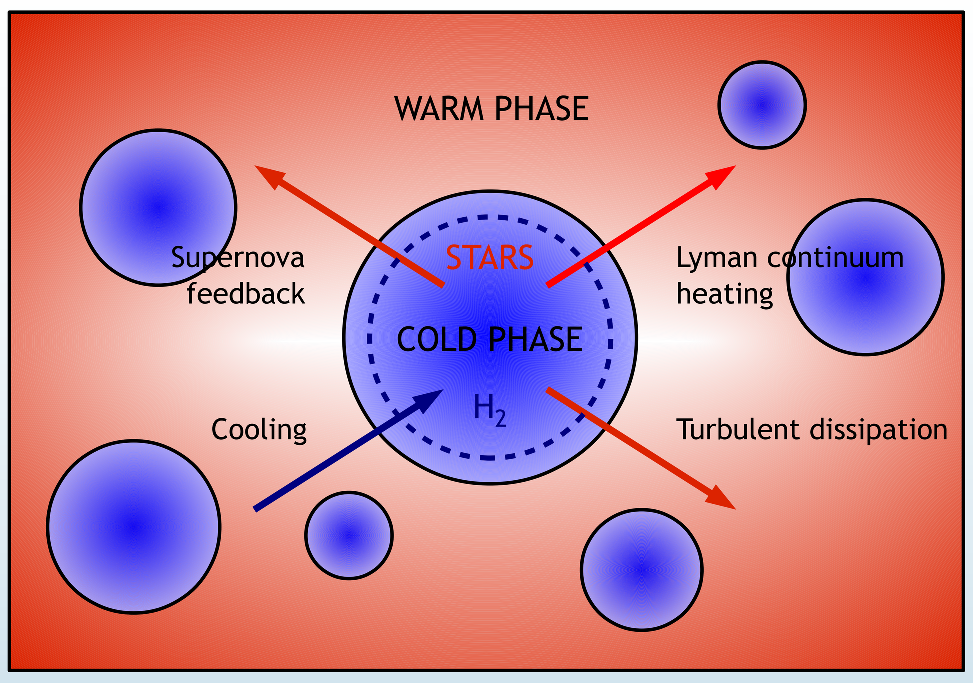
NUMERICAL MODEL



Two-phase model:

- Gas contents of each cell is split into *warm* and *cold phases* (Springel & Hernquist 2003)
- Density fractions ρ_c and ρ_w are determined by equilibrium of *effective (thermal + turbulent) pressures*
- Cold gas is converted into *stellar mass* at a rate $\dot{\rho}_s = \varepsilon_{core}\frac{\mathrm{SFR}_{ff} f_{H_2}\rho_c}{t_{c,ff}}$ where $t_{c,ff} \propto (G\rho_c)^{-1/2}$
- Approach similar to Krumholz et al. (2009) is applied to calculate the *molecular gas fraction*
- Local *star formation efficiency* based on Padoan & Nordlund (2011):

$$\mathrm{SFR}_{ff} = \int_{x_{crit}}^{\infty} x p(x)\,\mathrm{d}x \text{ where } x_{crit} \propto \frac{M^2_{c,\,sgs}}{\alpha_{vir}} \propto \frac{K^2}{G\rho_c c^2_{s,c}}$$

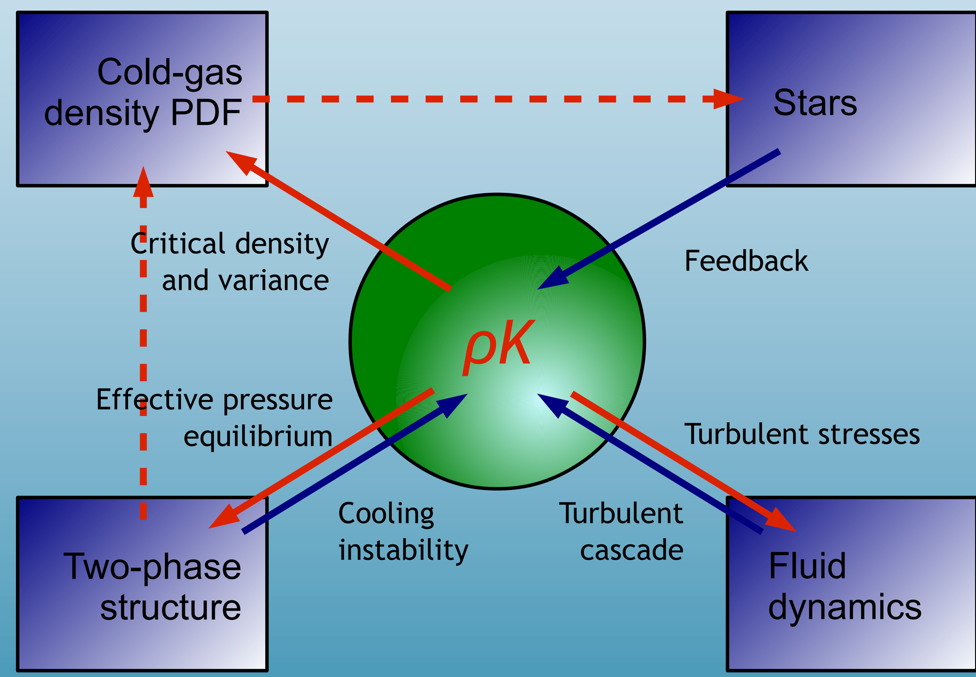
- Cold-gas density PDF is assumed to be *log-normal*, depending on the turbulent Mach number (Federrath et al. 2010) $\sigma^2 = \ln\left(1+b^2 M^2_{c,\,sgs}\right)$

Subgrid-scale turbulence energy model:

PDE for numerically unresolved turbulence energy (Schmidt & Federrath 2011):

$$\frac{\partial}{\partial t}\rho K + \nabla\cdot(\rho \mathbf{u} K) = \nabla\cdot\left(\rho C_\kappa \Delta K^{1/2}\nabla K\right) + \varepsilon_{SN} e_{SN}\dot{\rho}_{s,fb} + (1-f_{th})\varepsilon_{tt}\Lambda_{eff}\rho_w + \tau^*_{ij}S_{ij} - \frac{2}{3}\rho K d - \rho C_\varepsilon \frac{K^{3/2}}{\Delta}$$

- *Internal driving* below the grid resolution due to supernova feedback and cooling instabilities (Braun & Schmidt 2012)
- Production through the turbulent cascade from larger scales (*external driving*)

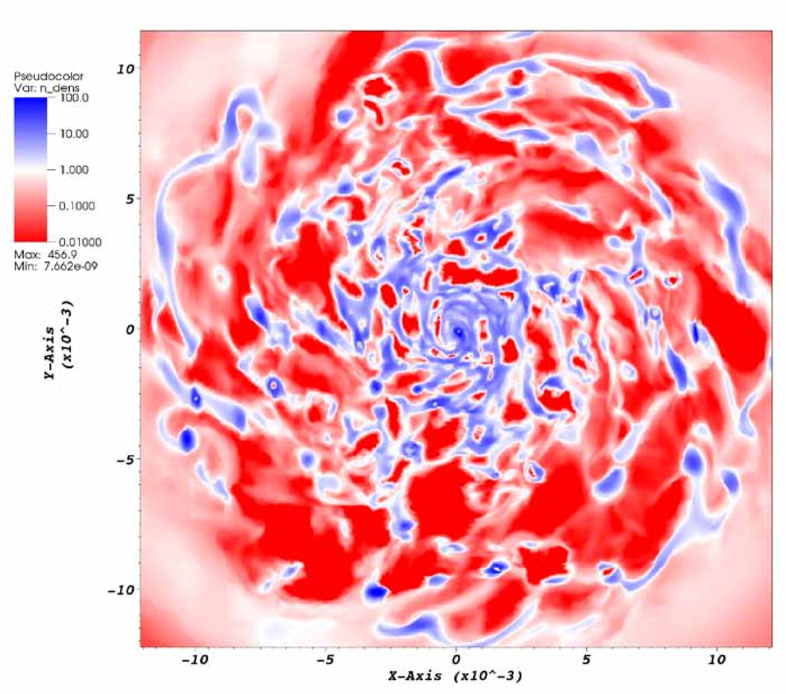


Isolated disk model:

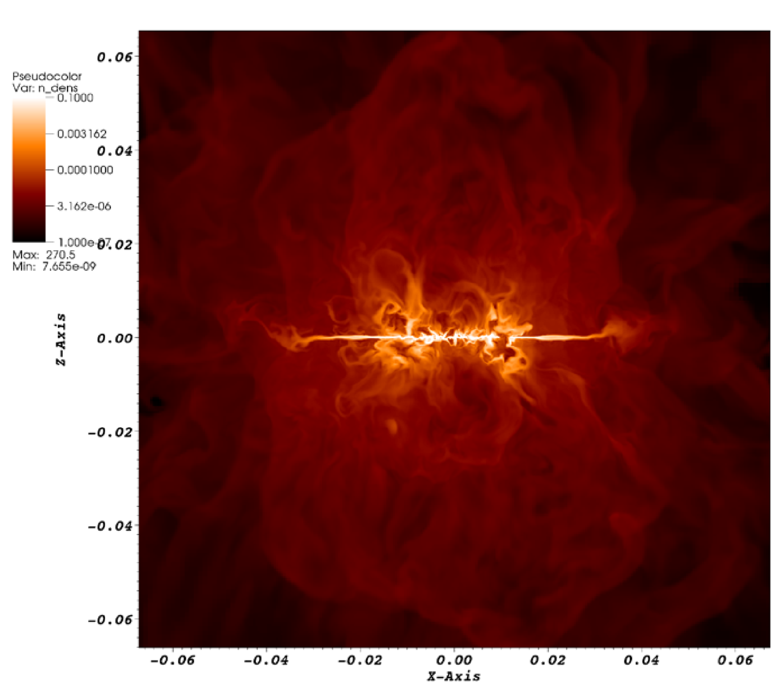
- Adiabatically stable gas disk (Wang et al. 2010)
- Implementation into the Nyx code (Almgren et al. 2013)

GASEOUS DISK

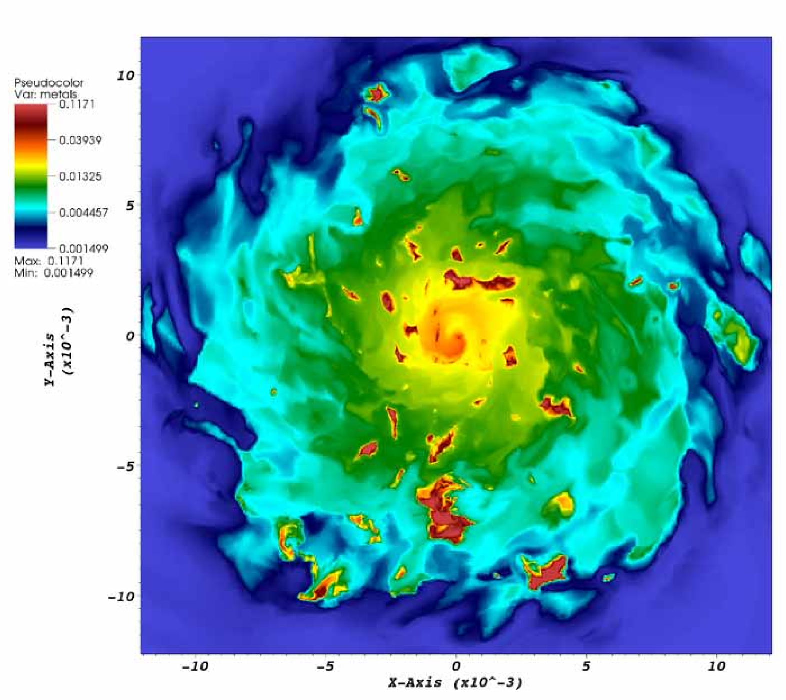
Number density (equatorial)



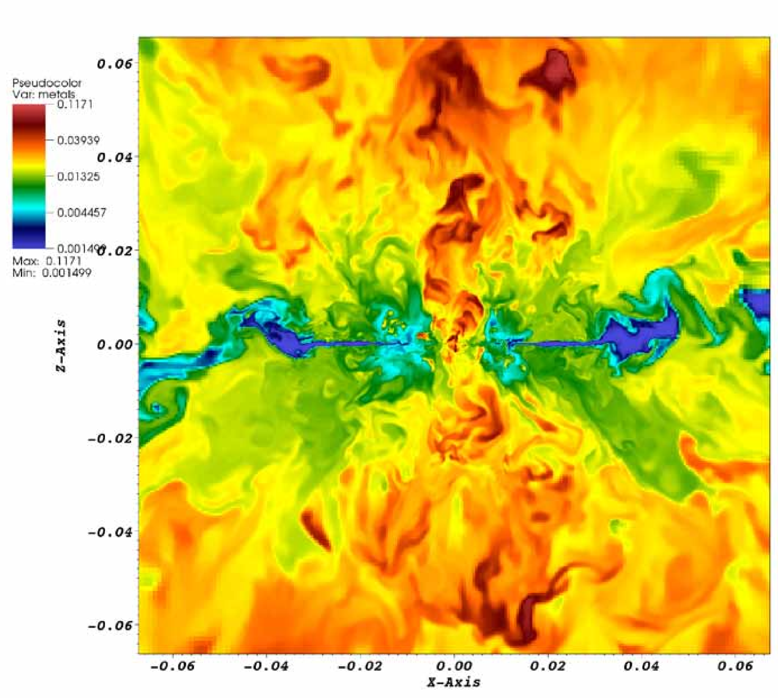
Number density (polar)



Metallicity (equatorial)

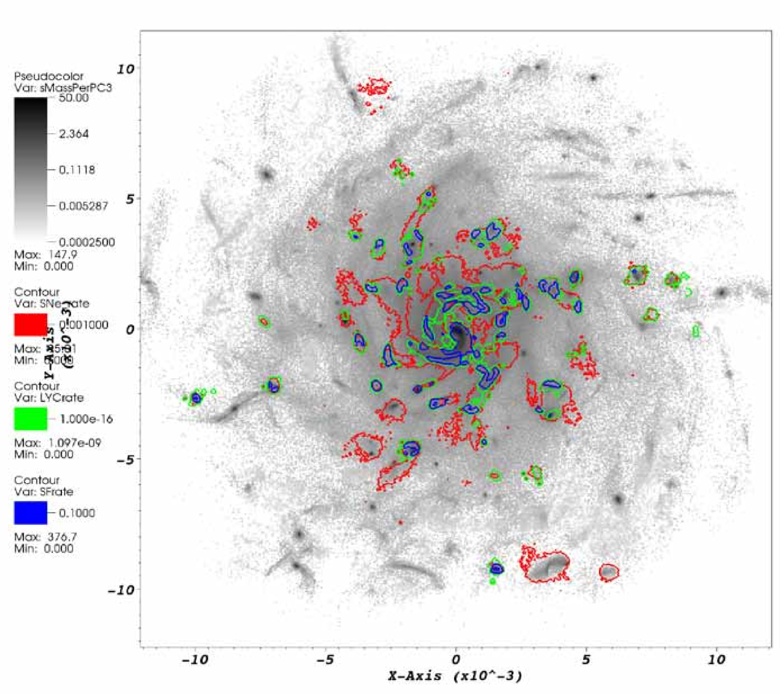


Metallicity (polar)

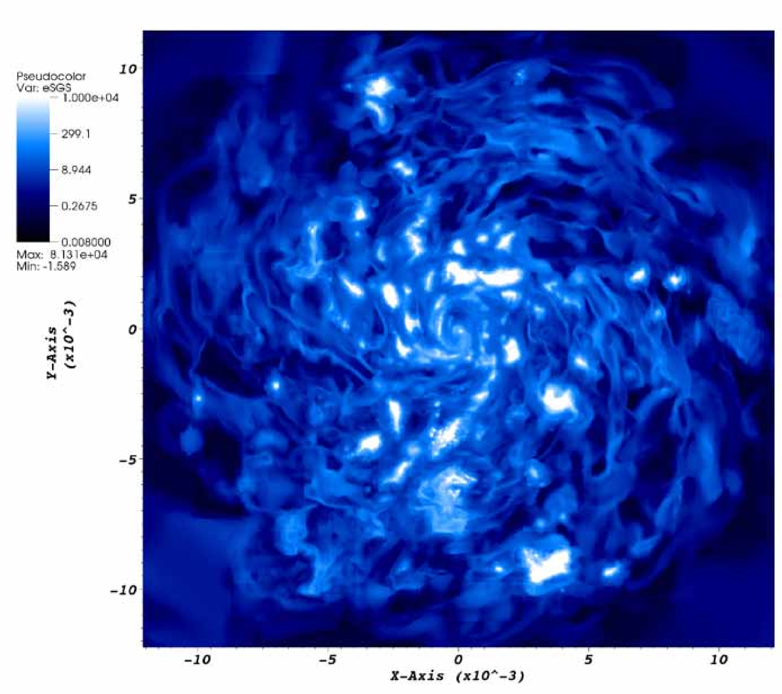


STELLAR DISK AND TURBULENCE

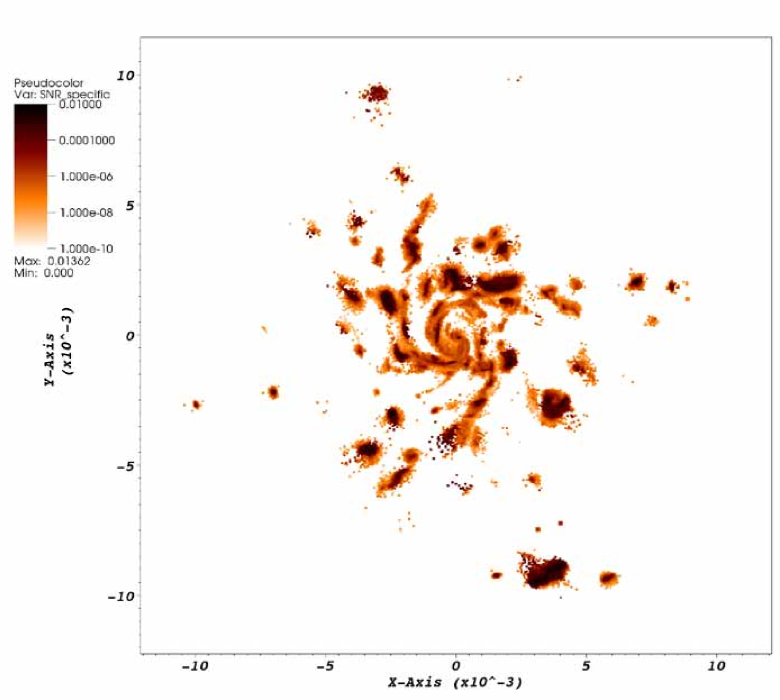
Stellar mass



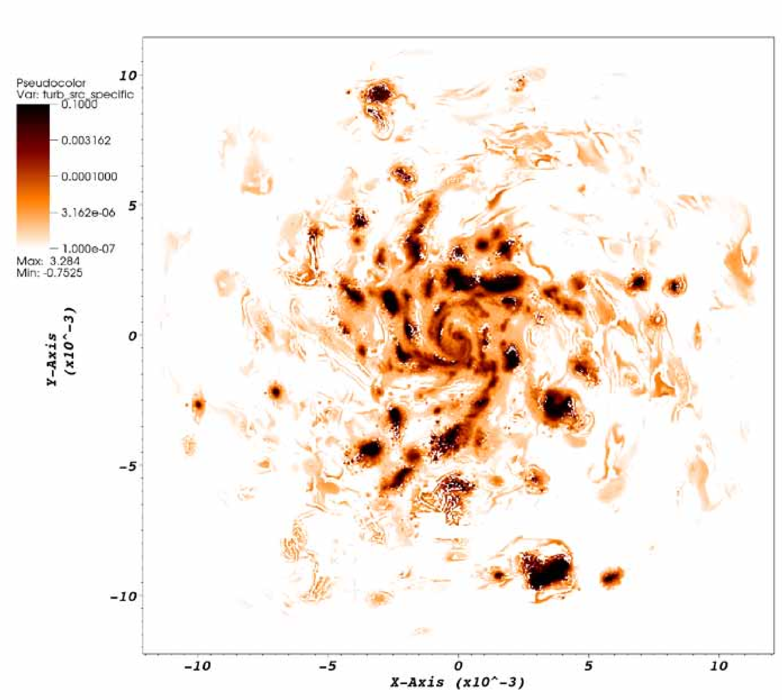
SGS turbulence energy



Supernova rate

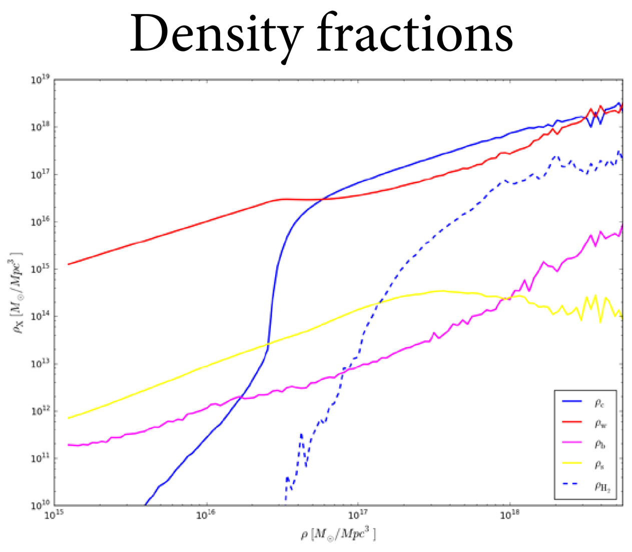


Internal turbulence driving

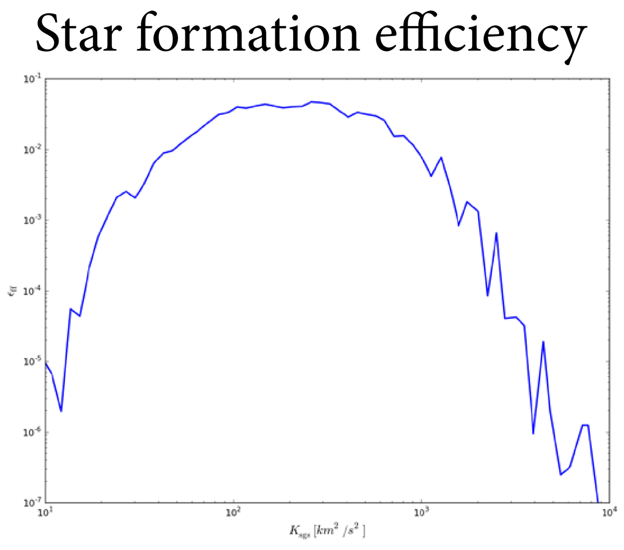


STATISTICS

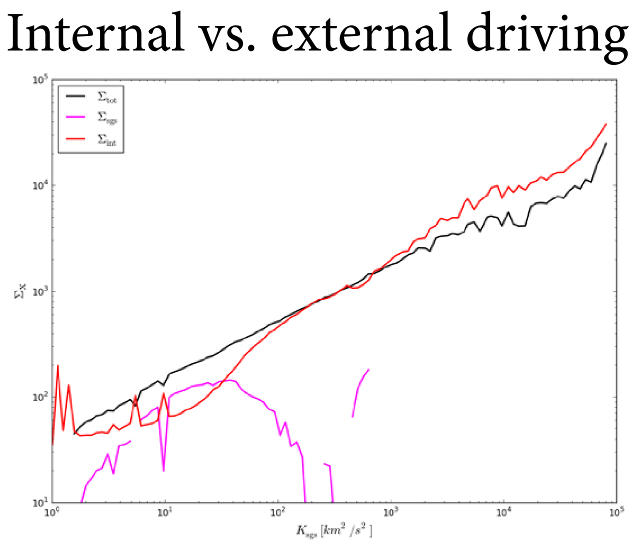
Density fractions



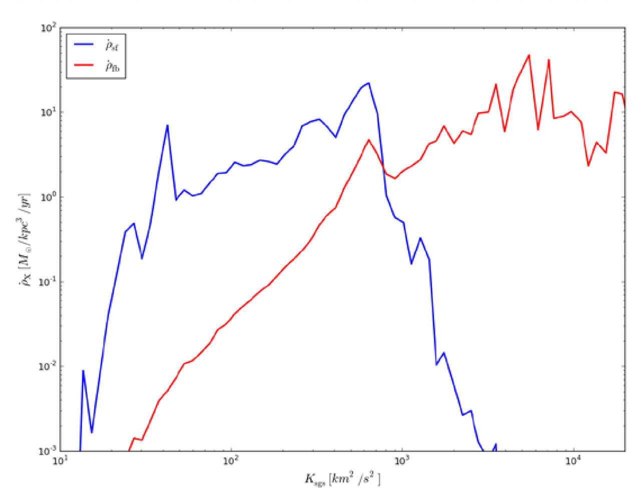
Star formation efficiency



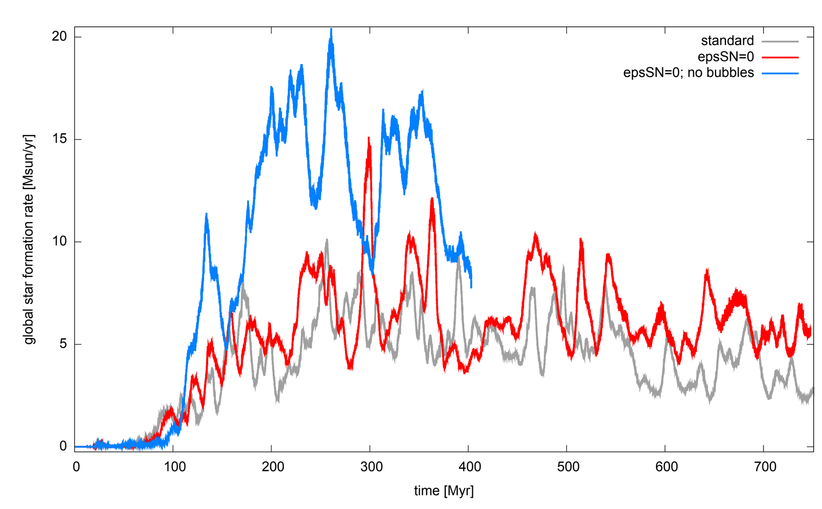
Internal vs. external driving



Star formation and feedback



Global star formation rate



- Star formation efficiency is maximal for moderate turbulence energy
- Feedback is associated with strong turbulence, external driving maintains a lower level of turbulence
- Apart from turbulent energy injection, hot gas bubbles produced by supernovae are crucial for regulation of star formation
- Feedback produces metal-enriched outflows from the disk