Star Formation in Cosmological Simulations: the Molecular Gas Connection

Kostas Tassis

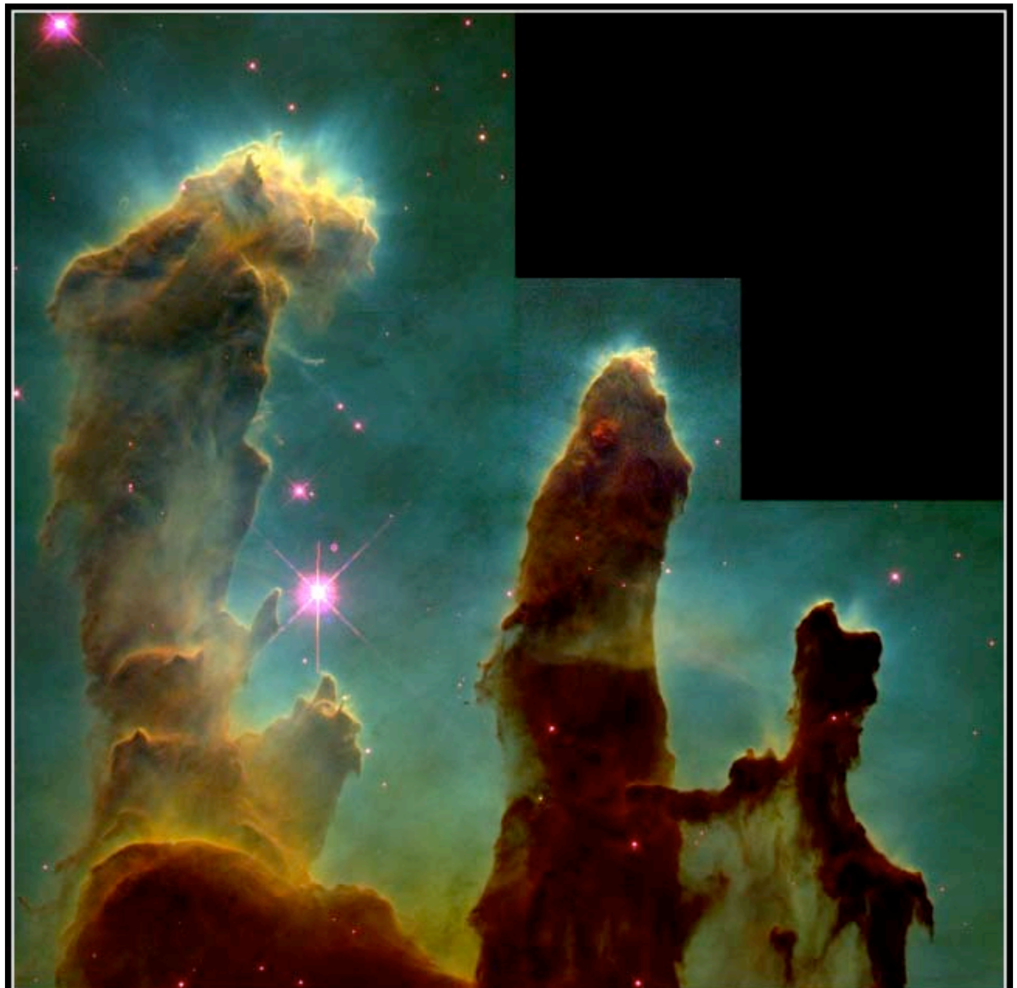
Jet Propulsion Laboratory
California Institute of Technology

Co-starring

Nick Gnedin

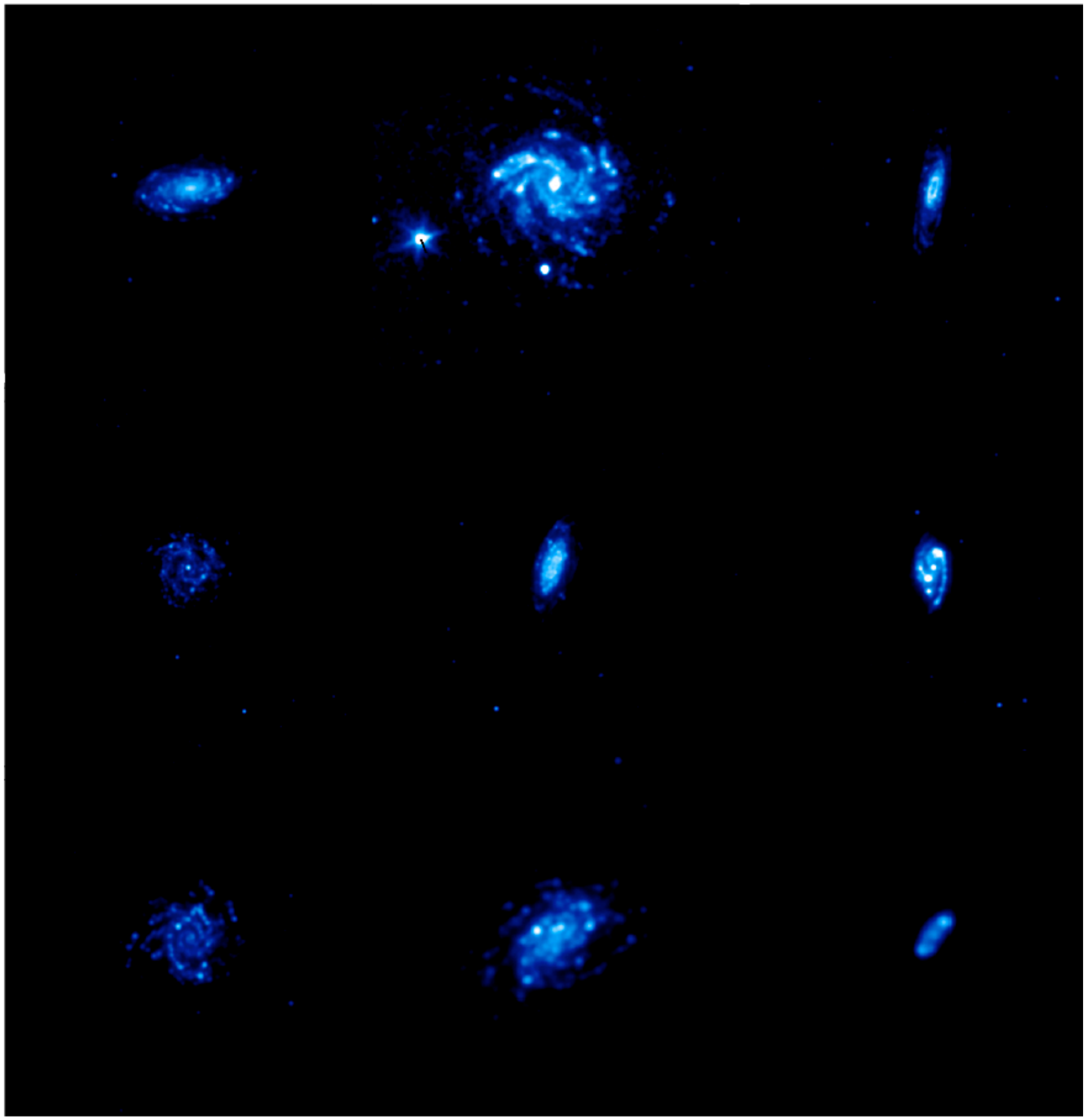
Andrey Kravtsov

Stars Form in Molecular Clouds



Gaseous Pillars • M16 HST • WFPC2
PRC95-44a • ST ScI OPO • November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA

HI cannot serve as proxy for H_2 & SF



SFR distributions from 24 μm SINGS + GALEX

F. Walter &
The HI Nearby
Galaxy Survey

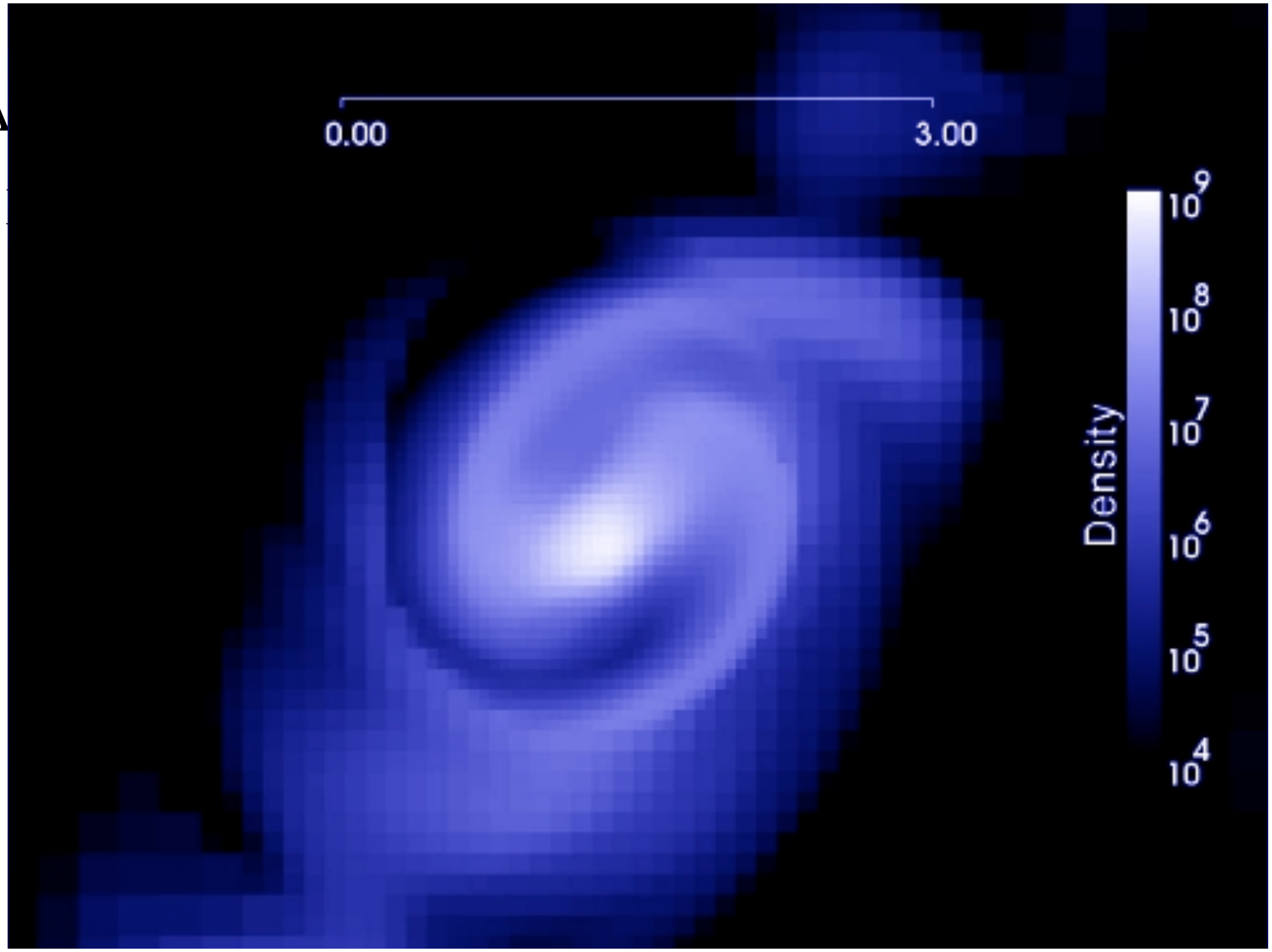
SF - H_2 connection

- Cosmological Simulations:
  - ISM physics not followed in detail
  - SF typically tight to cold gas (HI)
- Observations of high z galaxies:
  - ALMA will probe molecular content
  - Simulations must match this advance
- This work:
  - Formation, evolution of H_2 gas followed in cosmo sims
  - SF tied to molecular clouds

Starting Point

Pre-H_2 A

• 50



Starting Point

Pre-H_2 ART (Adaptive Refinement Tree):

- 50 pc resolution in high-redshift galaxies.
- Star formation recipe is based on a constant density threshold of 50cm^{-3} (independent of any gas property).
- Optically Thin Variable Eddington Tensor Approximation (OTVET) for following time-dependent and spatially-variable RT.
- Cooling rates and ionization/chemical balance are computed "on the fly".

H_2 Formation Model: gas + dust

- "Primordial" hydrogen balance (gas-phase reactions)

$$\dot{X}_{\mathrm{H\,I}} = R(T) n_e X_{\mathrm{H\,II}} - X_{\mathrm{H\,I}} \Gamma_{\mathrm{H\,I}} - 2\dot{X}_{\mathrm{H_2}}$$
$$\dot{X}_{\mathrm{H_2}} = \dot{X}^{\mathrm{gp}}_{\mathrm{H_2}}$$

- Adding dust heuristically

$$\dot{X}_{\mathrm{H\,I}} = R(T) n_e X_{\mathrm{H\,II}} - S_d X_{\mathrm{H\,I}} \Gamma_{\mathrm{H\,I}} - 2\dot{X}_{\mathrm{H_2}}$$
$$\dot{X}_{\mathrm{H_2}} = S_d S_{\mathrm{H_2}} \dot{X}^{\mathrm{gp}}_{\mathrm{H_2}} + R_d n_b X_{\mathrm{H\,I}} \left(X_{\mathrm{H\,I}} + 2X_{\mathrm{H_2}} \right)$$

H_2 Formation Model: parameters

Formation rate: $$R_{\rm d} = 3.5 \times 10^{-17} Z C_\rho \ {\rm cm}^3/{\rm s}$$ Wolfire et al. (2008)

- Dust/Gas ~ Z
- Molecular gas is inhomogeneous, clumping factor $C_\rho \equiv \langle\rho^2\rangle/\langle\rho\rangle^2 \sim 10$ for typical clumpy molecular cloud models (e.g.: Padoan et al. 1997; Ostriker et al. 2001)

Shielding factors:

$$S_{\rm d} = e^{-\sigma_{\rm d,eff}(N_{\rm HI}+2N_{\rm H_2})}$$

$$S_{\rm H_2} = \frac{1-\alpha_{H_2}}{(1+x)^2} + \frac{\alpha_{H_2}}{(1+x)^{1/2}} e^{-\frac{\sqrt{1+x}}{1200}}$$

a la Draine & Bertoldi (1996) see also Glover& Mac Low(2007)

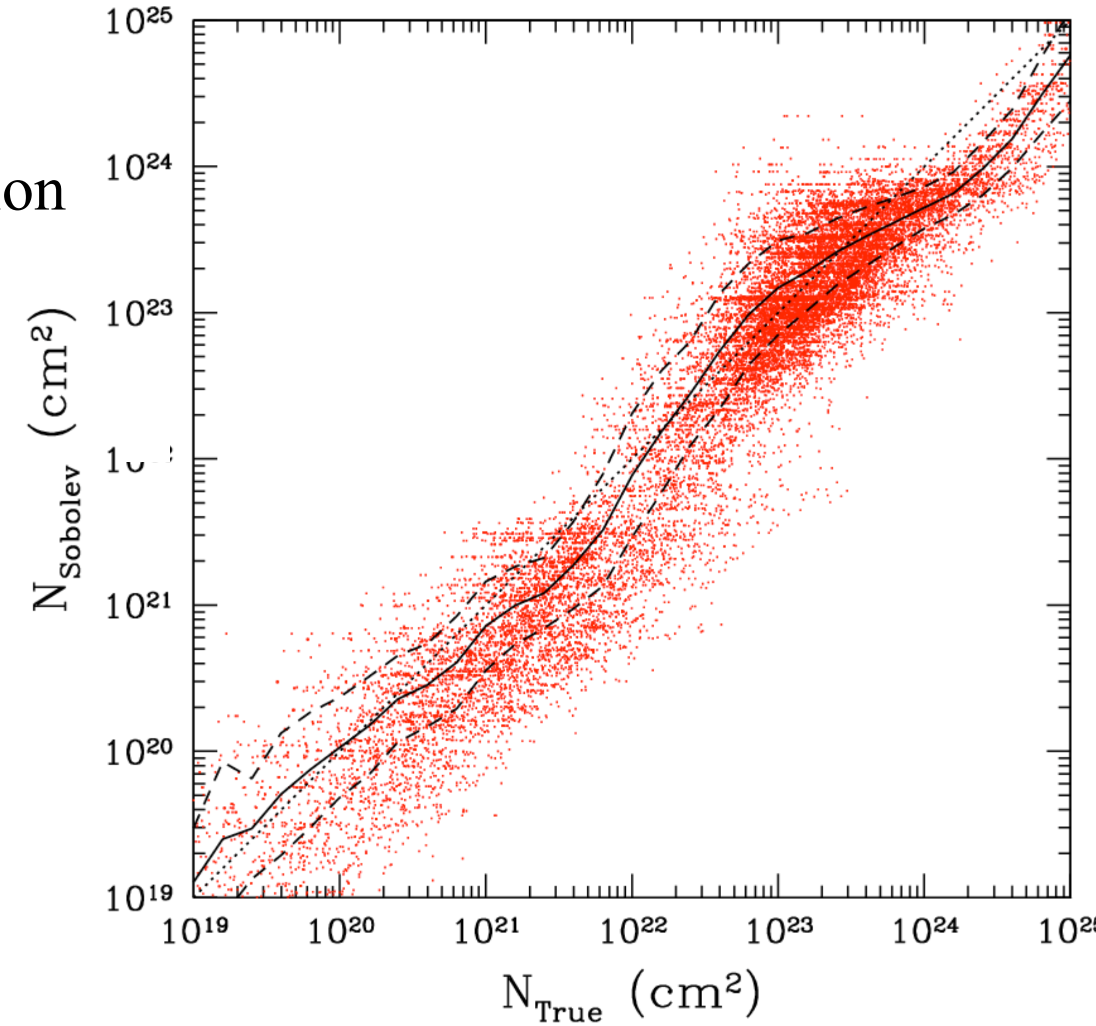
- Parameters α_{H_2} & $\sigma_{\rm d,eff}$ to be calibrated

H_2 Formation Model: column density

- Column densities for shielding factors from Sobolev-like approximation

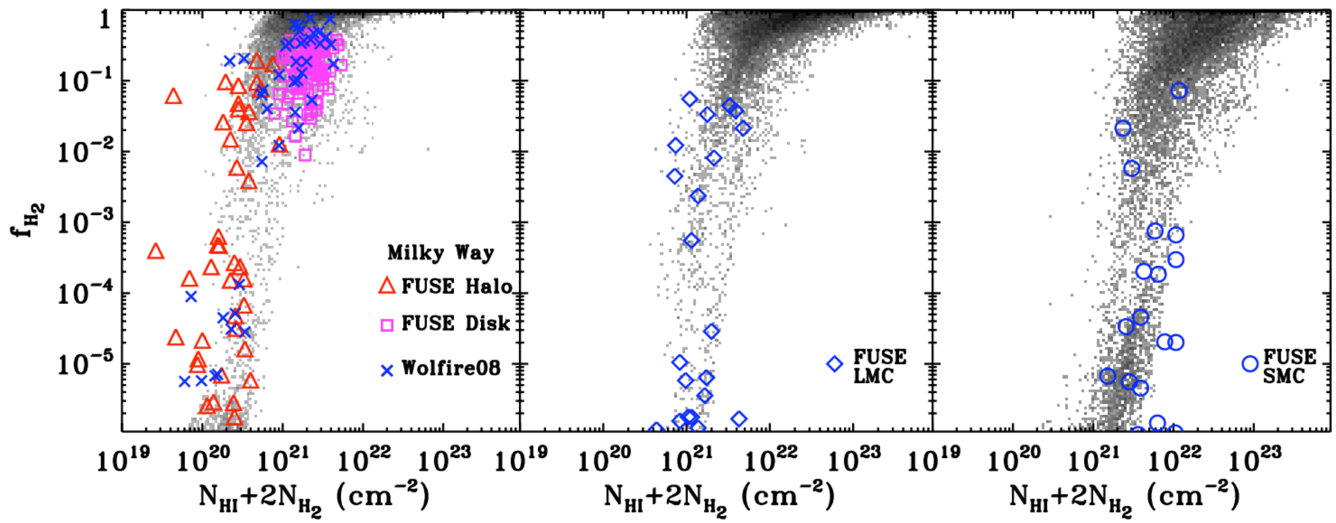
$$N_i \approx n_i L_{\rm Sob}$$

$$L_{\rm Sob} \equiv \frac{\rho}{|\nabla \rho|}$$

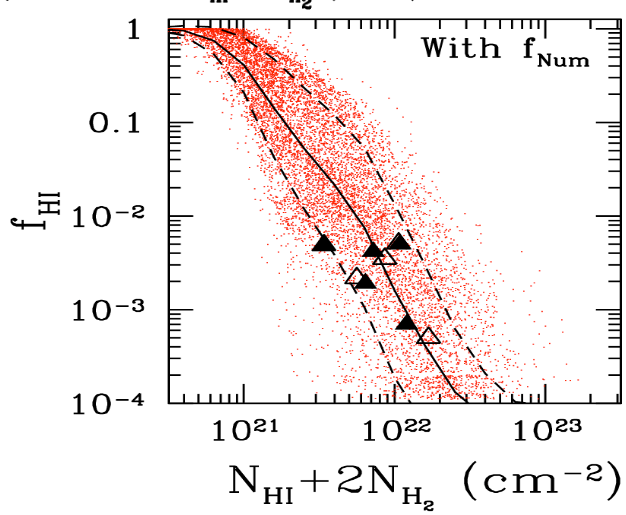


Training the Model

- H_2 fractions in translucent clouds have been measured by *Copernicus* & *FUSE* space missions
(Tumlinson et al 2002, Rachford et al 2002, Gillmon et al 2006, Wolfire et al 2008)



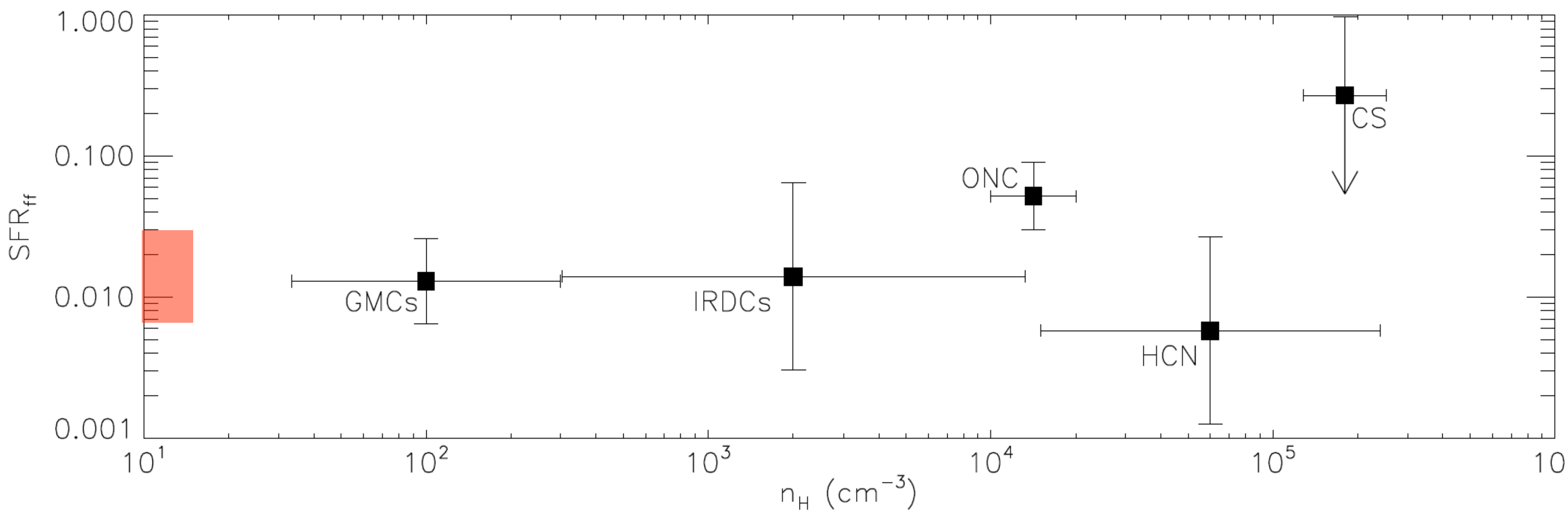
- HINSA measurements of HI fractions (Goldsmith & Li 2005)



Star Formation

$$\dot{\rho}_\star = \frac{\varepsilon_{\rm ff}}{\tau_{\rm sf}} \rho_{H_2}$$

Specific SFR per local free-fall time is not sensitive to the environment (both normal galaxies and starbursts), and is about 1-2% in molecular gas (star formation is ***slow***).

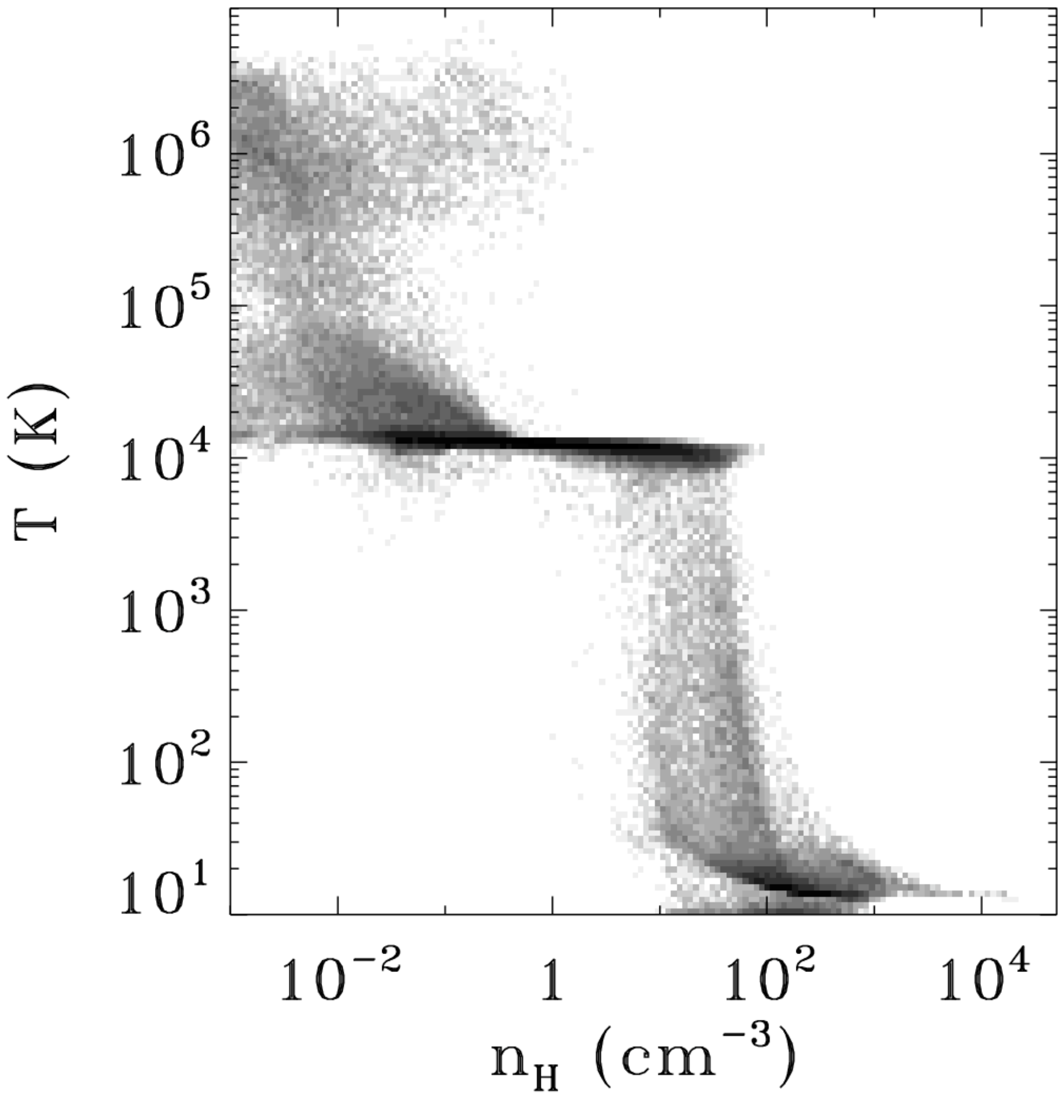


(Krumholz & Tan 2006)

Thermodynamics

Automatically get 3+phases:

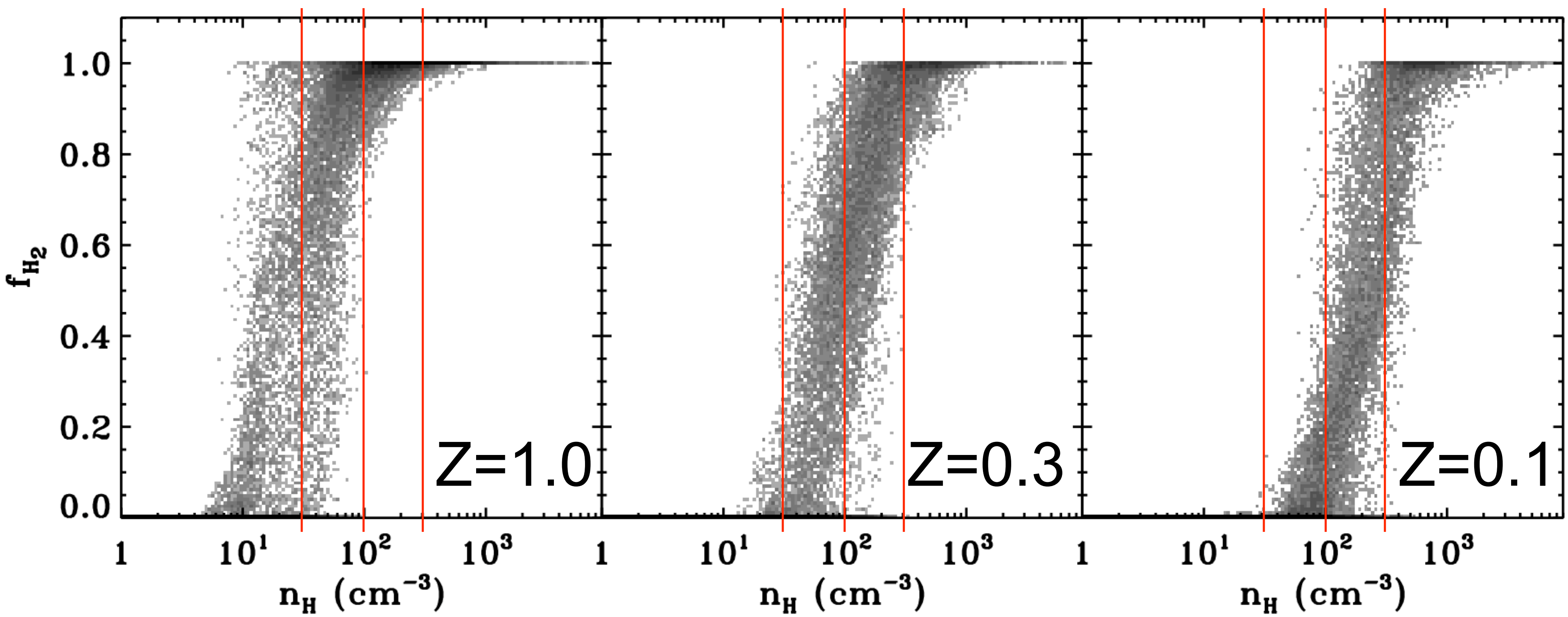
- Hot coronal gas
- Warm neutral and ionized medium
- Cold neutral and molecular gas



Atomic-to-molecular Transition

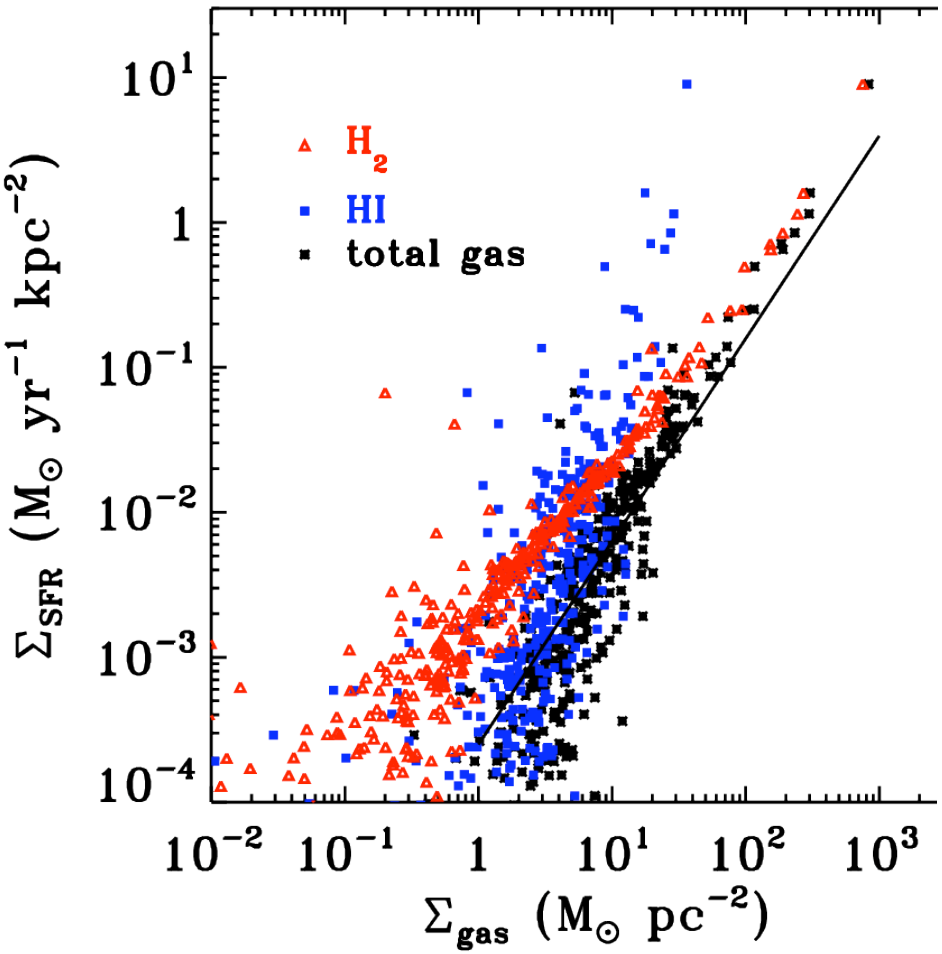
Transition between atomic and molecular phases

- very sharp
- scales with metallicity $n_{\rm t} \simeq 30 \left(\frac{Z}{Z_{\odot}}\right)^{-1}$ cm^{-3}



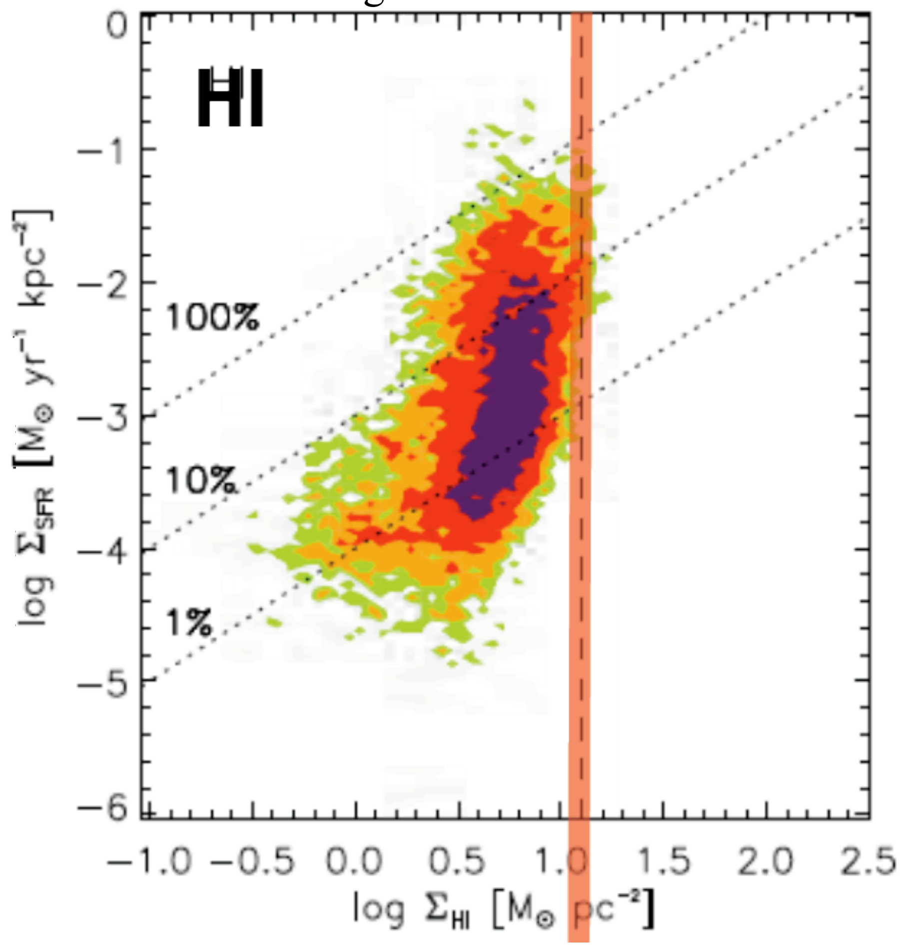
Kennicutt Plots

Simulation



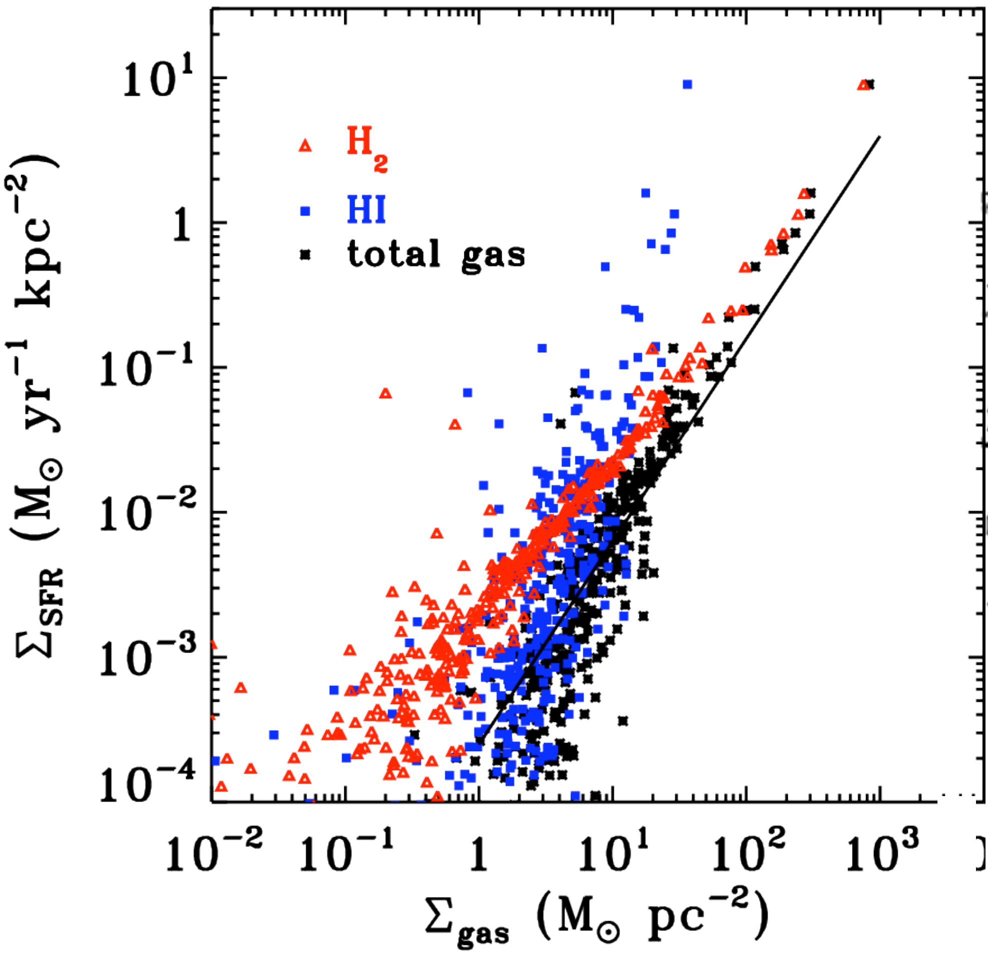
Reality (THINGS)

Bigiel et al. 2008



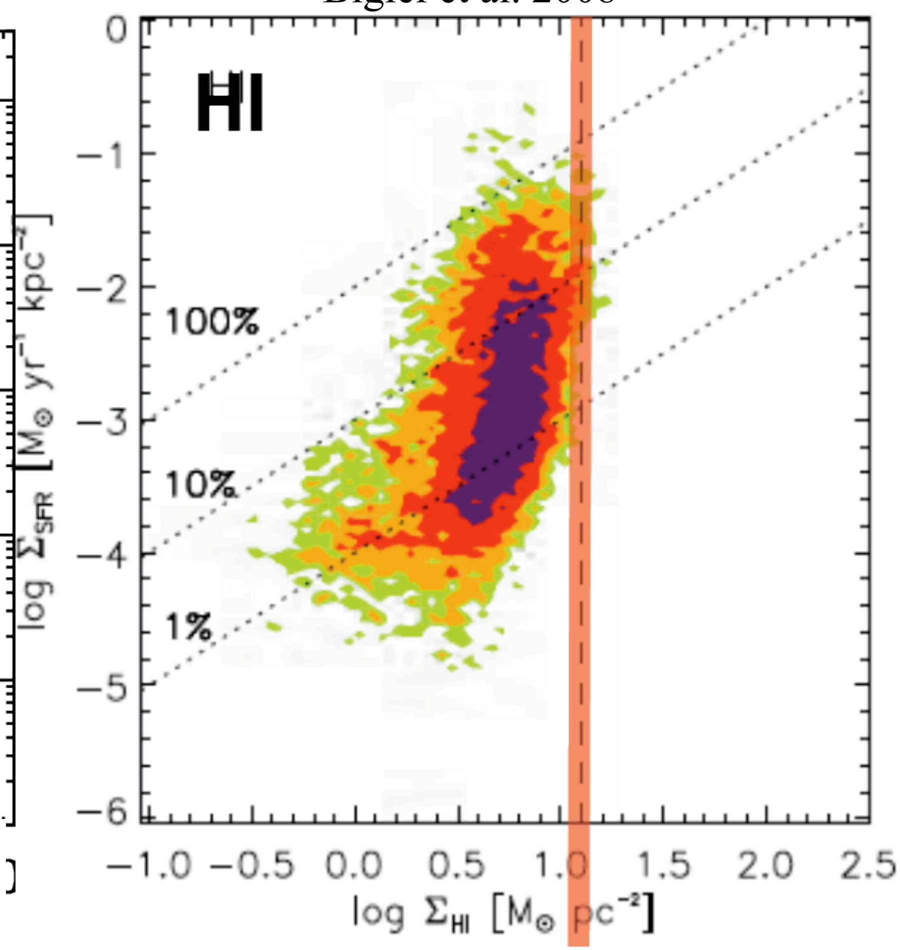
Kennicutt Plots

Simulation



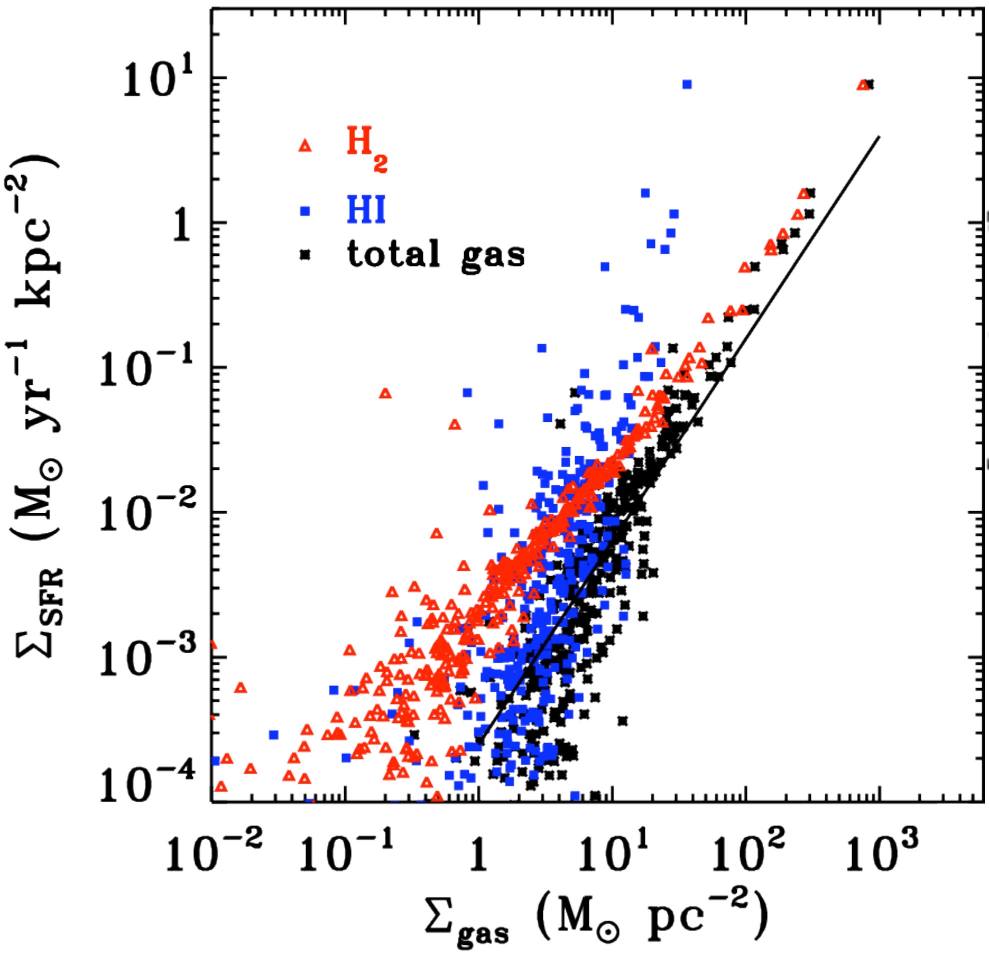
Reality (THINGS)

Bigiel et al. 2008



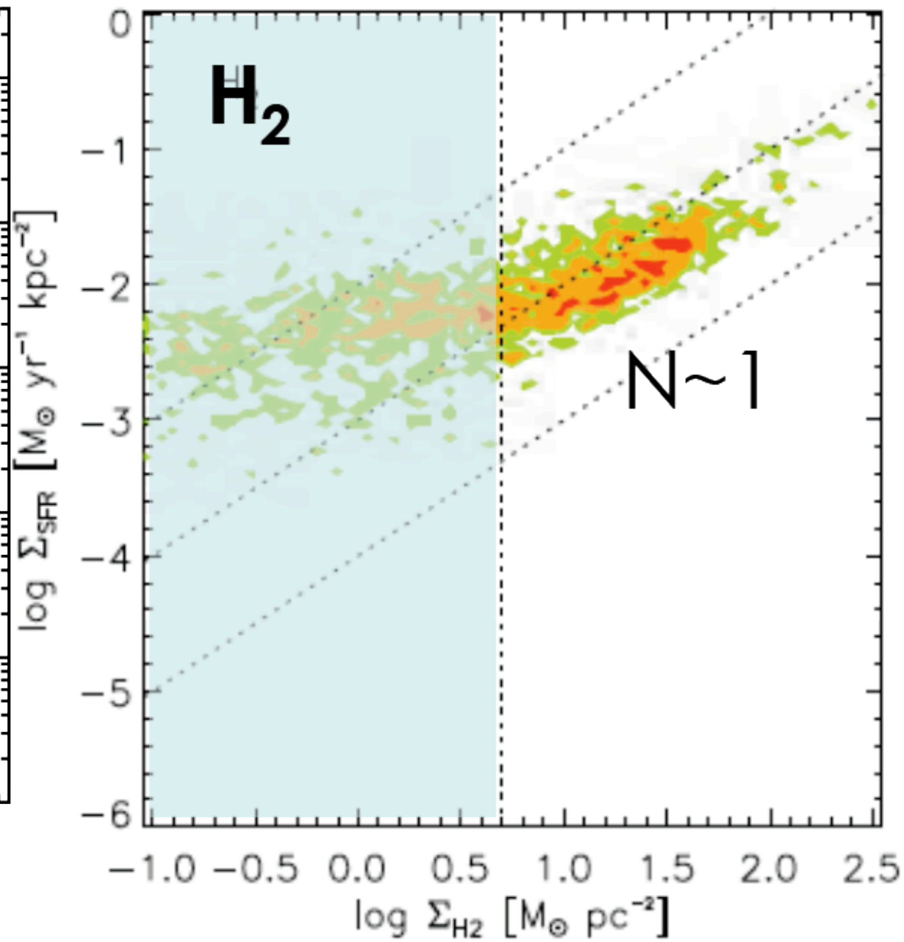
Kennicutt Plots

Simulation



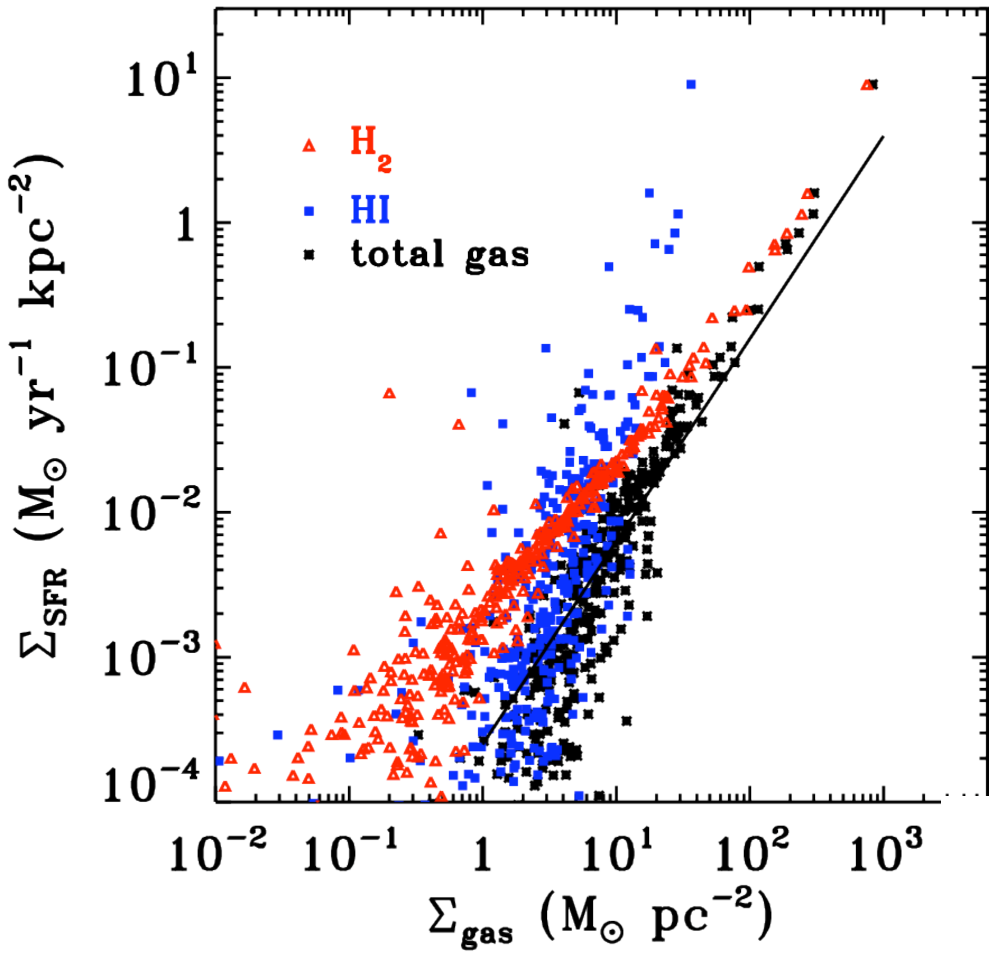
Reality (CO)

Bigiel et al. 2008



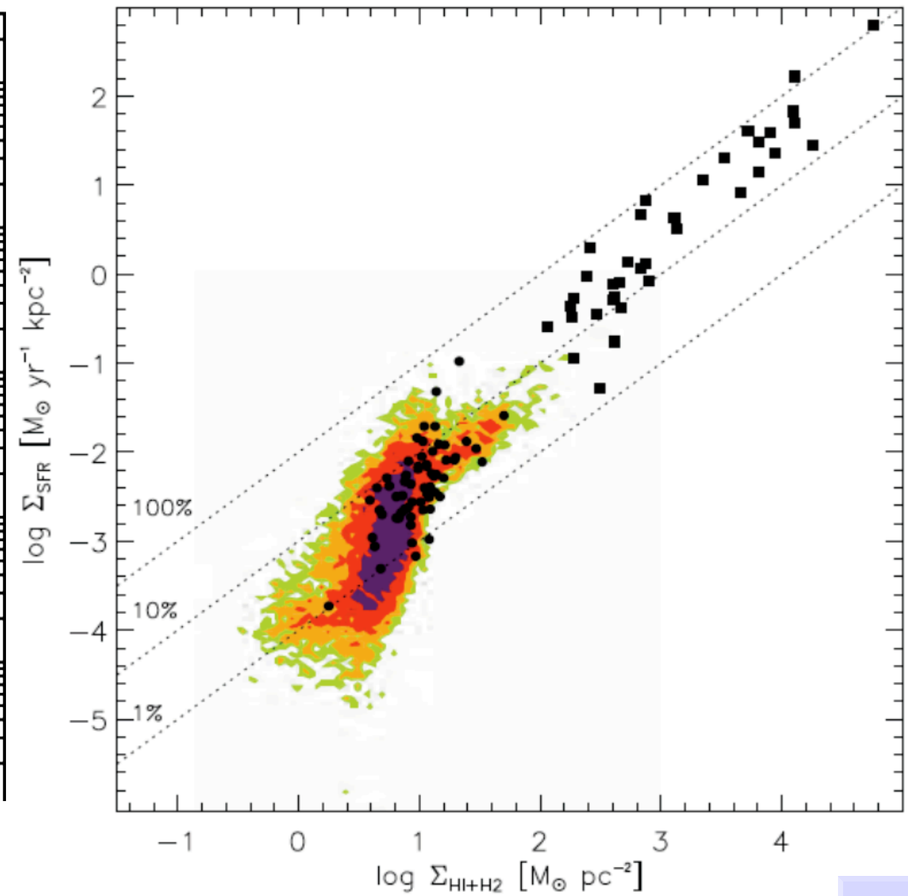
Kennicutt Plots

Simulation



Reality (THINGS+CO)

Bigiel et al. 2008



Conclusions

- *Transition from atomic to molecular gas is very sharp – lack of dependence of SFR on HI surface density in Kennicutt-like correlations.*

- *In the zeroth order, the SF density threshold scales inversely with metallicity,* $n_{SF} = 30/Z\ cm^{-3}$.

- *Since dust-to-gas ratio depends on the metallicity, it constitutes a feedback effect that needs to be accounted for in cosmological and galactic simulations.*