THE ROLE OF METALLICITY AND H_2 IN STAR FORMATION IN THE GALAXY

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ABSTRACT. A new law of star formation is proposed which suggests an explicit dependence on the abundance of metals and H_2.

Stars are formed out of gas and dust in the interstellar medium, of which the gas component constitutes about 98% by mass fraction. Gas exists in two forms - ionic or atomic and molecular. The latter is mostly H_2, classically traced by CO measurements as the formation of CO and other complex molecules is strongly dependent on the availability of H_2. The tracers of the current rates of star formation (SFR) are radio recombination studies of HII regions, the distribution of pulsars, supernova remnants and the infrared fluxes. The activity of star formation in the Galaxy is found to be mostly concentrated in regions of giant molecular complexes.

Studies of the correlation between SFR(Ψ_s) and the surface density of molecular hydrogen (ΣH_2) suggest that the two might be well correlated by a relationship of the form $\Psi_s \propto \Sigma H_2^k$, with k=1-1.6 (Rana and Wilkinson 1986, hereafter referred to as RW, and other references therein). Practically no correlation is found to exist between Ψ_s and Σ_{HI} or between Ψ_s and $\Sigma_{total\ gas}$. Again the scale heights of OB associations are roughly the same as those of H_2 and not of HI.

However, for reasons of simplicity, the models of chemical evolution (except RW 1986) usually take either Ψ_s = constant or $\Psi_s \propto \Sigma^k_{total\ gas}$, the Schmidt law with k = 1-2. Recently a new law of star formation proposed by Dopita (1985) has neglected any dependence on H_2. However impressive his fits may be, Dopita's law does not explain the prime role of H_2 in star formation.

The problem faced by models of chemical evolution of the Galaxy, is how to deal with H_2 quantitatively. However, it is known that formation of H_2 is critically dependent on the availability of catalysers, such as interstellar grains, unless the density of gas is as high as 10^9 H-atoms cm^{-3} (Williams 1985). It is also known that for catalysis of H_2 formation, the grains must have a temperature of approximately 20K (Schmidt 1967). Recent infrared studies (Burton et al. 1985) reveal that interstellar grains do have a temperature 20-25K and their scale heights

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are somewhat larger than those of H_2, but once again much lower than those of HI.

In fact a preliminary study by us (RW 1986) shows that the molecular fraction of the gas content (defined as $P2 = \Sigma_{H2}/(\Sigma_{H2} + \Sigma_{HI})$) in any given region of the disc is possibly correlated with the metallicity (Z) of that region. Since, strictly speaking, the grain temperature in the ISM satisfies its required catalysis condition for H_2 formation, the correlation is expected for the abundance of grains only. But as it is difficult to estimate the abundance of grains in the ISM, we have used (O/H) measurements from HII regions as an indicator for the metallicity. A least squares fit produces b = 1.3 ± 0.3 for an assumed form for $P_2 \propto Z^b$.

Once the grains initiate the formation of H_2, which is a molecule, the local pressure will drop (for a given temperature) due to the mean molecular weight, μ', increasing and the number density of particles n decreasing (the kinetic pressure $p \sim nkT/\mu' m_p$). So a nascent diffuse molecular cloud quickly becomes clumpy compared to the diffuse atomic clouds. This possibly is the reason why molecular clouds are always found to be very dense, clumpy and massive, and confined well within the zone of availability of grains even though HI extends well beyond the grains. Obviously, later on molecular clouds become the seats of star formation in the disc.

Therefore, the total star formation rate, Ψ_s, for any region of the disc may be given by

$$\Psi_s \propto \Sigma_{H_2}^k \propto (\Sigma_T \mu \chi Z^b)^k$$

where Σ_T is the total surface density, μ is the gas fraction, χ is the abundance of hydrogen by mass fraction and Z is the metallicity.

This new law of star formation explains well why Ψ_s in the solar neighbourhood has stayed practically constant, given the age-metallicity relation of Twarog (1980). It has also been shown to produce a consistent model of the chemical evolution of the disc without infall (RW 1986). In metal-poor galaxies such as the LMC and SMC, it also explains why there are large amounts of HI but not many stars nor much CO (Israel 1985).

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