Physics 235

Extragalactic Astrophysics
Prof. Crystal Martin
Properties of GMCs
Observed Mass Distribution of GMCs. I. Milky Way

- Compare \( \frac{dN}{dM} \sim M^{-1.3} \) to \( M^{-1.9} \) stellar initial mass function.
- Most clouds are low mass but most of the molecular gas in the most massive clouds.
- A \( 10^5 \) Msun cloud contains on average one O star.
- A \( 10^6 \) Msun cloud takes \( 3 \times 10^7 \) year to photoevaporate.

Fig. 1.—Cloud mass spectra for each of the three cloud catalogs. The masses in each catalog have been corrected by a constant factor as discussed in § 2. A least-squares fit to a truncated power law has been made to the SYCSW and SRBY catalogs over the range indicated by the solid line. The dotted line indicates the extrapolation of the fit to lower masses. The fitted parameters are in Table 2.
Observed Mass Distribution of GMCs. II. Local Group

- $dN/dM \sim M^{-1.5}$ in the inner MW
- $dN/dM \sim M^{-2.1}$ and $M^{-2.9}$ in outer MW and M31
- So there appear to be systematic differences with environment.
Formation of $\text{H}_2$
Molecular Fraction Depends on $P$

Fig. 16.—(a) Ratio of $H_1$ to $H_2$ surface density plotted against the hydrostatic disk pressure at the midplane, as given by Elmegreen (1989). The straight dashed line represents the mean slope of $-0.8$. (b) Molecular fraction plotted against midplane pressure. The straight dashed line represents the slope of 1.7 predicted by Elmegreen (1993). Data for the Milky Way is based on Dame et al. (1993), adopted a stellar scale length of 3 kpc (Sackett 1997) and $\Sigma_\ast = 35 \, M_\odot$ pc$^{-2}$ at the solar circle (Gilmore et al. 1989). [See the electronic edition of the Journal for a color version of this figure.]
Timescales for Molecule Formation & Destruction

• Via recombination of pairs of adsorbed H atoms on the surface of dust grains. Dust-to-gas mass ratio is typically 1:100.

\[ t = 1.5 \times 10^7 \text{ yr } (100 \text{ cm}^{-3} / n) \]

• Much less efficient without the dust. Gas-phase reactions important for Pop III stars.

• Photodissociation destroys molecules. In average interstellar radiation field, a hydrogen molecule lives \( \sim 600 \text{ yr} \). Interiors of GMCs are shielded from this radiation.

• Molecular hydrogen forms where external pressure is high and the radiation field is low.

\[ R_{\text{mol}} = \frac{n(H_2)}{n(HI)} \sim P^{2.2} \text{ J}^{-1} \]
Figure 1. $X_{\text{CO}}$ versus mass-weighted mean metallicity (in units of solar) for all $z = 0$ model galaxies with $\Sigma_{H_2} \sim 100$ $M_\odot$ pc$^{-2}$. The contours represent the number of snapshots in a given $X_{\text{CO}}-Z'$ bin, with the numbers increasing with increasing lightness of the contour. The dashed line outer contour encompasses all model galaxies, regardless of their gas surface density. Overlaid are observational data points from Bolatto et al. (2008), Leroy et al. (2011) and Genzel et al. (2012). The solid line shows our best fit to the simulations and is expressed in equation (8) and described in Section 4.
First Stars

“Population III”

The minimum mass that a virialized gas cloud must have in order to be able to cool in a Hubble time is computed, using a detailed treatment of the chemistry of molecular hydrogen.
Molecular Fraction Needed for Collapse vs. Molecular Fraction Produced

\( t_{\text{cool}} = t_{\text{hubble}} \)

Minimum halo temperature needed for baryonic collapse.

The molecular fraction produced in a Hubble time
Minimum Virial Temperature Needed to Collapse

Virialization requires $\rho/\langle\rho\rangle = 18\pi^2$. At constant entropy that’s $T/T_{\text{igm}} = (18\pi^2)^{2/3}$

No radiative cooling mechanism can help here.

$T_{\text{cool}} < t_{\text{hubble}}$

$T_{\text{vir}} < T_{\text{CMB}}$

$T_{\text{igm}}$

CLM - Physics 235
Minimum baryonic mass is redshift dependent

In CDM, low mass halos collapse first. But does the primordial gas cool?

\[ t_{\text{cool}}(H_2) = t_H \]

\[ \delta_{\text{crit}} = 3 \sigma (M,z) \]

For halos that formed early \((z_{\text{vir}} > 100)\), the gas can’t cool if \(M_h < 10^4 M_0\).

For halos that formed late \((z_{\text{vir}} < 10)\), the gas can’t cool if \(M_h < 10^8 M_0\).

\[ T_{\text{vir}} \approx 442 K \Omega_{m,0}^{1/3} (M/10^4 M_0)^{2/3} [(1+z_{\text{vir}})/100] \]

Expected in halos with \(T_{\text{vir}} = 10^3 - 10^4 K\). These halos form in abundance at \(z < 30\).