SFR@50

theoretical Filling the Cosmos with Stars

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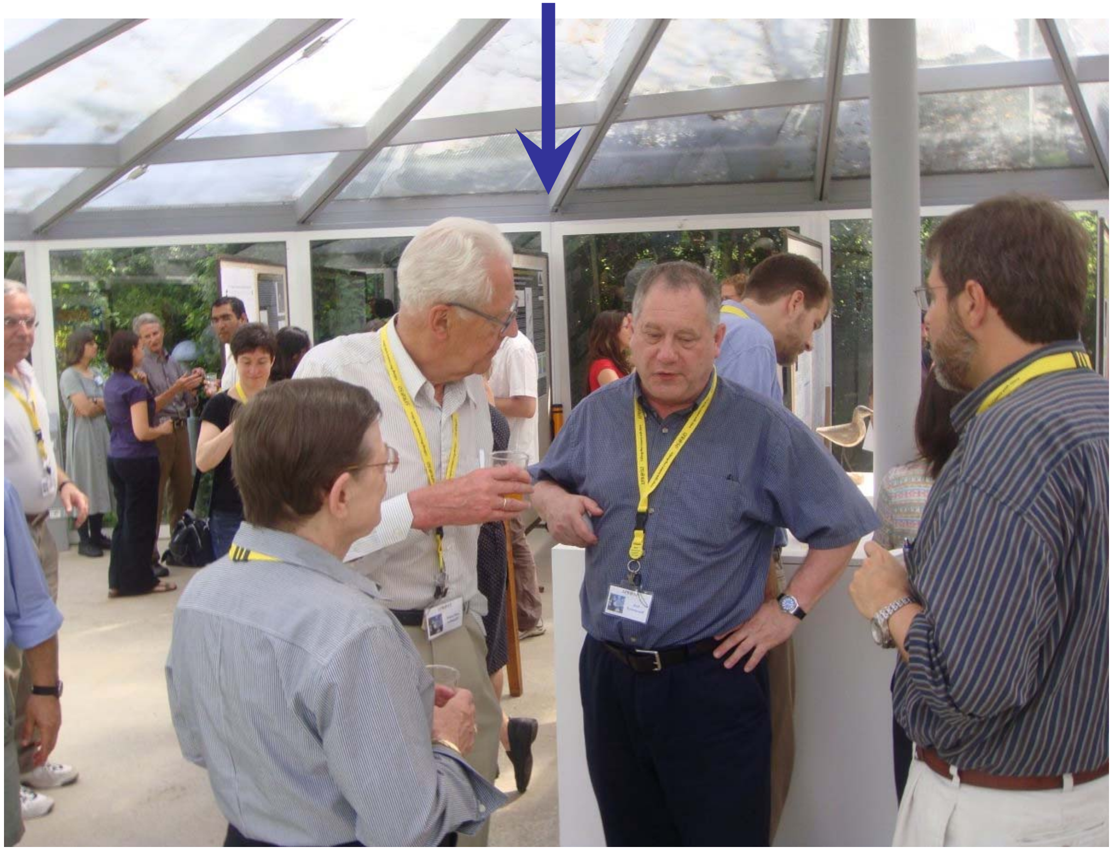
Schmidt-Kennicutt relation at z=0

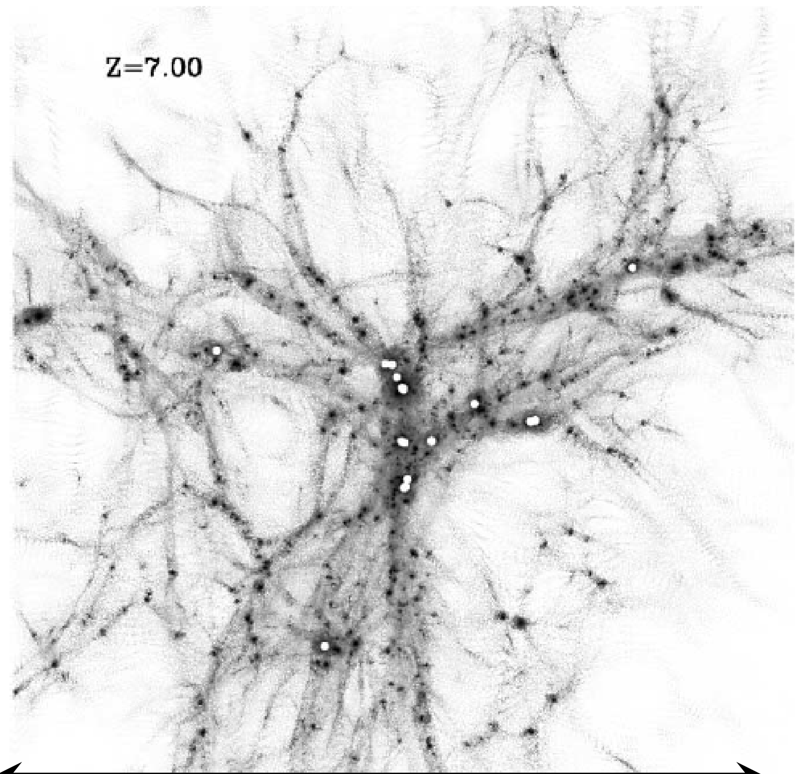
and at z=3…



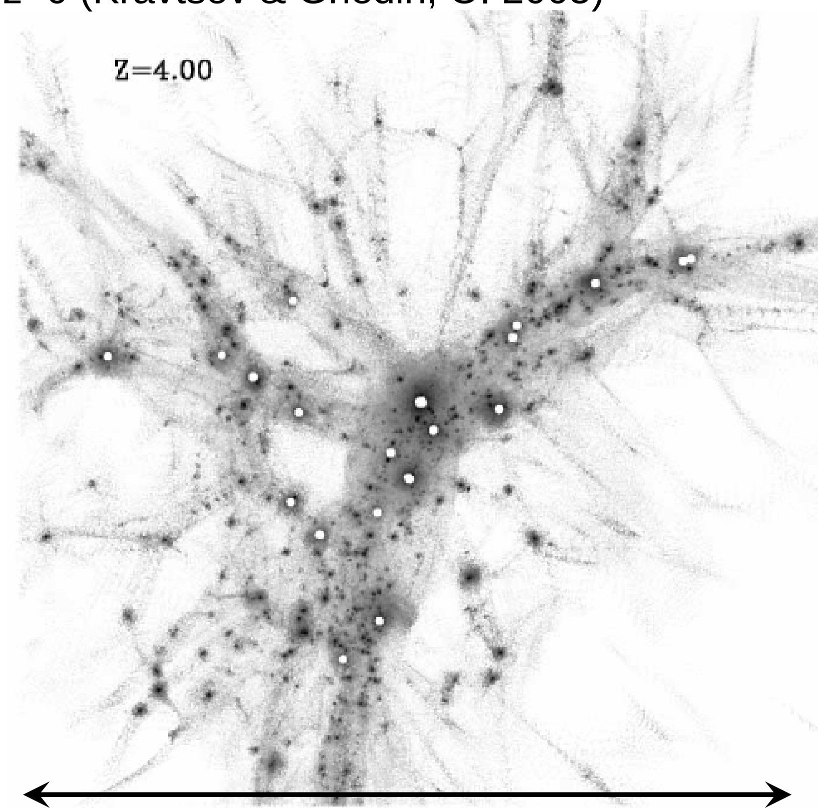
the challenge of proper treatment of star formation in cosmological simulations of galaxy formation

Ideally need resolution element in star forming regions of (at least) ~1-10 pc (i.e., >10^6 dynamic range in a box of 10 Mpc). Why? Molecular clouds form on these scales. The scale-height of cold gas disk in the MW is ~100 pc

dark matter distribution around a forming object at z=7 and z=4, which turns into a MW-sized object at z=0 (Kravtsov & Gnedin, O. 2005)

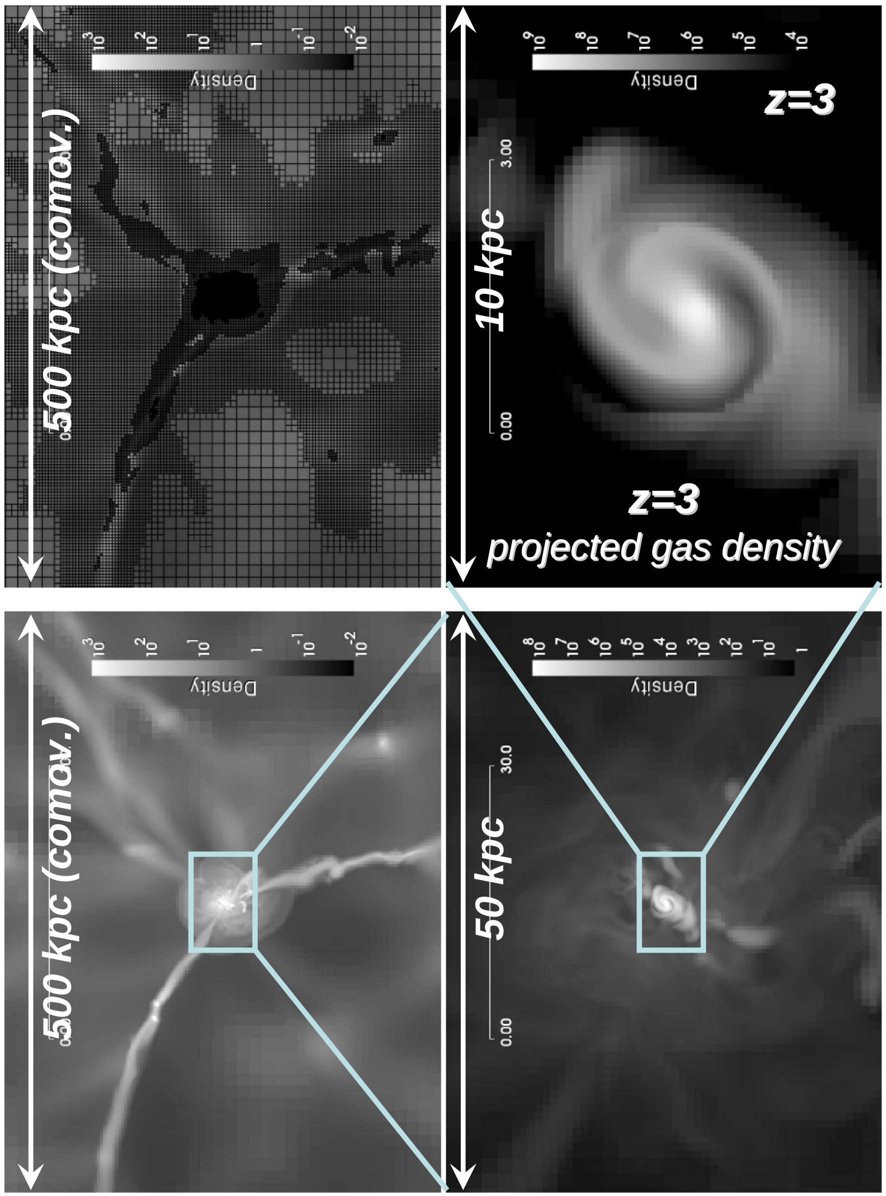


~1 comoving Mpc



~1 comoving Mpc

cosmological simulations of galaxy formation



- **A**daptive **R**efinement **T**ree (ART) code
  (Eulerian shock-capturing AMR hydro)
  Kravtsov '99, Kravtsov et al. 2002

- *N*-body dynamics of DM and stellar particles

- supernovae feedback (thermal) and metal enrichment, stellar mass loss

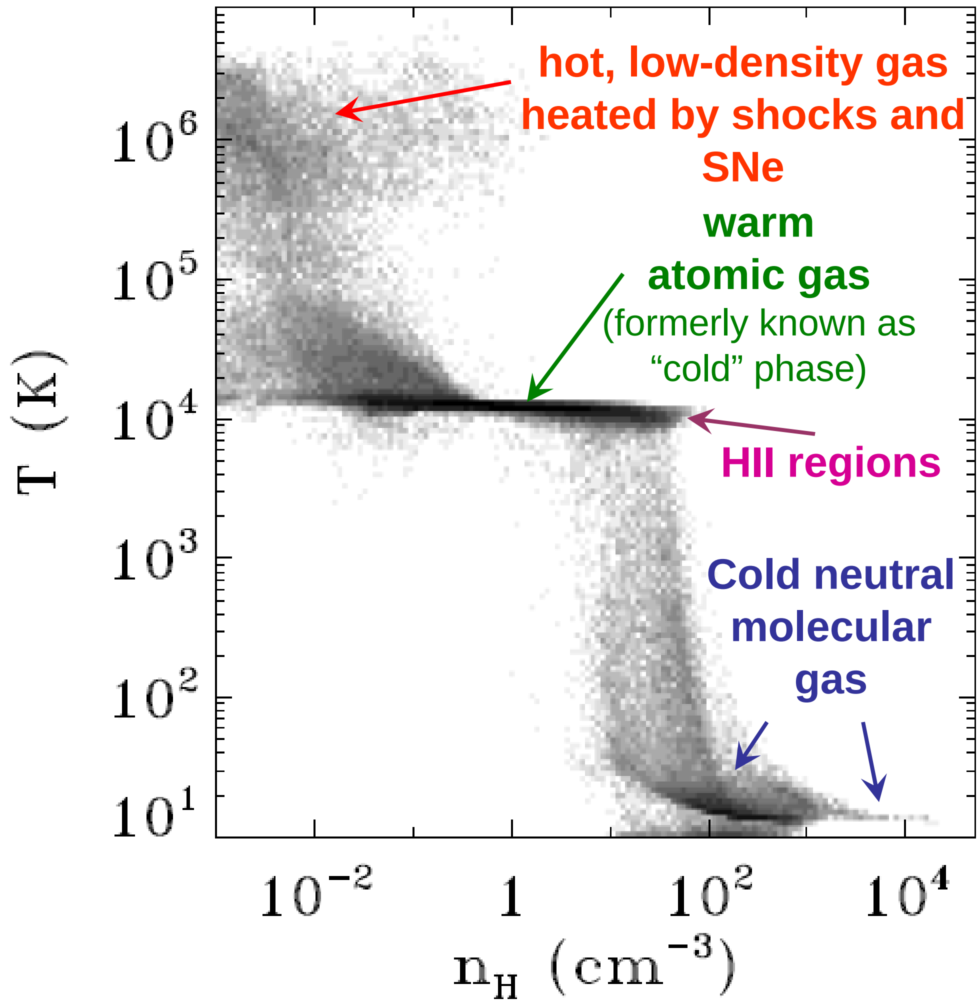
- radiative cooling and heating: Compton, UV background heating, density and *metallicity dependent net cooling/heating equilibrium rates taking into account atomic line and molecular processes* (cooling rates down to 10 K)

- approximate 3D radiative transfer using the optically thin Eddington tensor (OTVET) approximation (Gnedin & Abel 2001)

- peak spatial resolution ~20-50 pc (physical, slowly changes with redshift)

Multi-phase ISM in simulated galaxies

temperature-density diagram:
main phases of the ISM in simulated galaxies

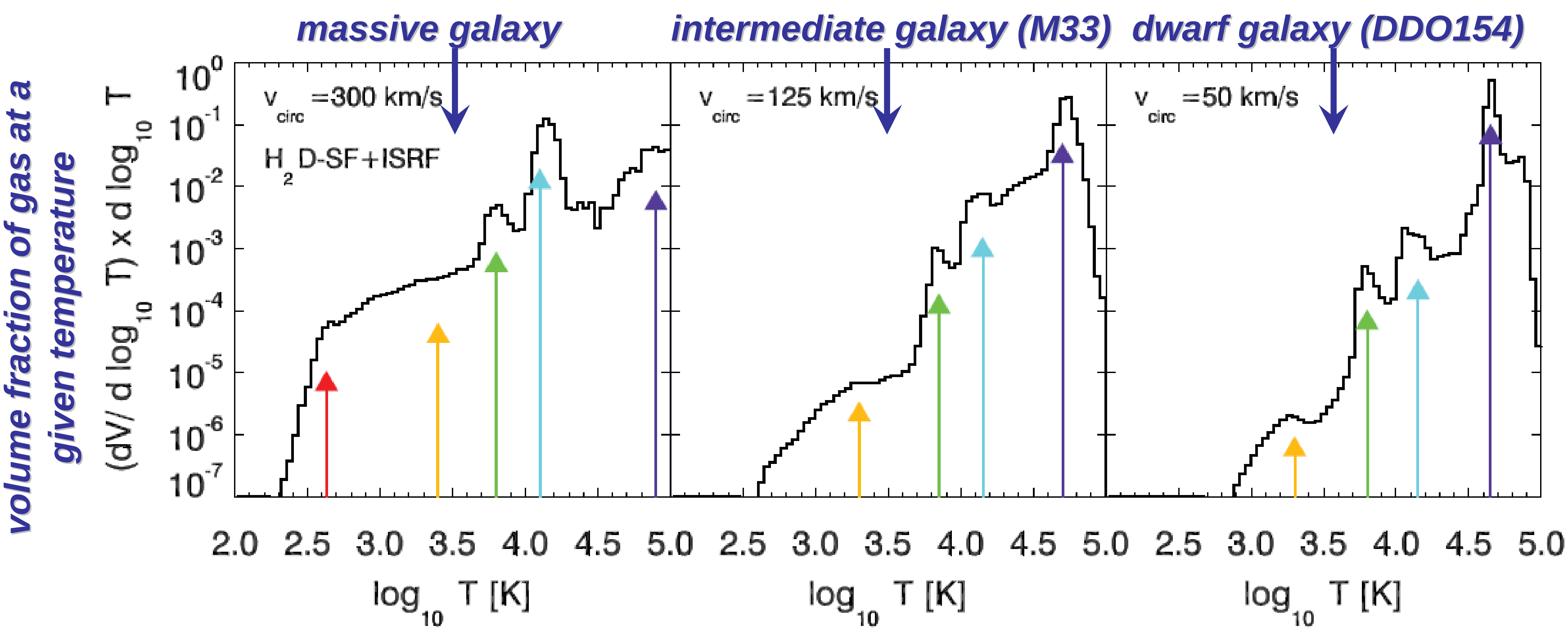


Gnedin, N., Tassis, Kravtsov 2009, ApJ 697, 55

Thermal phases of the ISM: gas temperature PDF

controlled simulations of realistic galaxies (designed to match specific local galaxies)

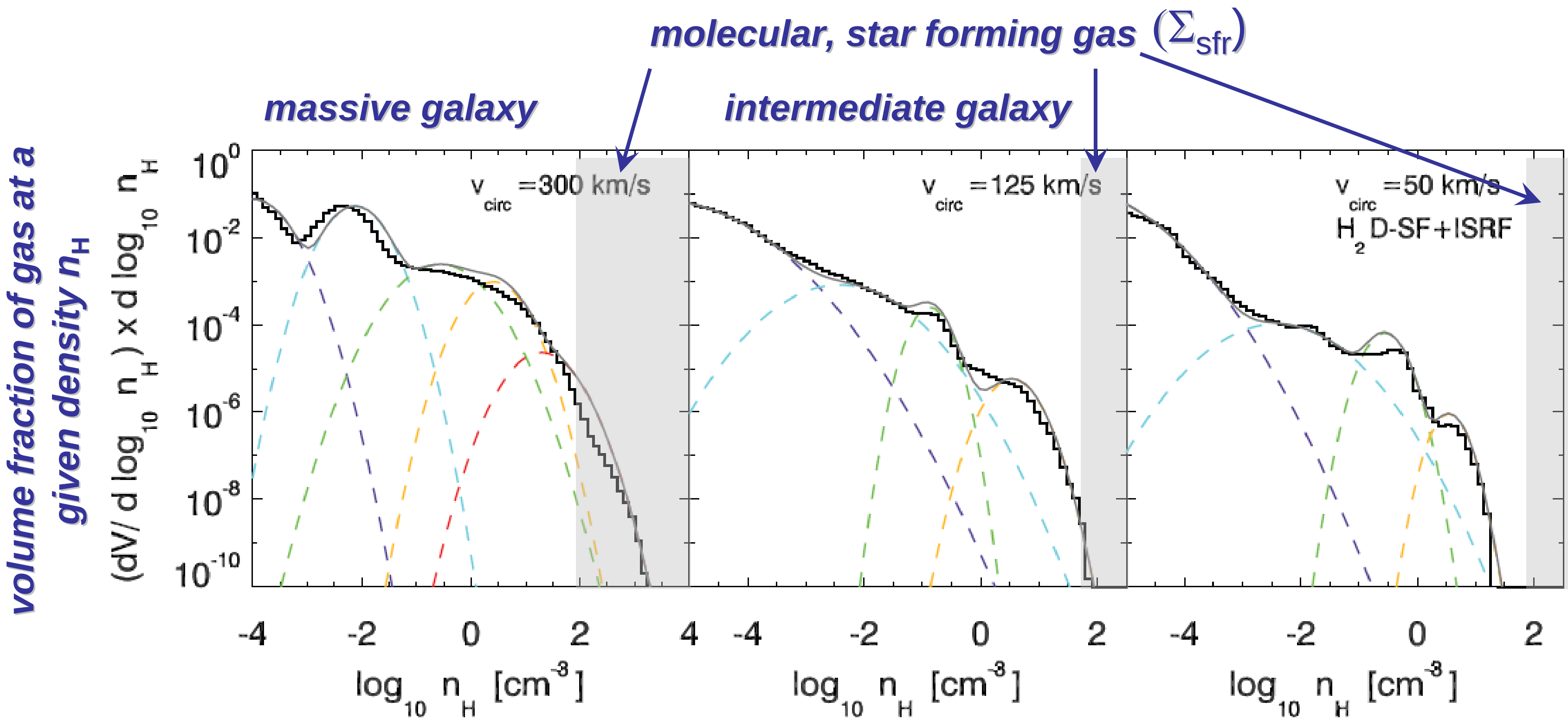
[Robertson & Kravtsov 2008 ApJ 860, 1083]



Thermal phases and the density PDF of the ISM

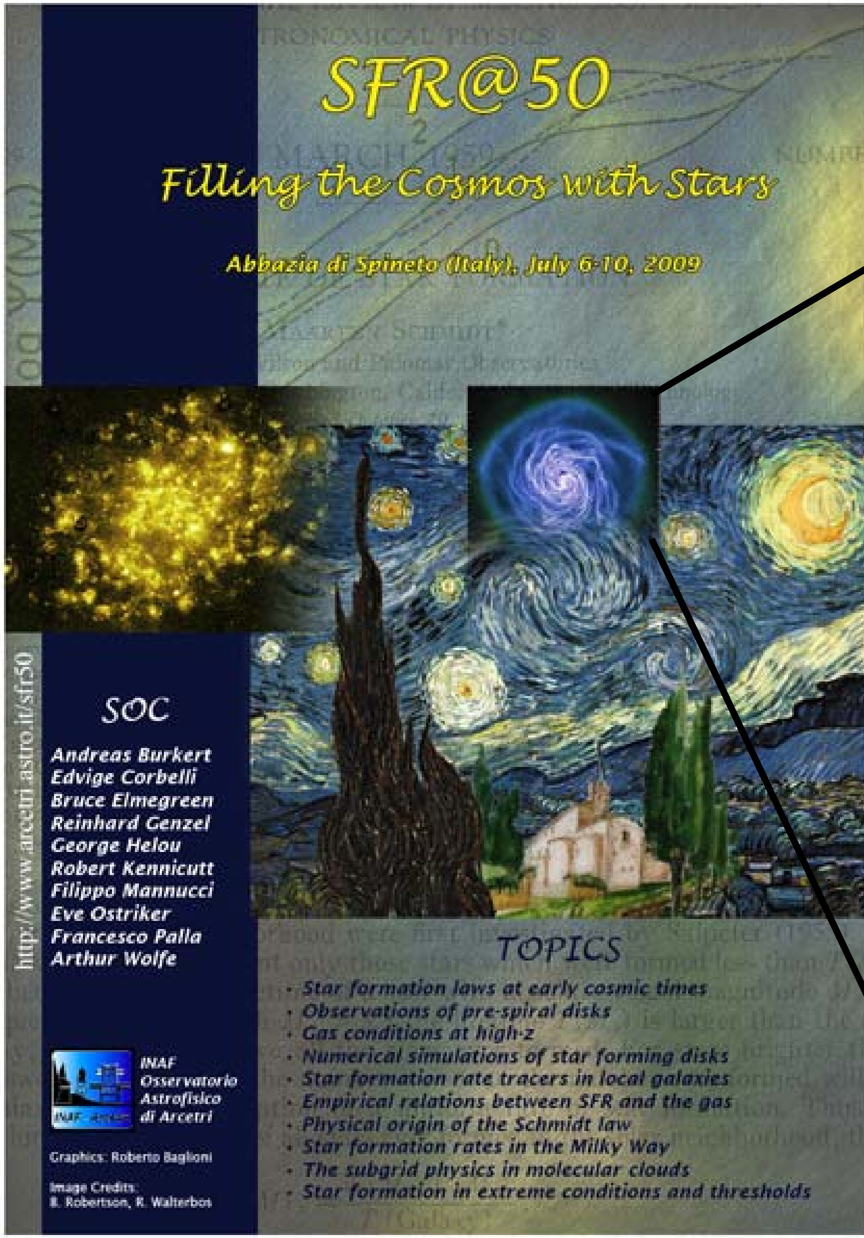
thermodynamics (i.e., balance of heating and cooling) of ISM clearly affects its density distribution

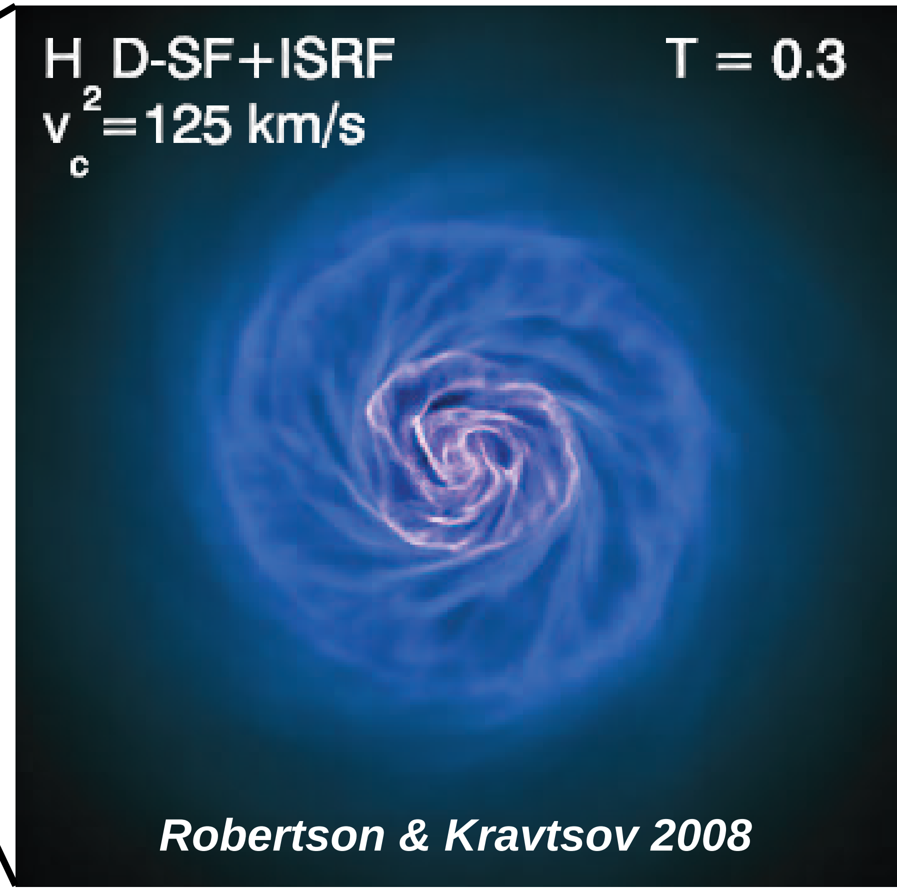
[Robertson & Kravtsov 2008 ApJ 860, 1083]



A bit of JPG science...

density PDF depends on gas surface density



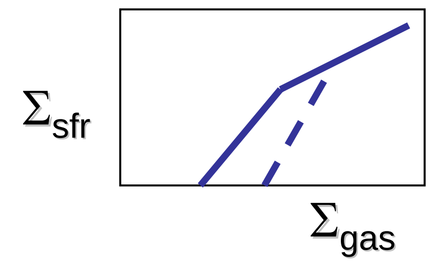


Kravtsov 2003; Wada & Norman 2007
Tasker & Bryan 2006

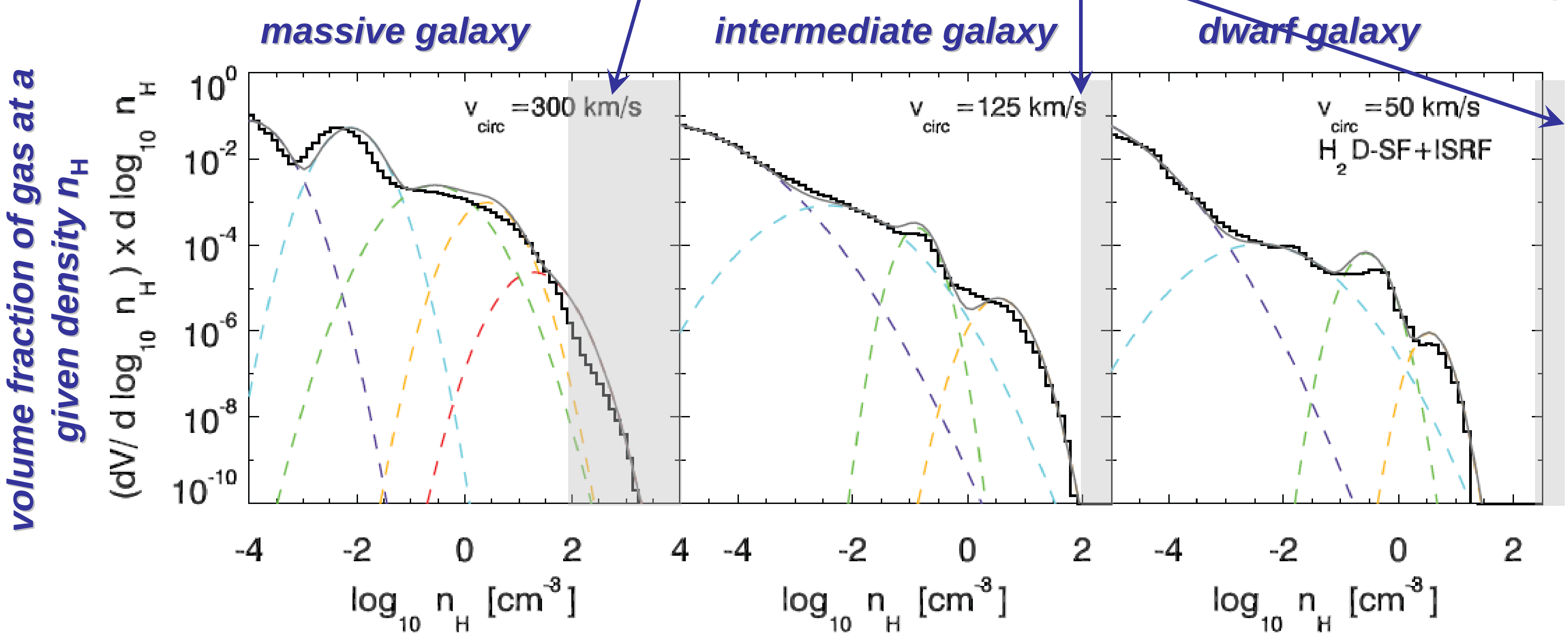
Thermal phases and the density PDF of the ISM

BOTH thermodynamics AND dynamics of the ISM affect its density distribution

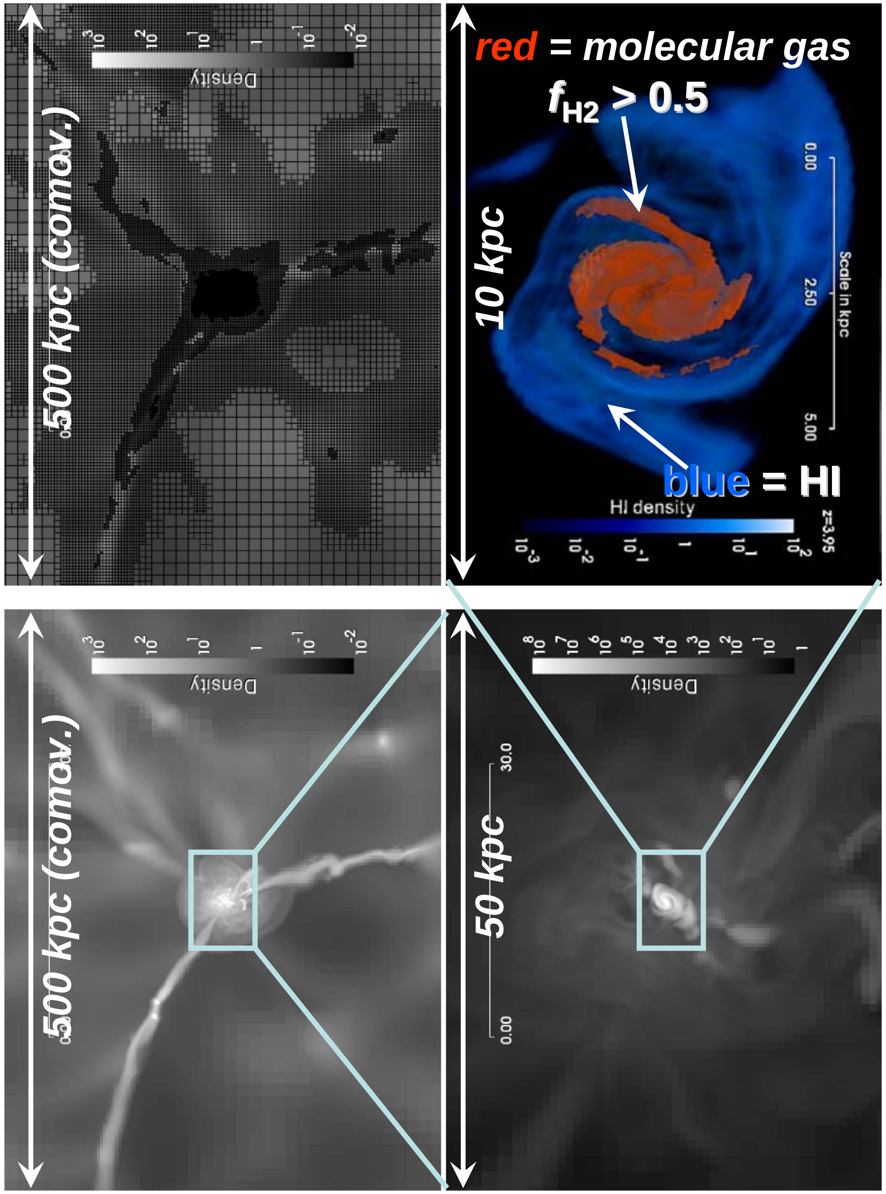
[Kravtsov 2003; Wada & Norman 2007; Tasker & Bryan 2006; Robertson & Kravtsov 2008 ApJ 860, 1083]



molecular, star forming gas (Σ_{sfr})



"on the fly" treatment of H2



see Gnedin, N., Tassis, Kravtsov 2009, ApJ 697, 55 for details (or ask me)

- ❑ peak spatial resolution in the disk ~20-50pc

- ❑ H2 formation of dust grains/destruction by UV with a model for approximate self-shielding, assuming dust-to-gas ratio scales linearly with metallicity of the gas

$$\dot{X}_{\rm HI} = R(T) n_e X_{\rm HII} - S_d X_{\rm HI} \Gamma_{\rm HI} - 2\dot{X}_{\rm H_2},$$

$$\dot{X}_{\rm H_2} = S_d S_{\rm H_2} \dot{X}^{\rm gp}_{\rm H_2} + R_d n_b X_{\rm HI}(X_{\rm HI} + 2X_{\rm H_2}),$$

$$R_d = 3.5 \times 10^{-17} Z C_\rho \ {\rm cm^3\ s^{-1}}$$

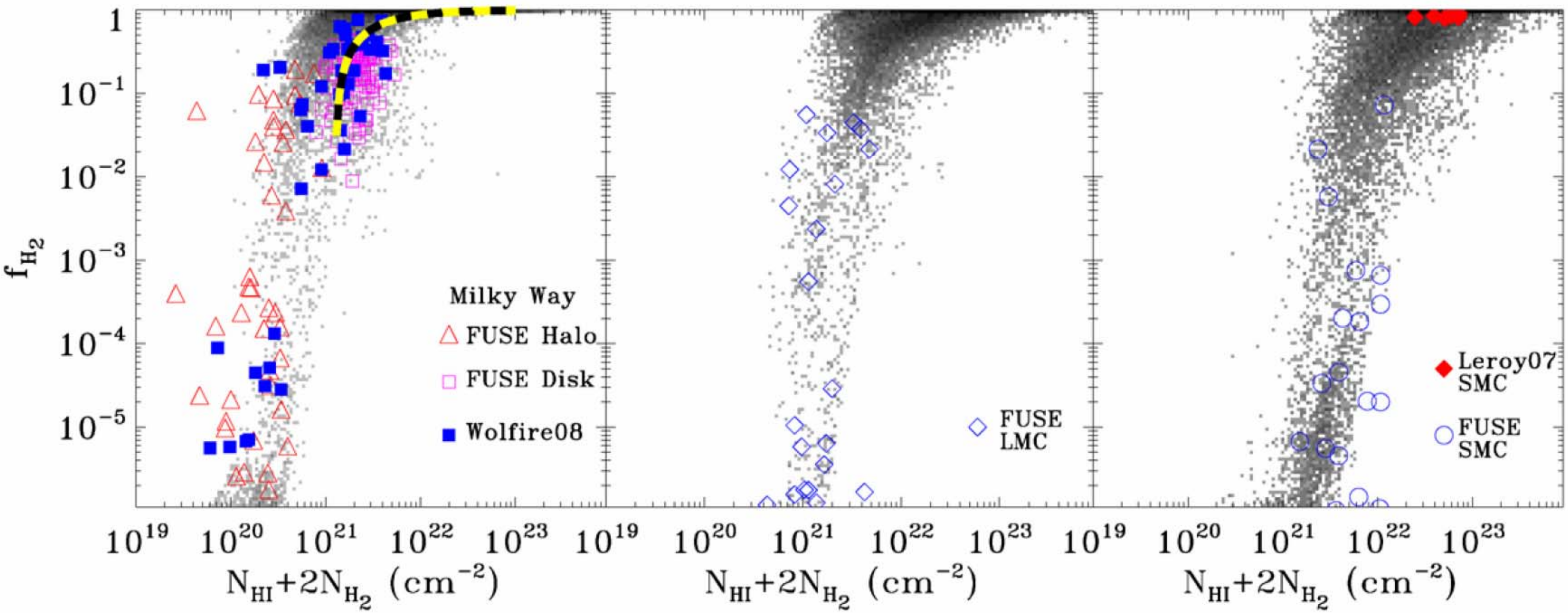
$$N_i \approx n_i L_{\rm Sob} \qquad L_{\rm Sob} \equiv \frac{\rho}{|\nabla \rho|}$$

Molecular fraction as a function of gas column density

Strong trends with metallicity (dust content)

Gnedin, N., Tassis, Kravtsov 2009, ApJ 697, 55;
see also Schaye 2001; Krumholz, McKee & Tumlinson 2009

molecular fraction

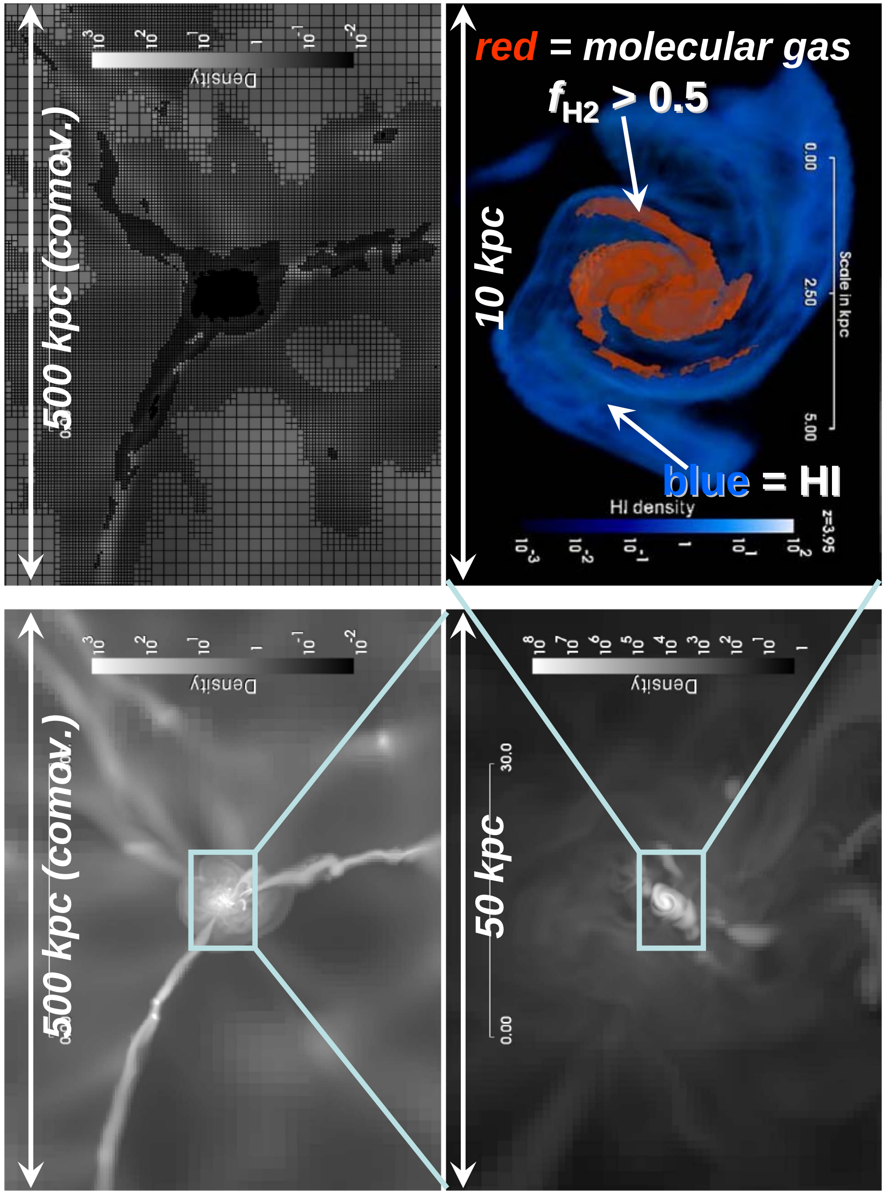


HI+H2 column density

the 3D number density corresponding to this transition can be parameterized as

$$n_t \simeq 30 \left(\frac{Z}{Z_\odot}\right)^{-1} \text{ cm}^{-3}$$

H2-based star formation in cosmological simulations of galaxy formation



see Gnedin, N., Tassis, Kravtsov 2009, ApJ 697, 55 for details

- Star formation only in the cells with dense, cold, high-f_{H2} gas + feedback

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

$$\epsilon_{\rm ff} = 0.01 \quad \tau_{\rm sf} = \tau_{\rm ff} = \sqrt{3\pi/32G\rho}$$

$$\tau_{\rm sf} = \min[\tau_{\rm ff}(100\,{\rm cm}^{-3}), \tau_{\rm ff}(\rho_{g,cell})]$$

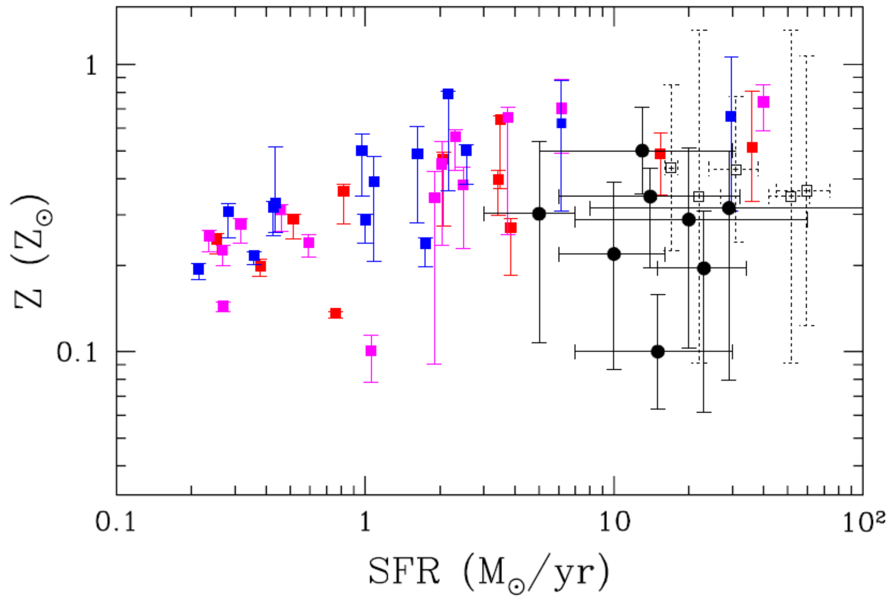
comparison with observations at z~3

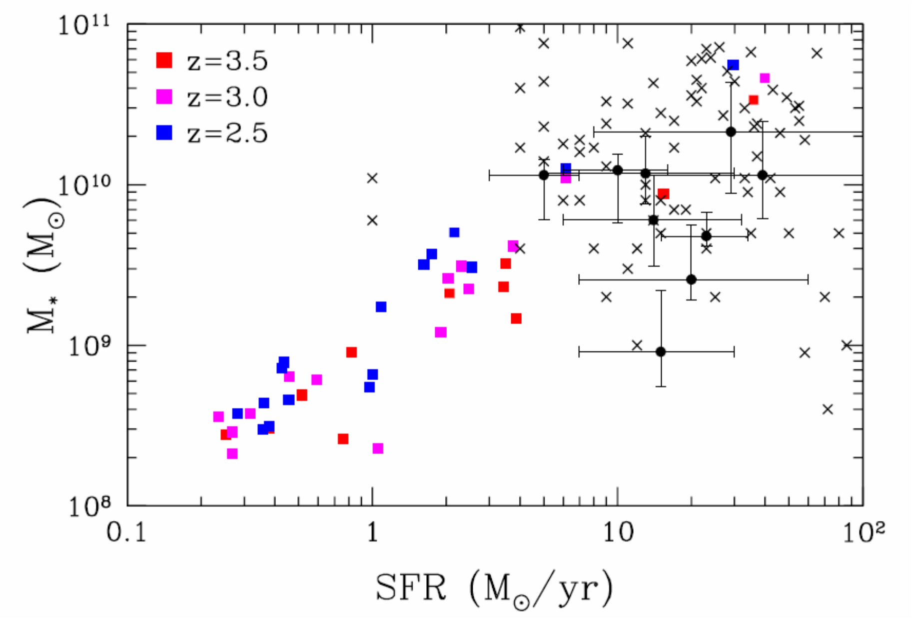
galaxy formation simulations with self-consistent evolution of metallicity, dust-to-gas, UV field, and non-equilibrium H2 formation

Gnedin & Kravtsov 2009, in prep.

***data**: Manucci et al. 2009; Erb et al. 2006; Pettini et al. 2001*

***colored points** = galaxies in simulations*

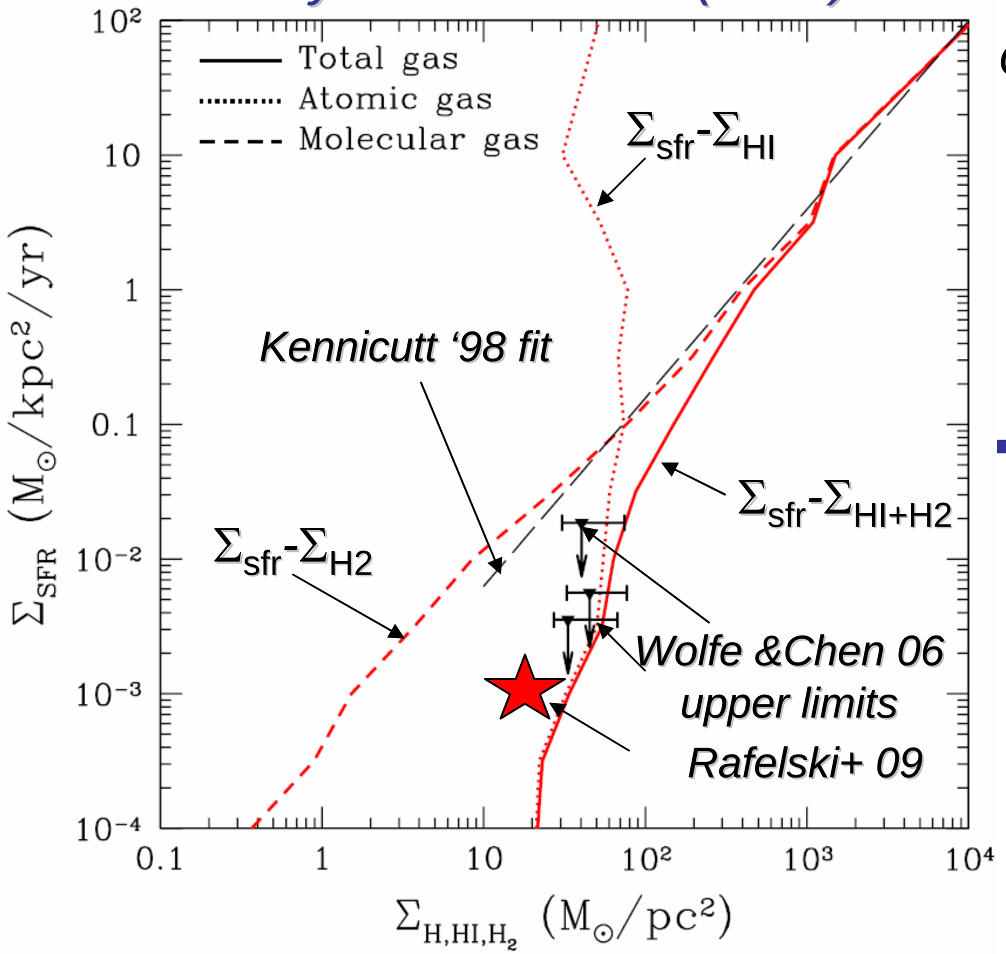




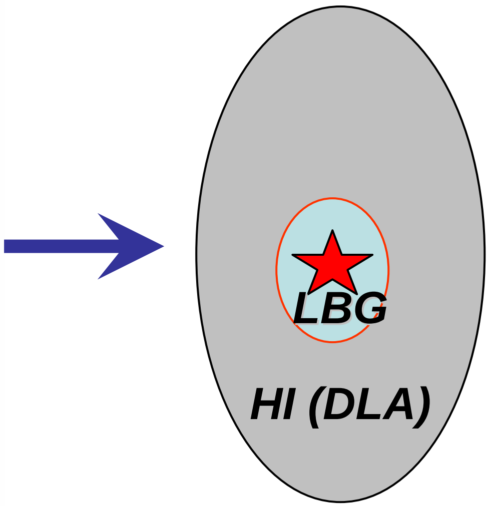
Schmidt-Kennicutt relation for simulated galaxies @ z=3

comparison with star formation constraints in the DLA systems by Wolfe & Chen (2006)

surface densities are measured in 500 pc patches



Gnedin & Kravtsov 2009 in prep.

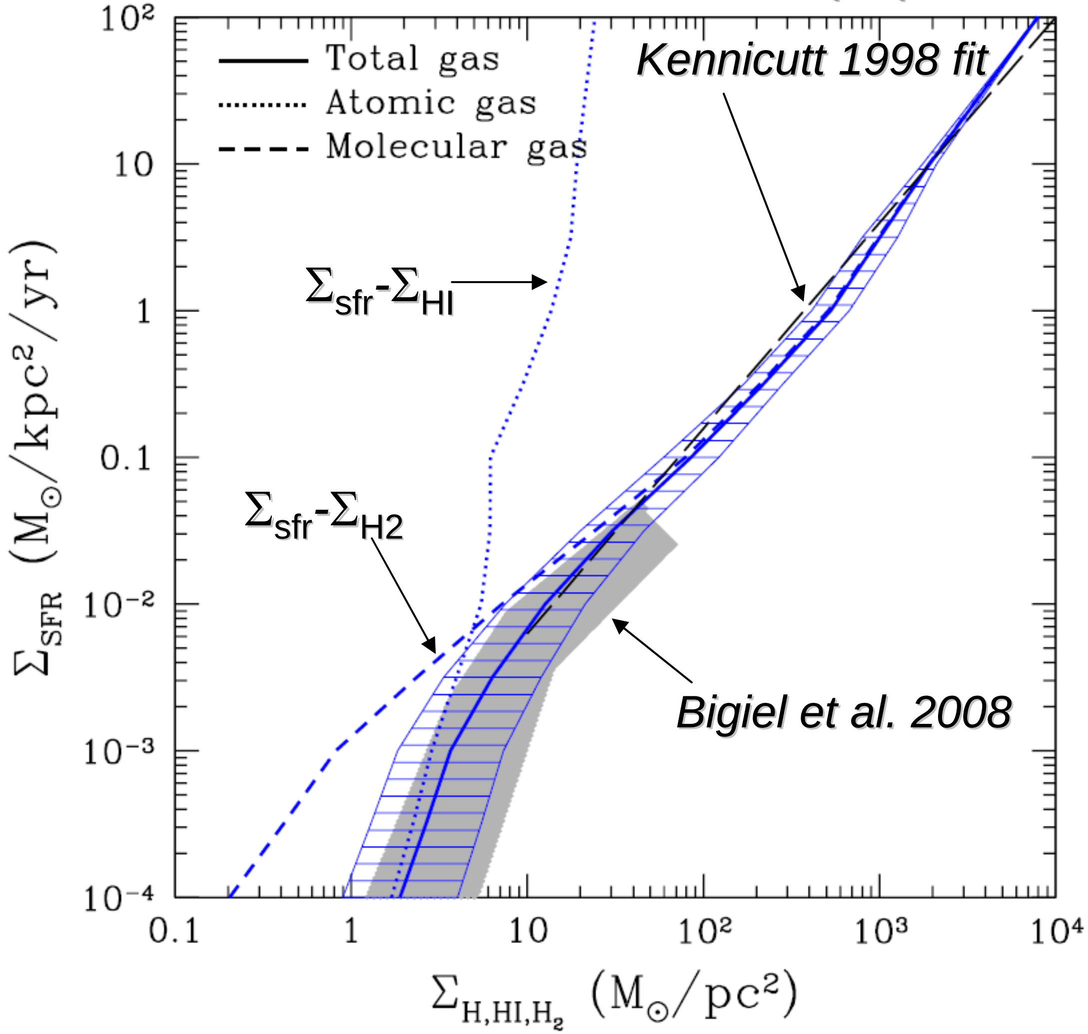


Why z=3 SK relation is different?

galaxies simulated to z=3 but with the dust-to-gas ratio fixed to the Milky Way value and using MW interstellar UV flux

Gnedin & Kravtsov 2009, in prep.

surface densities are measured in 500 pc patches



Summary

- both thermodynamics of gas (controlling the thermal phases) and large-scale instabilities are important in shaping the density PDF and the Schmidt-Kennicutt relation.

- fixed to reproduce local data on molecular fractions at different ties and column densities, simulations with new H2-based star formation produce populations of galaxies at z=3 with stellar masses, star formation rates, and metallicities in reasonable agreement with observations

- ***Different (steepening at higher Σ_{gas}) Schmidt-Kennicutt relation is predicted*** for lower-metallicity, high-UV field environments of high-z galaxies. This can explain why dense DLA systems do not show the expected associated UV flux, predicted by the local S-K relation (Wolfe & Chen 2006, Wild et al. 2007). Also, ***lower H2 content of DLAs*** compared to the MW, given their metallicity (e.g., Noterdaeme et al. 08)