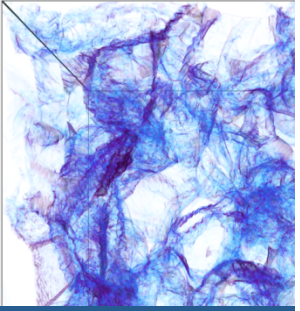

The Impact of the Star Formation Law & Feedback on Disk Galaxies

Wolfram Schmidt

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From Galactic to Extragalactic Star Formation, Marseille 2014

With thanks to

Ann S. Almgren, Harald Braun, Jan F. Engels, Christoph Federrath

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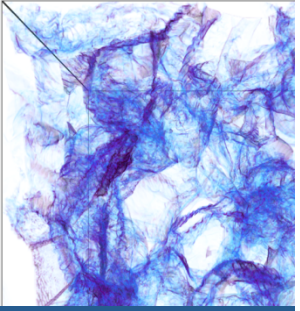
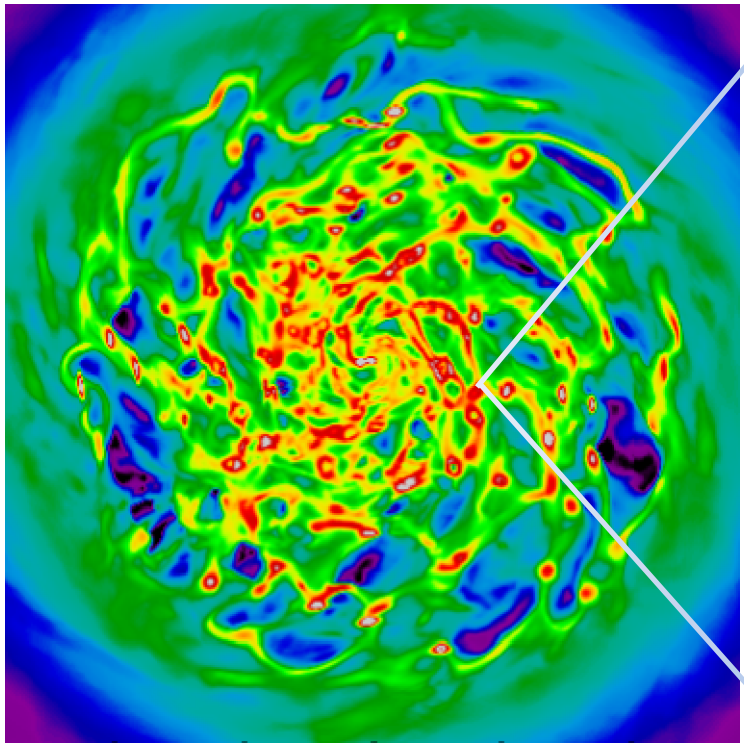


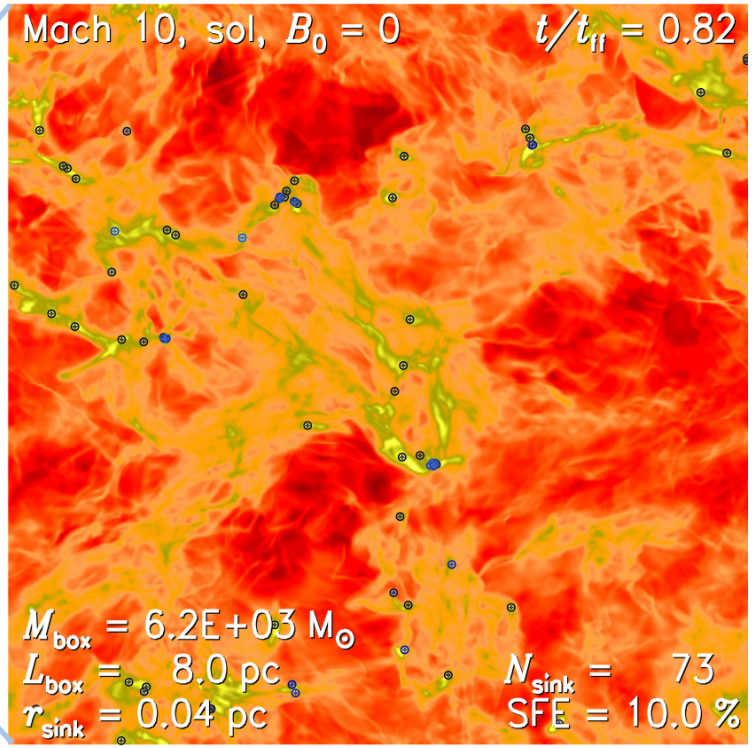
Galaxy simulation
(30 kpc)



Braun, Schmidt, Niemeyer, and Almgren; MNRAS 442 (2014)

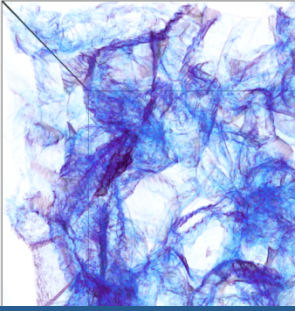
ρ

Self-gravitating turbulence simulation
(8pc)



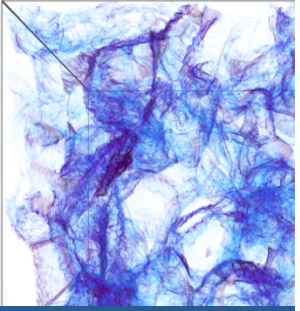
Federrath & Klessen, ApJ 761 (2012)

ρ'



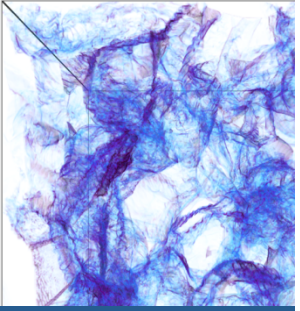
Analytical Models of Star Formation

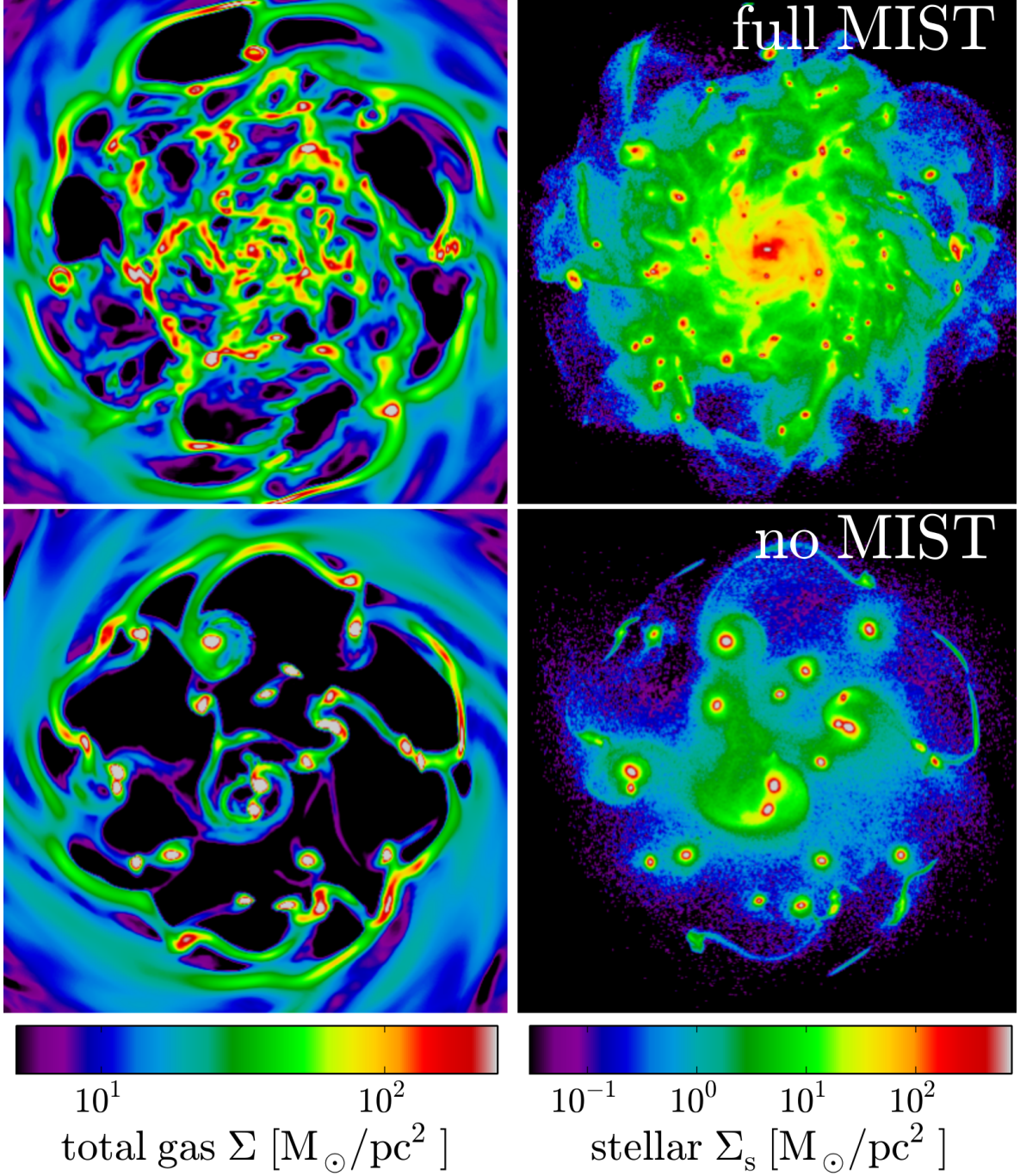
- Generic **star formation rate**: $\dot{\rho}_{\mathrm{s}} = \varepsilon_{\mathrm{ff}} \dfrac{\rho}{t_{\mathrm{ff}}}$
  - mean gas density $\rho = \rho_{\mathrm{tot}}, \rho_{\mathrm{c}}, \mathrm{or}\ f_{\mathrm{H}_2}\rho_{\mathrm{c}}$
  - free-fall time scale $t_{\mathrm{ff}} \propto (G\rho)^{-1/2}$
  - star formation efficiency $\varepsilon_{\mathrm{ff}}$
- Depends on **PDF of overdensity** $s = \log(\rho' / \rho)$
  - single free-fall: $\varepsilon_{\mathrm{sff}} = \dfrac{\varepsilon_{\mathrm{core}}}{\phi_{\mathrm{t}}} \displaystyle\int_{s_{\mathrm{crit}}}^{\infty} \dfrac{\rho'}{\rho} p(s')\,\mathrm{d}s'$
  - multi free-fall: $\varepsilon_{\mathrm{mff}} = \dfrac{\varepsilon_{\mathrm{core}} t_{\mathrm{ff}}(\rho)}{\phi_{\mathrm{t}}} \displaystyle\int_{s_{\mathrm{crit}}}^{\infty} \dfrac{\rho'}{\rho} \dfrac{p(s')}{t_{\mathrm{ff}}(\rho')}\,\mathrm{d}s'$
- **Criticial density** $s_{\mathrm{crit}} = \log(\rho_{\mathrm{crit}} / \rho)$ given by Krumholz et al. 2005, Padoan & Nordlund 2011, or Hennebelle & Chabrier 2011



Subgrid-Scale Model for Star Formation

- **Log-normal distribution** of density fluctuations
- Critical density is a function of
  - **turbulent Mach number** $M_\mathrm{t} \propto \sigma_\mathrm{t}(l) / c_\mathrm{s}$
  - **virial parameter** $\alpha \propto \sigma_\mathrm{t}^2(l) / \rho G l^2$
- Calibration from self-gravitating turbulence simulations e. g. by Federrath & Klessen (2012)
- **Large eddy simulations** of galaxies:
  - **subgrid** turbulent energy K : $\sigma_\mathrm{t}^2(\Delta), \Delta \sim 10\ \mathrm{pc}$
  - **clump scale** $l < 1\ \mathrm{pc}$: $\sigma_\mathrm{t}^2(l)$: $(l / \Delta)^{2\eta} K$
  - evaluate **local efficiency** from Mach number and virial parameter in each grid cell



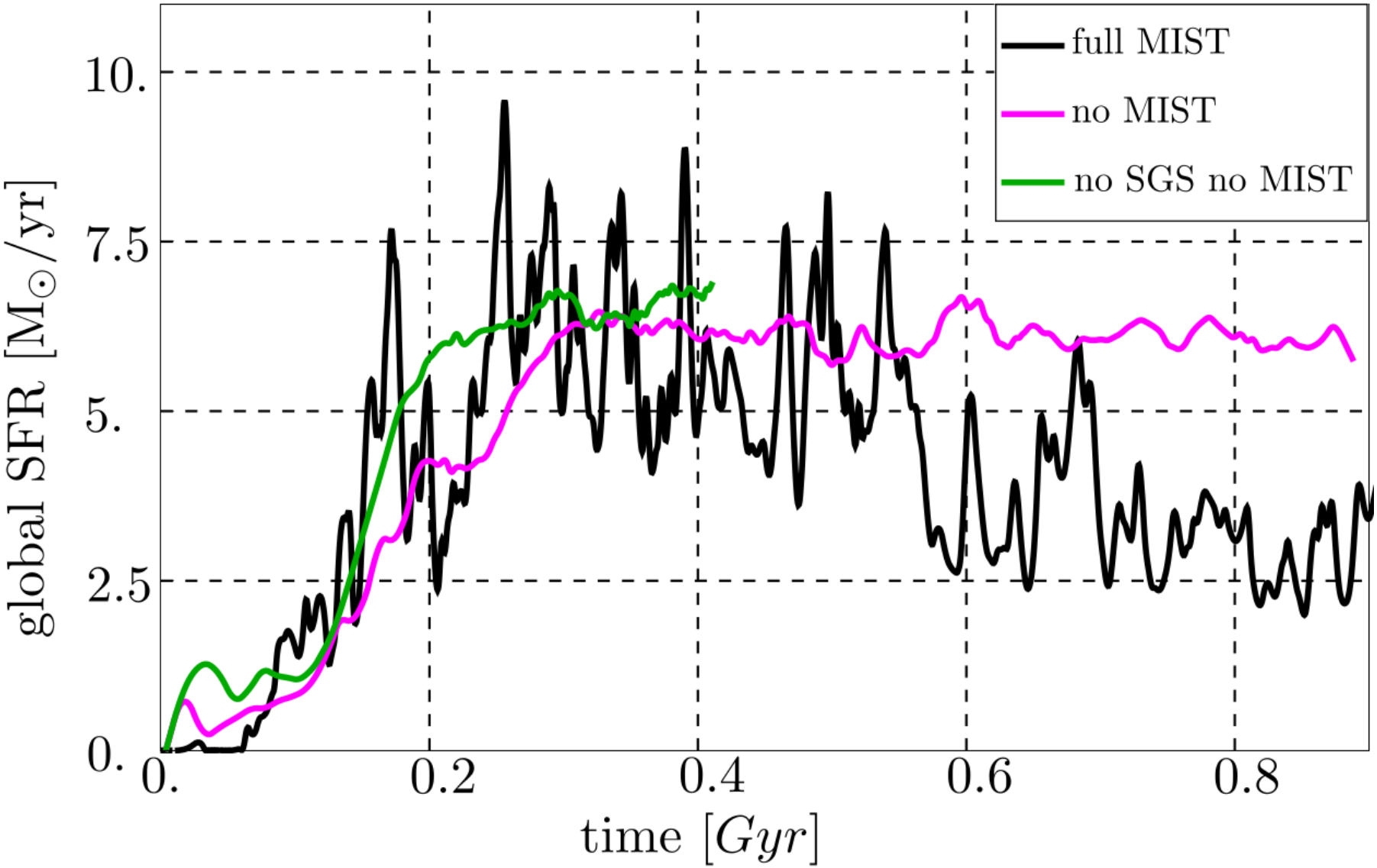


Nyx simulations of an isolated disk galaxy with **Multiphase Interstellar medium, Star formation and Turbulence model (MIST)**

Braun, Schmidt, Niemeyer, and Almgren; MNRAS 442 (2014)

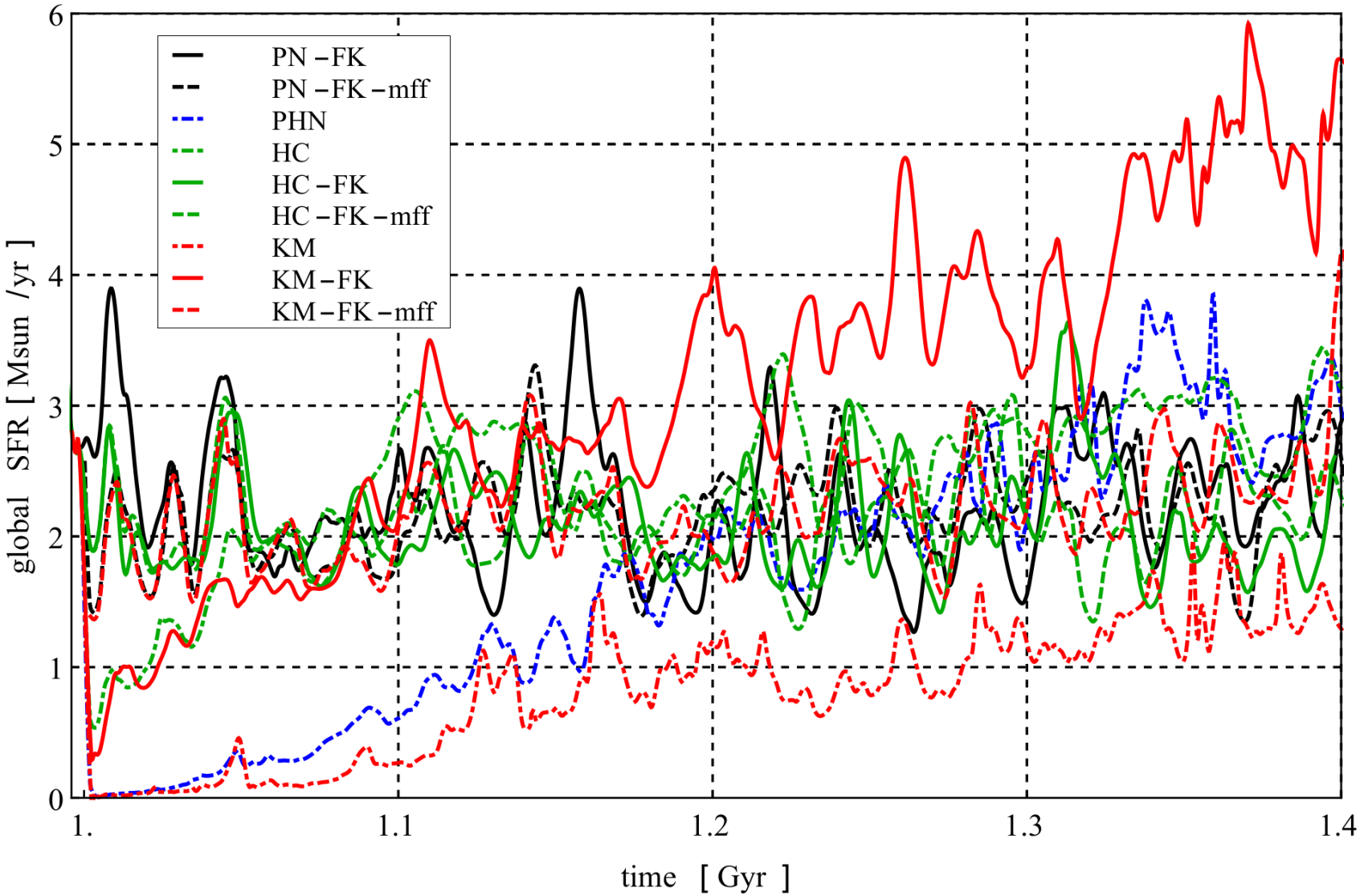
Global Star Formation Rate

Braun, Schmidt, Niemeyer, and Almgren; MNRAS 442 (2014)



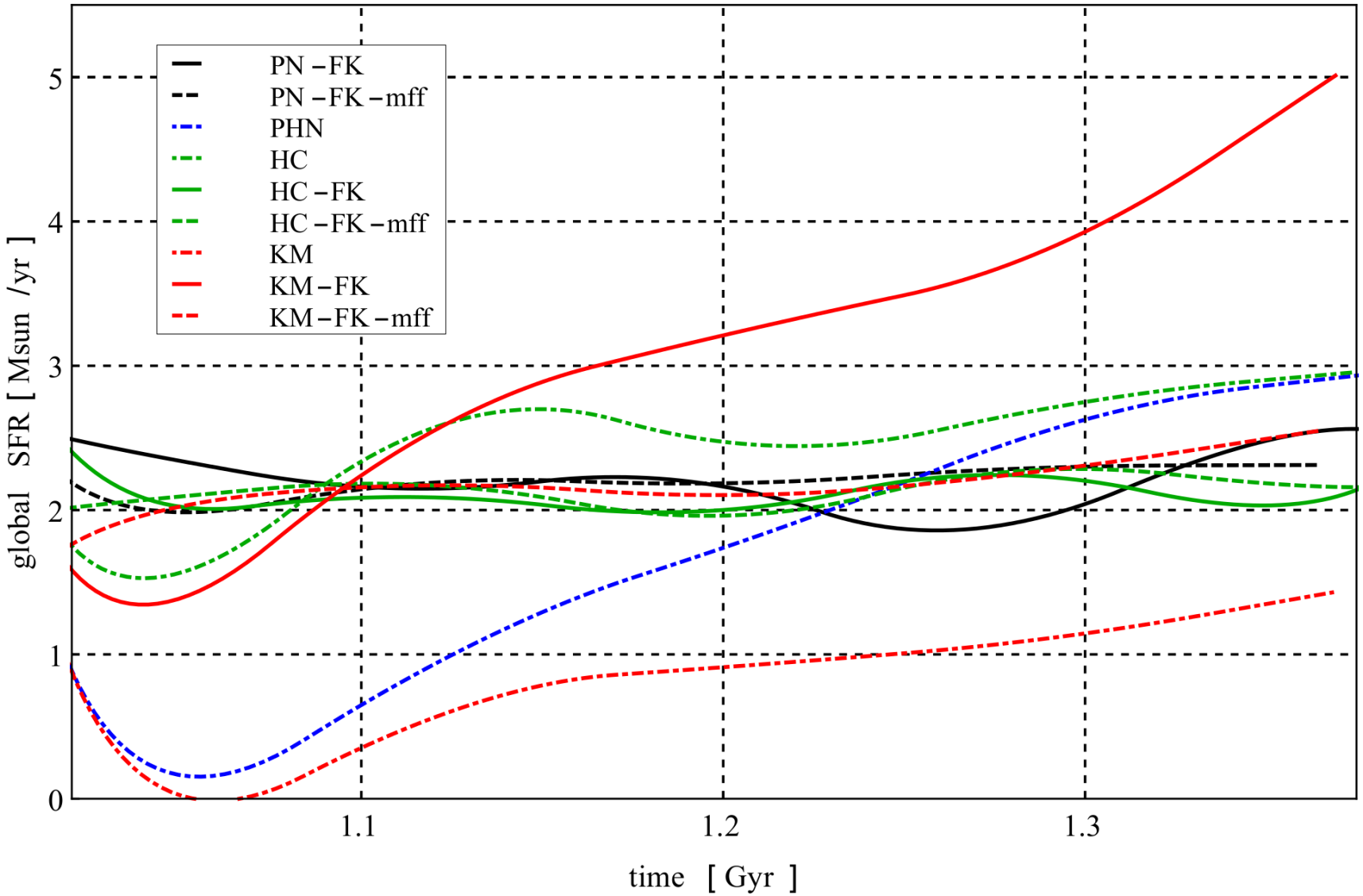
Global Star Formation Rate

Braun, Schmidt, Niemeyer, and Almgren in preparation

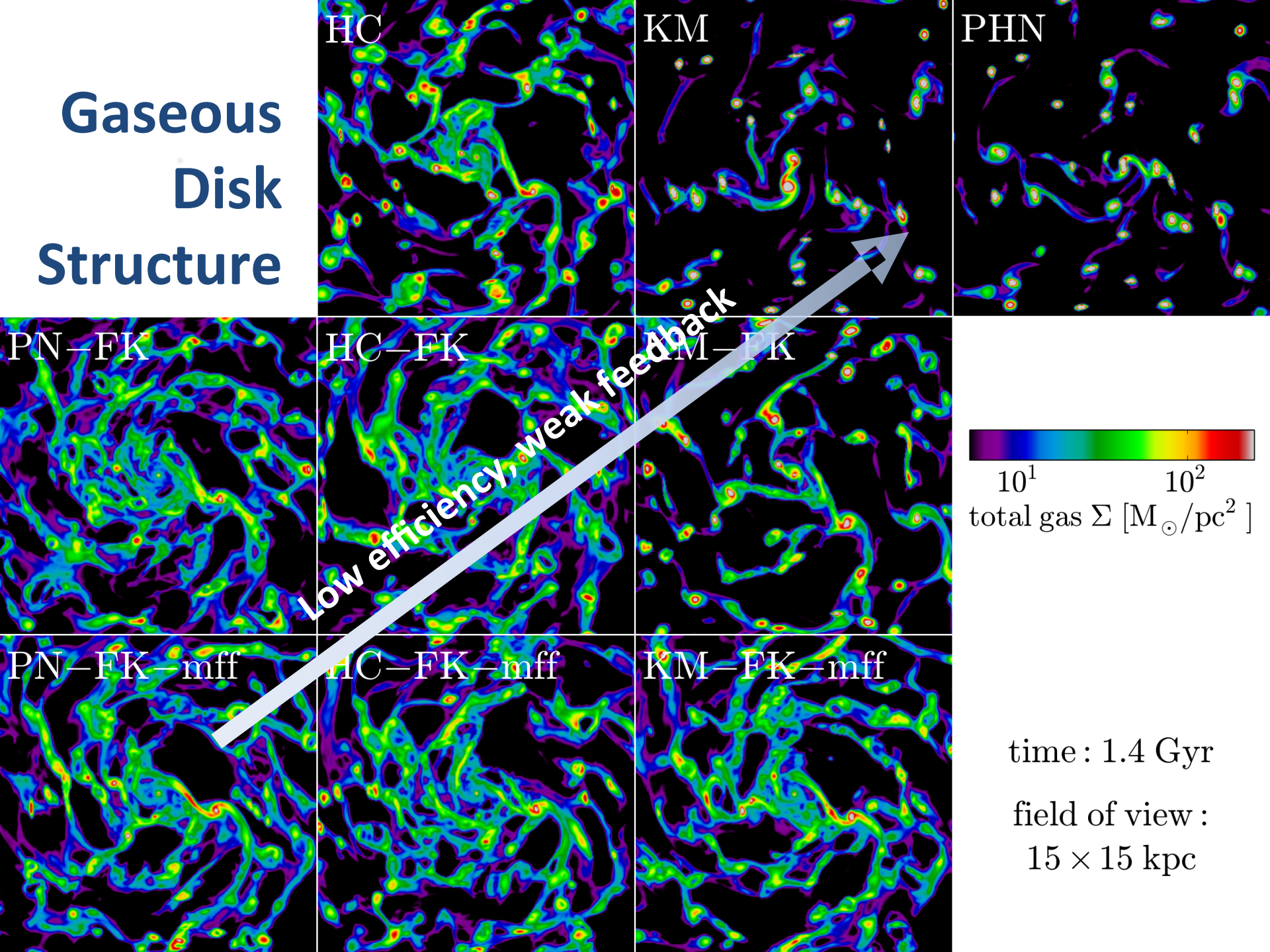


Smoothed Global Star Formation Rate

Braun, Schmidt, Niemeyer, and Almgren in preparation

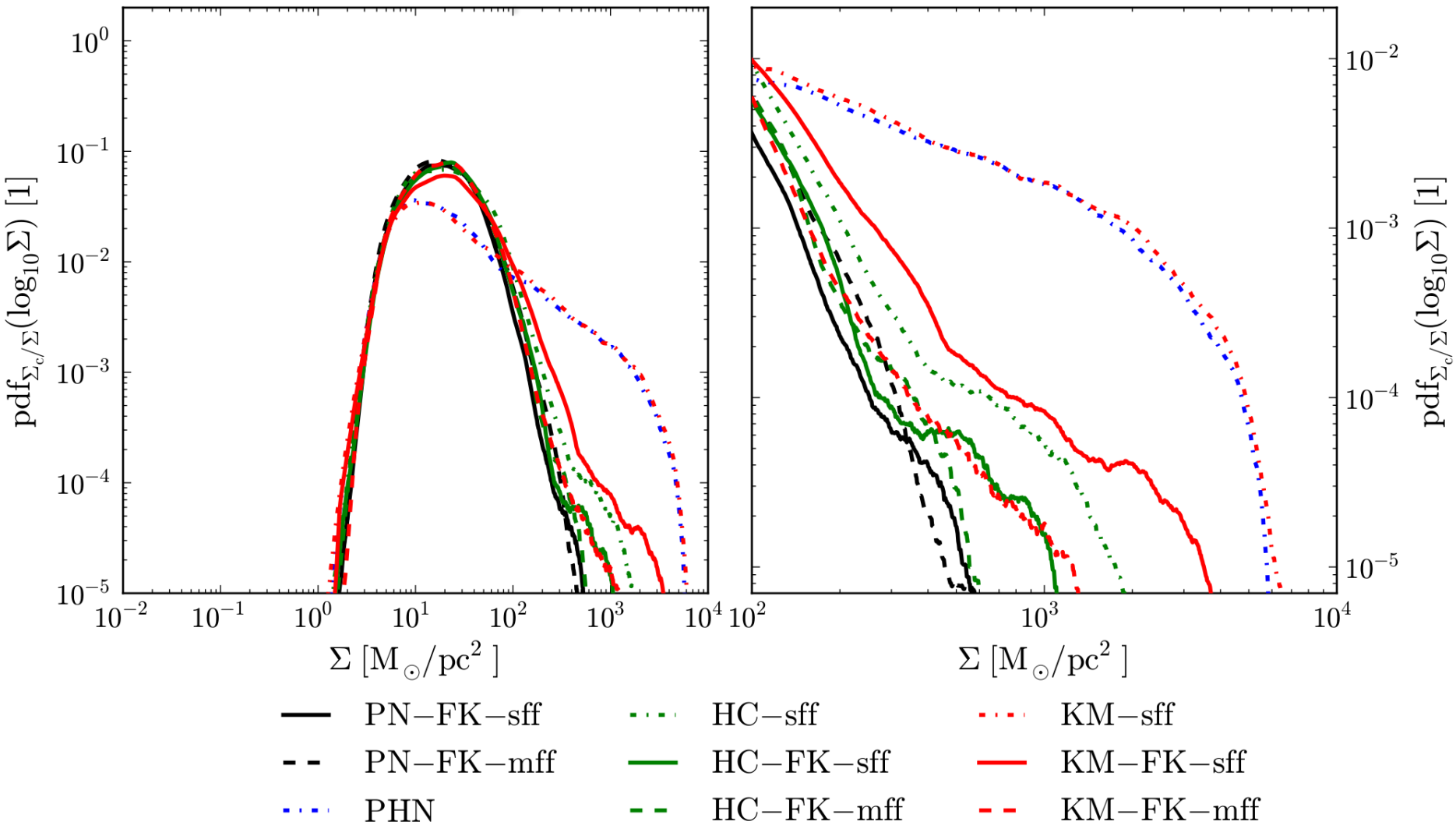


Gaseous Disk Structure

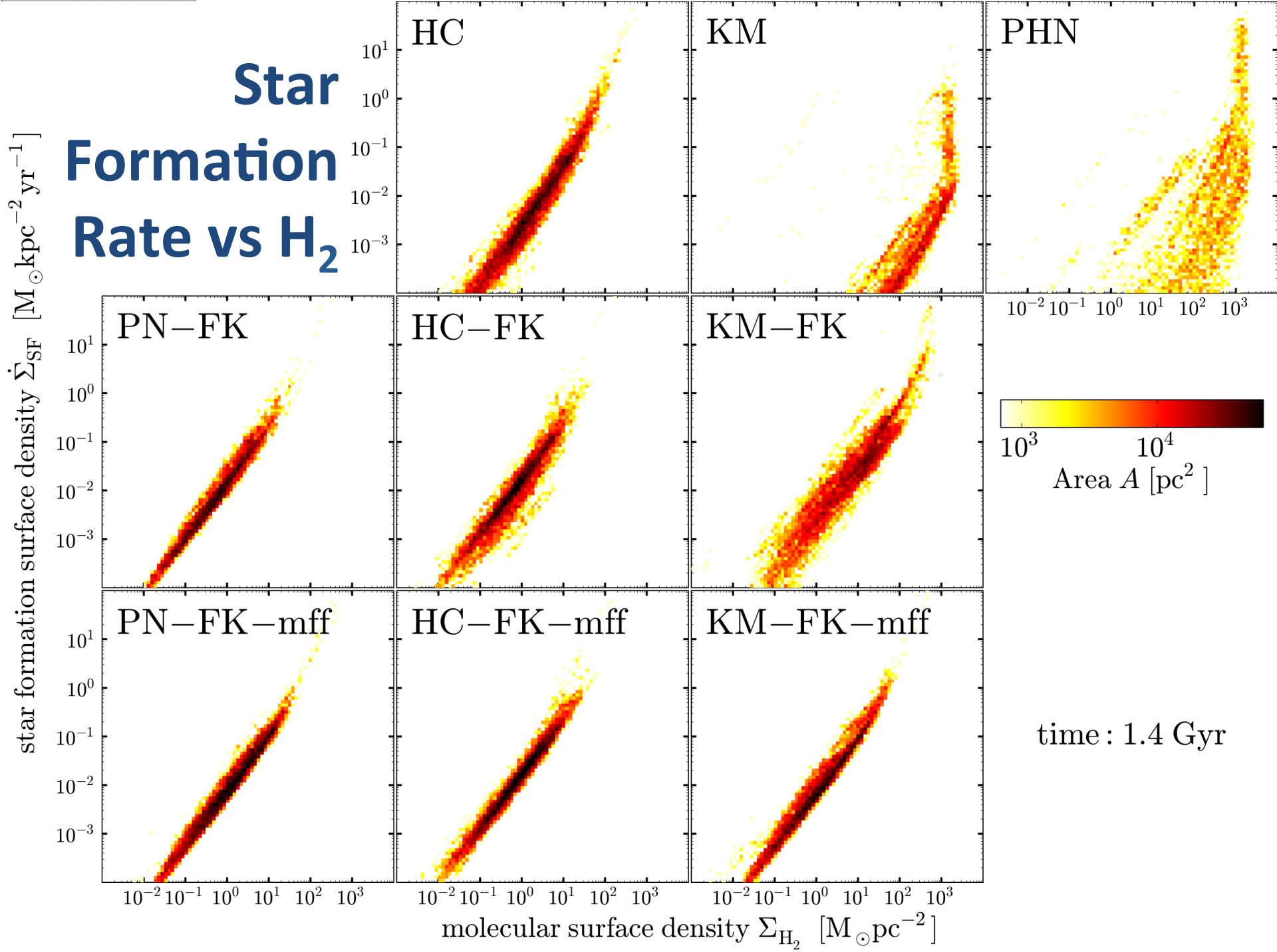


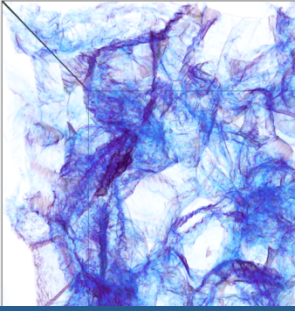
Cold Gas PDF

Braun, Schmidt, Niemeyer, and Almgren in preparation



Star Formation Rate vs H_2





Summary

- **Subgrid-scale model**:
  - multi-phase ISM with metal enrichment
  - local star formation efficiency (turbulent Mach number, virial parameter) ~ 0.01
  - thermal and turbulent feedback
- **Self-regulation** of star formation ($\sim M_{\rm sun}/{\rm yr}$)
  - robust with respect to SFR parameterization if multi-freefall and two-parameter model
- Predicts **linear dependence** of local SFR on **H_2 surface density** (const. H_2 depletion time)