The role of dense, molecular gas during early stages of galaxy formation and evolution

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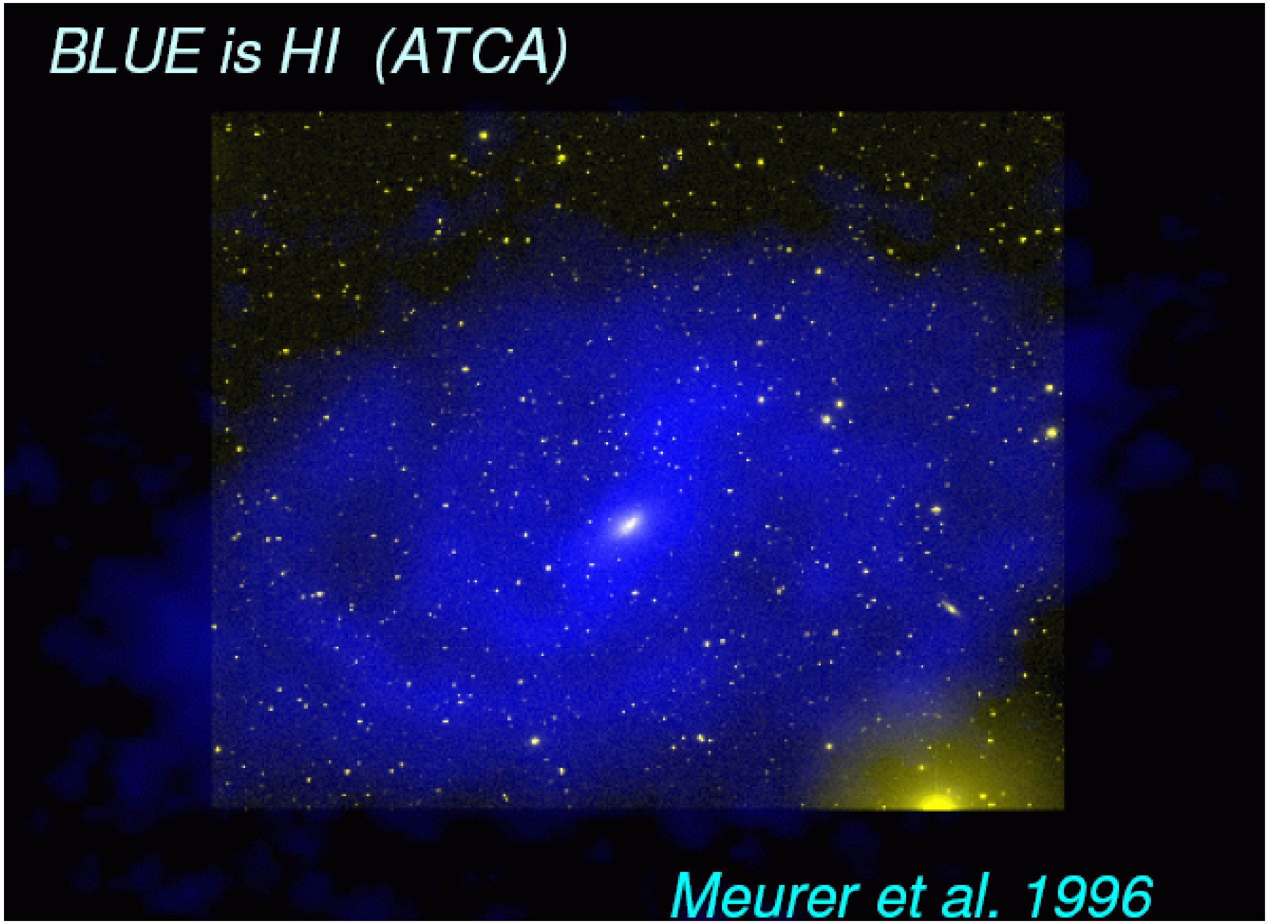
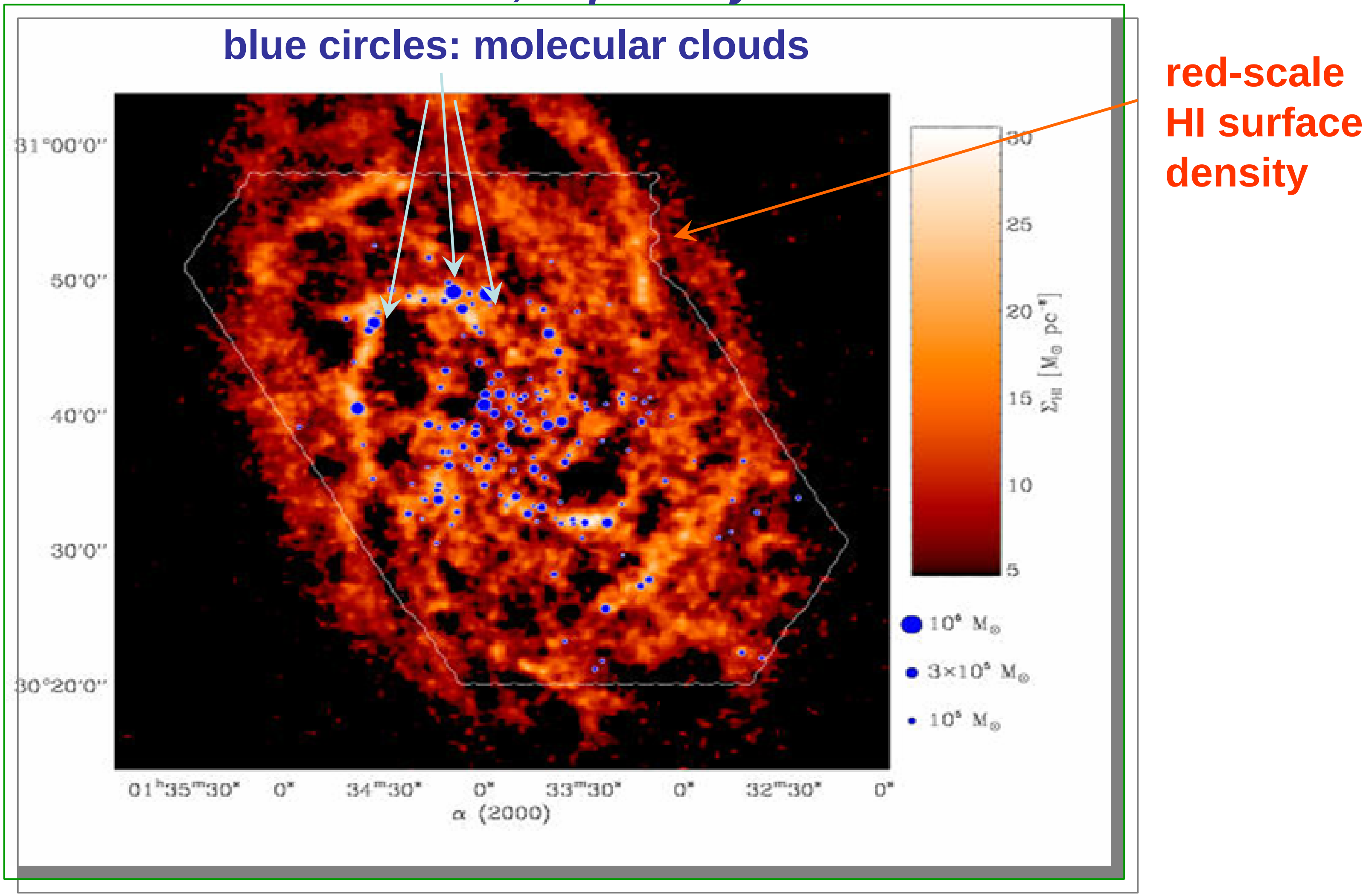
Much of the gas in dwarf & LSB galaxies (and outskirts of normal spirals) is inert to star formation

NGC 2915 (Blue Compact Dwarf)



Star formation in M33

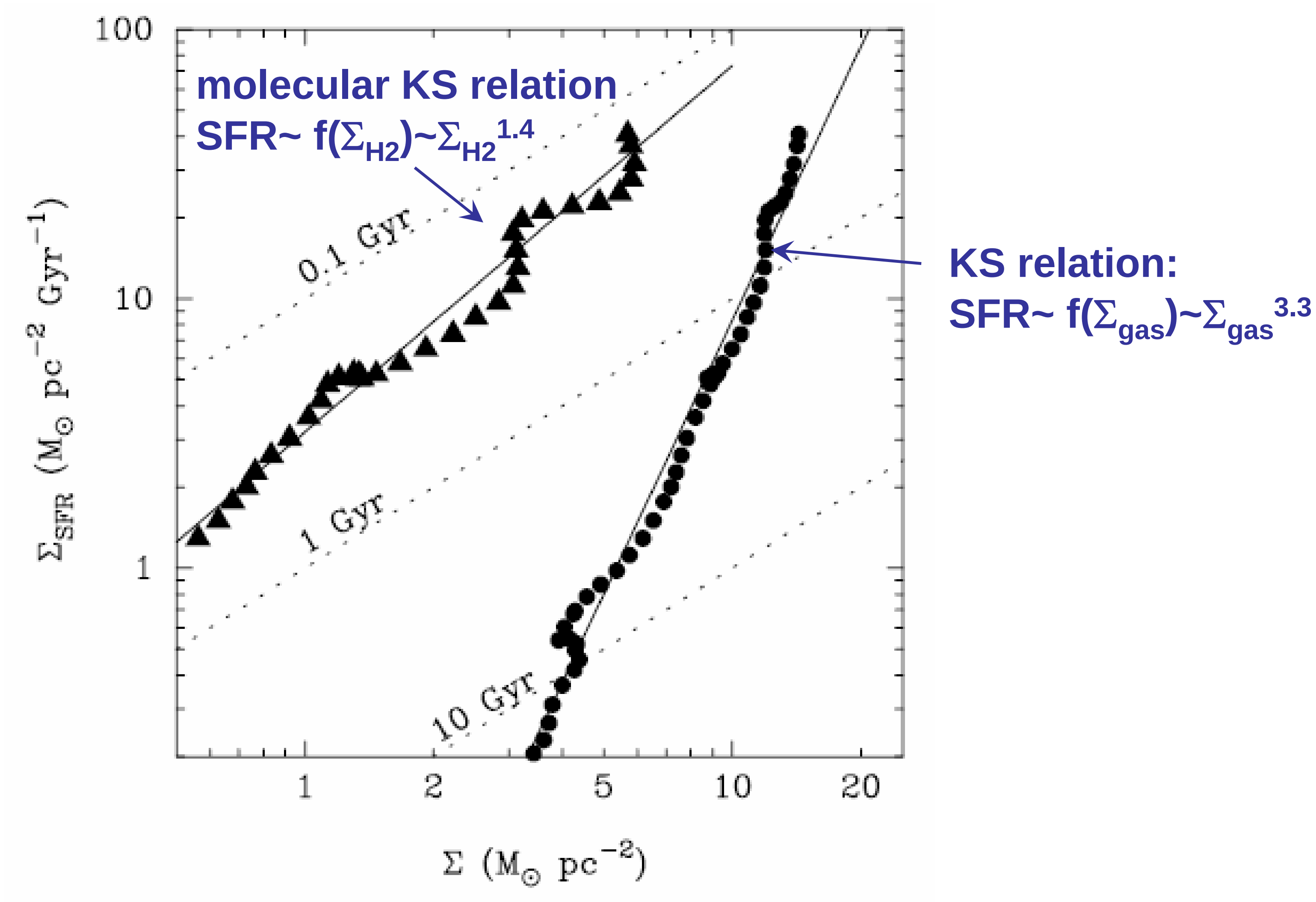
low molecular fraction, especially in the outskirts



CO map: Blitz et al. 03; HI map: Deul & van der Hulst (1987)

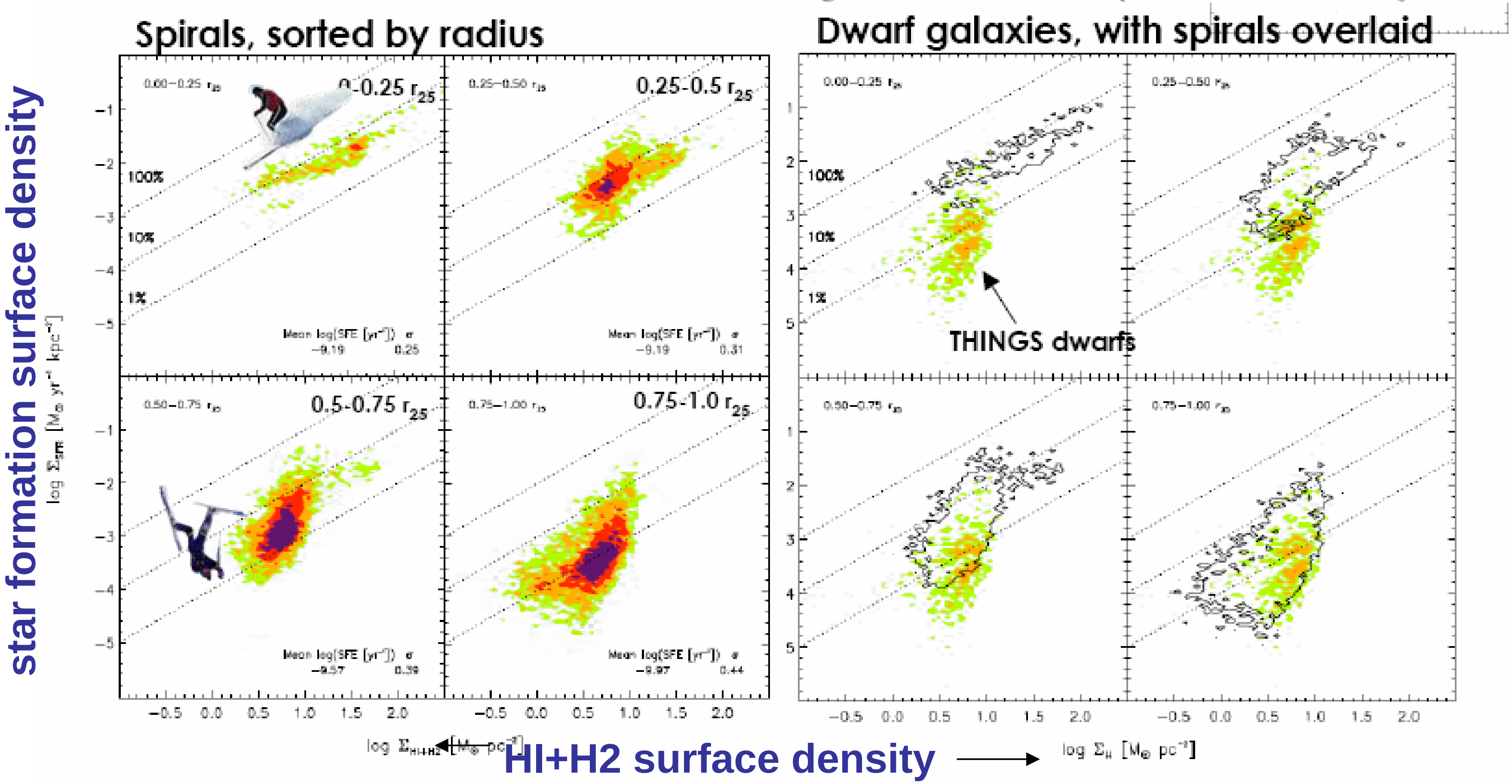
Kennicutt-Schmidt relation in M33 is very steep

Heyer et al. 2004; see also Boissier et al. 2003



Dwarfs look like the outskirts of massive disks in terms of SF

Bigiel et al. 2007 (THINGS team)



Clear radial dependence
SFR drops as f(radius)

->Dwarf galaxies resemble outer regions of galaxies

Adopted from a talk by F. Walter

Making sense of it

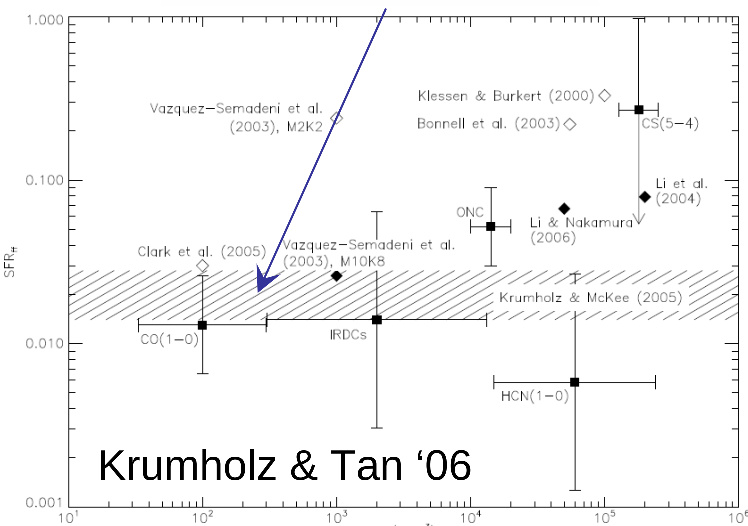
Locally, in individual molecular clouds:

$$\dot{\rho}_\star = \frac{\rho_g}{t_\star}$$

Krumholz & Tan (2006) show that for dense, molecular gas $\boldsymbol{t_*}$ scales as the free fall time of the dense gas: $\boldsymbol{t_* = t_{ff}/SFR_{ff}}$ with SFRff approximately independent of gas density

$$\mathrm{SFR_{ff}} \sim 0.01$$

SFRff



10^2 10^3 10^4 10^5

n (cm^{-3})

When star formation in a disk is averaged on some (~kpc) scale:

$$\langle \dot{\rho}_\star \rangle \propto \langle f_{\mathrm{SF}} \rangle \langle \rho_g \rangle^{1.5}$$

fraction of total gas mass eligiible for star formation

$$\Sigma_{\mathrm{SFR}} \propto \langle \dot{\rho}_\star \rangle h_{\mathrm{SFR}}$$

scale-height of young stars

$$\Sigma_g \propto \langle \rho_g \rangle h_g$$

scale-height of all gas

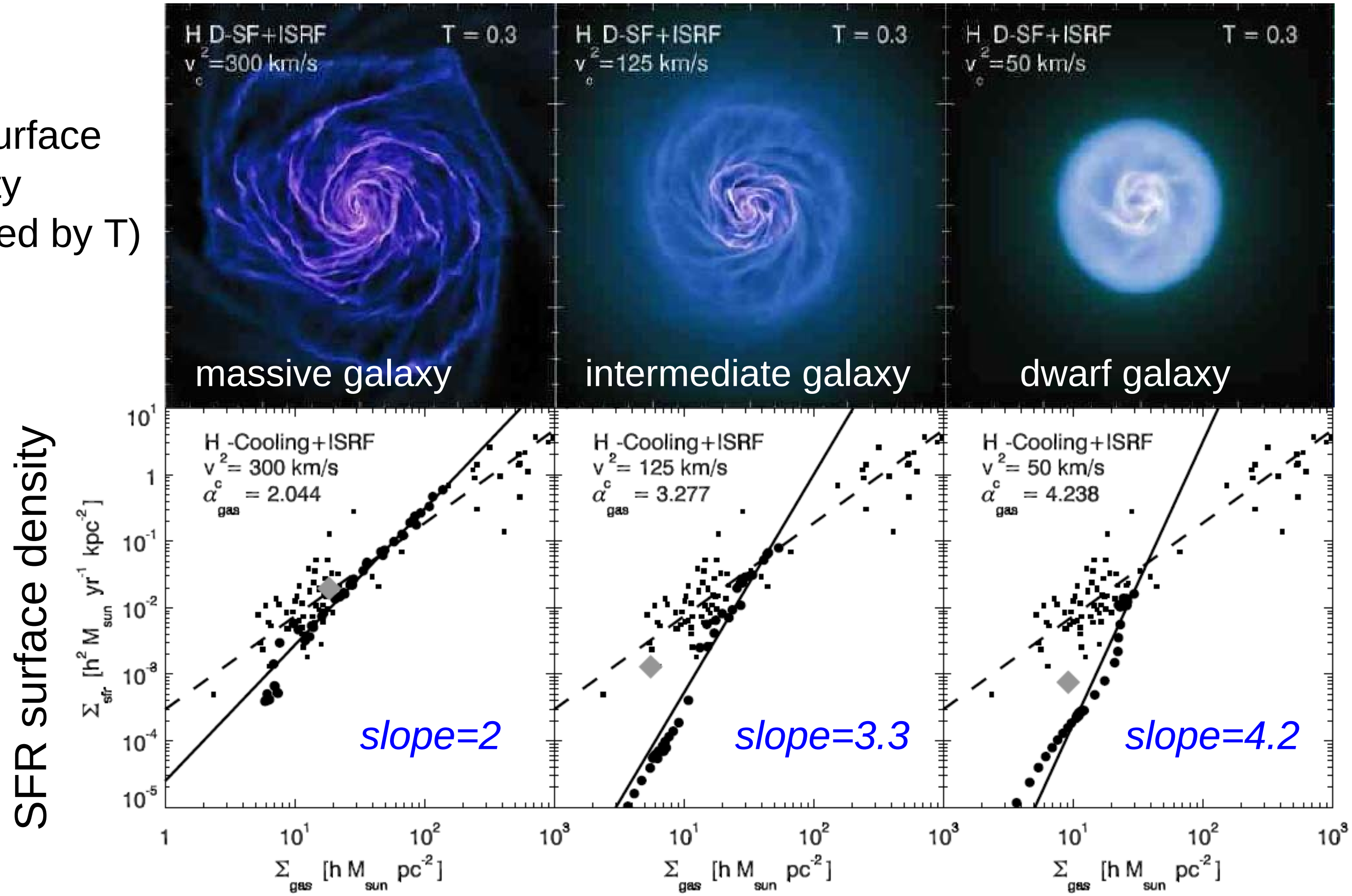
$$\Sigma_{\mathrm{SFR}} \propto \langle f_{\mathrm{SF}} \rangle \frac{h_{\mathrm{SFR}}}{h_g^{1.5}} \Sigma_g^{1.5}$$

An example: H2-based star formation in a model disk galaxy

$$f_{\mathrm{H2}} = f_{\mathrm{H2}}\left(\rho_g, T, Z_g, U_{\mathrm{isrf}}\right) \qquad \dot{\rho}_\star = f_{\mathrm{H2}}\frac{\rho_g^{1.5}}{t_\star} \qquad t_\star = 0.7\mathrm{Gyr}$$

Robertson & Kravtsov, ApJ submitted (*astro-ph/0710.2102*)

gas surface density (colored by T)



Scaling with H2 fraction and scale-heights is as expected

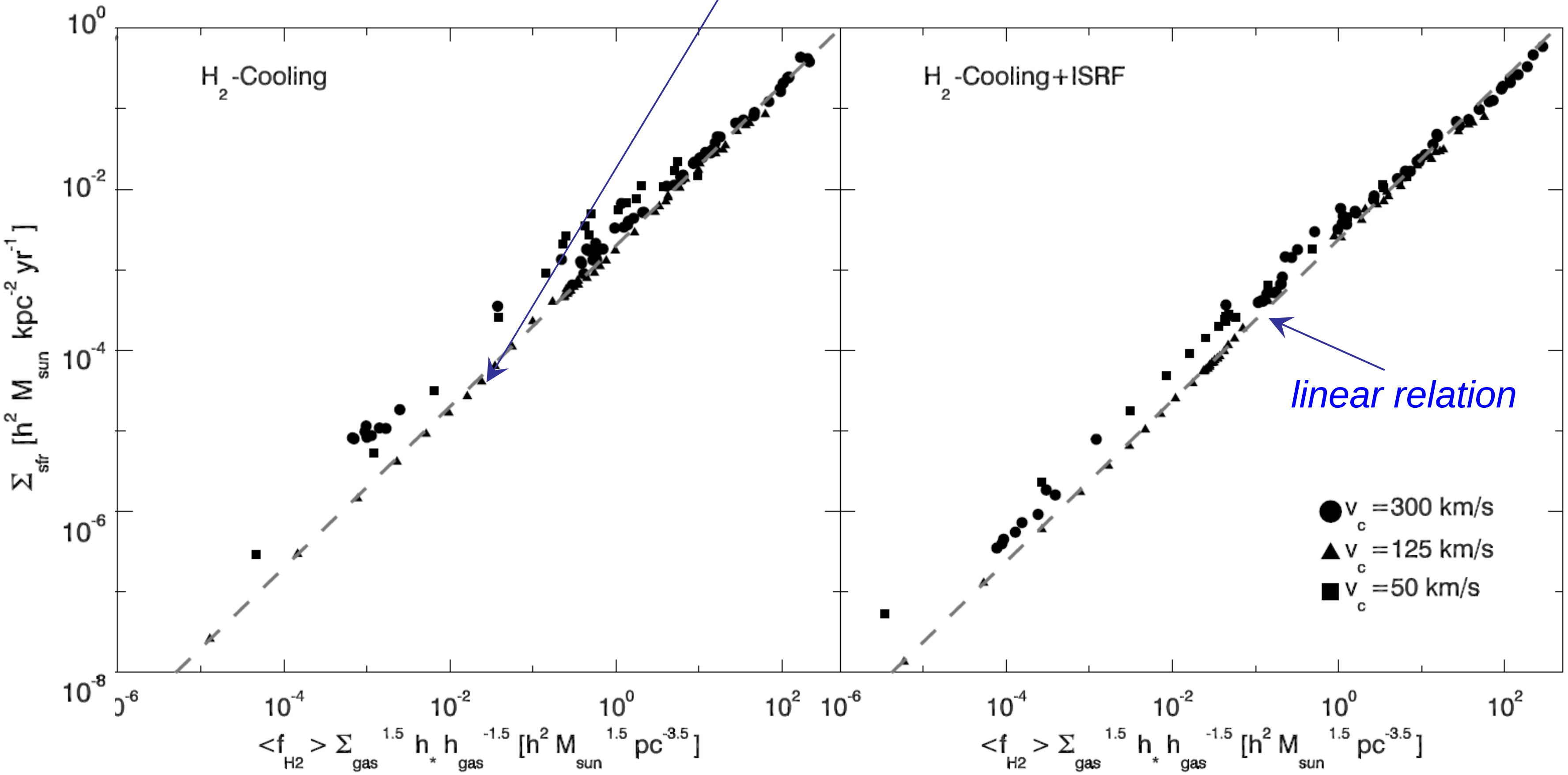
$$\dot{\rho}_\star \propto \langle f_{H2} \rangle \langle \rho_g \rangle^{1.5}$$

$$\Sigma_{SFR} \propto \langle \dot{\rho_\star} \rangle h_{SFR}$$

$$\Sigma_g \propto \langle \rho_g \rangle h_g$$

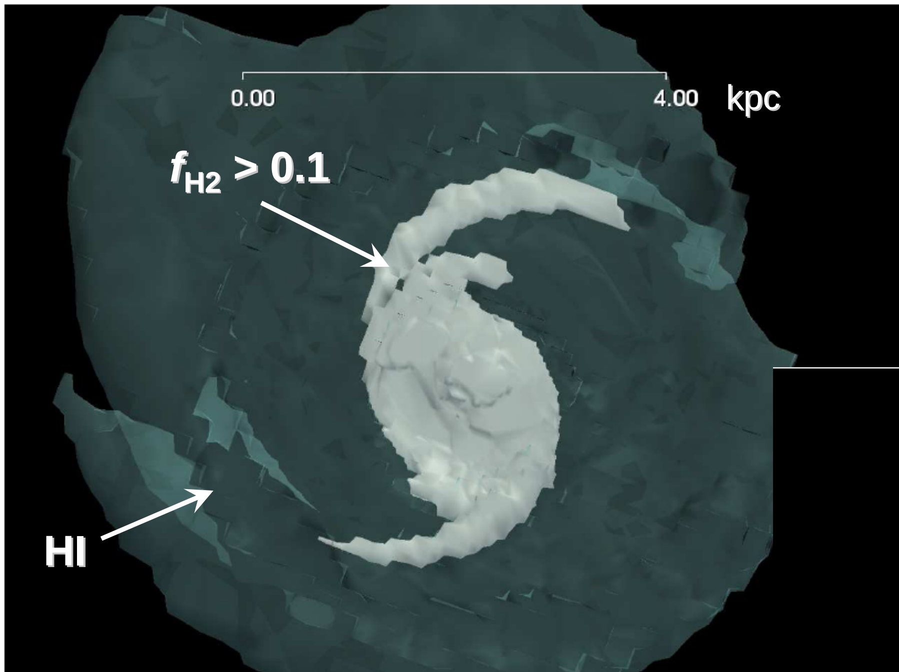
$$\Sigma_{SFR} \propto \langle f_{H2} \rangle \frac{h_{SFR}}{h_g^{1.5}} \Sigma_g^{1.5}$$

steepening of the relation is mainly due to the strong dependence of molecular fraction on gas surface density at low Σg



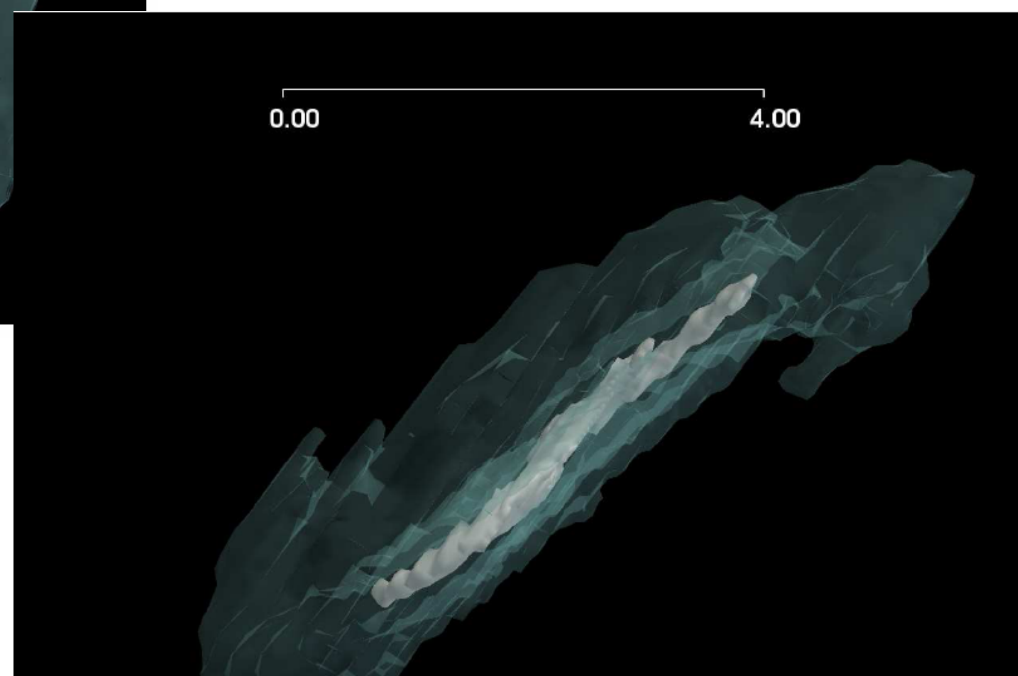
Modeling H2 in galaxy formation simulations

dense, molecular gas traces densest, high-pressure regions of the ISM



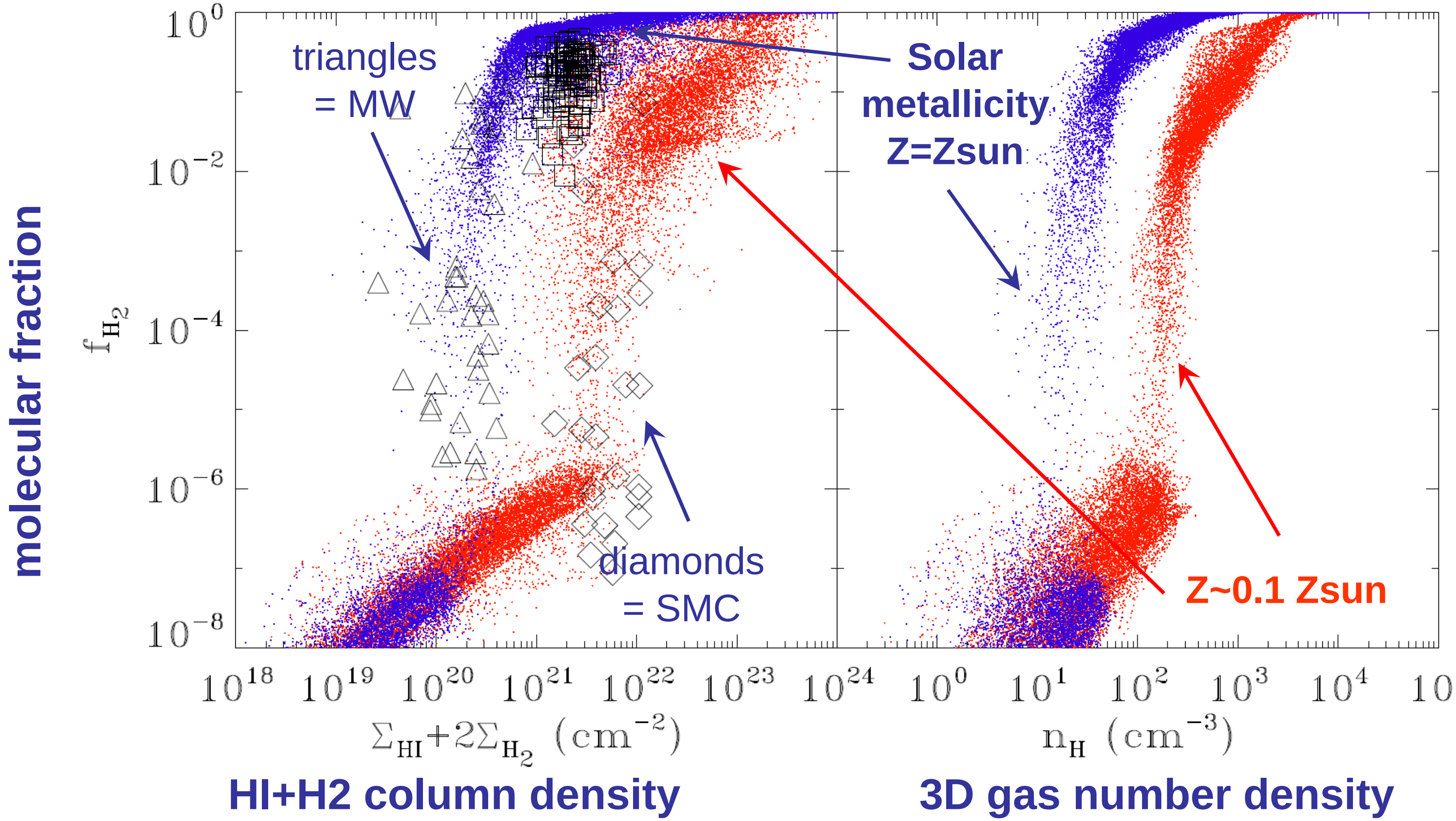
face-on and edge-on views of HI and H2 distribution in a z~4 gas disk

Galaxy formation simulation (ART code) with approximate 3D radiative transfer and a model for H2 formation on dust with approximate self-shielding using Sobolev approximation



Gnedin, N., Tassis, Kravtsov 2008, in prep

Molecular fraction as a function of gas surface and local 3D density



Strong trends with metallicity (dust content) and local UV flux

Gnedin, N., Tassis, Kravtsov 2008, in preparation

Implications

At high z (lower metallicities, higher UV flux), dense star forming gas is expected to be more compact compared to local galaxies. Most of the gas in low-mass systems, may then stay in atomic gas and be inert to star formation. This can have implications for a number of observations and theoretical expectations about galaxy evolution.

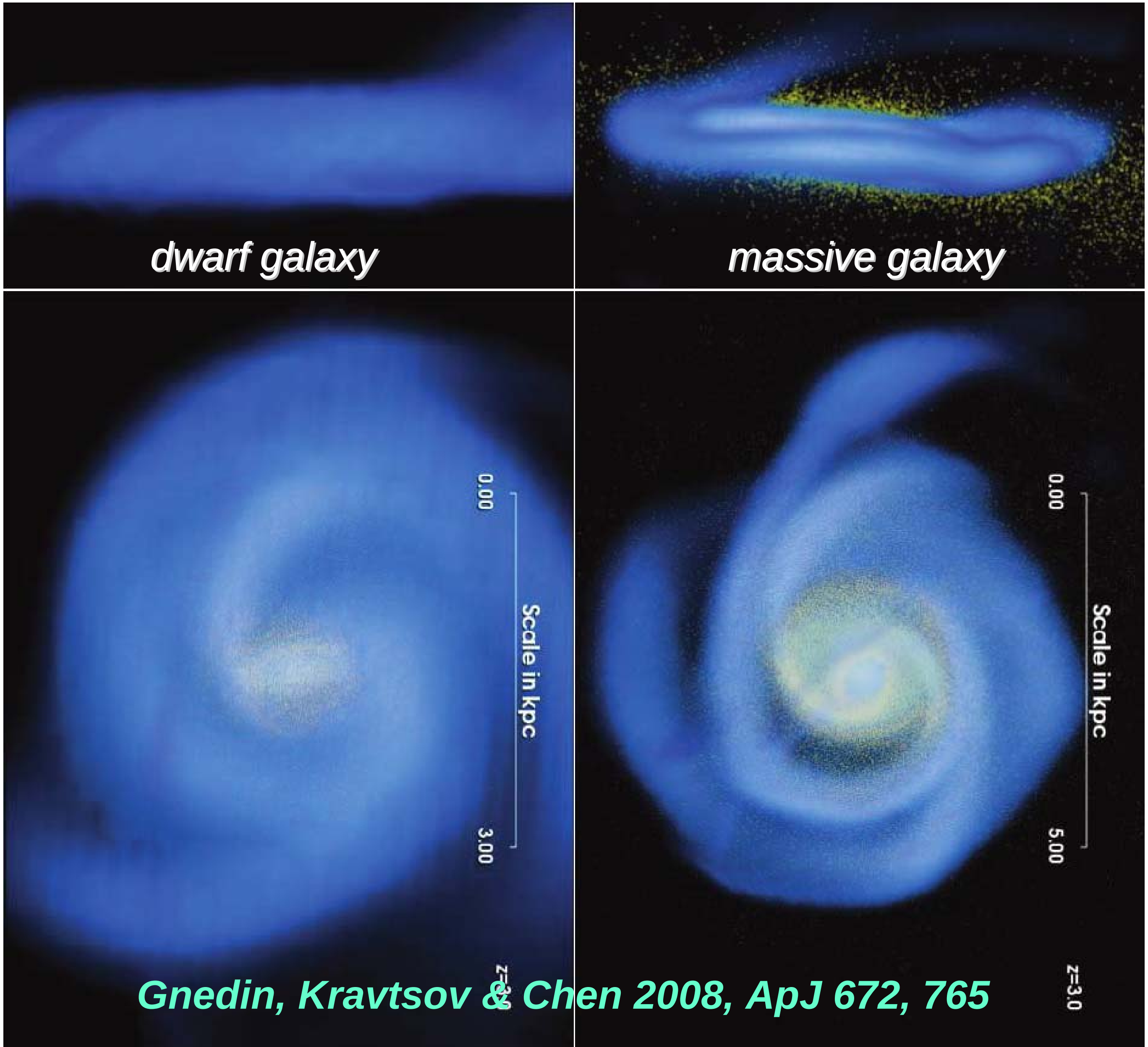
- ***Steeper Kennicutt-Schmidt relations*** can be expected in high-z galaxies. This can explain why dense DLA systems do not show the expected associated UV flux, predicted by the local KS relation (Wolfe & Chen 2007, Wild et al. 2007). Also, ***lower H2 content of DLAs*** compared to the MW, given their metallicity (e.g.Noterdaeme et al. 2008)

- Existence of ***very dense, compact (re<1 kpc) galaxies at z>2-3*** (e.g., Zirm et al. 2007, Toft et al. 2007)

- ***Low escape fractions of ionizing UV photons*** from most high-z galaxies (Gnedin, Kravtsov & Chen 2008).

- ***Existence of undisturbed, massive stellar disks at z~2.0-3.0*** (Stockton et al. 2007, Tacconi et al. 2008).

Distribution of young stars and HI in two simulated high-z galaxies



Gnedin, Kravtsov & Chen 2008, ApJ 672, 765

If young stars are deeply embedded in extended HI gas, the resulting escape fraction of UV photons is very small