Characteristics of the ISM and Feedback–Expelled Gas

Charlotte Christensen
University of Arizona
Tom Quinn, Fabio Governato, Romeel Dave
Alyson Brooks, Sijing Shen, Greg Stinson, James Wadsley
Motivation

- How does the structure of the ISM effect gas loss from SNe feedback?
  - Compare three different ISM models – primordial cooling, metal-line cooling, metal-line cooling + H$_2$
- What are the characteristics of the gas being expelled?
  - How much, from where, metallicity etc.
- Working with simulations of two low-mass spiral galaxies
Gasoline (Wadsley, et al., 2003)

- SPH code with
  - Cosmic UV background radiation
  - H & He ionization
  - **Metal line cooling** (Shen+ 2010)
  - Metal diffusion
  - Star formation
  - Supernovae feedback **(blastwave)** (Stinson+ 2006)
  - **Molecular Hydrogen** (Christensen+ submitted)

- Which reproduces
  - Damped Lyman-α systems (Pontzen et al., 2008, 2010)
  - Mass-metallicity relation (Brooks et al., 2007)
  - Broken exponential disks in spirals (Roskar et al., 2008)
  - Tully-Fisher relation (Governato et al., 2007)
  - Realistic rotation curves in dwarfs (Governato et al., 2010)
  - Reduced bulge mass in spiral galaxies (Guedes et al., 2011)
  - Change the angular momentum distribution (Brook et al., 2011, Pontzen et al., 2011)
  - ...

...
Implementing Molecular Hydrogen

- $\text{H}_2$ abundances per particle
- Integrated through simulation (Gnedin et al., 2009)
- Based on local formation and destruction rates
- Non-equilibrium
- Shielding of $\text{H}_2$ and HI
- Lyman-Werner Radiation
- Other gas-phase physics: $\text{H}_2$ cooling, collisional dissociation, formation via $\text{H}^-$
- $\text{H}_2$-based star formation
Implementing Molecular Hydrogen

- H₂ abundances per particle
- Integrated through simulation (Gnedin et al., 2009)
- Based on local formation and destruction rates
- Non-equilibrium

**Shielding of H₂ and HI**

- Lyman-Werner Radiation
- Other gas-phase physics: H₂ cooling, collisional dissociation, formation via H⁻
- H₂-based star formation
Simulations

- Two Low-Mass Spiral Galaxies
- Initial Conditions
  - Cosmological
  - Zoomed-in
  - Integrated to $z = 0$
- Final Galaxies
  - $M_{\text{vir}} = 2 \times 10^{11} M_\odot$
  - $V_{200} = 100 \times 130\text{ km/s}$
  - $12 + \log(O/H) = 8.2 \times 8.5$
- Resolution
  - Gas Particle Mass: $2.7 \times 10^4 M_\odot$
  - Force Resolution: 230 pc
  - Softening Length: $\sim 160 \text{ pc in disk}$
ISM Models

No Low T Cool  Metals  H$_2$ + Metals

- Grey-scale: HI surface density at THINGS resolution and sensitivity
- Red contours: H$_2$ surface density
Simulated Observations

- Stellar Disk Increases in Size from Left to Right
- Bulge is smaller in the “No Low T Cool” and “H₂ + Metals” models
Comparing to Observed Bulges

Christensen, C.

Log Bulge Scalelength

Bulge Magnitude

$M_{H_{\text{Bulge}}}$

$\log(r_e)$

No Low T cool Metals $H_2 +$ Metals

Obs. From Fisher et al., in prep
Resolved Kennicutt–Schmidt Relation

No Low T cooling

Metals

H₂ + Metals

Obs. Data from Bigiel+ '10

SFR Surface Density

Log Σ_{SFR} [M_☉ kpc^{-2} yr^{-1}]

Log Σ_{H} [M_☉ pc^{-2}]

Hydrogen Surface Density
Star Formation History

No Low T cooling
Metals
H₂ + Metals
Rotation Curves/Density Profile

Circular Velocity [km/s]

\[ \rho \text{DM} [M_\odot pc] \]

No Low T cooling
Metals
\( H_2 + \text{Metals} \)
Where Stars Form
Density and Surface Density

- No Low T cooling
- Metals
- H$_2$ + Metals

Log $\rho$ [amu/cc] vs. Radius [kpc]

Log $\Sigma_{gos}$ [amu/cm$^2$]
Gas Lost from Feedback

Cumulative Outflow / $10^9 [M_\odot]$

- Gas Ejected from disk
- Gas Lost from Halo

- No Low T cooling
- Metals
- $H_2 +$ Metals

Time [Gyr]
Source of Lost Gas

- Gas Ejected from Disk
- Gas Lost from Halo

No Low T cooling
Metals
H₂ + Metals

\[ \frac{dN}{dr} \]

Radius [kpc]

0 2 4 6 8
Why the different profiles?

- Changing amounts of gas loss
- Two competing phenomena:
  - Cooling reduces gas loss
  - Clumpiness increases effectiveness of feedback
- The **No Low T Cool ISM** model produces more efficient feedback by having a high minimum temperature and less efficient cooling in the halo
- The **Metals** ISM model has a somewhat clumpy ISM but less gas is lost because of the extra cooling
- The **H₂+ Metals** model produces more efficient feedback because **shielding produces a clumpier ISM**
Simulated low-mass spiral galaxies with: primordial cooling, metal-line cooling, and with H$_2$

Changing the ISM can dramatically change the effectiveness of feedback and the structure of the galaxy

About half of the feedback-heated gas is expelled from the halo. It primarily originates from small radii.