Schmidt-Kennicutt relations in SPH simulations of disc galaxies with effective SN thermal feedback

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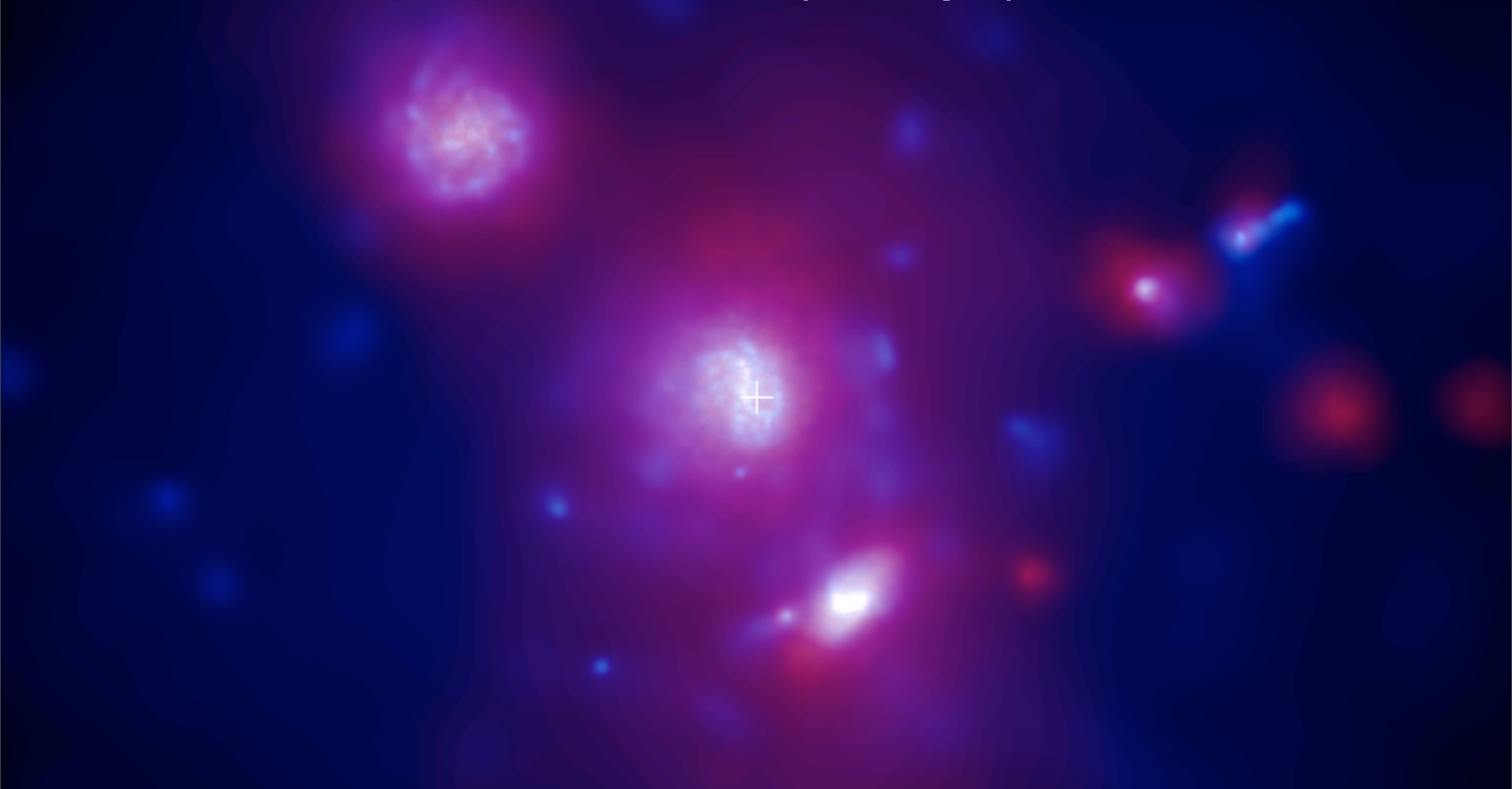
Paper: P.M., Murante, Borgani, Dolag, 2011, MNRAS, 421, 2485

Aim: simulating spiral galaxies in a cosmological context at moderate (~1 kpc) resolution



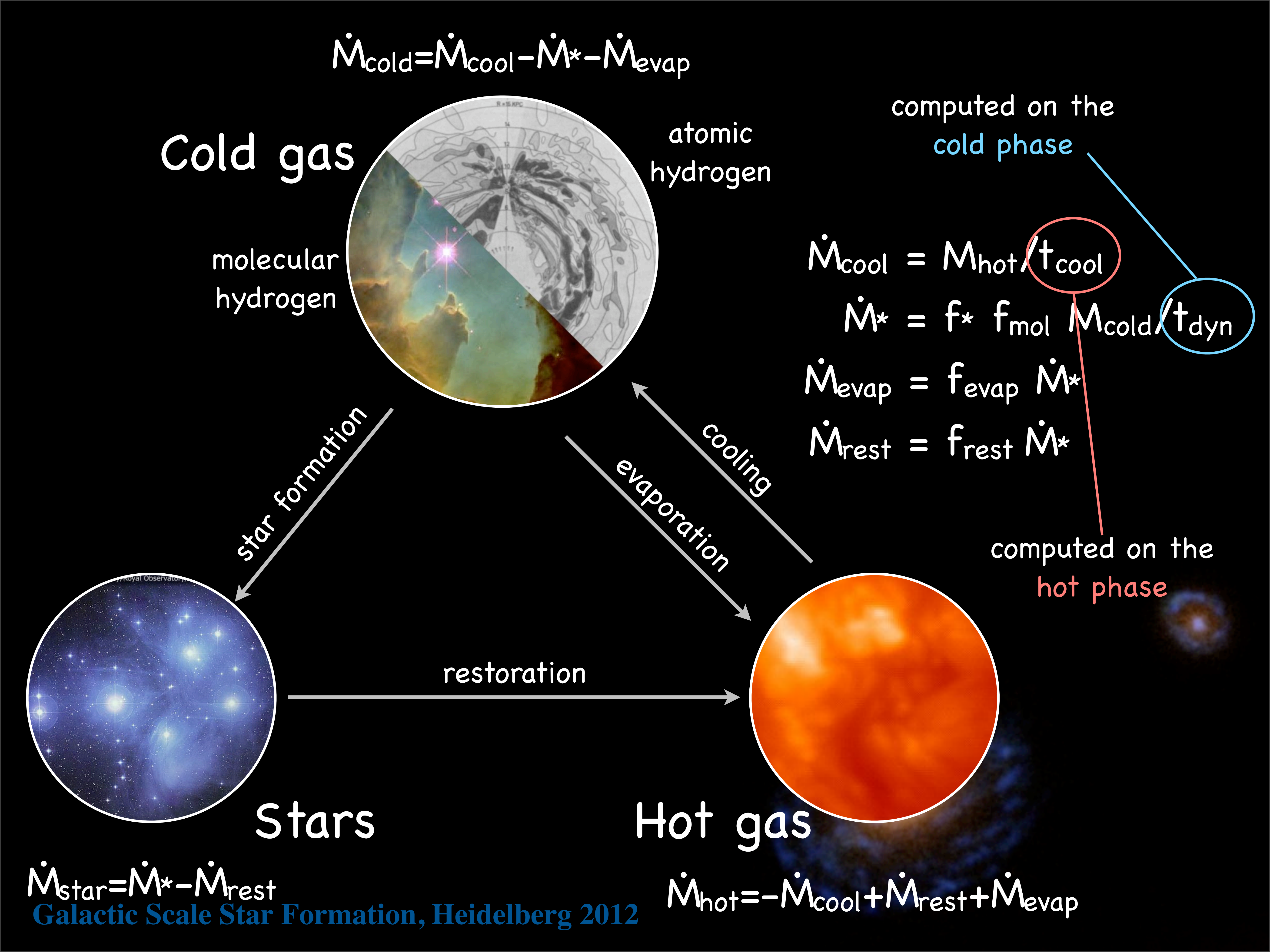
18 Mpc/h box with 2x256^3 particles, 0.7 kpc softening,
image obtained with gadgetviewer

MUlti-Phase Particle Integrator (MUPPI):

a new sub-resolution model for star formation and feedback in SPH simulations with Gadget-3 (Springel 2005)

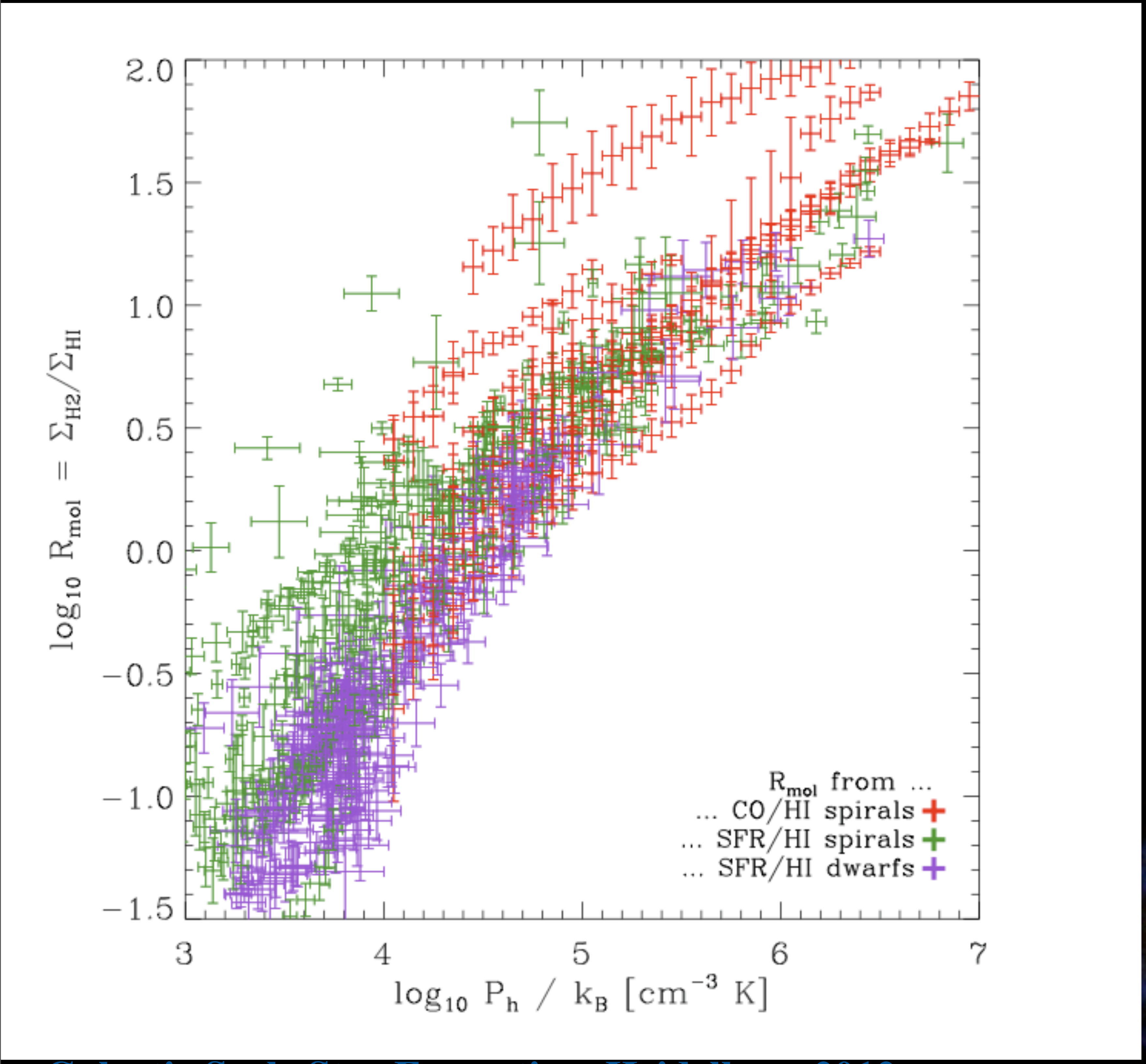
Murante, P.M., Giovalli, Borgani, Diaferio, 2010, MNRAS 405, 1491

- gas in multi-phase particles is composed by two phases in thermal pressure equilibrium, plus a stellar component;
- gas molecular fraction is scaled with pressure;
- the evolution of the multi-phase ISM is described by a system of ODEs;
- the system of ODEs is numerically integrated within the SPH time-step (NO equilibrium solutions);
- energy from SNe is injected into the hot diluted phase; SPH hydro is done on this phase
  - ...entrainment of the cold phase...
- particles respond immediately to energy injection



$\dot{M}_{cold}=\dot{M}_{cool}-\dot{M}_{*}-\dot{M}_{evap}$
Cold gas
atomic hydrogen
molecular hydrogen
computed on the cold phase
$\dot{M}_{cool} = M_{hot}/t_{cool}$
$\dot{M}_{*} = f_{*}\ f_{mol}\ M_{cold}/t_{dyn}$
$\dot{M}_{evap} = f_{evap}\ \dot{M}_{*}$
$\dot{M}_{rest} = f_{rest}\ \dot{M}_{*}$
star formation
cooling
evaporation
computed on the hot phase
restoration
Stars
Hot gas
$\dot{M}_{star}=\dot{M}_{*}-\dot{M}_{rest}$
$\dot{M}_{hot}=-\dot{M}_{cool}+\dot{M}_{rest}+\dot{M}_{evap}$

Molecular fraction f_{mol}



Leroy et al. (2009)

Inspired by Blitz & Rosolowsky, we scale the molecular fraction with SPH pressure - NOT the same quantity the observers use!

$$f_{mol} = 1/(1+P_0/P)$$

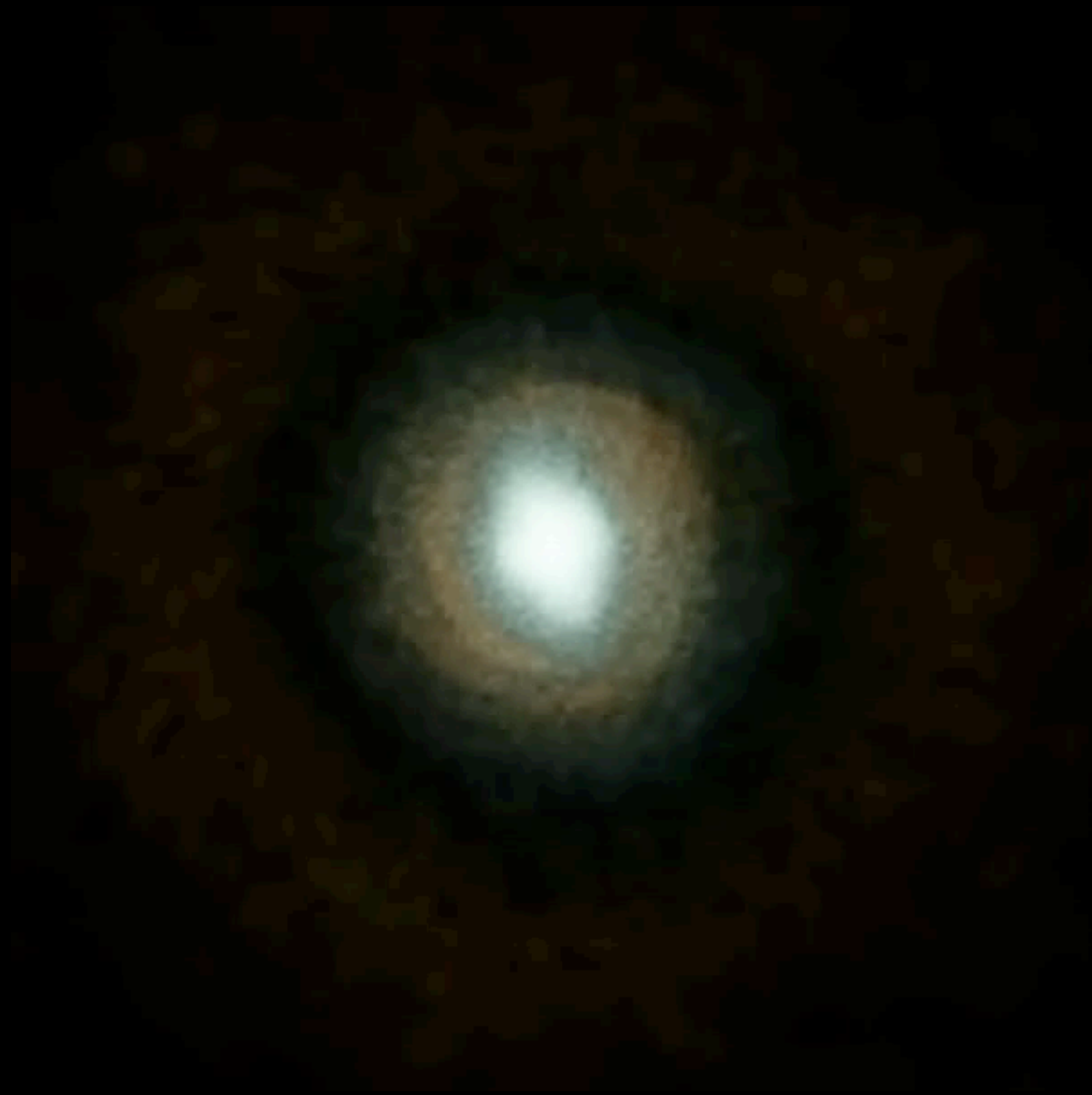
Isolated galaxy tests:
thermal feedback, primordial cooling

- isolated Milky Way at two resolutions
- isolated LSB Dwarf galaxy
- rotating isolated halo of ~10^{10} M_{sun}

Initial conditions have been kindly provided by Lucio Mayer, Simone Callegari and Volker Springel

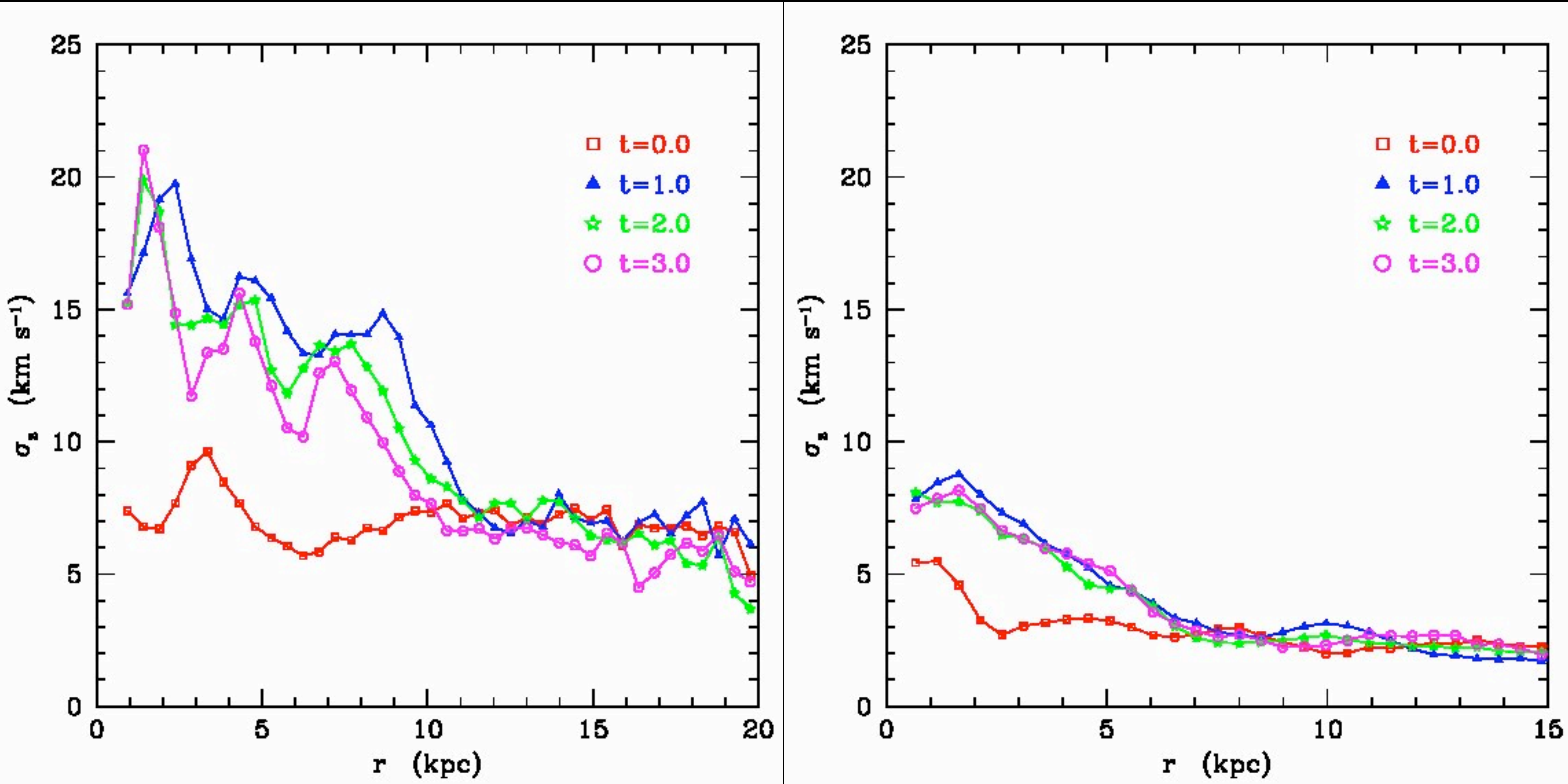
Name	softening (kpc)	$M_{\rm dm}$ ($M_\odot$)	$m_{\rm dm}$ ($M_\odot$)	$M_\star^{(1)}$ ($M_\odot$)	$m_\star^{(2)}$ ($M_\odot$)	$R_\star$ (kpc)	$M_{\rm cold}$ ($M_\odot$)	$m_{\rm gas}$ ($M_\odot$)	$R_{\rm cold}$ (kpc)	gas fraction
MW	0.69	$9.4 \cdot 10^{11}$	$3.5 \cdot 10^{6}$	$4.2 \cdot 10^{10}$	$1.3 \cdot 10^{6}$	4.8	$3.3 \cdot 10^{9}$	$7.4 \cdot 10^{4}$	5.6	7.3%
MW_HR	0.41	$9.4 \cdot 10^{11}$	$6.9 \cdot 10^{5}$	$4.2 \cdot 10^{10}$	$2.6 \cdot 10^{5}$	4.4	$3.2 \cdot 10^{9}$	$1.5 \cdot 10^{4}$	5.4	7.1%
DW	0.42	$1.6 \cdot 10^{11}$	$8.1 \cdot 10^{5}$	$7.8 \cdot 10^{9}$	$1.6 \cdot 10^{5}$	8.5	$1.9 \cdot 10^{9}$	$3.9 \cdot 10^{4}$	8.3	20%
SH	0.042	$1.4 \cdot 10^{10}$	$-^{(3)}$	$1.4 \cdot 10^{7}$	$2.2 \cdot 10^{3}$	0.77	$1.4 \cdot 10^{9}$	$8.7 \cdot 10^{3}$	5.2	99%

Milky Way galaxy



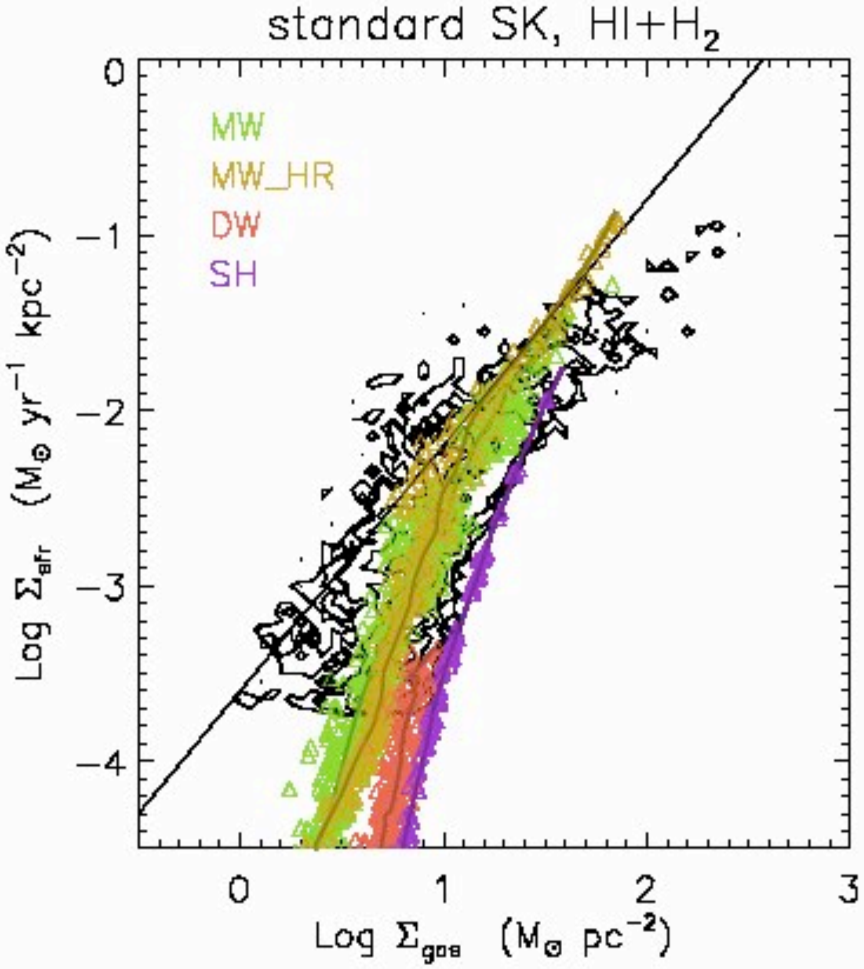
images made with SPLOTCH code by Dolag et al. 09

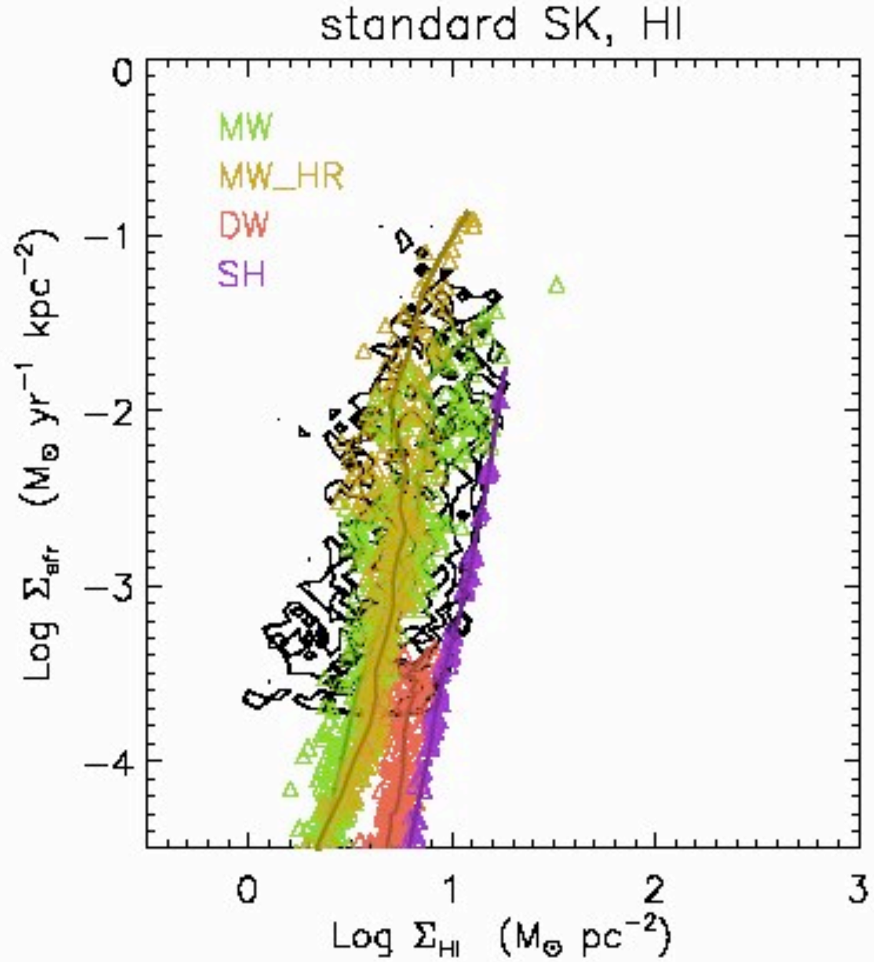
Velocity profiles of gas

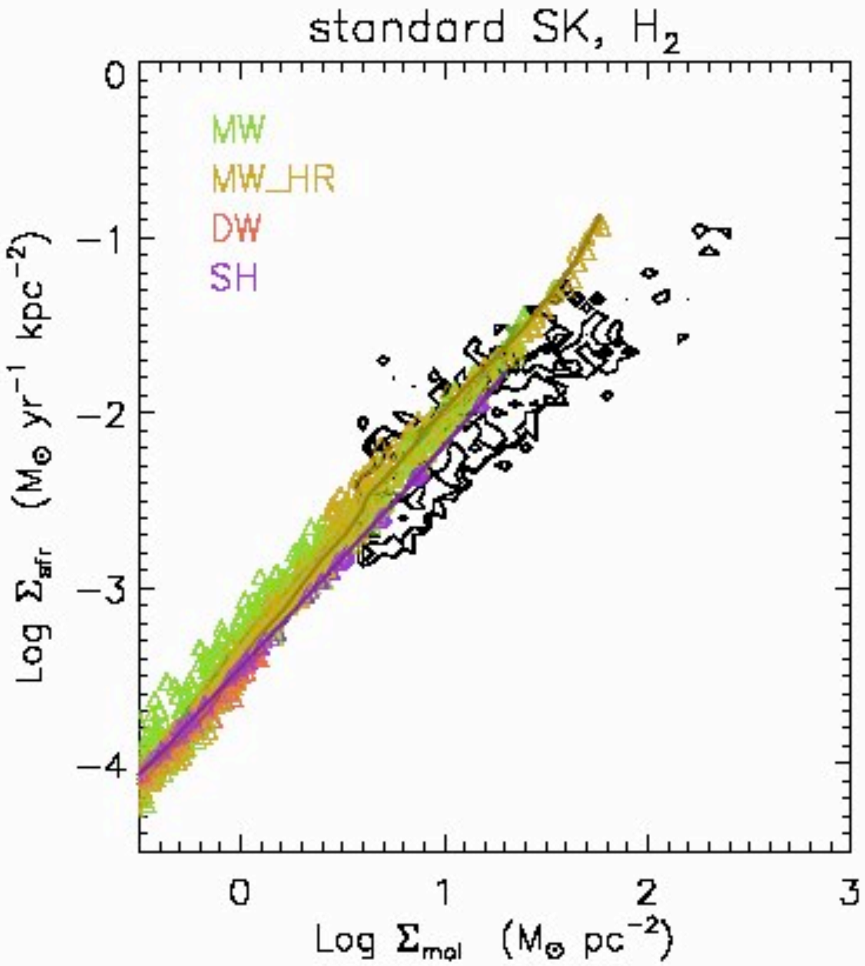


consistent with Tamburro et al (2008), Ianjamasimanana et al. (2012) - talk by de Block

Galactic Scale Star Formation, Heidelberg 2012

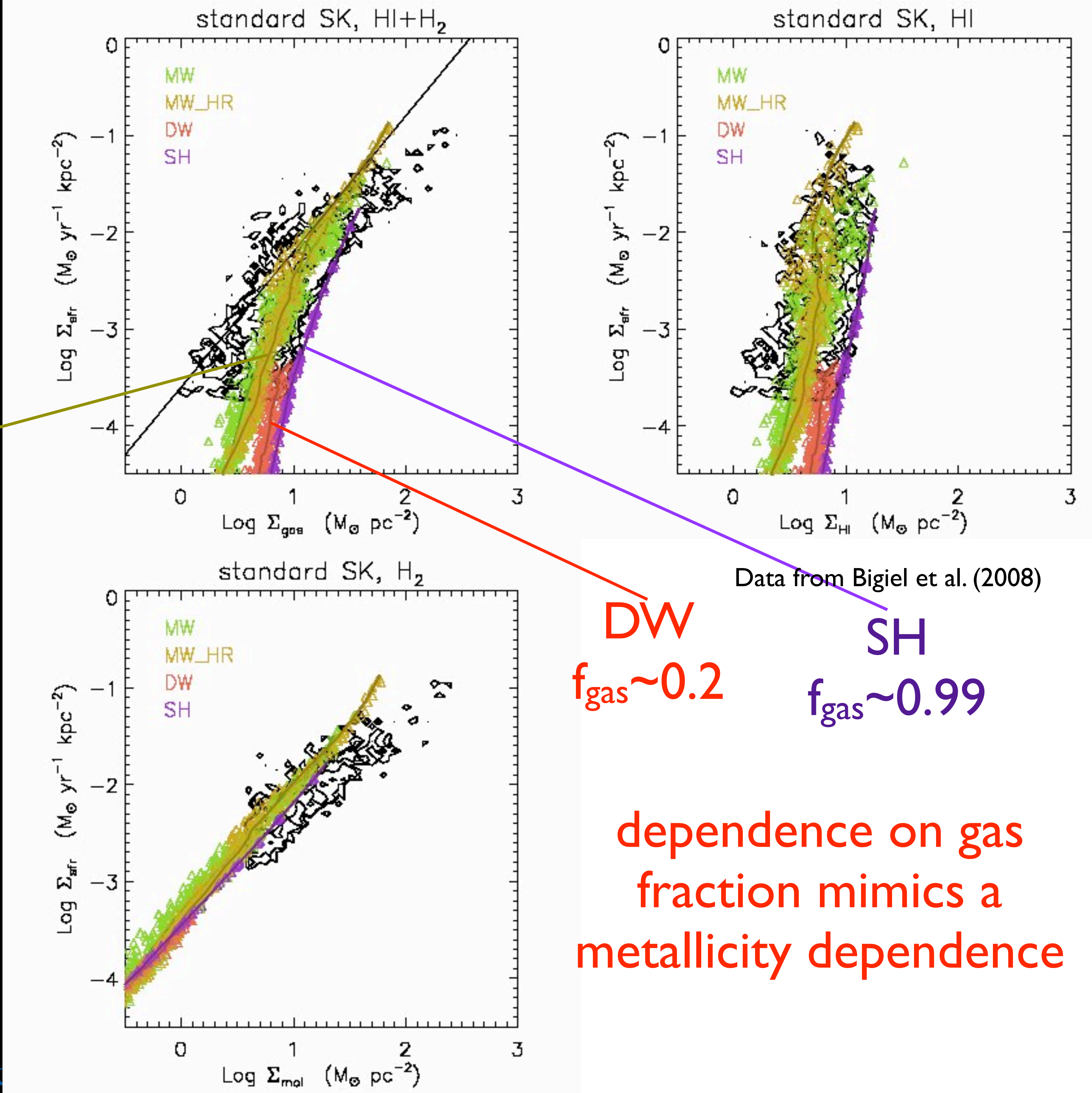






Data from Bigiel et al. (2008)

Galactic Sc

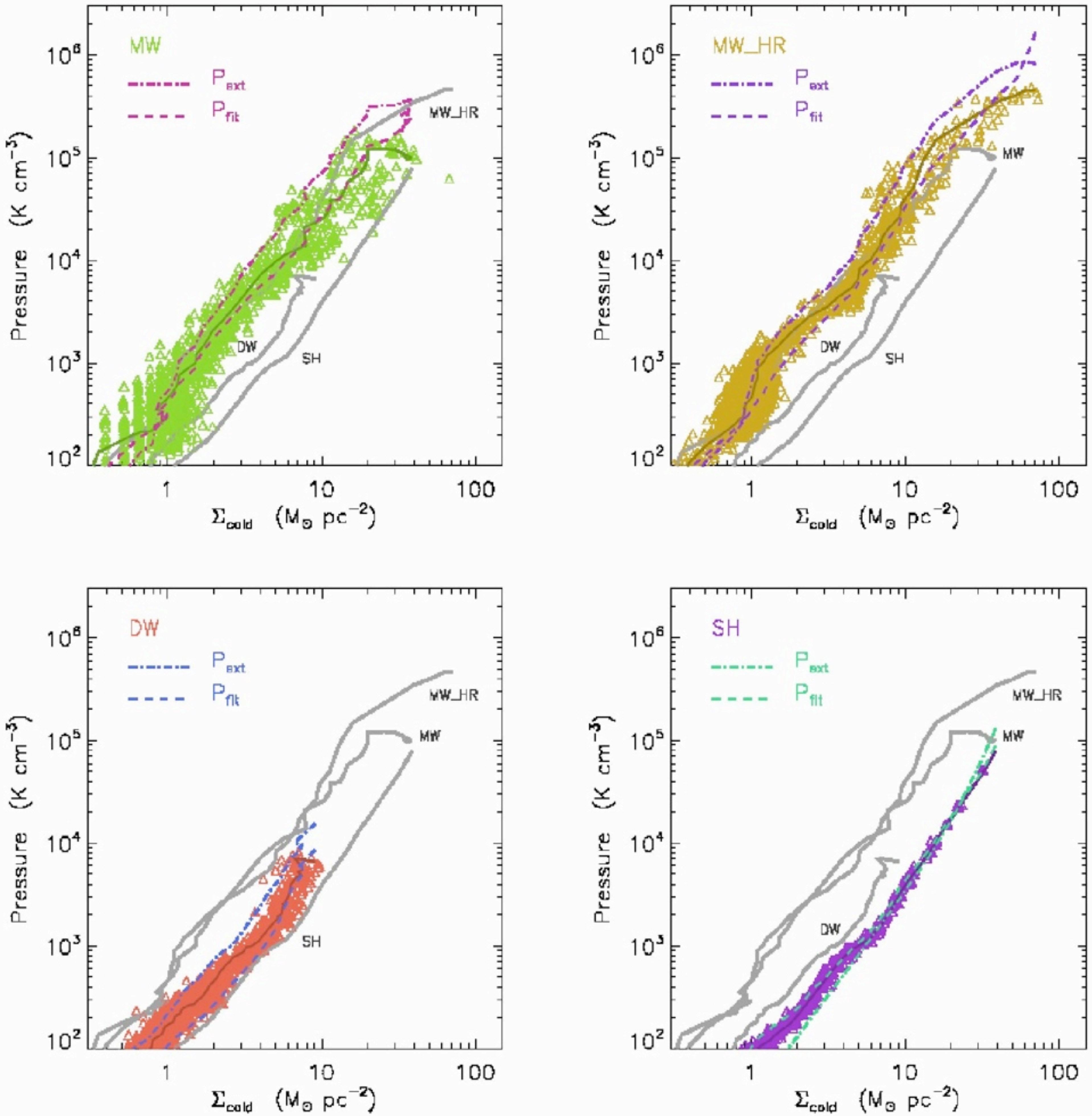

standard SK, HI+H2
standard SK, HI
standard SK, H2
MW
MW_HR
DW
SH
Log Σsfr (M⊙ yr−1 kpc−2)
Log Σgas (M⊙ pc−2)
Log ΣHI (M⊙ pc−2)
Log Σmol (M⊙ pc−2)
Data from Bigiel et al. (2008)
MW
fgas~0.1
DW
fgas~0.2
SH
fgas~0.99
dependence on gas fraction mimics a metallicity dependence

Elmegreen (1989)

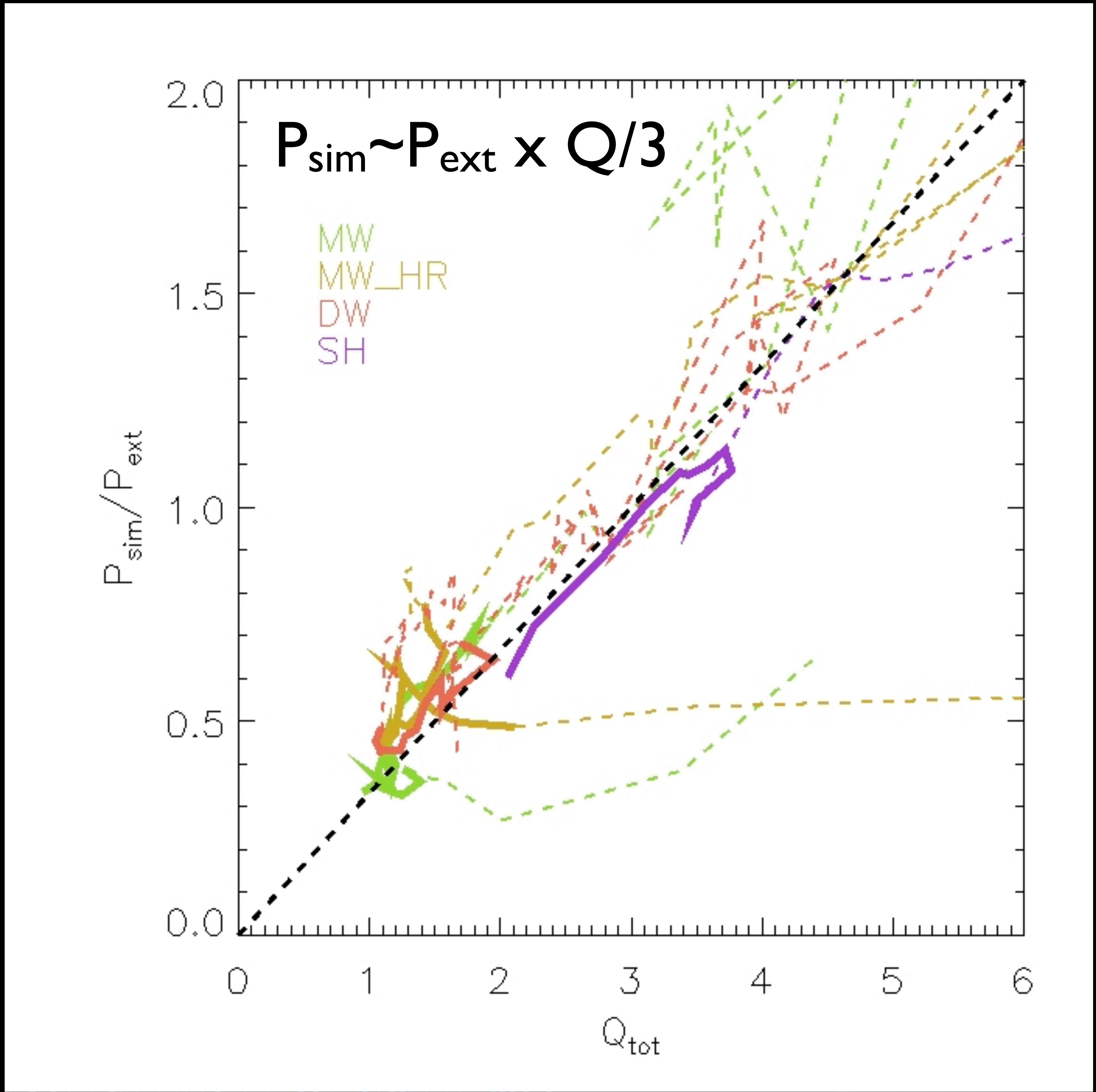
"external" pressure on a molecular cloud for a disc in vertical hydrostatic equilibrium:

$$P_{\rm ext} \simeq \frac{\pi}{2} G \Sigma_{\rm cold} \left(\Sigma_{\rm cold} + R \Sigma_\star \right)$$

$$R = \sigma_{\rm cold} / \sigma_\star$$


MW
P_ext
P_fit
MW_HR
DW
SH
Pressure (K cm^-3)
Σ_cold (M_⊙ pc^-2)
MW_HR
P_ext
P_fit
MW
DW
SH
DW
P_ext
P_fit
MW_HR
MW
SH
SH
P_ext
P_fit
MW_HR
MW
DW

Galactic S



P_sim~P_ext x Q/3
MW
MW_HR
DW
SH
P_sim/P_ext
Q_tot
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6

Elmegreen (1989)

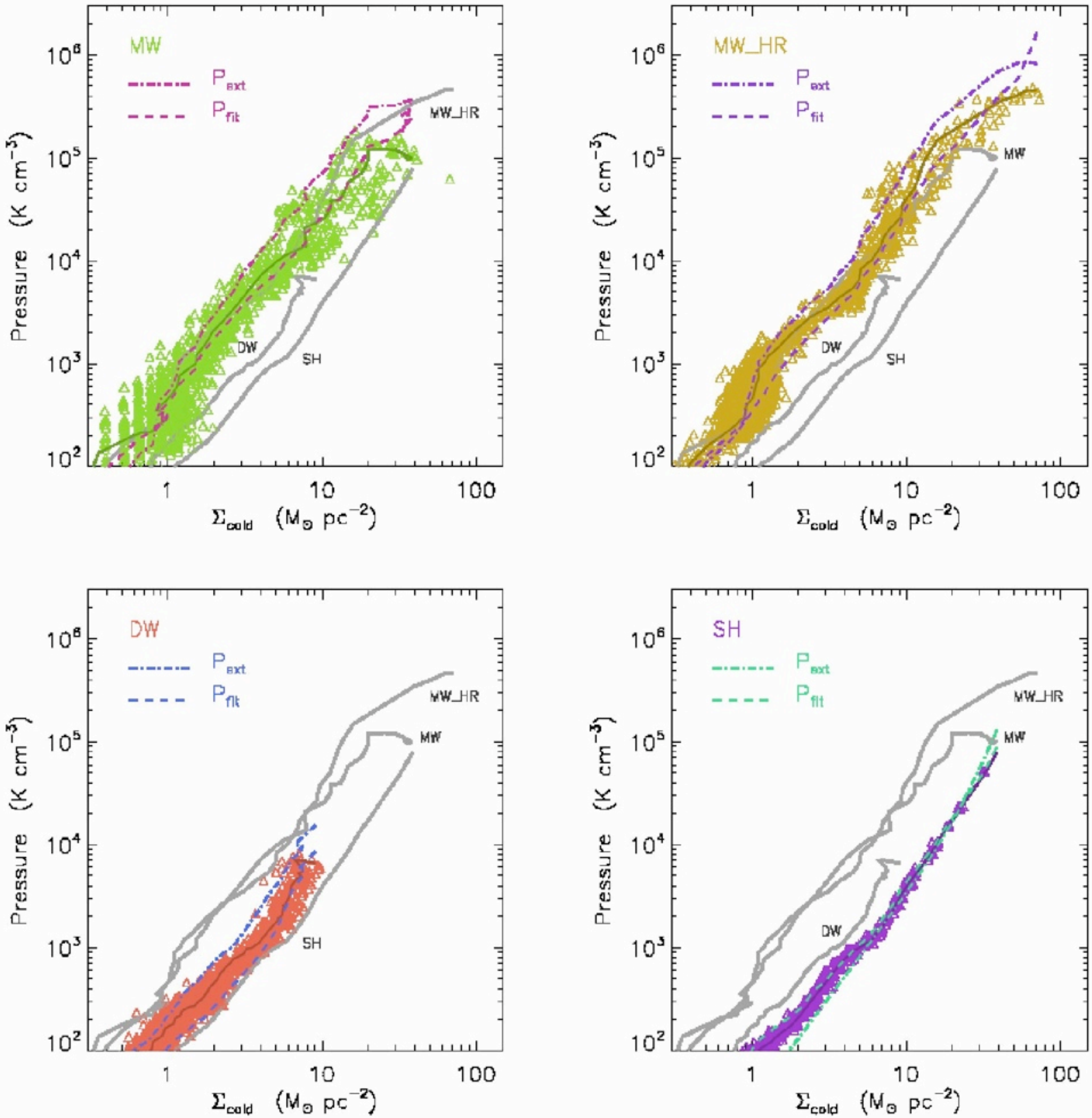
"external" pressure on a molecular cloud for a disc in vertical hydrostatic equilibrium:

$$P_{\rm ext} \simeq \frac{\pi}{2} G \Sigma_{\rm cold} \left(\Sigma_{\rm cold} + R \Sigma_{\star} \right)$$

$$R = \sigma_{\rm cold} / \sigma_{\star}$$

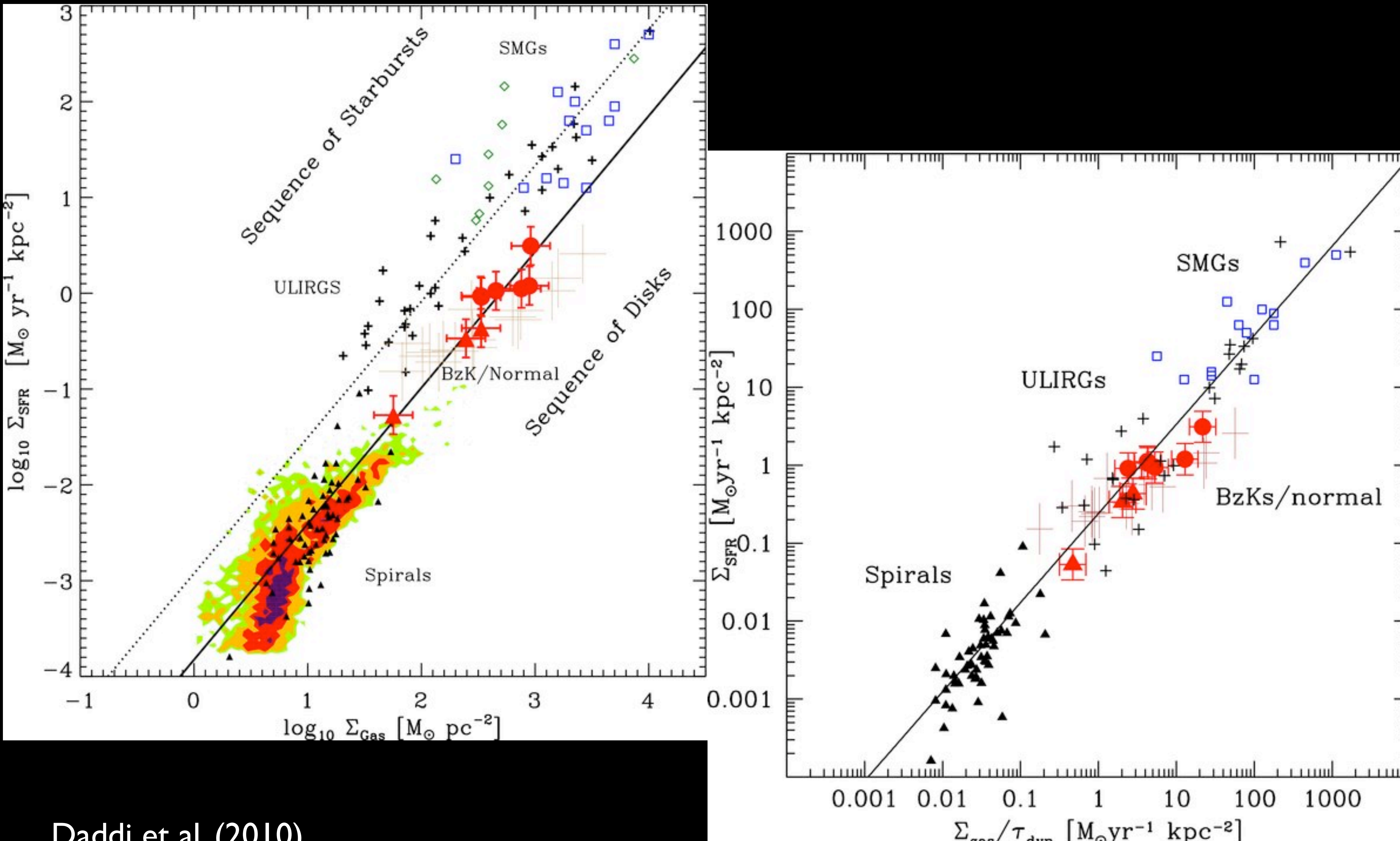
$$P_{\rm fit} = P_{\rm ext} \times \frac{Q_{\rm tot}}{3} = \frac{1}{6} \Sigma_{\rm cold} \sigma_{\rm cold} \kappa$$

NB: vertical pressure profiles P(z) are rather flat, like in Tasker & Bryan (2008)

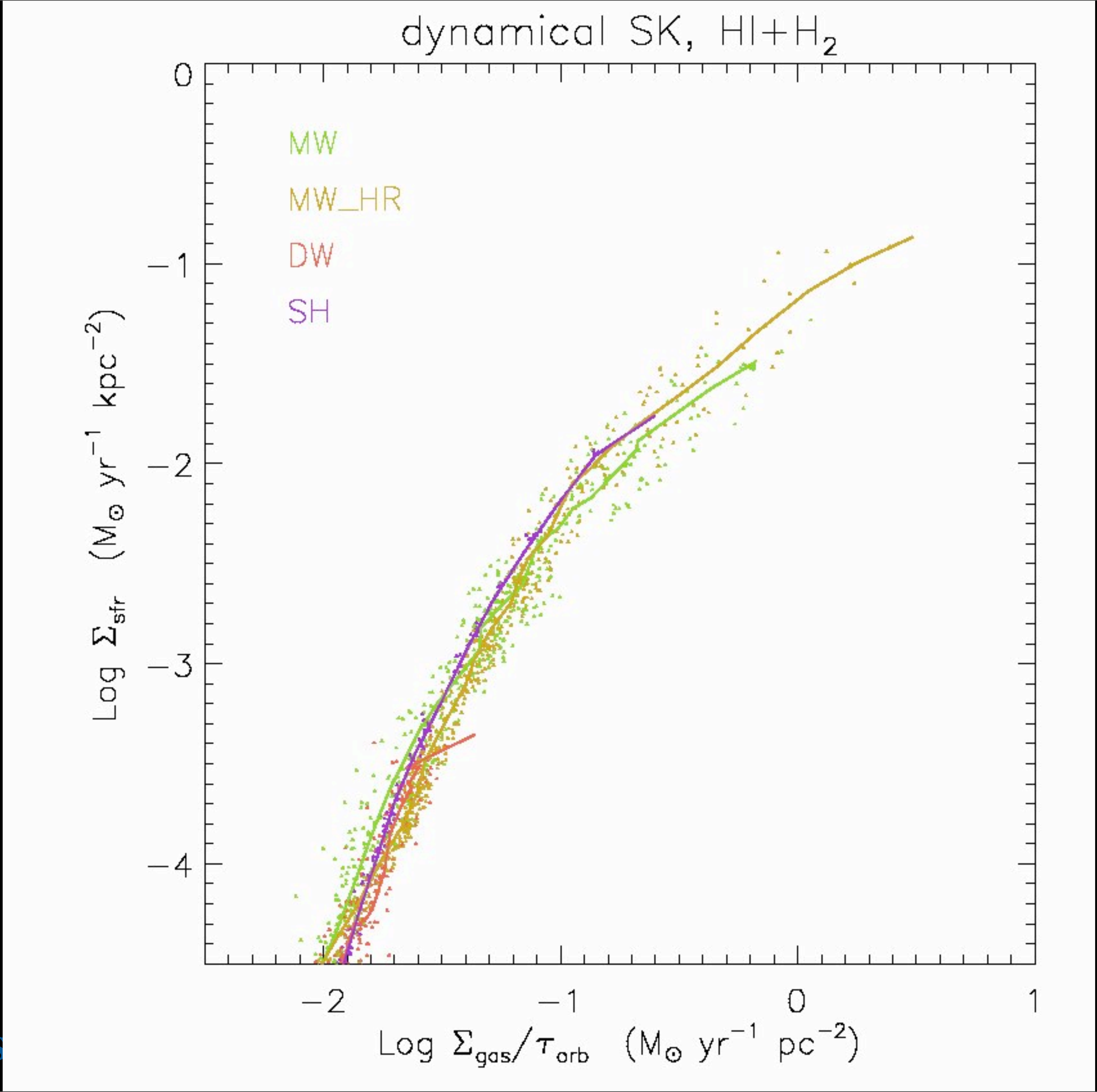

MW
P_{ext}
P_{fit}
MW_HR
DW
SH
Pressure (K cm^{-3})
Σ_{cold} ($M_\odot$ pc^{-2})
10^2
10^3
10^4
10^5
10^6
1
10
100

Galactic S

A double relation at high redshift?



Daddi et al. (2010)



dynamical SK, HI+H2
MW
MW_HR
DW
SH
0
−1
−2
−3
−4
Log Σsfr (M⊙ yr−1 kpc−2)
−2
−1
0
1
Log Σgas/τorb (M⊙ yr−1 pc−2)

Galactic S

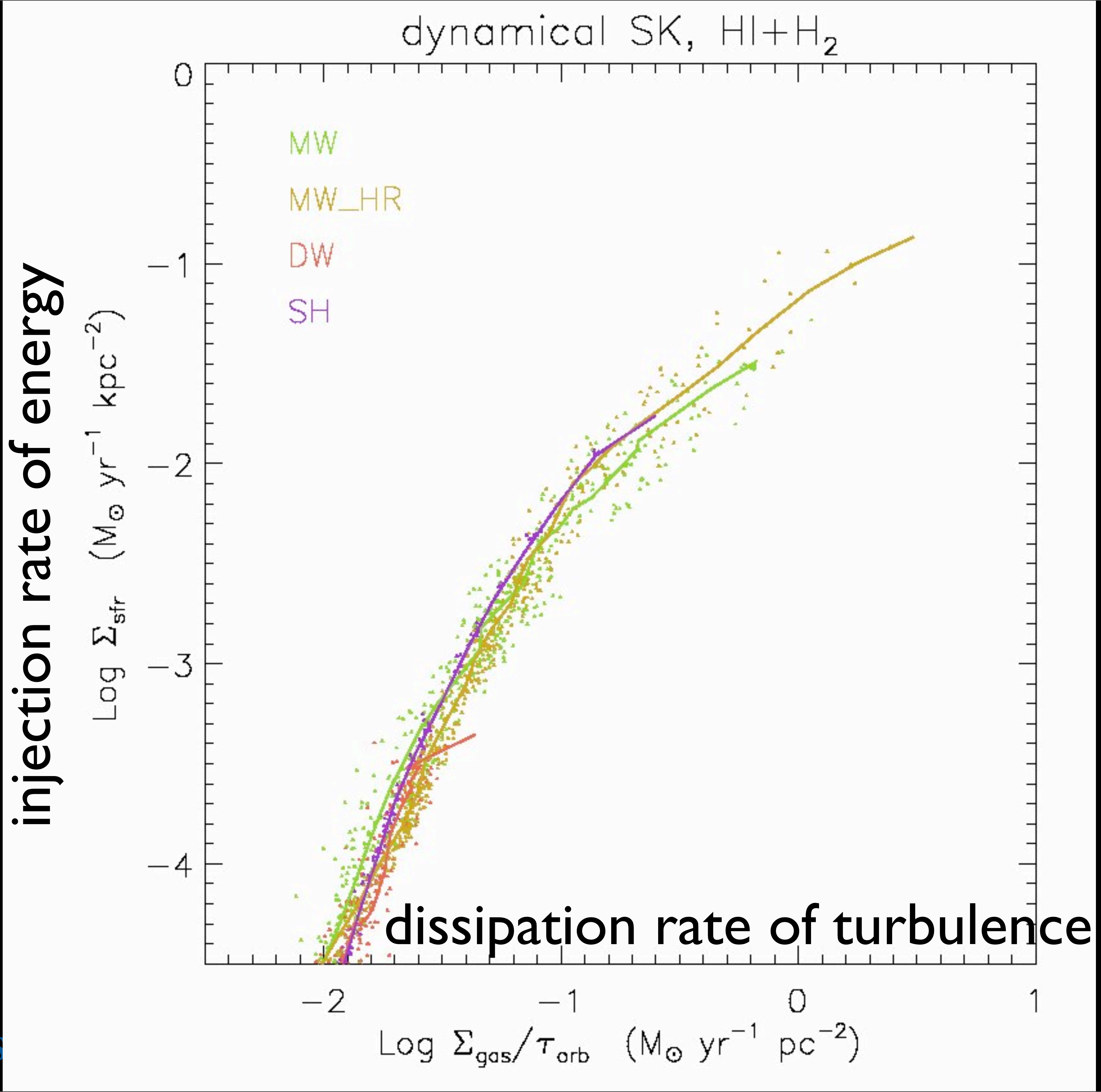
Proposed explanation:

$$H_{\rm eff} = \Sigma_{\rm cold}/2\rho_{\rm cold}$$

$$P = \rho_{\rm cold}\sigma^2_{\rm cold} = \frac{1}{6}\Sigma_{\rm cold}\sigma_{\rm cold}\kappa$$

$$t_{\rm cross} = H_{\rm eff}/\sigma_{\rm cold}$$

$$t_{\rm cross} = \frac{3}{\kappa} \simeq \frac{3}{\sqrt{2}}\tau_{\rm orb}$$


dynamical SK, HI+H2
MW
MW_HR
DW
SH
0
−1
−2
−3
−4
−2
−1
0
1
Log Σsfr (M⊙ yr−1 kpc−2)
Log Σgas/τorb (M⊙ yr−1 pc−2)
injection rate of energy
dissipation rate of turbulence

Galactic S

Conclusions

- MUPPI attempts to model the sub-grid physics through a two-phase model of the ISM
- scaling molecular fraction with pressure leads to a standard SK relation that depends on gas fraction
  - it mimics a metallicity dependence
- disc pressure is well reproduced by

$$P_{\rm fit} = P_{\rm ext} \times \frac{Q_{\rm tot}}{3} = \frac{1}{6}\Sigma_{\rm cold}\sigma_{\rm cold}\kappa$$

- all galaxies stay on the same "dynamical" SK
- this may be the result of energy balance