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The infall time-scale in the solar neighbourhood

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The Galactic disc is supposed to have been formed from gas condensing out from the halo. The rate at which this infall of gas occurs, the amount of infall, and the time scales over which gas falls on to the disc have important consequences for the chemical evolution of the Galaxy. However there are large uncertainties in the observed data about infall, and even basic questions like the actual origin of the gas, the amount of infall etc., have not been answered.

In this work, we have used the observed metallicity distribution of low mass stars (the G-dwarf distribution) and the age-metallicity relation (AMR) to constrain the amount of infall and the infall time scale. Along with the infall time scales the history of star formation in the solar neighbourhood can also be determined.

Observationally, the G-dwarf metallicity distribution is $dN/d\log Z$, where N is the number of stars and $Z = Z(t)/Z_\odot$, the metallicity relative to the solar metallicity. G-dwarfs are low mass stars and hence live throughout the life of the Galactic disc. We can therefore, assume that all G-dwarfs that have been born are present today. Hence, for a constant mass-spectrum of stars at birth, assuming that f is the fraction of stars that are G-dwarfs, and S_G the surface mass density of G-dwarfs, using the equations of chemical evolution (see Tinsley 1980) we can write,

$$\psi = \frac{S_{G1}}{f \cdot N_1 \cdot \ln 10} \frac{dN}{d\log Z} \frac{dZ}{dt} \frac{1}{Z}, \quad \ldots (1)$$

where, ψ is the star formation rate (SFR), S_{G1} is the total mass of G-dwarfs today, and N_1 is the number of G-dwarfs today, i.e., at $t = t_d$, where t_d is the age of the Galactic disc. The value of $dN/d\log Z$ is obtained from the metallicity distribution function of G-Dwarfs, while dZ/dt is nothing but the derivative of the AMR.

We can substitute the expression for the SFR (equation (1)) into equations of chemical evolution to get,

$$\frac{d\sigma_g}{dt} = i(t)\left[1 - \frac{(C_1/Z)(dN/d\log Z)(Z_1 - Z)}{\sigma_g - (C_2/Z)(dN/d\log Z)}\right] \quad \ldots (2)$$

$$\frac{dZ}{dt} = \frac{(Z_1 - Z)\, i(t)}{\sigma_g - (C_2/Z)(dN/d\log Z)}, \quad \ldots (3)$$

where, $C_1 = (1 - R)\ (S_{G1}/(f{\cdot}N_1{\cdot}\ln 10))$, and $C_2 = yC_1$. The gas surface mass density is denoted by σ_g, $i(t)$ the rate of infall, and Z_1 is the infall metallicity. The returned fraction is denoted by R, and y is the yield of iron.

We assume that star formation in the disc begins as the disc begins to form. We have considered two forms of infall :

Case A : $i(t) = A \exp(-t/\tau)$, and

Case B : $i(t) = At^p \exp(-t/\tau)$.

The amplitude, A, is calculated using

$$\sigma_T(t = t_d) = \int_0^{t_d} i(t)dt, \qquad \ldots (4)$$

where, $\sigma_T(t_d)$ is the total surface mass density of the disc today. We have adopted a disc age of 13 Gyr. We define the infall time scale as the time taken for 66% by mass of the disc to form. For Case A, this is nearly equal to exponential decay time-scale τ.

The quantities y and C_1 can be found once we specify the initial and the final conditions. We find that once the form of the infall rate has been chosen, the only adjustable parameter left in the system is $\sigma_T(t_d)$. y and C_1 have to be adjusted to reproduce the conditions at $t = 0$. Once C_1 and y are determined, equation (1) is solved to obtain the variation of the SFR, which in turn is used to calculate the initial mass function (IMF). The IMF is calculated for each case using the present day mass function from Basu & Rana (1992). The infall time scale τ, has to be adjusted so that the IMF calculated from the predicted SFR can reproduce the adopted $\sigma_T(t_d)$. Thus for each G-dwarf distribution we have considered different values of $\sigma_T(t_d)$ and determined the infall time-scale for different values of Z_1.

We have used three different metallicity distributions : (1) The distribution of Pagel (1989) corrected for a possible spread in metallicity (distribution A), (2) the distribution of Sommer-Larsen (1991) corrected for a possible spread in metallicity, retaining his scale height correction for stars (distribution B), and (3) the distribution of Sommer-Larsen (1991) corrected for a possible spread in metallicity, but using a scale height correction from Grennon (1991) (distribution C). The three distributions differ in their mean metallicities and half-widths.

We accept a solution if the IMF calculated from the observed present day mass function from the SFR obtained from equation (1) gives a total surface mass density equal to $\sigma_T(t = t_d)$ used in equation (4), the AMR obtained by solving equation (3) matches the observations and the ratio of the past average to the present star formation rate as calculated from equation (1) lies between 0.4 and 3 (Miller & Scalo 1979) to allow continuity of the slope of the calculated initial mass function (IMF).

We find that despite the uncertainties involved, the infall time-scale, which we have defined as the time taken for 66% by mass of the disc to be formed can be constrained fairly well. Figure 1 shows the variation of the infall time-scale as a function of the present total surface mass density. The different curves are for the different G-dwarf distributions used, and for different values of Z_1. Figure 2 shows the resulting AMR. We can see how the observations can rule out certain values of σ_T and hence infall time-scales. We can draw the following conclusions from this work :

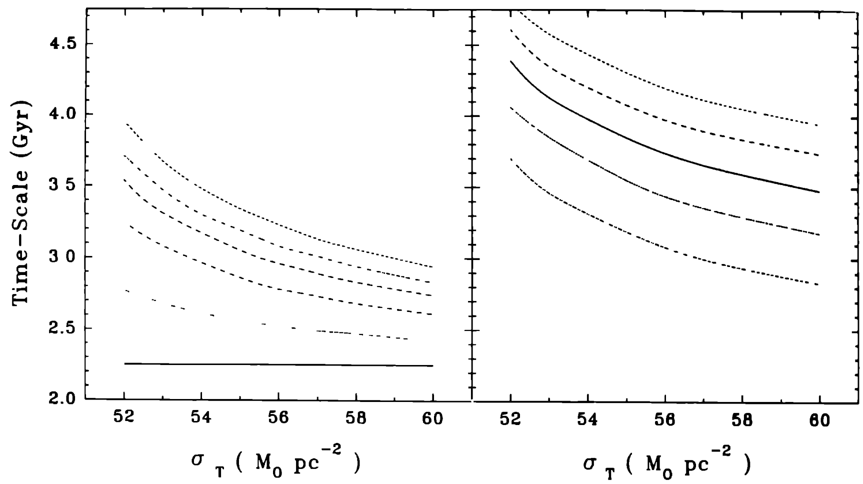

Figure 1. (a) The variation of the infall time-scale with the total surface mass density of the disc at the solar neighbourhood today for an exponentially decreasing infall rate. The solid line is for distribution C with log Z_i = −1.5, the dotted line is for distribution C, but Z_i = 0. The dot-dashed curve and long dashed curve are for distribution B with log Z_i = −1.5 and Z_i = 0 respectively. The chain dotted and medium dashed lines are for distribution A with log Z_i = −1.5 and Z = 0 respectively. (b) The variation of the infall time-scale as a function of $\sigma_T(t_d)$ for different values of p for Case B infall. The chain dotted line is for p = 0, the dotted and solid lines are for p = 0.25 and p = 0.50 respectively. The long and short dashed lines are respectively for p = 0.75 and p = 1.00.

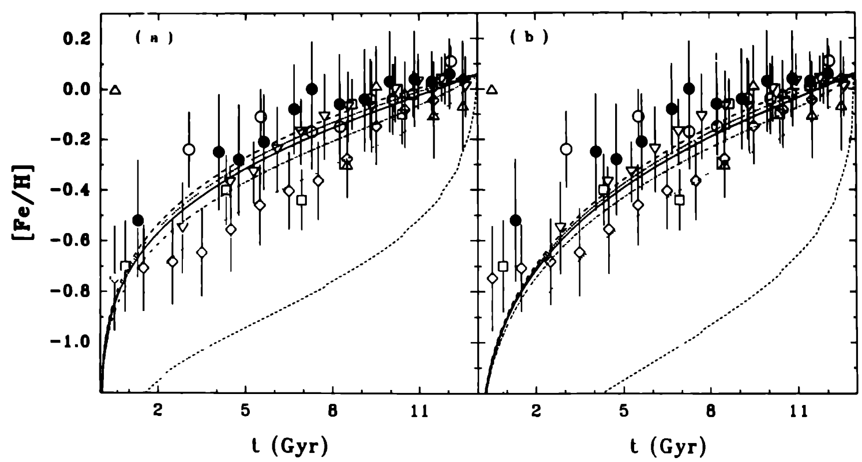

Figure 2. (a) The age-metallicity relation predicted for distribution A with zero metallicity infall for different values of $\sigma_T(t_d)$, the current total surface mass density of the disc at the solar neighbourhood. (b) The same for distribution B. In both figures the symbols are as follows : inverted triangles—data from Twarog (1980); open circles—data from Carlberg *et al* (1985); squares—Nissen *et al.* (1985), filled circles—Meusinger *et al.* (1991); triangles—Strobel (1991), and diamonds—Rana & Basu (1992). The long-dashed line is the AMR predicted for $\sigma_T(t_d)$ = 60 $M_\odot$ pc^{-2}, short-dashed—the AMR for $\sigma_T(t_d)$ = 57 $M_\odot$ pc^{-2}, the solid line is the AMR for $\sigma_T(t_d)$ = 55 $M_\odot$ pc^{-2}, the dot-dashed for $\sigma_T(t_d)$ = 52 $M_\odot$ pc^{-2}, the dotted for $\sigma_T(t_d)$ = 50 $M_\odot$ pc^{-2}, and the medium dashed represent the AMR predicted for $\sigma_T(t_d)$ = 48 $M_\odot$ pc^{-2}.

(1) The infall time scale at the solar neighbourhood is fairly small. For the forms of infall chosen, the infall time scale can be restricted to be between 2.25 and 4.00 Gyr for a wide variations in parameters.

(2) The predicted star formation rates show a maximum at ~ 2 Gyr. Most can be fitted to the form $\psi = a(t^n)\exp(-bt)$, with n in the range 0.4-0.5, and $(1/b)$ between 4 and 5 Gyr

for the case of a purely exponential infall. The second form of infall gives rise to similar SFRs, but the peak occurs at a later time, the delay increasing with increasing p.

(3) The rate of star formation today at the solar neighbourhood is between 2.5 and 3.75 $M_\odot$ pc^{-2} Gyr^{-1}. The current rate of infall at the solar neighbourhood is around 0.1-0.3 $M_\odot$ pc^{-2} Gyr^{-1}. This is only about 10-20% of the mass currently being locked up into stars. The total infall on to the Galaxy is about 0.1 to 0.2 $M_\odot$ yr^{-1}. This agrees with the observational estimates of Mirabel & Morras (1984) and Wakker (1991).

(4) If the galactic disc has zero mass at $t = 0$, a constant rate of infall cannot reproduce the age-metallicity relation at the solar neighbourhood. The star formation rate it predicts is also unacceptable.

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