H$_2$ in Dwarf Galaxies

- Dwarfs are an extreme environment for SF

- SF traces H$_2$ better than HI and total H
  (for example, Bigiel et al 08)

- H$_2$ important coolant at 200 K < T < 3000 K
  (Glover & Abel 08, Gnedin et al 10)
H$_2$ in Dwarf Galaxies

- Dwarfs are an extreme environment for SF

However, H$_2$ is difficult to observe in dwarfs

- SF traces H$_2$ better than HI and total H
  (for example, Bigiel et al 08)

- H$_2$ important coolant at 200 K < T < 5000 K
  (Glover & Abel 08, Gnedin et al 10)
Simulations of H$_2$ In Galaxies

- Until recently, most simulations of galaxies did not include H$_2$

- New Simulations with GMCs/H$_2$
  (Gnedin et al 09, 10a, 10b, Papadopoulos & Pelupessy10, Pelupessy et al 06, Pelupessy & Papadopoulos 09, Robertson & Kravtsov 08)
  - Link H$_2$, metallicity and Kennicutt-Schmidt Law
Simulations of H$_2$ In Galaxies

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  - Link H$_2$, metallicity and Kennicutt-Schmidt Law

- H$_2$ in cosmological sims. to z=0
The Code

- **Gasoline** (Wadsley et al. 04), an SPH code with
  - Cosmic UV background radiation
  - H & He ionization
  - Metal cooling
  - Metal diffusion
  - Star formation
  - Supernovae feedback

- **Which reproduces**
  - Damped Lyman-α systems (Pontzen et al. 08, 10)
  - Mass-metallicity relation (Brooks et al. 07)
  - Broken exponential disks in spirals (Roskar et al. 08)
  - HI holes
  - Tully-Fisher relation (Governato et al. 07)
  - Realistic dwarfs (Governato et al. 10)
H$_2$ Implementation

- H$_2$ abundances per particle
  - Integrated through simulation
  - Non-equilibrium
  - Based on local formation and destruction rates

Isolated MW-like Disk Galaxy:
Z = Z$_\odot$, LW = 10 X Draine field

(FUSE, Gillmon et al. 06 & Wolfire et al. 08)
Formation and Destruction

- Forms on dust (metals)  
  (Wolfire et al 08)
  - Metallicity
  - Density
  - Gas clumpyness  
    (McKee & Ostriker et al 07)

- Destroyed by LW radiation
  - Flux from local young stars
  - Self-shielding and shielding by dust  
    (Draine & Bertoldi 96)
  - Column length/density  
    (Pavlovski et al 02)
  - Metallicity
A Dwarf Galaxy Simulated 4 Ways

- \( \Lambda \text{CDM} \) cosmology
- Zoomed-in initial conditions
- Final Galaxy:
  - \( M_{\text{vir}} = 4 \times 10^{10} M_\odot \)
  - \( V_{200} = 58 \text{ km/s} \)
- Resolution
  - \( M_{\text{GP}} \approx 4 \times 10^4 M_\odot \)
  - \( h \geq 30 \text{pc in disk} \)
Star-Formation Law

- Probabilistic, based on local gas properties

- Formation time: $t_{\text{dyn}} \propto \rho^{-1/2}$
- Efficiency: $c^*$
- Threshold density allowed: $\rho_{\text{min}}$

(Stinson et al 06)
Comparing Four Simulations

- No H$_2$, Standard SF
  - $c^* = 0.1$, $\rho_{\text{min}} = 10$ amu/cc

- H$_2$, Standard SF
  - $c^* = 0.1$, $\rho_{\text{min}} = 10$ amu/cc

- H$_2$, H$_2$ based SF
  - $c^* = H_2/(HI + H_2)$ 0.1, $\rho_{\text{min}} = 0.1$ amu/cc

- H$_2$, High-H$_2$ based SF
  - $c^* = H_2/(HI + H_2)$ 0.1, $\rho_{\text{min}} = 0.1$ amu/cc,
  - $H_2/(HI + H_2) \geq 0.1$
Reproducing the Resolved Kennicutt-Schmidt Law at $z=0$

- HI
- Mock THINGS
  (Walter et al 08)
  observation
Reproducing the Resolved Kennicutt-Schmidt Law at z=0

- HI
- Mock THINGS
  (Walter et al 08) observation
- H$_2$
Reproducing the Resolved Kennicutt-Schmidt Law at $z=0$

- HI
  - Mock THINGS
    (Walter et al 08) observation
- H$_2$
- SFR
  - Mock FUV and 24$\mu$m observations
  Sunrise, Jonsson 06
Reproducing the Resolved Kennicutt-Schmidt Law at z=0

- HI
- Mock THINGS (Walter et al. 08)
- H₂
- SFR
  - Mock FUV and 24µm observations

Bigiel et al. 08

![Graph showing the Kennicutt-Schmidt Law comparison between observations and mock data.
]
Stellar Profiles

- No H$_2$
- H$_2$
- H$_2$ SF
- High H$_2$ SF

Diagram showing the stellar density as a function of radius for different conditions.
Stellar Profiles

No H$_2$

High H$_2$ SF

Sunrise, Jonsson 06
Star-Formation Histories

- No H$_2$
- H$_2$
- H$_2$ SF
- High H$_2$ SF
Conclusions

- More accurate modeling of physics
- Resolved Kennicutt-Schmidt Law similar in all simulations
- H$_2$ extends young stellar disks
- H$_2$ extends SFH
Future Work

- Star formation maps at high redshift
- Wider range of galaxy masses at similar or higher resolution
  - Scaling relations
- Increasing mass resolution
  - Mock CO observations
- Comparisons to ALMA