The Schmidt-Kennicutt Law: Some Analytic Perspectives

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UCSD, December 2006

DISK MODE: motivated by gravitational instability of cold disks

star surface density

gas surface density

$$\Sigma_{SFR} = (SFE)\,\frac{\Sigma_{gas}}{t_{dyn}}$$

$$\propto \Sigma_{gas}\,\Omega$$

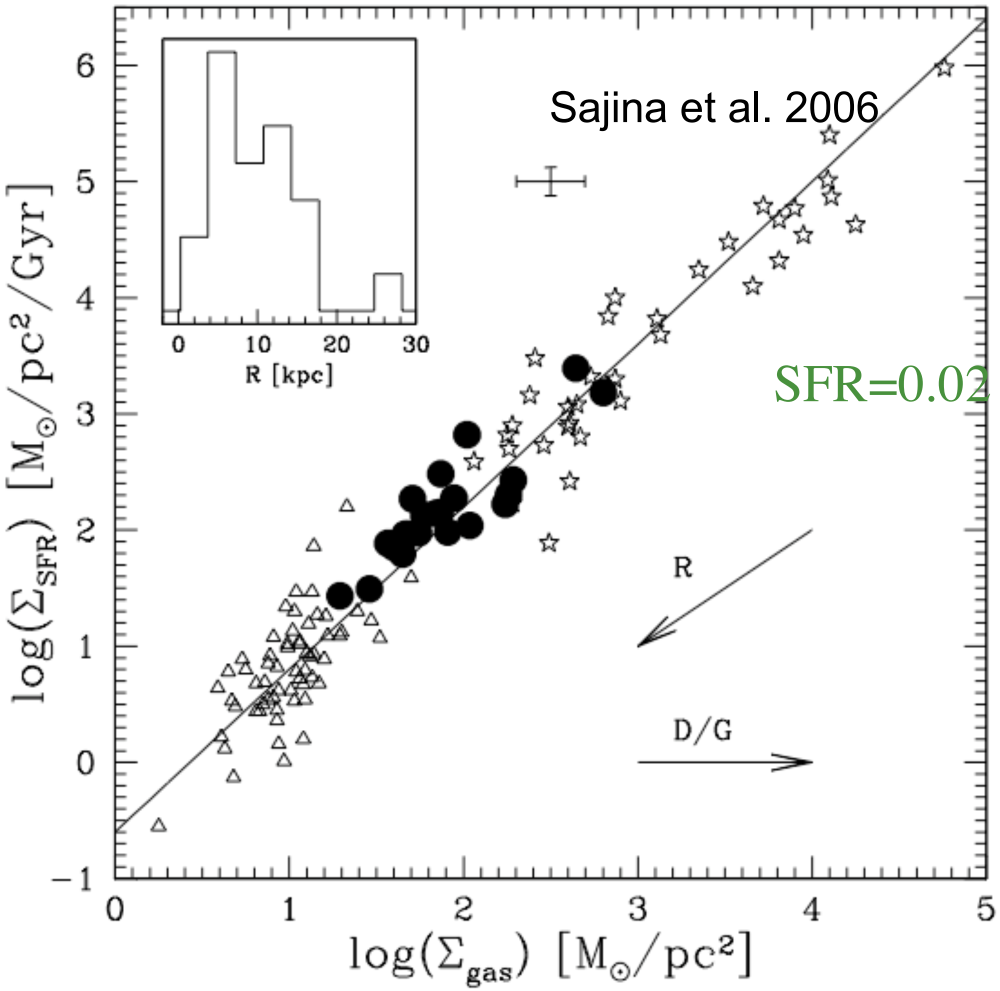
$$\overset{\propto}{\sim} \Sigma_{gas}^{3/2}$$

Star formation efficiency

$$SFE = \frac{\sigma_{gas}\, v_{cool}\, m_{*,SN}}{E_{SN}^{\,initial}}$$

$$\approx \quad 0.02$$

A GLOBAL STAR FORMATION LAW FOR DISKS



SFR=0.02 (GAS SURFACE DENSITY)/t_{dyn}

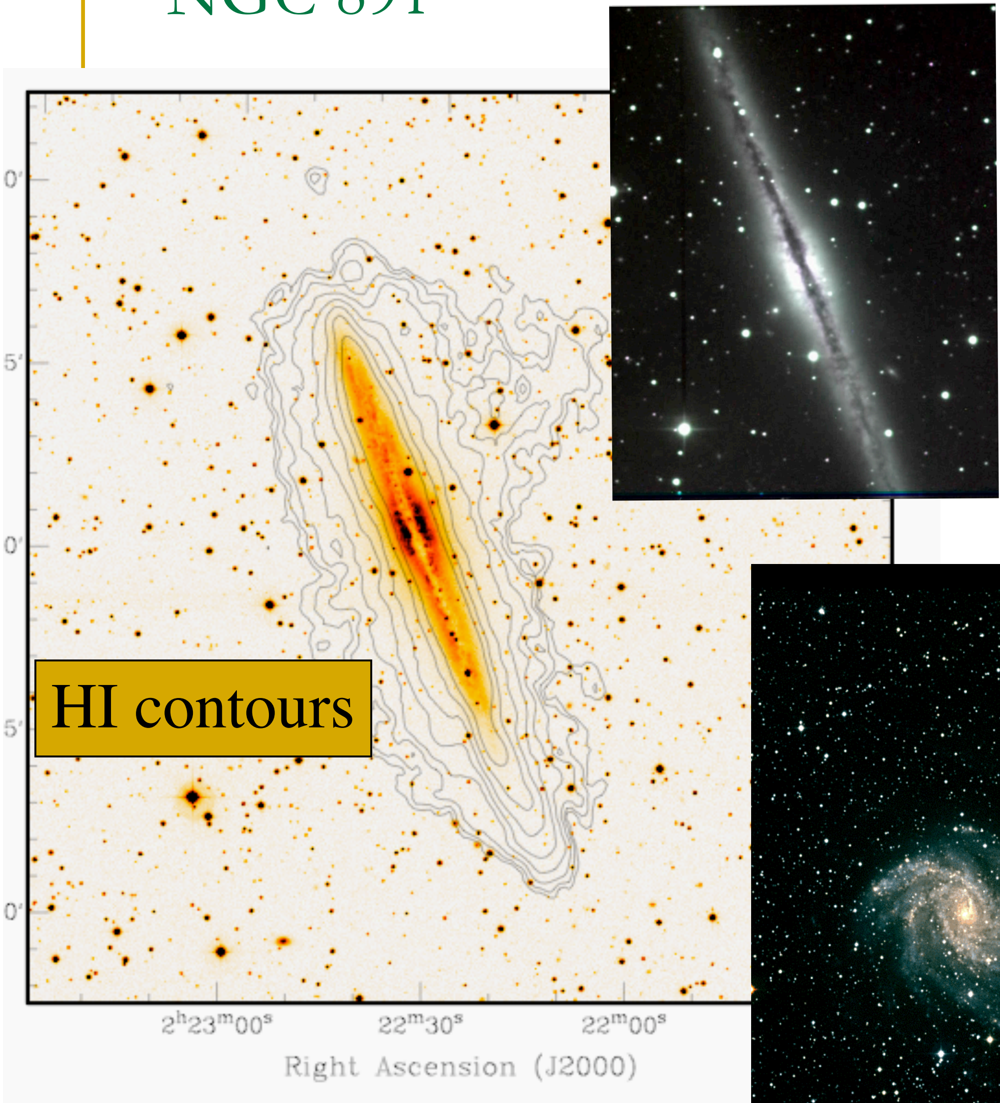
fits quiescent and starburst galaxies

Need cold gas accretion via infall and/or minor mergers to maintain global disk instability

Need low efficiency: due to SN feedback

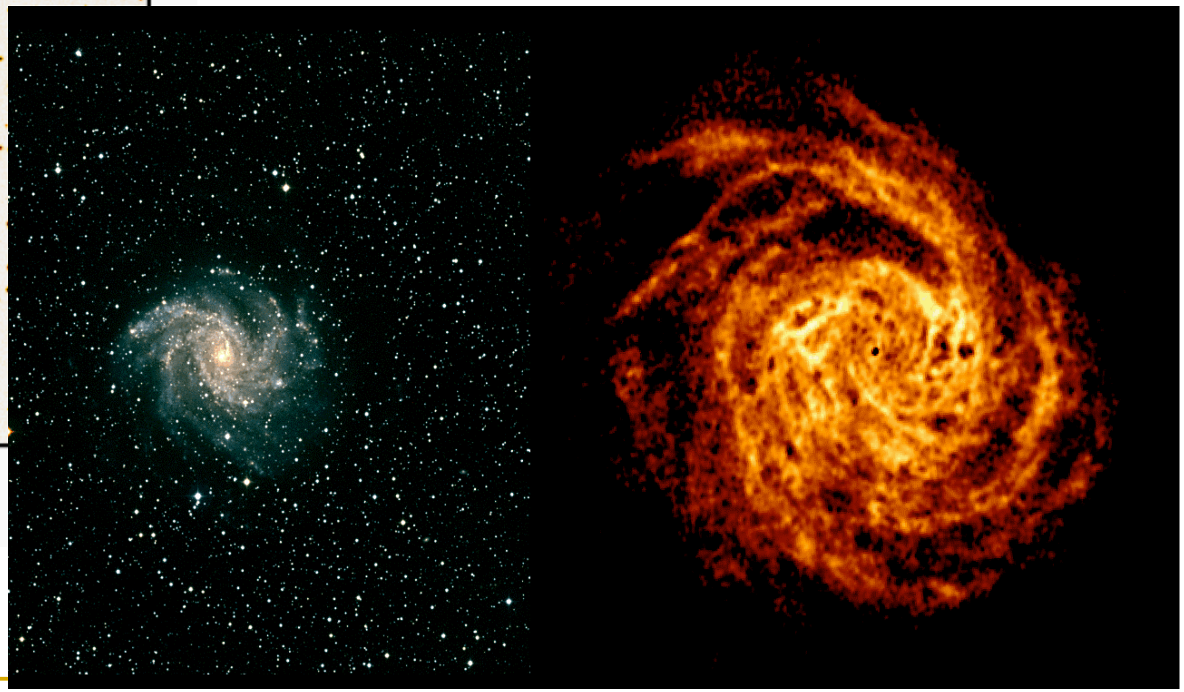
LOCAL COLD GAS FEEDING BY INFALL

NGC 891



Oosterloo et al. 2005

NGC 6946



Boomsma et al 2005

Back of envelope (A):

JS + Colin Norman 2007

Toomre disk instability+ SN feedback +cloud collisions

$$\dot{\rho}_* = \left(\underline{m_{SN} v_c}\,\sigma / E_{SN}\right) G \rho_{gas}^{\ 3/2}$$

$$\dot{\Sigma}_* = \left(\underline{m_{SN} v_c} / E_{SN}\right) G \Sigma_{tot}^{\ 1/2}\ \Sigma_{gas}^{\ 3/2}$$

⇒ SFR/unit area $\propto \Sigma_{tot}^{1/2} \Sigma_{gas}^{1.5}$

NB:

1. Total surface density gives soft rollover in SFR as opposed to sharp threshold
2. For gas-dominated systems infer n=2: may explain SFR in dwarfs and DLAs

Back of envelope (B):

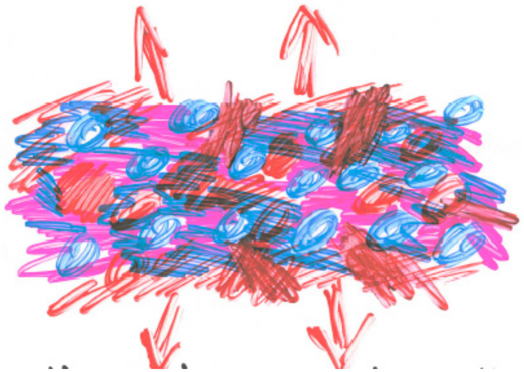
Toomre + SN feedback + multiphase ISM

⇒ SFR/unit volume $\propto$ Porosity x $\sigma^{2.8}$ x $\rho_{gas}^{\ 1.4}$

The Rate of Star Formation

$$\text{porosity} \sim \begin{pmatrix} \text{number of} \\ \text{SN bubbles} \\ \text{generated} \\ \text{per unit time} \end{pmatrix} \times \begin{pmatrix} \text{maximum 4 - Volume} \\ \text{of a bubble limited by} \\ \text{ambient ISM pressure} \end{pmatrix}$$

$$\sim (\text{star formation rate}) \times \left(\frac{1}{(\text{pressure})^{1.36}} \right)$$



Three-phase ISM

$$HI \sim 1000K$$
$$H_2 \sim 10 - 100K$$
$$Hot\ phase \sim 10^6 K$$

Perhaps porosity self-regulates!

Application to starbursts…expect high turbulent velocities but similar <ISM density>

SFR = POROSITY x EFFICIENCY x (TURBULENT PRESSURE)$^{1.36}$

$$\dot{\rho}_* \approx Q^{Porosity} G^{1/2} \rho^{3/2} \left(\sigma / \sigma_f\right)^{19/7}$$

$$\sigma_f = 0.0501 v_c n^{3/266} E_{51}{}^{72/133} \xi^{-10/133} m_{SN}{}^{-7/19} \approx 30\ km/s$$

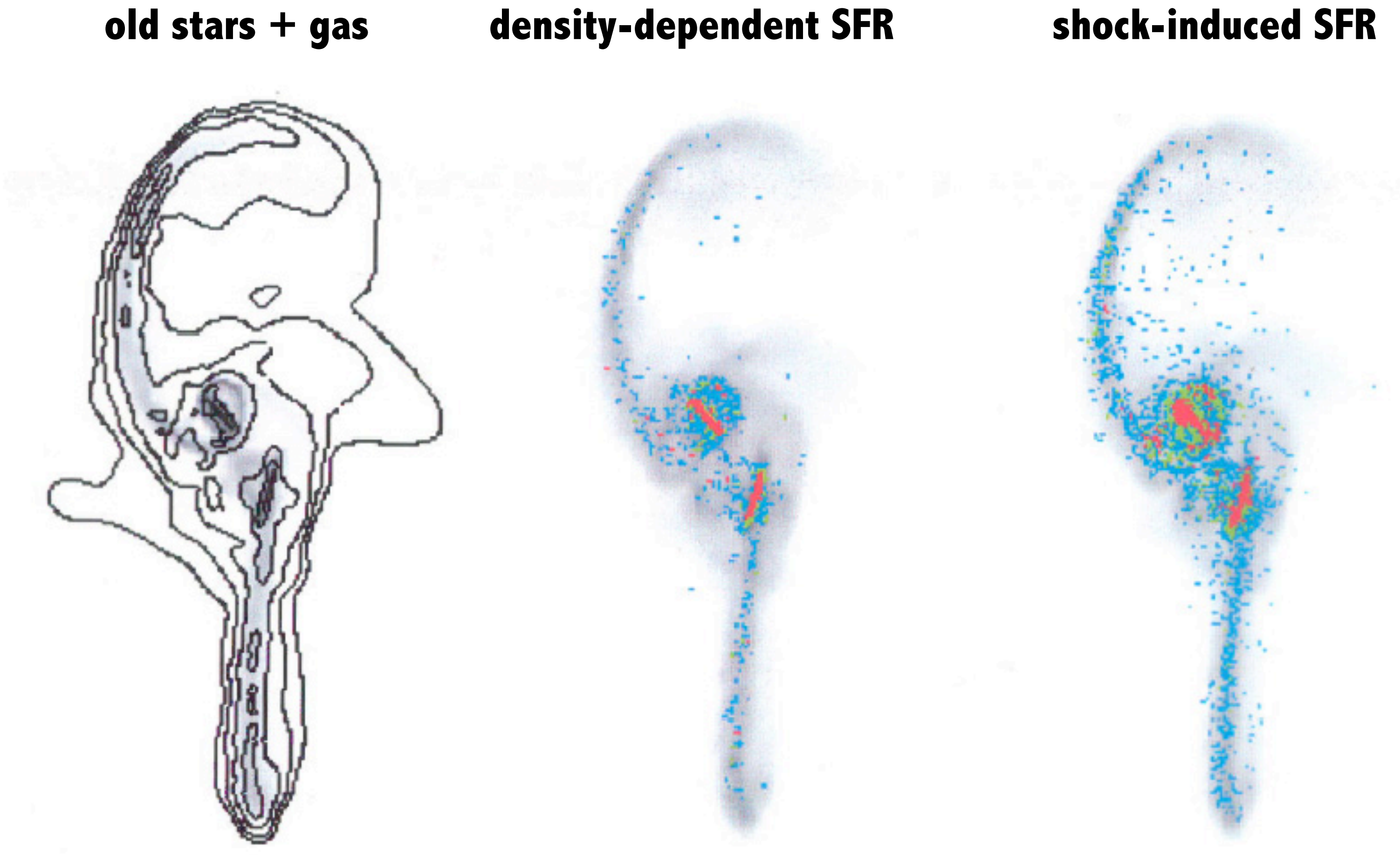
$$v_c = 413\ km/s$$

Conjecture:

Turbulent velocities are high → porosity is low

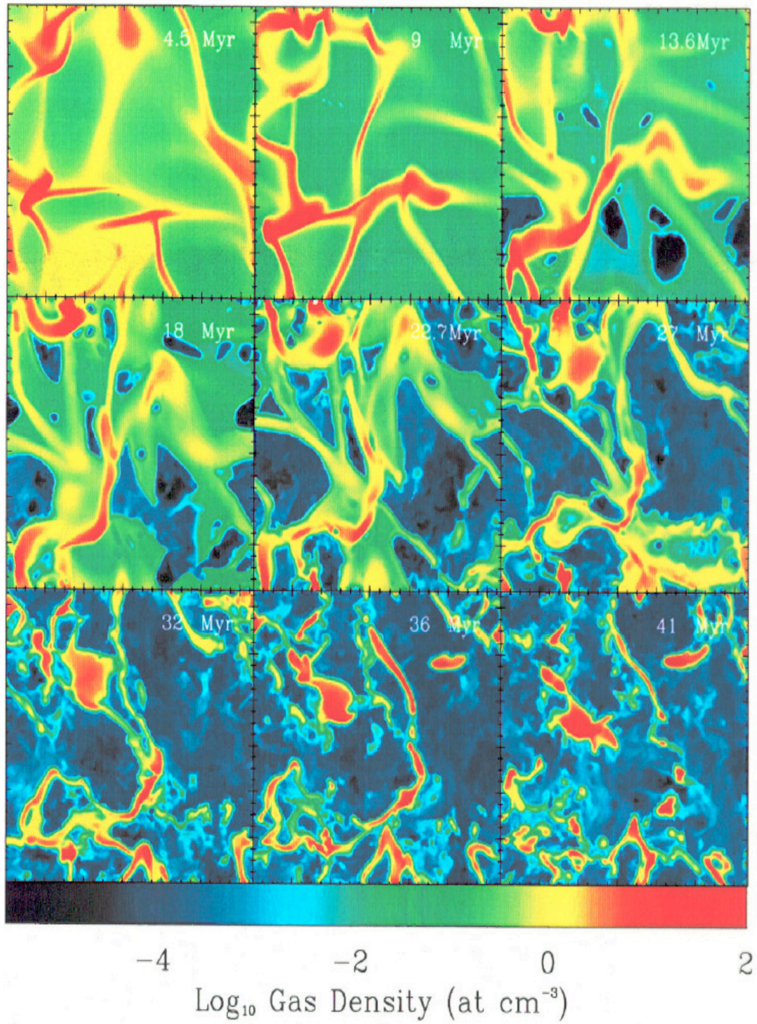
Hence even starbursts stay on the Schmidt-Kennicutt law!

Star Formation Rate Simulation
The Mice (NGC 4676 a,b)

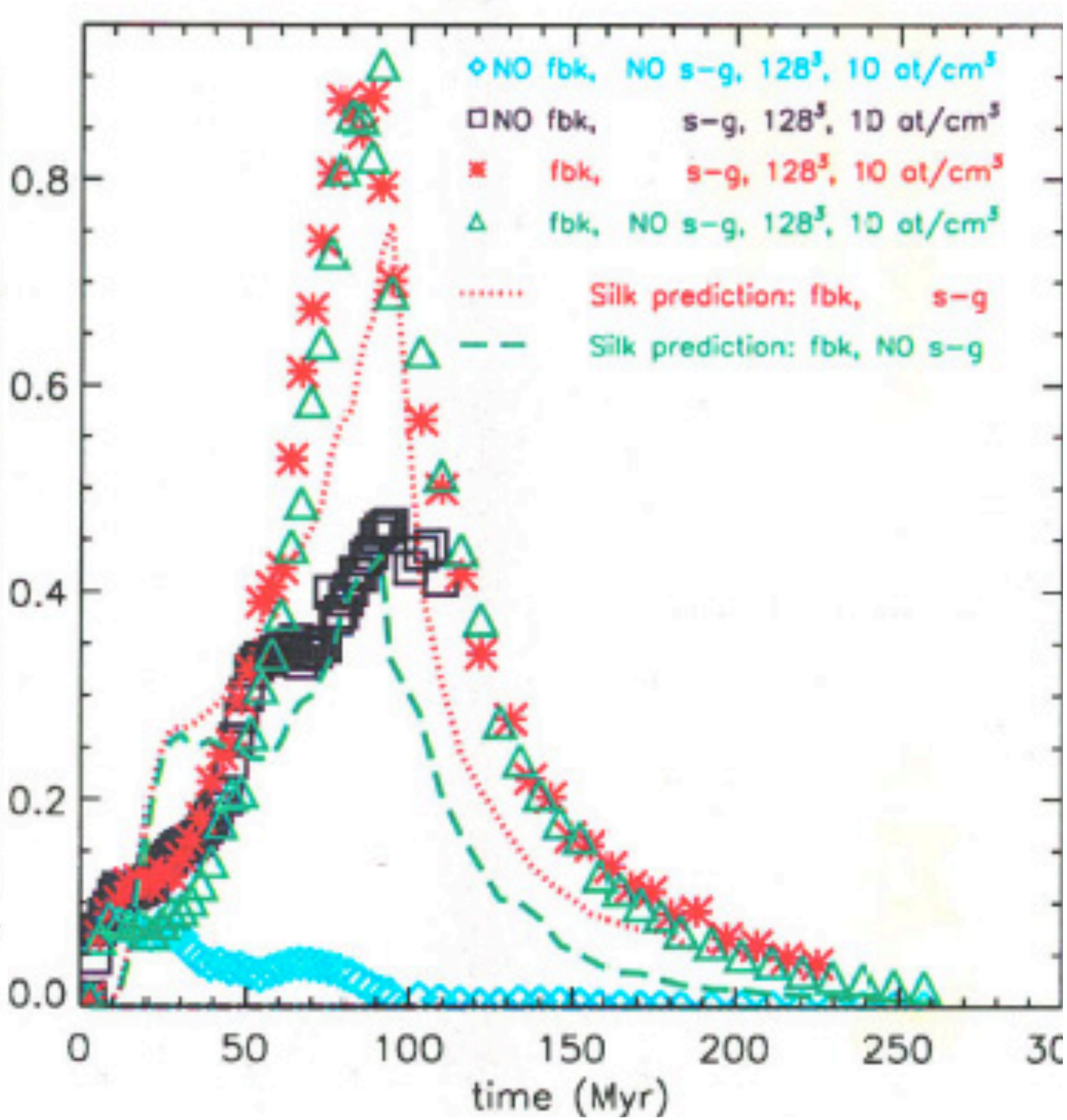


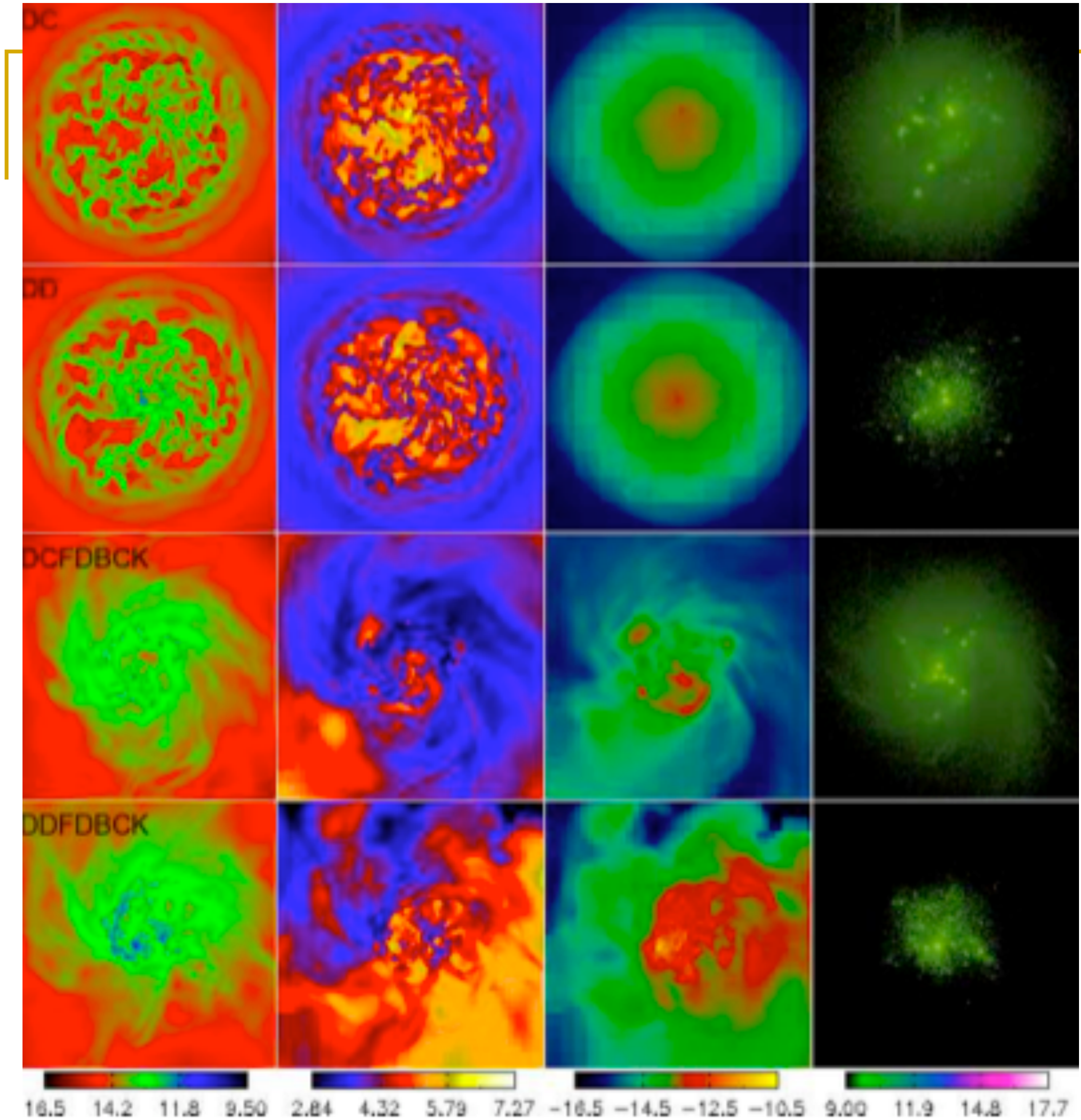
Barnes (2004)

SFR with SN feedback in a multiphase ISM

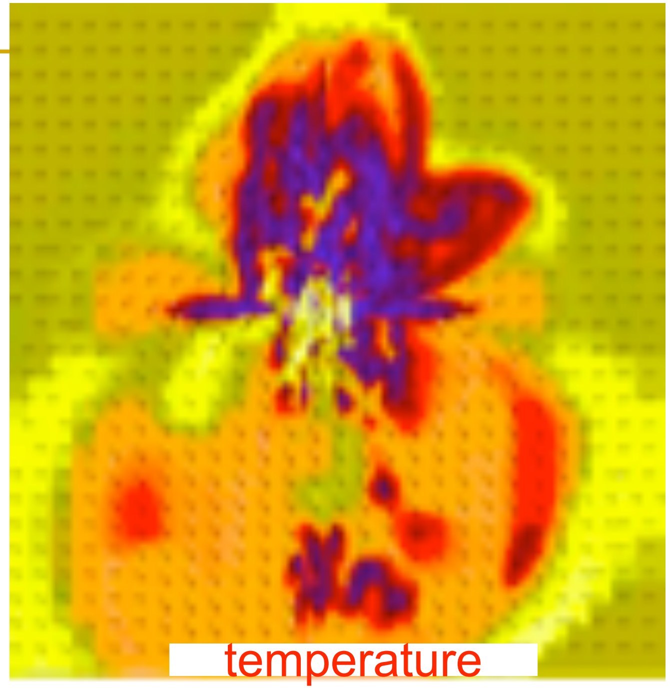


Slyz et al. 2005

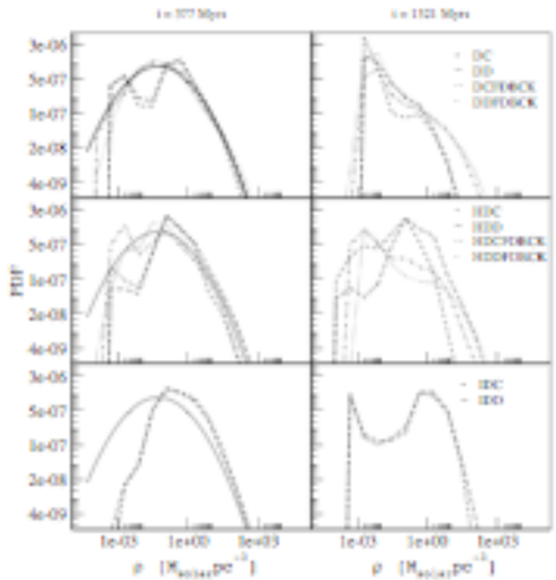




gas density temperature pressure star density

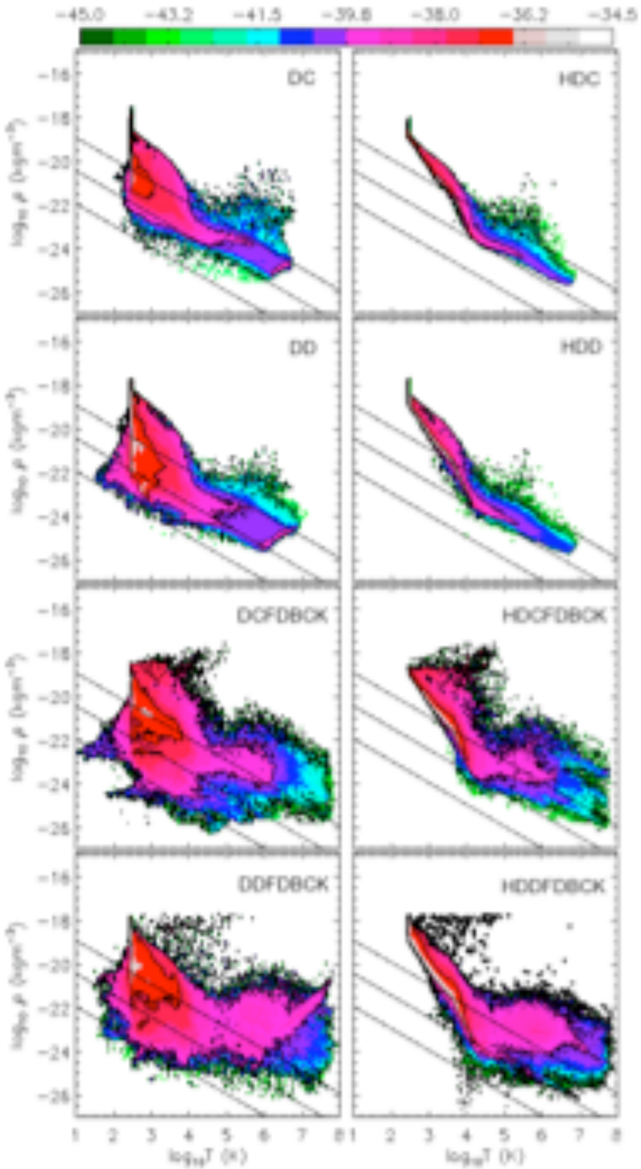


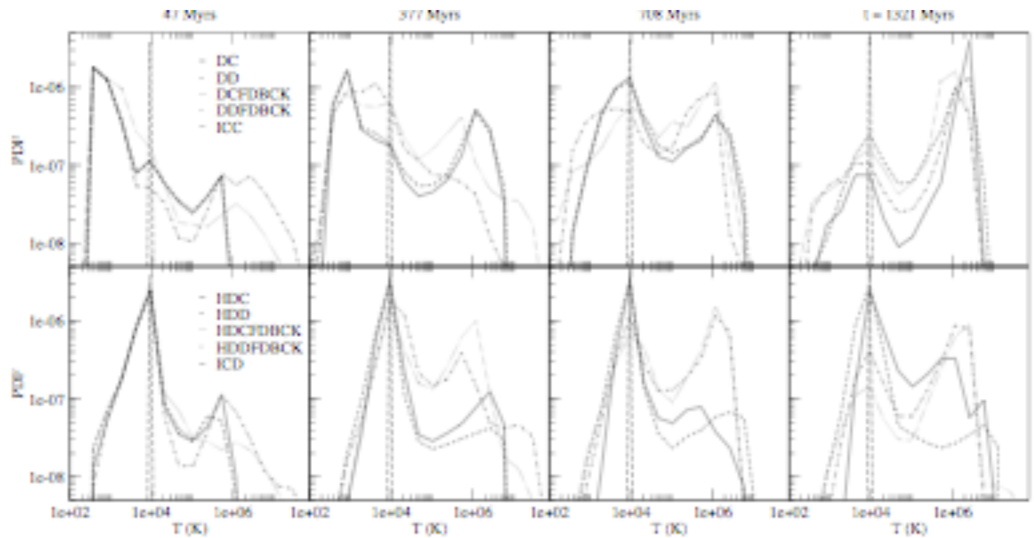
temperature



gas density PDF

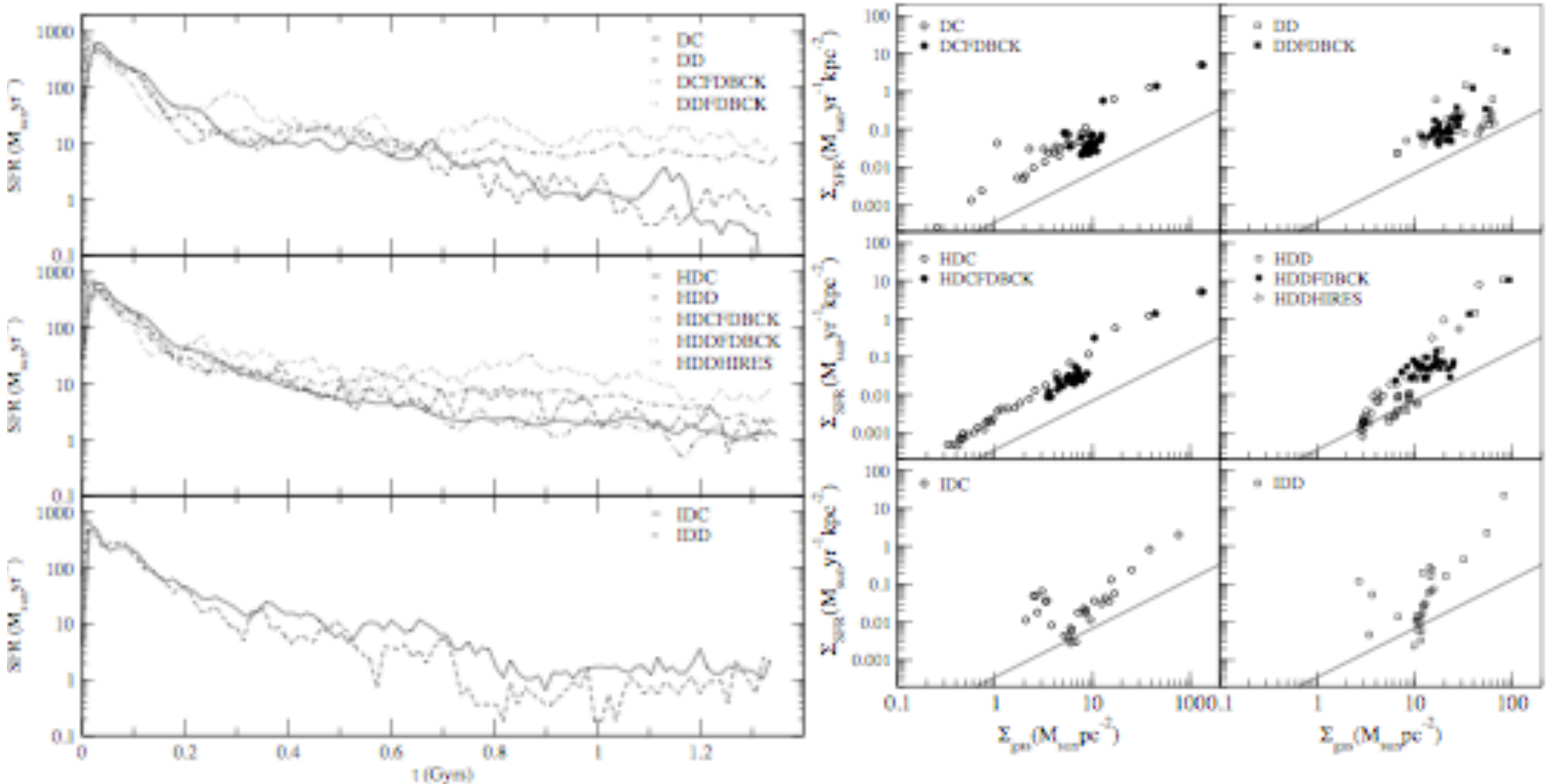
Tasker and Bryan 2007





gas temperature PDF

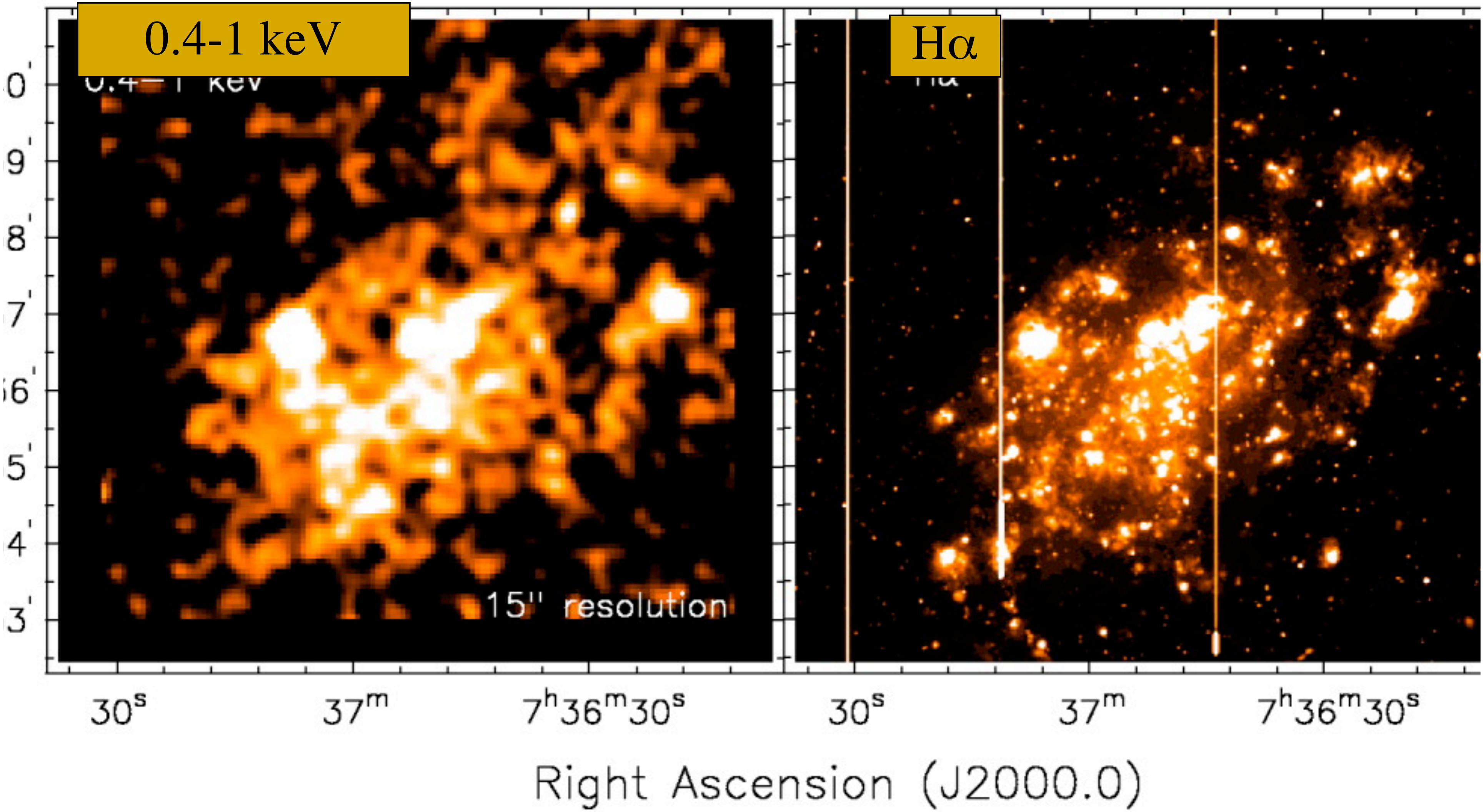
Tasker and Bryan 2007



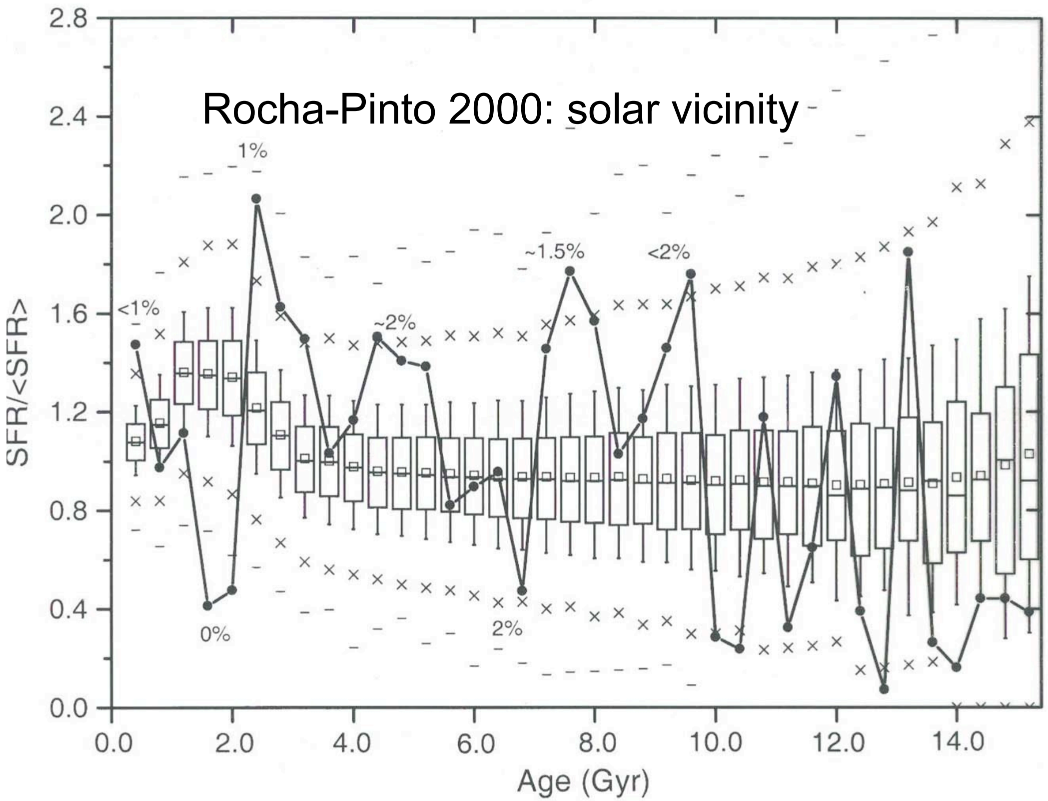
Tasker and Bryan 2007

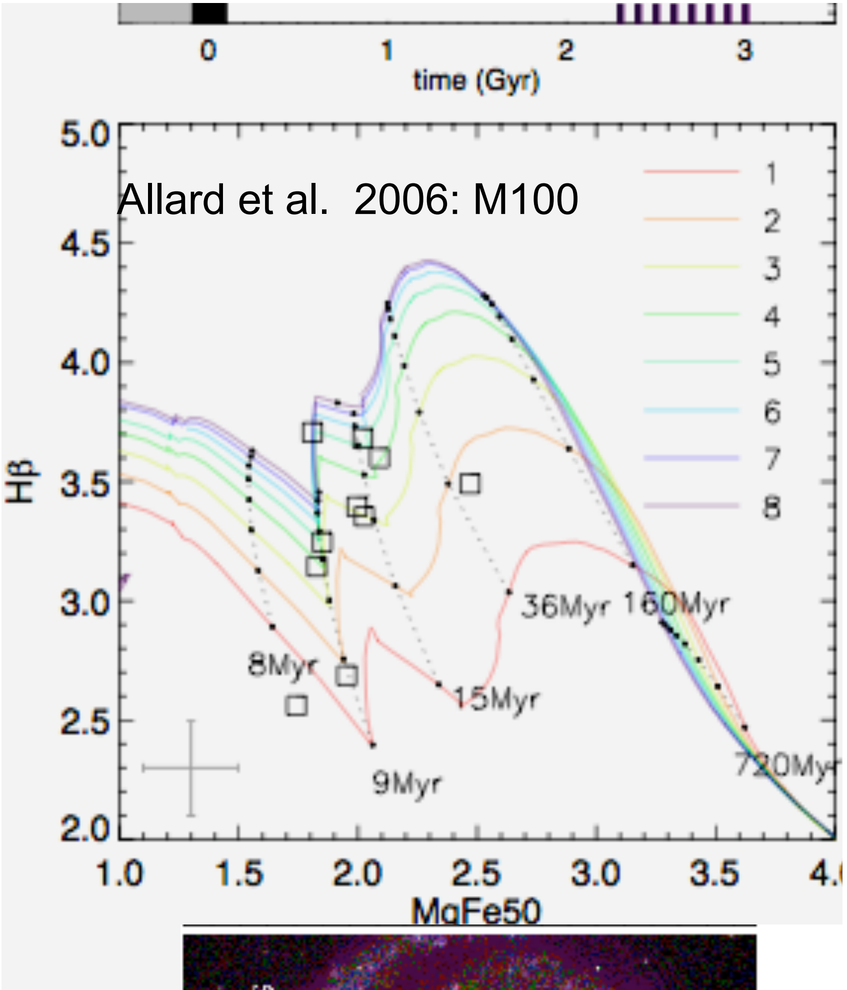
NGC 2403

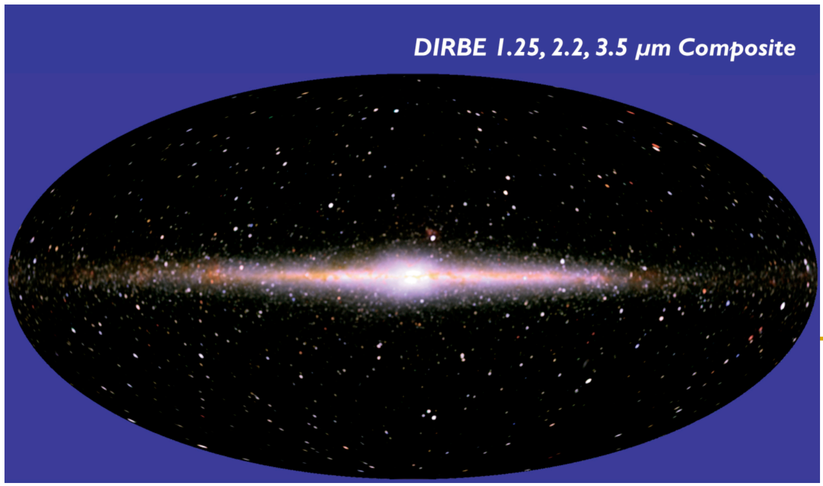
Fraternali et al 2002

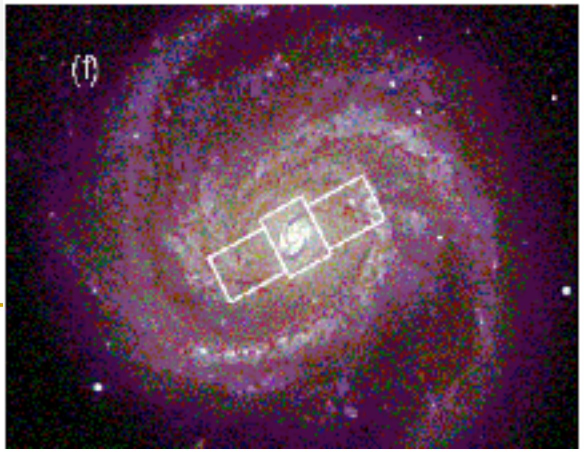


HISTORY OF STAR FORMATION

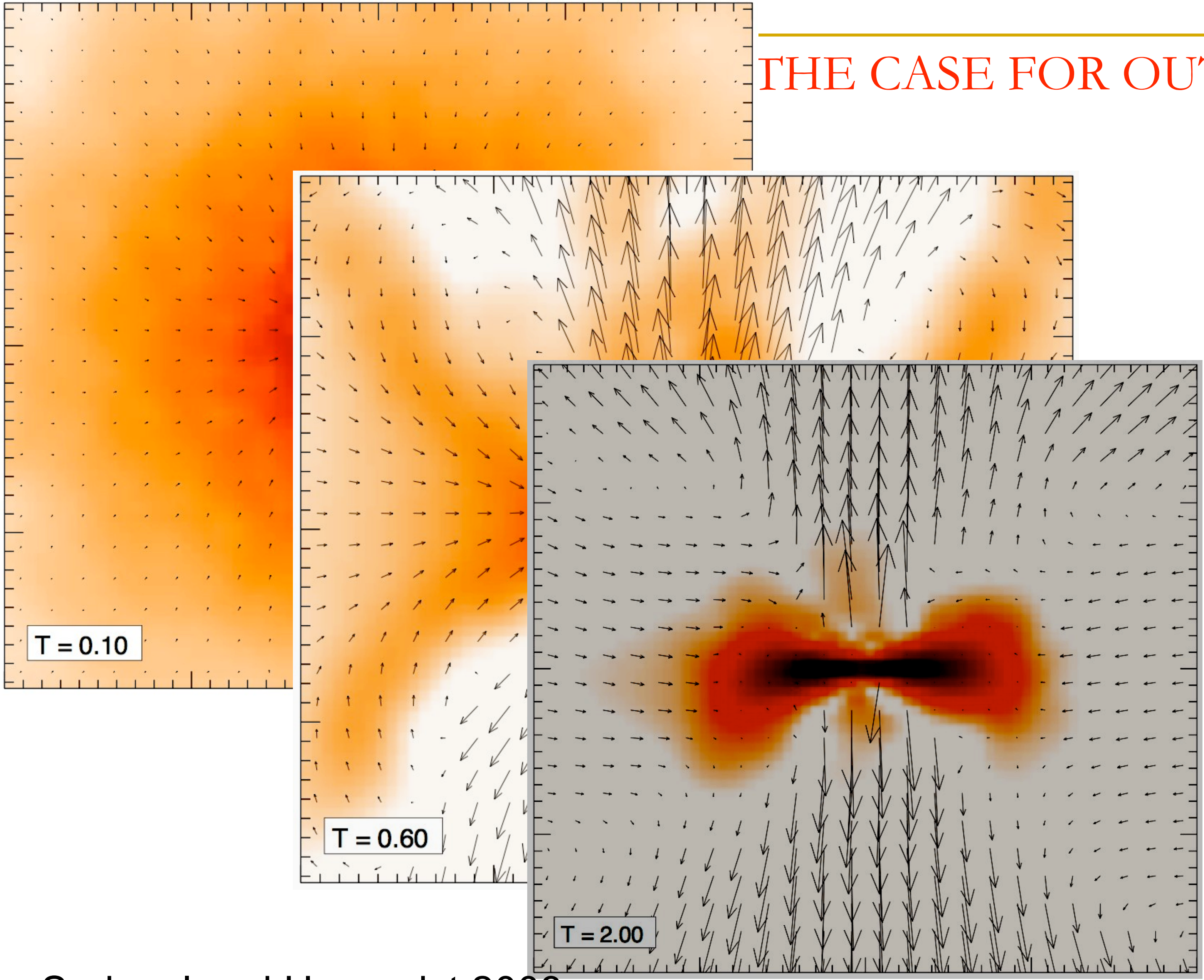






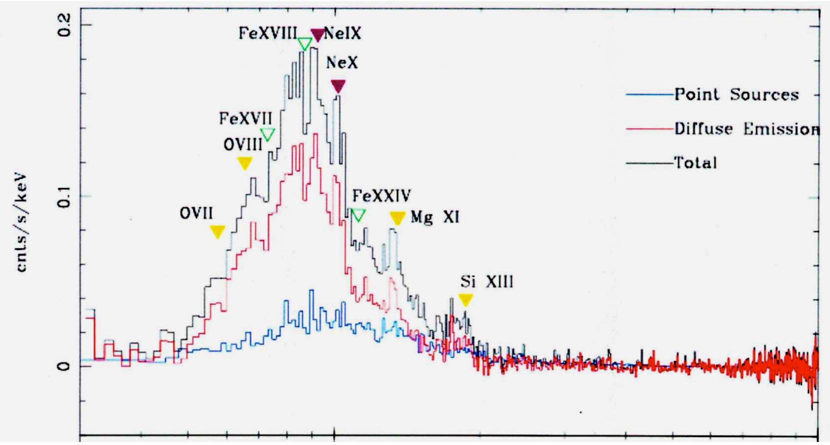


THE CASE FOR OUTFLOWS

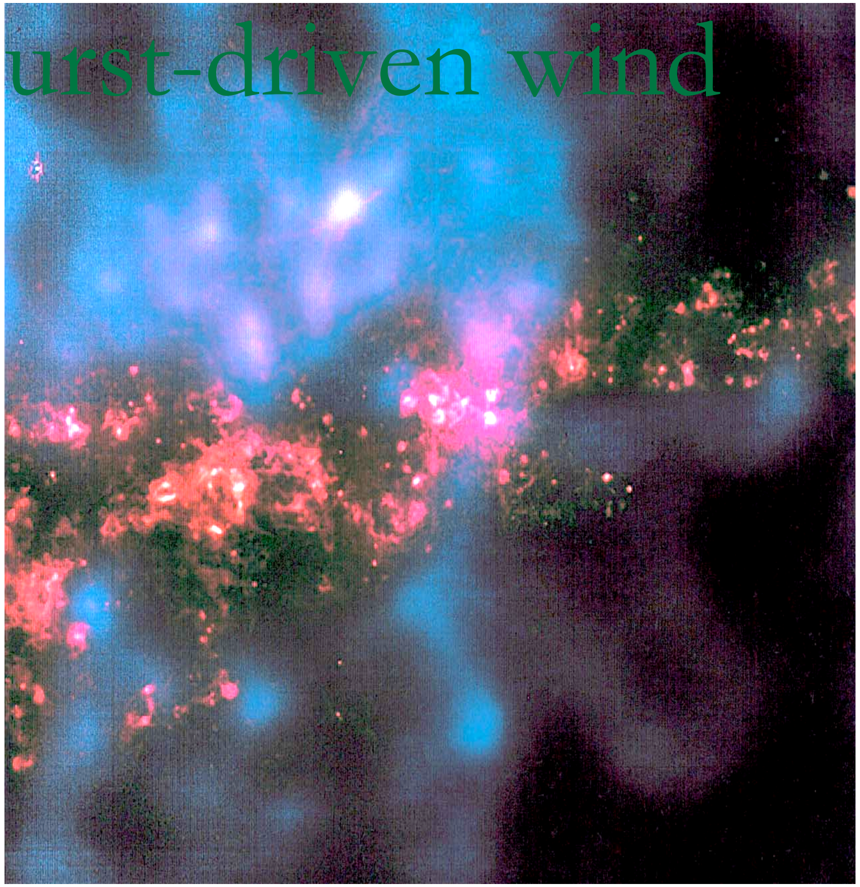


Springel and Hernquist 2003

NGC 1569: starburst-driven wind



Oppenheimer and Dave 2006



C. Martin

Outflow rates are implied….in dwarfs

outflow rate ~ porosity x density / t$_{dyn}$

$$\dot{M}^{SN}_{gasoutflow} \propto \dot{M}_{sfr}\sigma^{-2.7}$$

And in giants…

$$\dot{M}^{AGN}_{gasoutflow} \sim L^{AGN}/cv_w \propto \sigma^3$$

THE END

FRESH INGREDIENTS ARE NEEDED!