VERTICAL AND RADIAL DISTRIBUTIONS OF GAS AND YOUNG OBJECTS IN THE GALAXY AND THE SCHMIDT'S LAW OF STAR FORMATION

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ABSTRACT : The thickness of the disc distribution of young objects is shown to be significantly smaller than that of the interstellar gas over the whole Galaxy, as predicted by the Schmidt's law of star formation. The radial distribution of the density of young objects at $z = 0$, compared with that of the gas, is also consistent with the Schmidt's law. The exponent in this law is found to be between 1.5 and 2. A brief discussion of simple models of galactic evolution using the Schmidt's law is made.

I. INTRODUCTION : Schmidt (1959) has suggested that on a large scale the rate of star formation in the Galaxy varies with a power $n > 1$ of the density of interstellar gas :

$$\rho_* \propto - d\rho_g/dt\big|_* = \nu \, \rho_g^{\ \ n}$$

where ρ_* and ρ_g are the densities of young objects and gas, respectively, and ν and n are "universal" constants. Schmidt discussed several ways of finding n from observations.
Some are indirect and rest heavily on models of galactic evolution, thus their results are subject to caution. Two tests, however, are more direct and model independant.
i) If the index n of the Schmidt's law is larger than 1, stars form more rapidly per unit mass of gas in the galactic plane where ρ_g is maximum than far from the plane ; thus young objects form a thinner disc than the gas. If the z-distribution of gas is gaussian (as observations suggest), the z-distribution of young objects is also gaussian with a width $n^{1/2}$ times smaller. Schmidt used this method for the solar neighborhood and found $n \approx 2$-3. Much more data are presently available to extend this study.
ii) A direct comparison of the radial distribution of the densities of young objects and of gas also provides a direct check. However nearly all authors who have dealt with this problem have compared surface (projected) densities, and not volume densities : this is not the same thing since the thicknesses of the distributions vary with galactocen-

tric radius, and the poor correlations usually observed between surface densities does not mean that the Schmidt's law is invalid.
We have reinvestigated these tests using information presently available. The present paper gives only a brief summary of the results which will be discussed extensively in a paper submitted to Astronomy and Astrophysics, where references to the data used will be found.

II. VERTICAL DISTRIBUTION : the vertical distribution of gas is obtained by summing up the contributions of the cloud and intercloud HI media and of the H_2 molecules. The resulting z-distribution is close to gaussian, with values of $<|z|>$ given in Table I. There is a major difficulty in this study : the distribution of H_2 molecules is derived from the surveys of the CO emission line at 2.6 mm in a complex and uncertain way ; the conversion factor from CO to H_2 may even depend from galactocentrie distance because of a probable gradient in the abundance of carbon, as discussed by Peimbert (this Colloquium) ; this effect fortunately does not affect much the results in most of the Galaxy. When deriving from the published catalogues of optical young objects their z-distribution, care must be given to a strong selection effect due to interstellar extinction which plays against detection of distant objects at low galactic latitudes and thus yields an overestimate of their z-thickness. Radio objects are free from this effect. In table I, results for the $<|z|>$ distribution of various types of young objects are given ; those which might be severely affected by this bias are between brackets. HII regions provide a slight underestimate of the thickness of the places of star formation since they have smaller diameters and are more easy to detect close to the galactic plane where the gas density is larger. This bias is probably not very important.

R(kpc)	gas	O stars	±	B stars	±	O-B clusters	±	Optical HII regions	±	Radio HII regions	±	Supernova remnants	±
4-5	48									23	9	29	14
5-6	49									32	11		
6-7	51							(73	30)	33	10		
7-8	53	(83	22)					(50	15)	32	9	59	24
8-9	59	44	7			39	10	34	7	35	9		
9-10	63	43	5	48	4	40	7	55	10	32	9		
10-11	78	95	17	64	5	55	10	74	14	101	35	63	32
11-12	99	76	13			71	15	60	14	67	27		
12-13	120	(114	24)					86	30				
13-14	139	(118	42)					97	49				
14-15	155							183	98				

Table I. Thicknesses of the distributions of gas and young objects. The values of $<|z|>$ are given in parsecs together with the rms statistical errors due to the limited samples.

Table I shows that the z-distribution of young objects is clearly thinner than that of the gas over the whole Galaxy, as predicted by the Schmidt's law. A weighted average gives n = 1.95 ± 0.20 ; the error does not take into account possible systematic errors on the distance scales and thickness of the gas disk.

III. RADIAL DISTRIBUTION : Only radio objects can be used here, and the most interesting by far are the giant HII regions (Smith et al, 1977) which represent a complete sample up to 7 kpc from the Sun. Our derivation of the radial distribution of the surface density of Lyman continuum photons produced by young stars is similar to that of Smith et al., but we used a revised catalogue of HII regions and our results are slightly different. Volume densities are obtained by dividing by the thickness of the distribution. They are correlated with those of the gas in figure 1. The results have been grouped into only 4 ranges of galactocentric distances in order to decrease the statistical errors which are very large. The observed correlation agrees with the predictions of the Schmidt's law. The value of n we find is about 1.6 in agreement with that obtained by the previous method ; n would be somewhat closer to 2 if there were less H_2 in the central regions of the Galaxy, as suggested by Peimbert (this Colloquium).

IV. DISCUSSION AND CONCLUSIONS : The good agreement between the values of n obtained using two independent methods suggests that Schmidt's law is indeed valid, and that stars are formed not only from molecular clouds detected in the CO surveys but from the HI component as well. (Note that there is star formation in the outer parts of the Galaxy where there are very few CO molecules). It should be emphazised that all indicators of star formation that have been considered here correspond to stars of large masses (O-B stars), thus the present study provides no information on smaller mass stars. The Schmidt's law is not a priori incompatible with an often-used parametrization of star formation in the Galaxy of the type :

$$\sigma = -d\sigma_g/dt|_* = \mu(R)\sigma_g^{k}$$

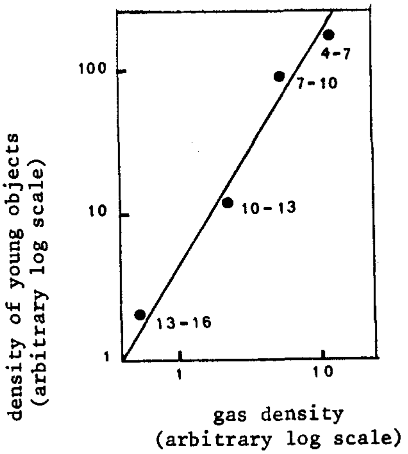

Figure 1 : Correlation between the density of gas at z = 0 and the density of Lyman continuum photons at z = 0. The range of galactocentric distances in kpc is indicated next to each point.

where the σ's are surface densities ; k a constant ($0.5 \lesssim k \lesssim 1$) and μ (R) depends on galactocentric distance but not on time (see e.g. Smith et al, 1977 ; Vigroux et al, 1976). However a detailed study shows that this parametrization is not consistent with Schmidt's law unless $n \simeq 1.1$. A simple model of galactic evolution using Schmidt's law has been described by Talbot and Arnett (1975). This model predicts far too little relative rate of star formation and gas surface density in the inner parts of the Galaxy compared with observations. Some preliminary model calculations that we have made indicate that changes in the Initial Mass Function or in the initial conditions of the model are not likely to solve the dicrepancy. It appears that, if the Schmidt's law is universal, one cannot escape the conclusion that infall of extragalactic or halo matter, or radial motions of gas, play a major role in galactic evolution.

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