Dust from AGBs and the ISM in the Early Universe

Dust-catalyzed H_2 Formation

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Undergraduate Research Symposium, 23 September 2011

The galactic ISM

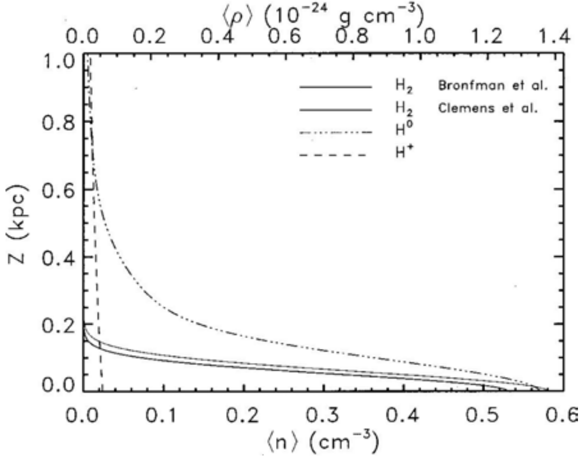
Wolfire, M.G. (2010) The phase structure of the ISM in galaxies

Three-phase model

Cold (T $\sim$ 100 K) neutral atomic gas (CNM)
Warm (T $\sim$ 8000 K) neutral atomic gas (WNM)
Cold (T $\sim$ 10 K) molecular gas - H_2, CO etc.

The importance of H_2

H_2 is in high abundance where stars form: Ferrière, K. (2001) The interstellar environment in our galaxy



Are molecules needed for SF or is this coincidental? Glover & Clark (2011) Is molecular gas necessary for star formation?

The importance of dust

Bromm et al. (2001) H_2 generation in the gas phase governs the formation of the first stars

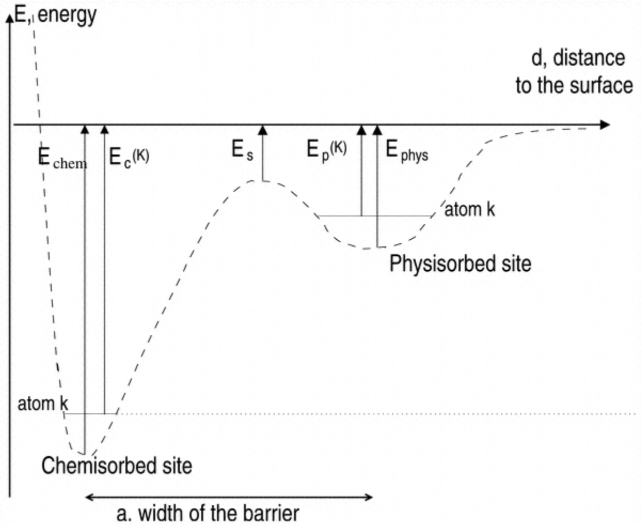
Gas phase reactions

$H^+ \; e^- \rightleftharpoons H$
$H^+ + H \rightarrow H_2^+$
$H_2^+ + e^- \rightarrow 2H$
$\mathbf{H^- + H \rightarrow H_2 + e^-}$
$H_2^+ + H + e^- \rightleftharpoons H_2 + H$
$\mathbf{H_2 + \gamma \rightarrow 2H}$
$H^- + \gamma \rightleftharpoons H + e^-$

H_2 does not survive in the UV field unless there is shielding by dust. However, when there *is* dust, the dust-catalyzed reaction forms H_2 much more effectively than gas phase reactions!

How H_2 forms on dust

Cazaux & Tielens (2004) H_2 formation on grain surfaces



Cazaux & Spaans (2009) HD and H_2 formation in low-metallicity dusty gas clouds at high redshift

Rate equation

$$R_d(H_2) = \frac{1}{2} n(H) v_H S(T_g, T_d) \times ((n_{gr}\sigma\epsilon_{H_2})^{carbon}) + (n_{gr}\sigma\epsilon_{H_2})^{silicon})) \, \alpha \, \frac{Z}{Z_\odot}$$

Dust sources

Supernova - fast - takes only the lifetime of a massive star

AGB - requires lower mass star to evolve

The IMF in the early universe

Bromm et al. (2002) The Formation of the First Stars. I. The Primordial Star-Forming Cloud

It was believed that the first stars were massive: 100 $M_\odot$ to 200 $M_\odot$ or supermassive - even up to 1000 $M_\odot$

Schneider, R. et al. (2005) Constraints on the IMFs of the first stars; Stacy, A. et al. (2010) The first stars: the formation of binaries and small multiple systems

Earliest stars **NOT** only heavyweights - implied from WMAP data! Implication is that stars that evolve into AGBs coexisted with Pop. III as far as $z \approx 10$

Is the dust from AGBs enough to make a difference in H_2 formation and the fragmentation tendencies of the first galaxies?

Hydrodynamic Model

1 pc^3 box
Start cloud as isothermal sphere of about 0.5 pc radius
Initial density 10^5 cm^{-3}
Initial temperature 8500 K
Source of metals and dust - the AGB
Driven supersonic turbulence to mix the cloud
Full primordial chemical reaction network with dust and metals included
Initial abundance of cloud from atomic cooling halos
Radiation field from the AGB and background sources