The Relationship Between Mid-Plane Pressure and Molecular Hydrogen Fraction in Galaxies

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ZAH

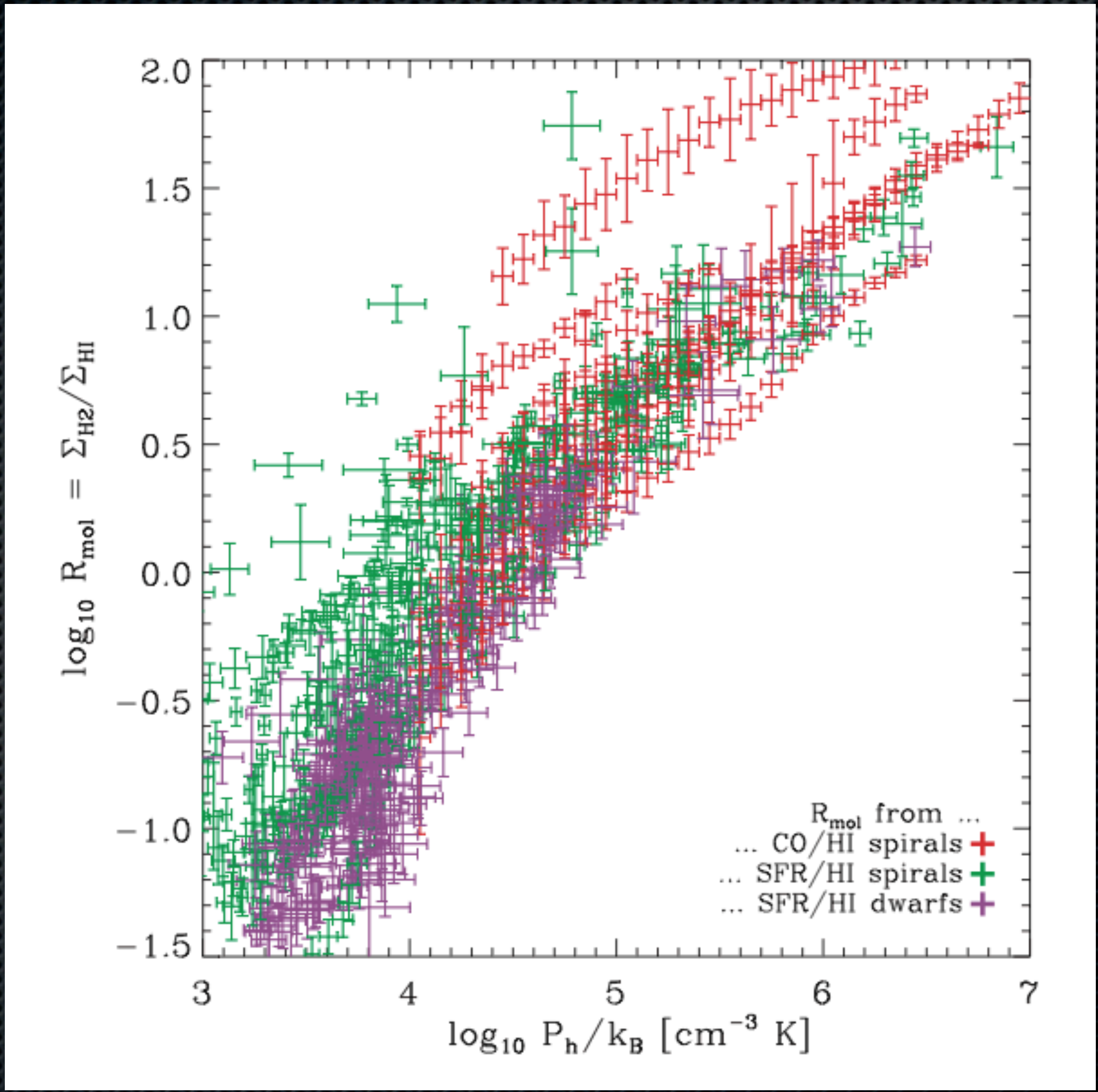
The importance of H_2

$$\Sigma_{\mathrm{SFR}} \propto \Sigma_{\mathrm{H_2}}$$

Rownd & Young 99, Wong & Blitz 02, Gao & Solomon 04

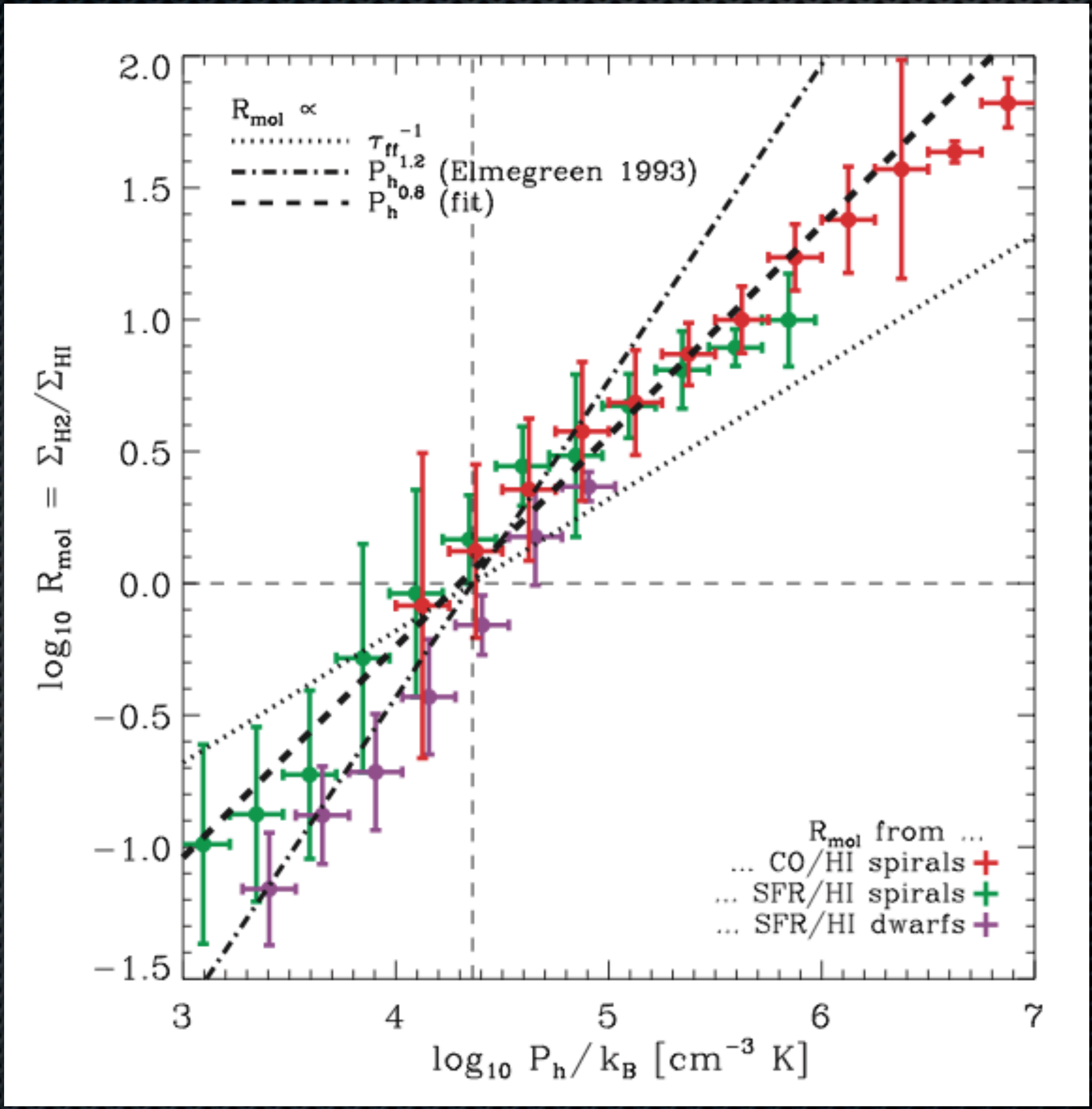
- Does correlation imply causation?
- Or does it merely imply a common cause?
- Gravitational instability can drive both star formation and H_2 formation together.

H_2 fraction correlates with midplane pressure

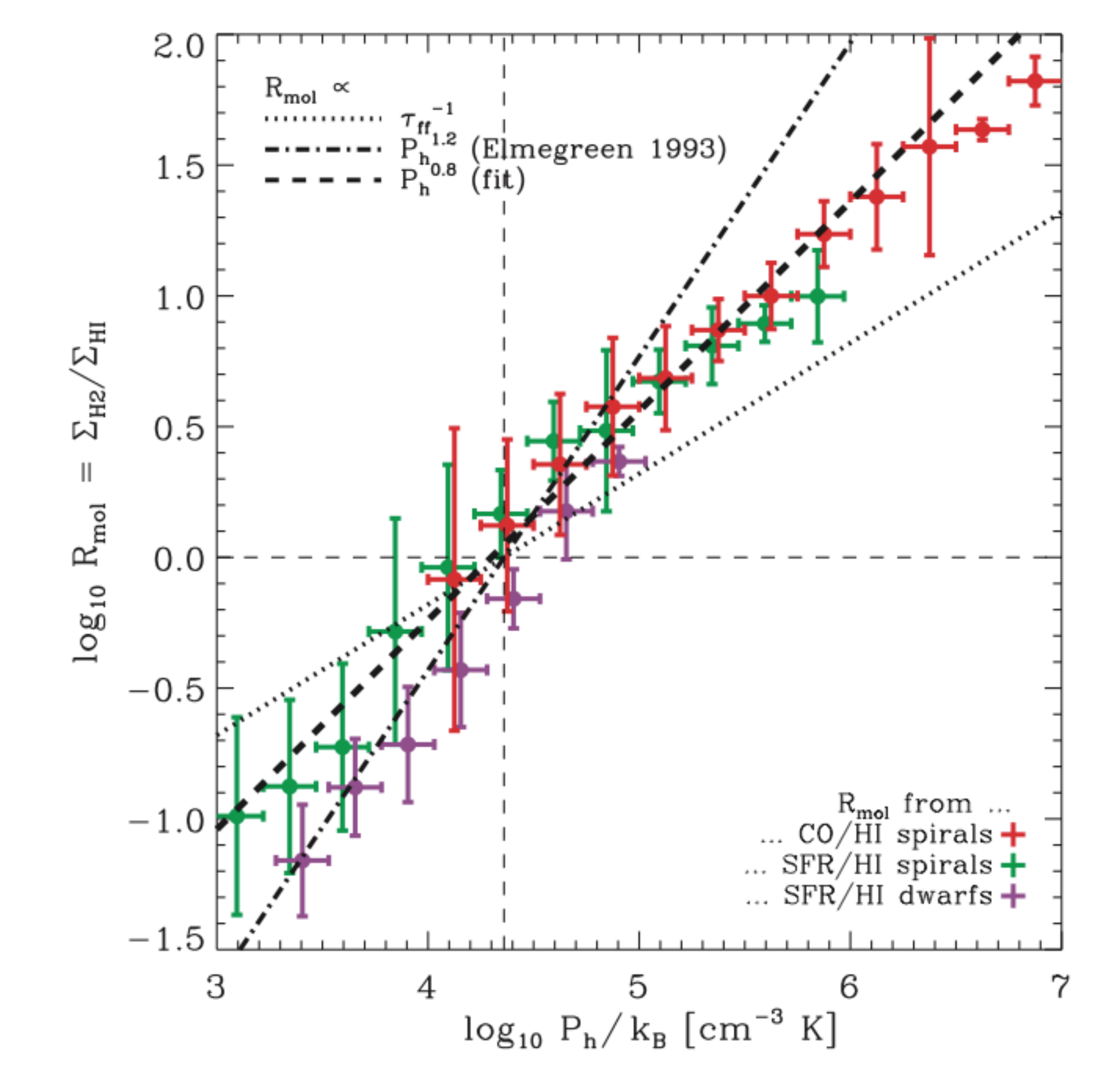


Leroy + 08

H_2 fraction correlates with midplane pressure



Leroy + 08



Equilibrium models suggest this due to balance between radiative dissociation and dust formation.

Leroy + 08

Relation can be derived analytically

Leroy + 08

$$R_{mol} = \Sigma_{H_2} / \Sigma_{H\ I}$$

$$SFE = SFE(H_2) \frac{R_{mol}}{R_{mol} + 1}$$

$$P_h \simeq \frac{\pi}{2} G \Sigma_{gas} \left(\Sigma_{gas} + \frac{\sigma_g}{\sigma_{*,z}} \Sigma_* \right)$$

Elmegreen 89
Elmegreen & Parravano 94

$$R_{mol} \propto P_h^{2.2} j^{-1}$$

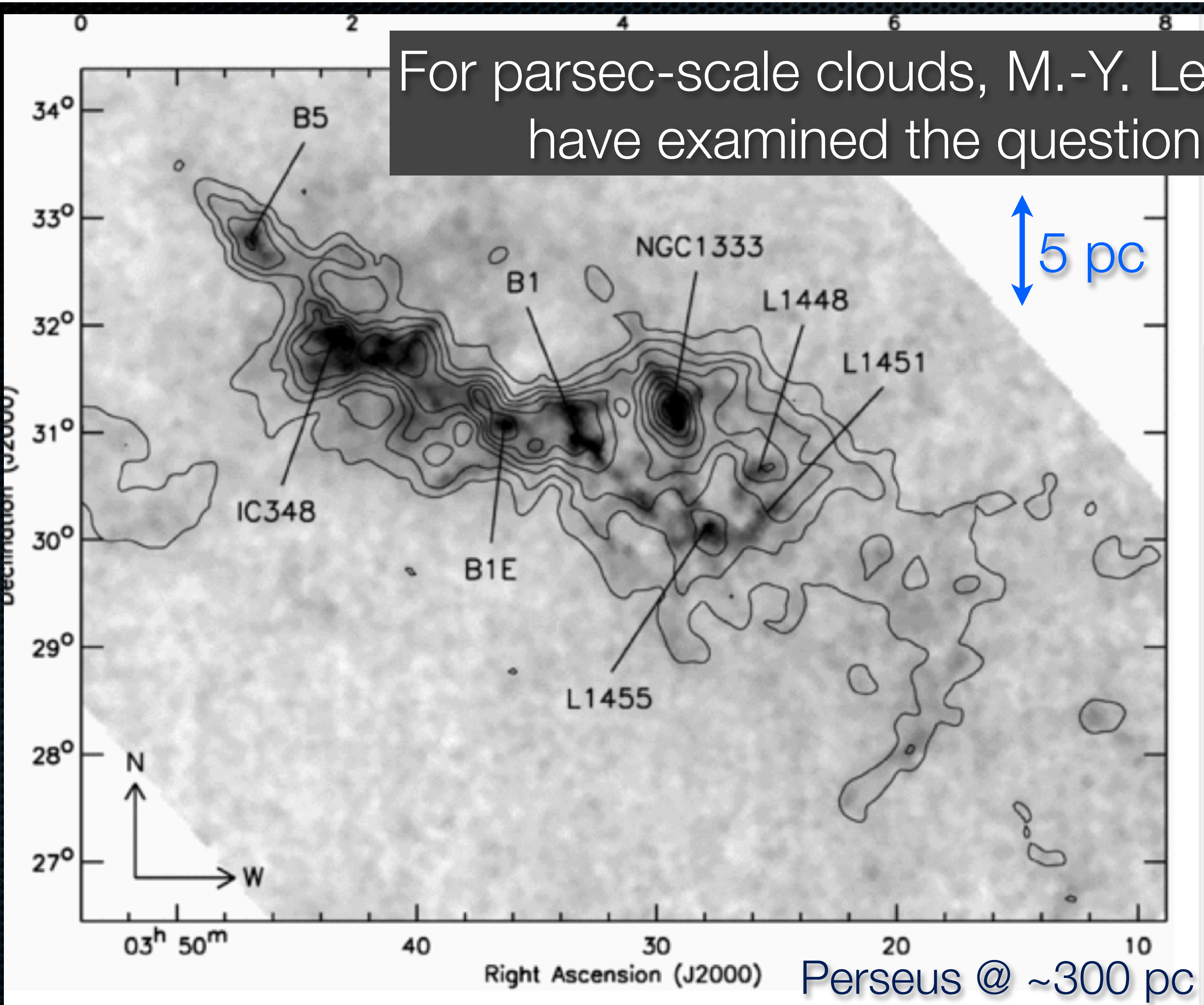
Elmegreen 93

Then assuming $j \propto \Sigma_{SFR} \propto \Sigma_{H_2}$

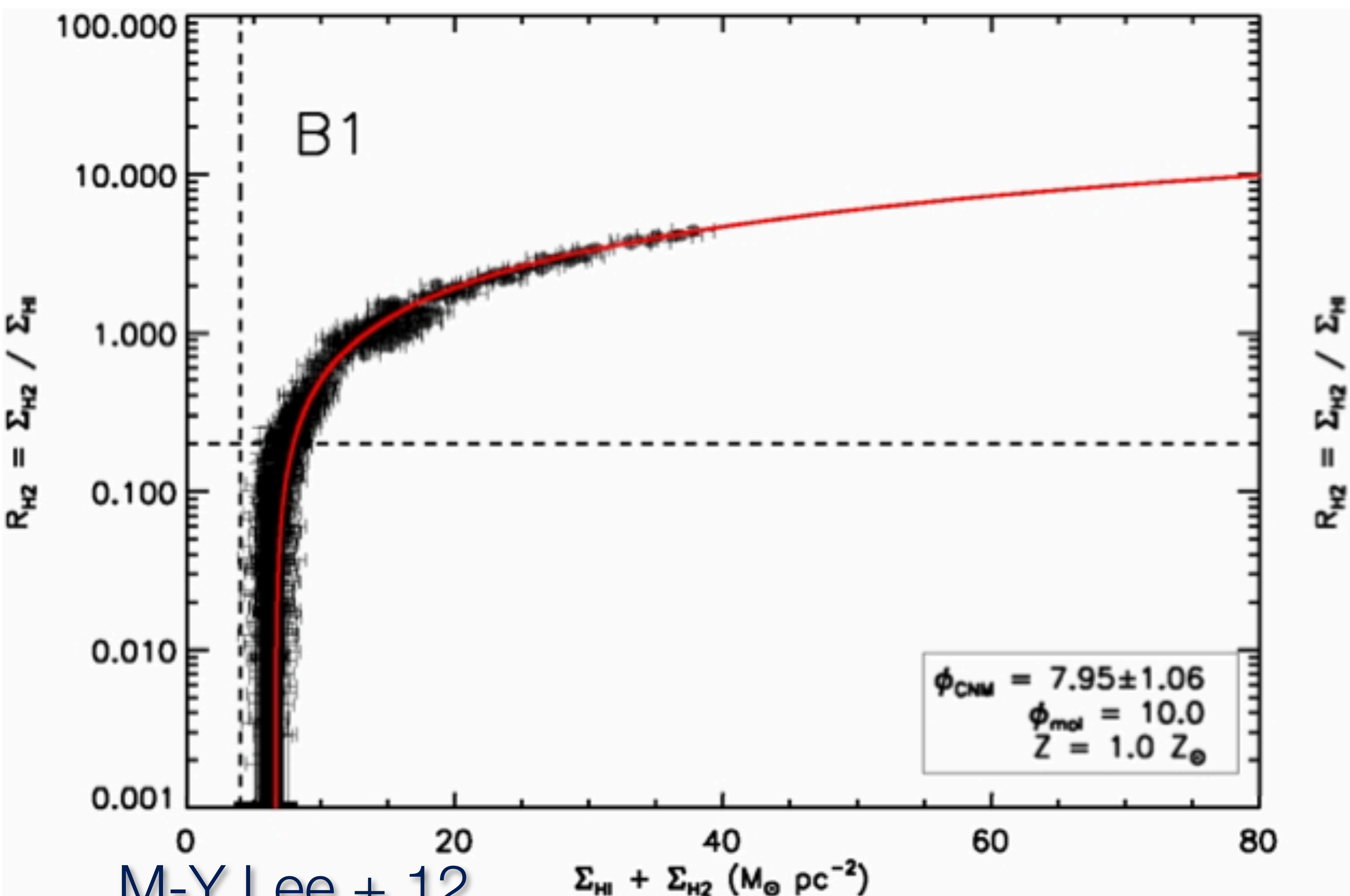
$$\implies R_{mol} \propto P_h^{1.2}$$

Are equilibrium H_2 fractions a good model for molecular clouds?

For parsec-scale clouds, M.-Y. Lee +12 have examined the question.



For these very small objects, equilibrium works great!



M-Y Lee + 12

What about GMCs? Models:

- ZEUS-MP MHD driven turbulence
  - $v_{rms} = 5$ km s^{-1}
  - $B_0 = 5.85$ μG
- chemical network following dominant paths for CO & H_2 formation and dissociation
- six-ray approximation for radiative cooling
- other species in chemical equilibrium
- detailed thermal model
- CO & H_2 self shielding and dust shielding treated following Draine & Bertoldi 96
  - CO self-shielding factors from Lee et al 96
  - neglects line shifts by velocity gradients

Our model reproduces full UMIST chemical model well.

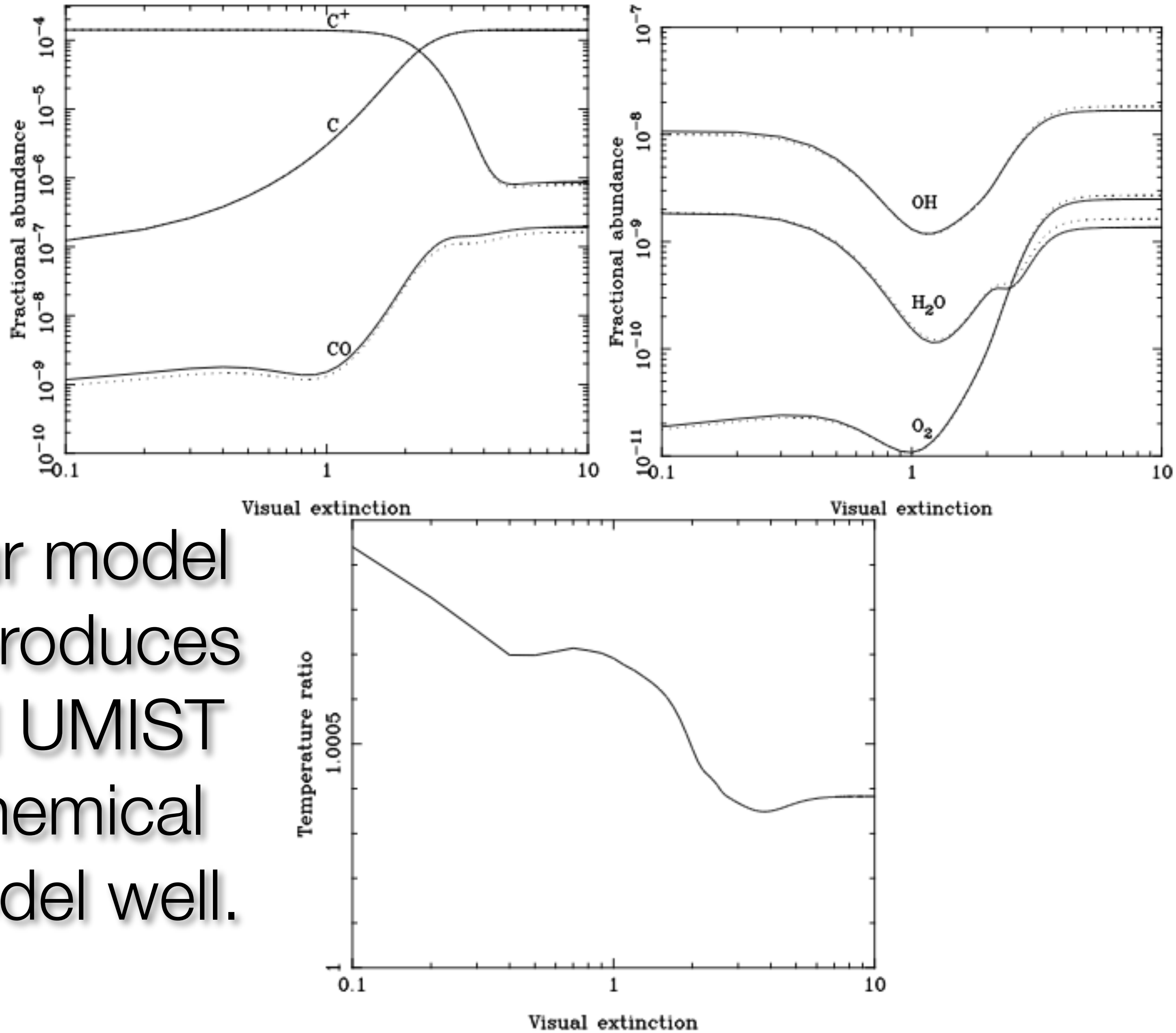


Figure 1. (a) Abundances of C^+, C and CO, plotted as a function of A_V, at the end of our static, single-zone simulations with $n_0 = 100\,\mathrm{cm}^{-3}$. The results produced by our simplified chemical model are given as dotted lines, while the results of the UMIST model are shown by solid lines. (b) As (a), but for the OH, H_2O and O_2 abundances. (c) As (a), but showing the ratio of gas temperature produced by the simplified model to that produced by the full UMIST model. Note that we plot the ratio rather than the individual temperatures because the difference between the models is very small.

(Glover et al. 2010)

Resolution study of time evolution shows good convergence

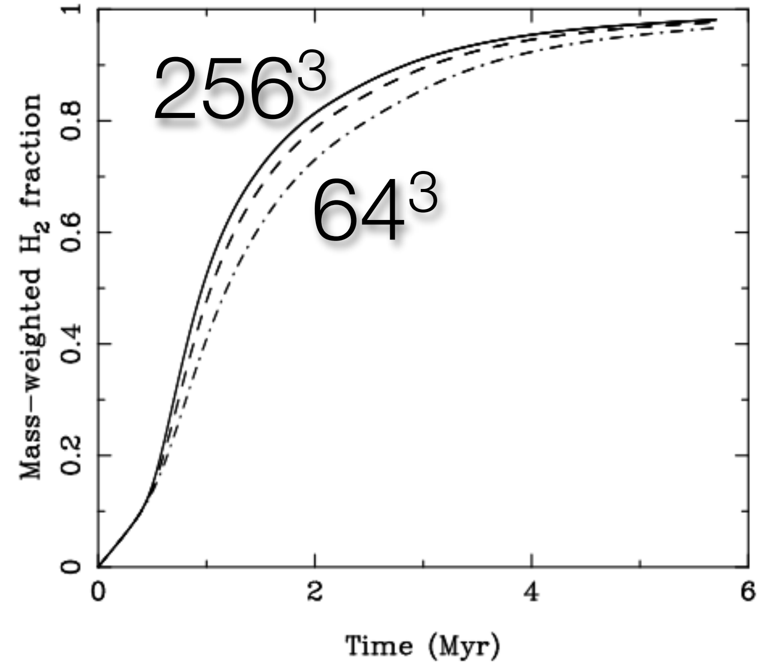
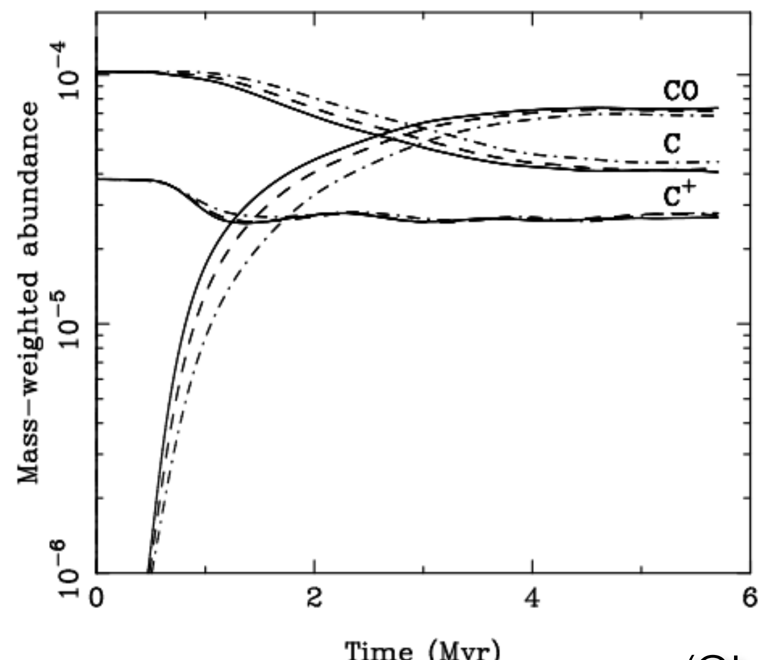


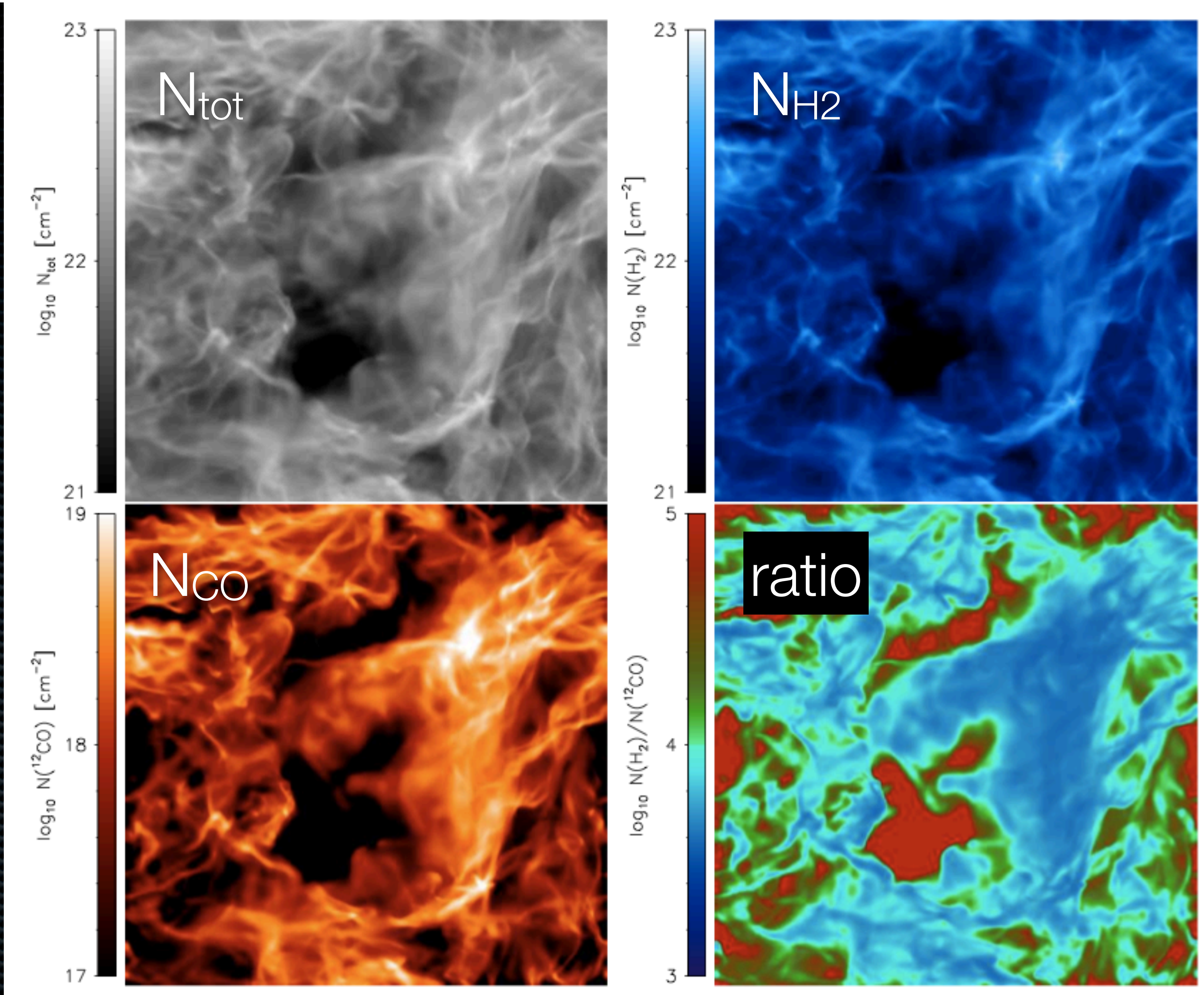
Figure 4. Time evolution of the mass-weighted H_2 abundance in simulations R1, R2 and R3, which have numerical resolutions of 64^3 zones (dot-dashed), 128^3 zones (dashed) and 256^3 zones (solid), respectively.

Note fast formation times!



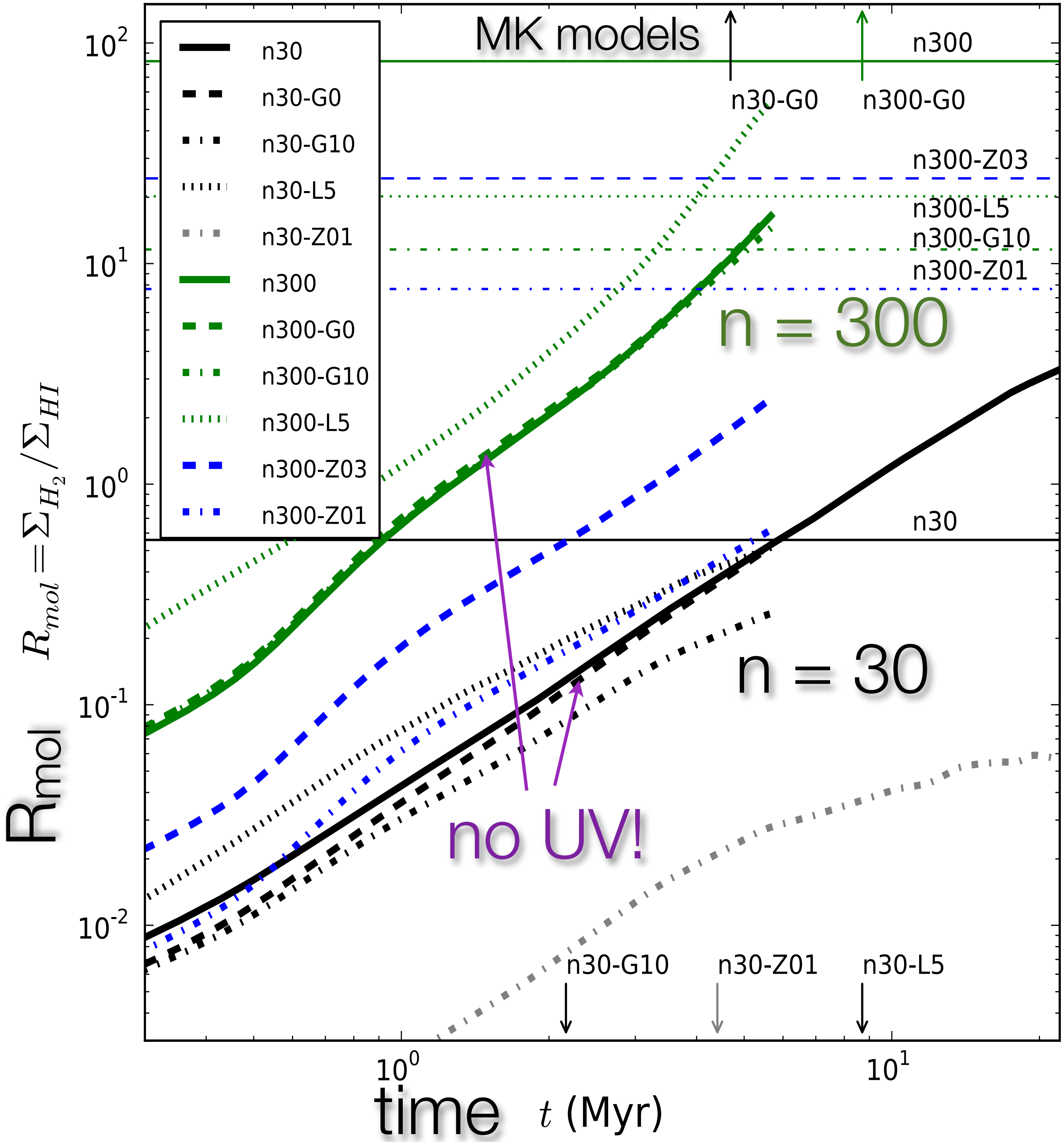
(Glover et al. 2010)

Figure 5. Time evolution of the mass-weighted abundances of atomic carbon, CO, and C^+ in simulations with numerical resolutions of 64^3 zones (dot-dashed), 128^3 zones (dashed) and 256^3 zones (solid).



(Glover et al. 2010)

Mac Low & Glover 11



Comparison to equilibrium models shows radiation balance is unimportant compared to local density.

Krumholz, McKee & Tumlinson 09 and McKee & Krumholz 10 computed models of equilibrium abundance spherical clouds balancing radiative dissociation against dust formation

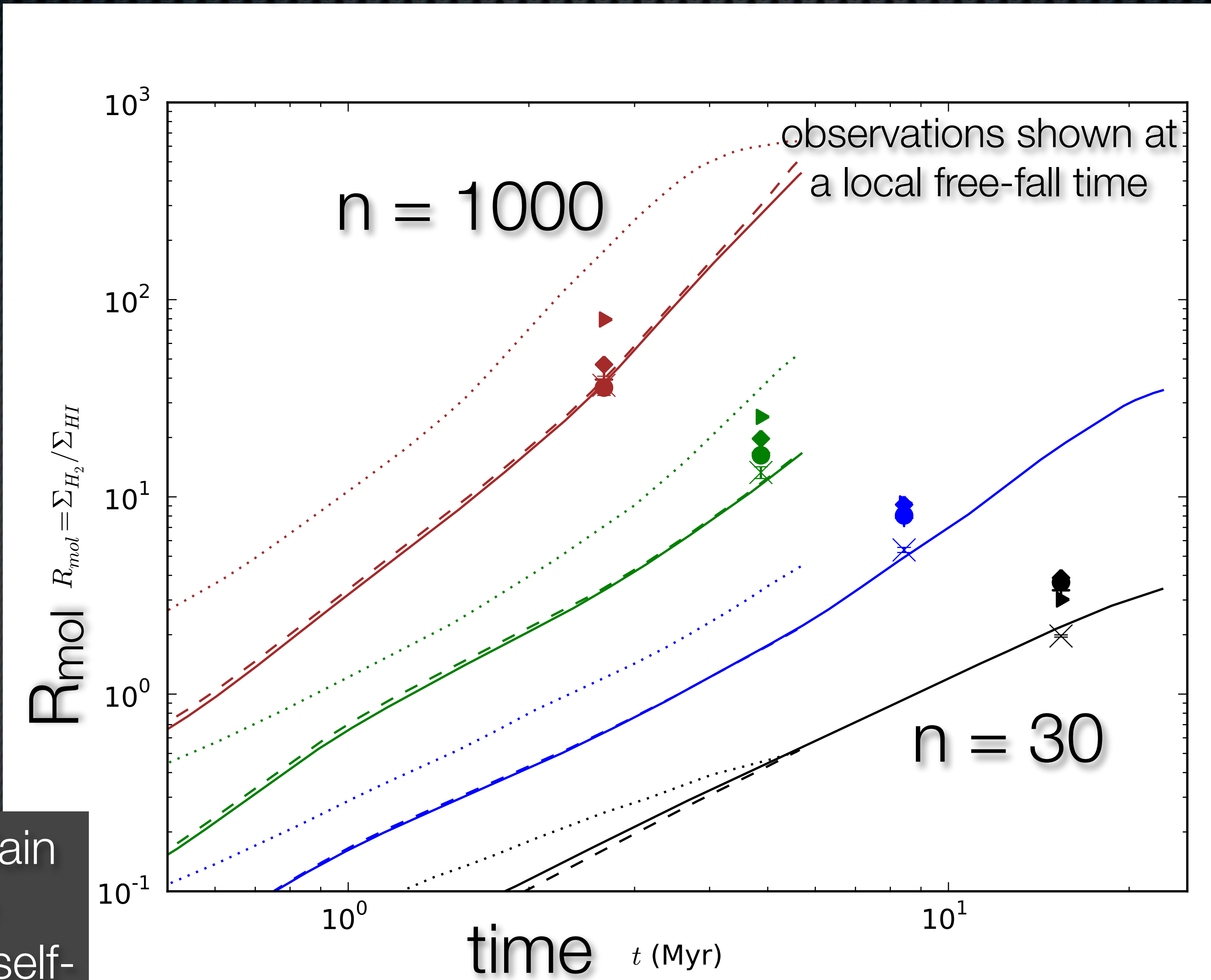
H_2 Fraction dependence on density can masquerade as dependence on pressure

At roughly constant temperature, magnetic field, and turbulent velocity,

$R_{mol} \sim P$

equivalent to

$R_{mol} \sim n$



Ostriker et al 10 explain constant effective temperature through self-regulation.

Mac Low & Glover 11

Gravitational instability leads to molecular cloud formation rather than vice-versa.

- Midplane pressure works to predict SF because $\Sigma(H_2) \propto \Sigma(SFR)$. But why does H_2 matter?
- CNM is 60 K. Cooling from 60 K to 10 K not a major factor.
- Gravitational instability produces dense gas that quickly forms H_2.
- Thus, H_2 and CO just trace dense gas that is already gravitationally unstable and collapsing (Krumholz, Leroy & McKee 11, Glover & Clark 12)