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The history of star formation in the local disc from the G dwarf metallicity distribution

H. J. Rocha-Pinto and W. J. Maciel

Instituto Astronômico e Geofísico, Av. Miguel Stefano 4200, 04301-904 São Paulo SP, Brazil

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ABSTRACT

We address the question of the occurrence of star formation bursts in the solar neighbourhood by using the metallicity distribution of the G dwarfs. We present a method to recover the star formation history using simultaneously the metallicity distribution and the age–metallicity relation. The method associates the number of stars in a given metallicity interval with the corresponding time interval predicted by the age–metallicity relation. We take into account corrections relative to observational errors, cosmic scatter and scaleheight effects. The method is tested by simulations of the chemical evolution of a galaxy with irregular star formation rate, and our results show that it is possible to recover the star formation history fairly well. The application of the method to the solar neighbourhood shows evidence for at least two strong events of star formation: a burst 8 Gyr ago, and a lull 2–3 Gyr ago. These features confirm some previous studies on the star formation history in the local disc.

Key words: stars: formation – stars: late-type – Galaxy: evolution – solar neighbourhood.

1 INTRODUCTION

The star formation rate (hereafter SFR) is one of the main parameters for galactic evolution studies. Previous attempts to recover the SFR history in the solar vicinity have yielded a present relative birthrate $b(T_G)$ close to unity, where T_G is the present time, and $b(T_G)$ is the ratio between the present SFR, $B(T_G)$, and the average past SFR, $\langle B \rangle$. This fact has led many authors to conclude that the SFR history in the solar neighbourhood was almost constant, or slightly decreasing over the lifetime of the Galaxy (see Scalo 1986 for a review).

However, $b(T_G) \sim 1$ indicates only that $B(T_G) = \langle B \rangle$, and not that $B(t) = \langle B \rangle$ at any time t, an expected result on the assumption that the SFR has been constant. There is no specific information on the past behaviour of the SFR in the function $b(T_G)$. In particular, there is no indication that the SFR must be a smooth monotonic function of time, a hypothesis generally adopted for its computational simplicity or by the theoretical faith in the power of self-regulation in complex systems (Noh & Scalo 1990).

In fact, several pieces of evidence strongly suggest that the local SFR has been quite irregular, with well-marked periods of enhancement and quiescence extending for about 1–3 Gyr. This evidence comes from several independent studies relative to (i) stellar age distributions (Twarog 1980, revisited by Noh & Scalo 1990 and Meusinger 1991a); (ii) Ca II emission in late-type dwarfs (Barry 1988; Soderblom, Duncan & Johnson 1991); (iii) the distribution of Li abundances (Scalo, private communication); (iv) the present-day mass function (Scalo 1987); (v) stellar kinematics (Gómez et al. 1990; Marsakov, Shevelev & Suchkov 1990); and (vi) the white dwarf luminosity function (Noh & Scalo 1990; see also Díaz-Pinto et al. 1994).

The major results emerging from these studies were summarized by Majewski (1993). He recognizes the occurrence of at least three star formation bursts, named bursts A, B and C. Burst A is a present star formation burst, while bursts B and C occurred approximately 5–6 and 8 Gyr ago, respectively. Between bursts A and B there is a long era of quiescence in the star formation activity, which is probably reflected in the Vaughan–Preston gap in the distribution of chromospheric emission among late-type dwarfs (Vaughan & Preston 1980; Barry 1988; Henry et al. 1996).

The occurrence of bursts is likely to leave signatures in the metallicity distribution of G dwarfs, in the sense that there will be more stars with metallicity corresponding to the gas mean metallicity at the time of the burst. In the present work, we make an effort to recover the SFR history from these possible signatures in the metallicity distribution of nearby long-lived stars, as recently derived by us (Rocha-Pinto & Maciel 1996). In Section 2, we present the method to recover the SFR history. Section 3 describes the simulations we have performed in order to test our method. In Section 4, we present the results from the application of the method to the solar neighbourhood, and our main conclusions.

2 A METHOD TO RECOVER THE SFR

We want to relate the number of stars born in the time interval $(t, t + \mathrm{d}t)$ with the total number of stars observed at a time T, which have metallicities in the range $(z, z + \mathrm{d}z)$. The first function corresponds to the absolute SFR, $B(t)$; the second corresponds to the metallicity distribution of the region studied at time T, denoted $N(z|T)$.

Let $Z(t)$ be the mean gas metallicity, which defines an age–metallicity relation (AMR) for the system under study. The number of stars born in the interval $(t, t + \mathrm{d}t)$ with metallicities in $(z, z + \mathrm{d}z)$ is

$$\mathrm{d}^2 n(z, t) = B(t) P(z, t)\, \mathrm{d}t\, \mathrm{d}z, \tag{1}$$

where $P(z, t)$ is a probability function for a star born at t to have a metallicity z. According to Tinsley (1975) and Basu & Rana (1992),

$$P(z, t) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left\{ -\frac{[z - Z(t)]^2}{2\sigma^2} \right\}, \tag{2}$$

where σ is the cosmic abundance scatter in the interstellar medium at birth. Integrating equation (1) over time we have

$$N(z|T)\, \mathrm{d}z = \frac{1}{\sigma\sqrt{2\pi}} \int_0^T B(t) \exp\left\{ -\frac{[z - Z(t)]^2}{2\sigma^2} \right\} \mathrm{d}t\, \mathrm{d}z. \tag{3}$$

It can be seen from equation (3) that $B(t)$ can be obtained if we have the metallicity distribution $N(z|T)$ and the age–metallicity relation $Z(t)$.

Assuming that the AMR is a monotonic function of time, and that there is no cosmic scatter in the interstellar medium, each star born at t will have a well-defined metallicity $Z(t)$, so that we can write for a time interval Δt

$$B(t)\Delta t = N(Z)\Delta Z, \tag{4a}$$

where ΔZ is the corresponding metallicity variation. Equation (4a) becomes, for $\Delta t \rightarrow 0$,

$$B(t)\, \mathrm{d}t = N(Z)\, \mathrm{d}Z. \tag{4b}$$

This procedure is analogous to assigning a *chemical age* to each star, defined as the age for which the mean gas metallicity is Z. The recovery of the SFR history in our method is based on a distribution of chemical ages.

However, *there is* a real cosmic scatter in the interstellar medium and, as a consequence, the metallicity z of a star is generally different from the mean gas metallicity Z at birth. In order to improve the distribution of chemical ages, we need to transform the observed metallicity distribution $N(z|T)$ into a distribution of mean metallicities at birth, $N(Z|T)$. Hereafter, for the sake of simplicity, we will omit the epoch T relative to the metallicity distribution, which will be noted simply as $N(z)$. Substitution of equation (4b) into equation (3) yields

$$N(z) = \frac{1}{\sigma\sqrt{2\pi}} \int_{Z(0)}^{Z(T)} N(Z) \exp\left[-\frac{(z - Z)^2}{2\sigma^2} \right] \mathrm{d}Z, \tag{5}$$

where we have also omitted the time dependence of the metallicity. Equation (5) shows that $N(z)$ is the convolution of the desired function $N(Z)$ with a cosmic scatter Gaussian function.

Equation (5) is much simpler than equation (3). The method of solving it is the same as used by Rocha-Pinto & Maciel (1996) to correct the observed metallicity distribution for observational errors and cosmic scatter, and was first used by Pagel & Patchett (1975). The observed metallicity distribution must be approximated by a Gaussian function for deconvolution purposes. The mean metallicity distribution is obtained by

$$N(Z) = N(z) + \delta N_0(z)\big|_{z=Z}, \tag{6}$$

where

$$\delta N_0(z) = G_1^0(z) - G_0^0(z); \tag{7}$$

here G_0^0 is the Gaussian function adjusted to $N(z)$, and G_1^0 is its deconvolution, assuming $\sigma = 0.20$ dex.

That formalism assumes that the metallicity distribution is complete and representative of the chemical evolution of the system. To eliminate some possible bias from scaleheight effects, we must consider the Sommer-Larsen (1991) f-factors. In this case, the mean metallicity distribution is given by

$$N(Z) = \frac{N(z)}{f(z)} + \delta N_1(z)\bigg|_{z=Z}, \tag{8}$$

where f is the Sommer-Larsen factor, and

$$\delta N_1(z) = G_1^1(z) - G_0^1(z). \tag{9}$$

G_0^1 is the Gaussian function adjusted to $N(z)/f(z)$, and G_1^1 is its deconvolution, assuming $\sigma = 0.20$ dex. Once we find $N(Z)$, the SFR history can be recovered by equation (4b).

3 SIMULATING THE SFR RECOVERY

We can test the validity of the assumptions of the method by means of simulations of the chemical evolution of a galaxy experiencing an irregular SFR. We assume a galaxy with no infall, and with a prescribed relative SFR, $b(t)$. The initial mass function $\xi(\log M)$ and $b(t)$ are connected by the procedures described by Miller & Scalo (1979). We have used a present-day mass function similar to that of the solar neighbourhood (Scalo 1986), and the stellar lifetimes of Bahcall & Piran (1983).

The functions $\xi(\log M)$ and $b(t)$ are suitably converted into their corresponding quantities according to the formalism developed by Tinsley (1980), $\phi(M)$ and $\psi(t)$, by the equations

$$\phi(M) = \frac{\log \mathrm{e}}{\mathcal{M}} \frac{\xi(\log M)}{M} \tag{10}$$

and

$$\psi(t) = \frac{b(t)}{T_\mathrm{G}} \mathcal{M}, \tag{11}$$

with

$$\mathcal{M} = \log \mathrm{e} \int_{M_\mathrm{min}}^{M_\mathrm{max}} \xi(\log M)\, \mathrm{d}M, \tag{12}$$

where we take $M_\mathrm{max} = 62\,\mathrm{M}_\odot$ and $M_\mathrm{min} = 0.1\,\mathrm{M}_\odot$ (Miller & Scalo 1979).

The equations for the evolution of the gas mass (m_g) and metallicity (Z) are given by

$$\frac{\mathrm{d}}{\mathrm{d}t} m_\mathrm{g}(t) = -[1 - R]\psi(t); \tag{13}$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\left[m_\mathrm{g}(t) Z(t) \right] = -Z(t)[1 - R]\psi(t) + y[1 - R]\psi(t), \tag{14}$$

where y is the metal yield, and R is the mass fraction returned to the interstellar medium.

The AMR for this galaxy is directly obtained by solving the above equation for $Z(t)$. The metallicity distribution is derived by the following procedure. Assuming a sample comprising N_tot stars, the number of stars born at $(t, t + \Delta t)$ is

$$B(t)\Delta t = b(t) \frac{N_\mathrm{tot}}{T_\mathrm{G}} \Delta t. \tag{15}$$

The time interval Δt corresponds to a metallicity interval $\Delta Z(t)$. For each star born in $(t, t + \Delta t)$, we associate a randomly chosen metallicity in the interval $[Z(t), Z(t) + \Delta Z(t)]$. To simulate the intrinsic cosmic scatter, this metallicity is further shifted by a random Gaussian deviation $\sigma = 0.20$ dex.

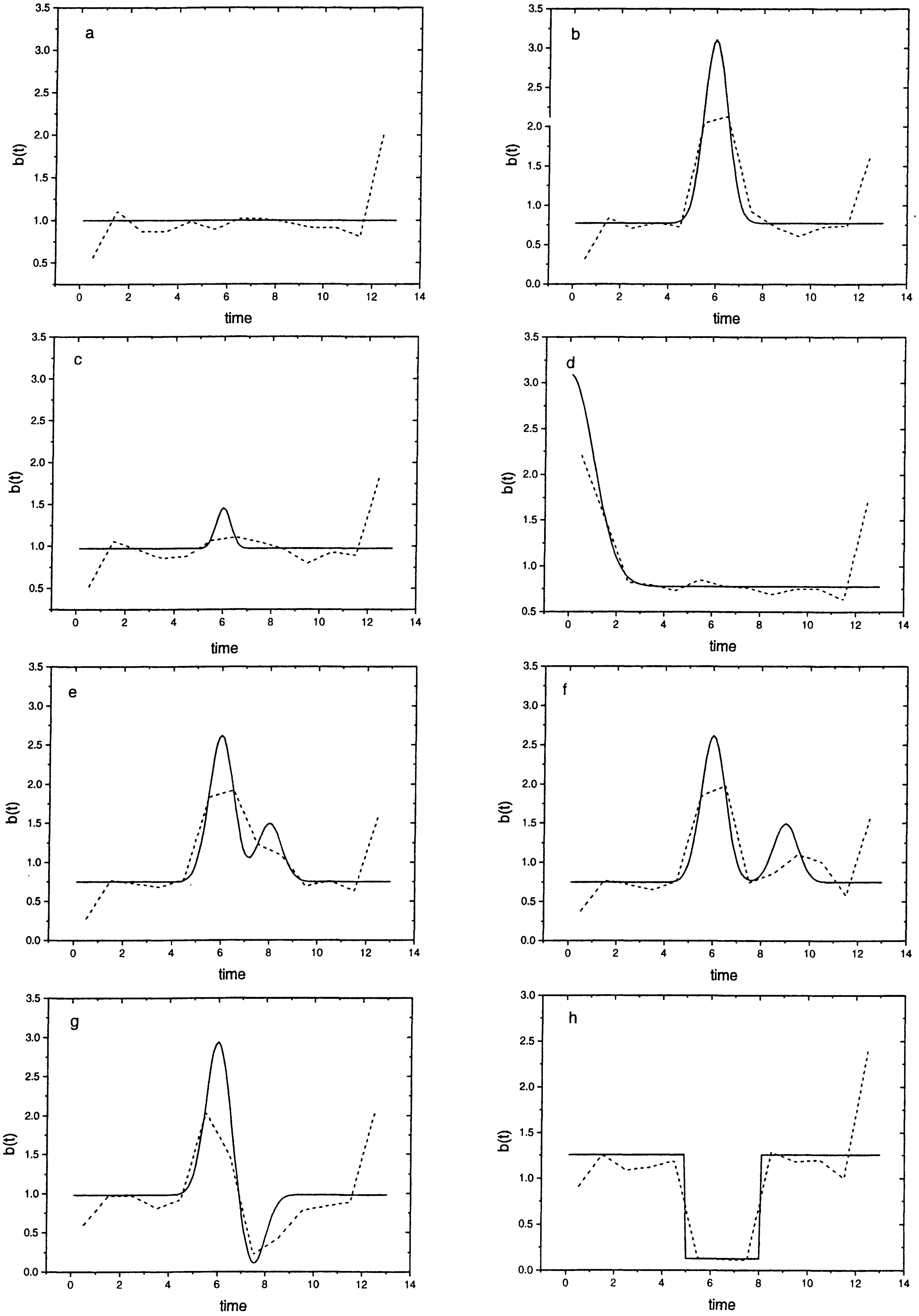

Figure 1. Simulations showing the original (solid lines) and recovered (dashed lines) SFRs.

We have used several input parametrizations for the SFR history corresponding to cases (a)–(h), as shown in Fig. 1. Each parametrization is used in the derivation of the AMR and the metallicity distribution. These last two functions are used in order to recover the original SFR history. The recovered SFR histories are also shown in Fig. 1, compared with the original histories.

Fig. 1 includes several examples, ranging from a constant SFR (Fig. 1a) to several burst or series of bursts (Figs 1b–g), and also including epochs of particularly low SFR (Figs 1g and h). We see from Fig. 1 that there is a good agreement between the original SFR histories (solid lines) and the recovered ones (dashed lines) in the whole time range, except at the extremes $t = 0$ and $t = 13$ Gyr. Fig. 1(a) corresponds to an originally constant SFR. The recovered SFR is nearly constant, showing a certain degree of noise. This could mask less intense star formation events, making them indistinguishable from constant star formation activity.

The bursts of Figs 1(b) and (c) occur at the same time, but the intensity of the burst in Fig. 1(c) is six times lower than in Fig. 1(b), and its duration is almost half the duration of the larger burst. While the recovered SFR in Fig. 1(b) does indicate the occurrence of the burst, in Fig. 1(c) it is barely noticeable. The method is likely to smear out the star formation events, in the sense that large-amplitude bursts are recovered as broad-looking less intense features. As a consequence, we expect that the method has a finite resolving power, that is, star formation events occurring in a very short time-scale cannot be recovered. This is illustrated by Figs 1(e) and (f). The original SFR in Fig. 1(e) is composed of two bursts with their maxima separated by 2 Gyr, the second being less intense than the first. The recovered SFR combines these bursts together in a large star formation event. The second, less intense burst is noticeable as a small bump at $t \sim 8$ Gyr (Fig. 1e, dashed line). Fig. 1(f) shows a similar case, where the bursts are separated by 3 Gyr. In this case, we can successfully isolate both bursts, suggesting that the resolution of our method is about 1.5 Gyr.

A feature shared by all recovered SFR histories deserves more attention. All histories show a burst at $t = 13$ Gyr. This burst is probably an artificial feature created by the method, implicit in the counting procedure that transforms the metallicity distribution into a distribution of chemical ages [equation (4b)]. The method assumes that all stars with $z > Z(T_G)$ were born at T_G, which greatly overestimates the real number of stars born at T_G.

A similar problem occurs in the recovery of $b(t)$ at $t = 0$. All SFR histories, except that in Fig. 1(d), show a scarcity of stars born at $t = 0$ relative to the original histories. In fact, the number of stars born at $t = 0$ does not include the stars with [Fe/H] < -1.2, which are removed from the sample, according to the chemical criterion adopted by Rocha-Pinto & Maciel (1996), in order to separate halo and disc objects. As a conclusion, we expect the present method to produce correct results with a resolution of about 1.5 Gyr during the whole time-span of galactic evolution, *except* at the extremes $t = 0$ and $t = 13$ Gyr.

4 APPLICATION TO THE LOCAL DISC

4.1 The age–metallicity relation

For the recovery of the SFR history in the local disc, we have used the metallicity distribution of G dwarfs recently derived by Rocha-Pinto & Maciel (1996). Unfortunately, there is no well-established AMR in the literature. There are many determinations of this relation, but they are generally not consistent with each other, so we have decided to take into account several AMRs. These include the empirical AMRs of Twarog (1980), Carlberg et al. (1985), Meusinger, Reimann & Stecklum (1991) and Edvardsson et al. (1993), and the parametrization of the AMR given by Rana (1991). All these relations are shown in Fig. 2, where we take the present time to be 13 Gyr. To allow their use in our method, all empirical AMRs were parametrized by an arbitrary increasing function of time.

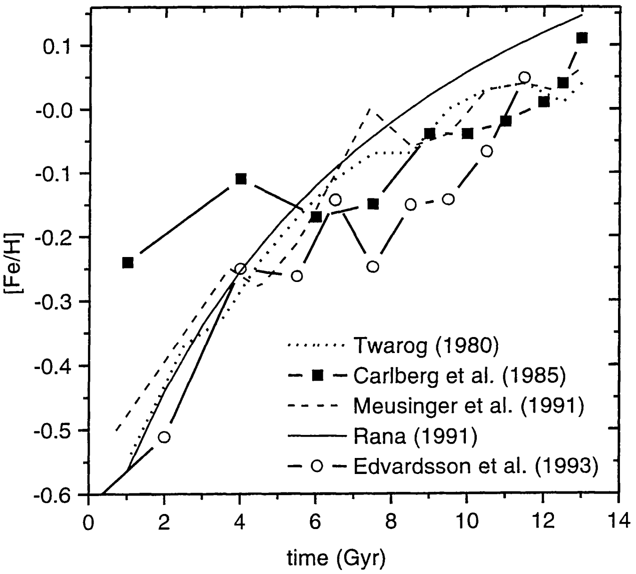

Figure 2. AMRs from the literature.

The AMR by Carlberg et al. (1985) is in remarkable disagreement with the others concerning the early period of galactic evolution, suggesting that the gas was initially very rich. There is a general suspicion that this relation is biased toward old metal-rich stars (Meusinger et al. 1991; however, see Strobel 1991 and Marsakov et al. 1990). We decided to consider the SFR history derived from this relation as less conclusive than the others.

The AMR by Edvardsson et al. (1993) is a byproduct of a comprehensive analysis of spectroscopic abundances of 189 F and G stars. The curve shown in Fig. 2 corresponds to average points in 1-Gyr bins, and generally agrees with the AMRs by Twarog (1980, 329 stars) and Meusinger et al. (1991, 536 stars), except at times roughly in the range 7–11 Gyr, when the AMR by Edvardsson et al. (1993) gives lower abundances by approximately 0.1 dex.

From the work of Edvardsson et al. (1993), the cosmic scatter in the insterstellar medium varies between 0.10 and 0.28 dex, with a most probable value of 0.20 dex. This value agrees well with a previous estimate by Twarog (1980). In our work, we will generally adopt a somewhat lower value, $\sigma = 0.15$ dex. For a given AMR, the method for the recovery of the SFR masks almost completely the chemical evolution if we assume an abundance scatter of the same order as the dispersion in the metallicity distribution, which is ~ 0.20 dex according to Rocha-Pinto & Maciel (1996).

4.2 The local SFR history

In Fig. 3, we show the SFR histories resulting from the use of the adopted AMRs, again with the present time corresponding to $t = T_G = 13$ Gyr. We also show the location of the peaks of bursts A, B and C (Majewski 1993), and the region corresponding to the Vaughan–Preston gap.

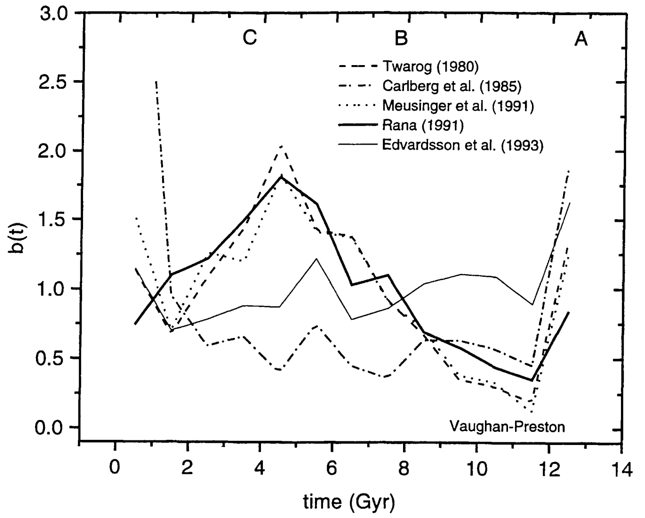

Figure 3. Derived SFR histories in the local disc for each adopted AMR. Also shown are the location of the peaks of bursts A, B and C (Majewski 1993), and the region corresponding to the Vaughan–Preston gap.

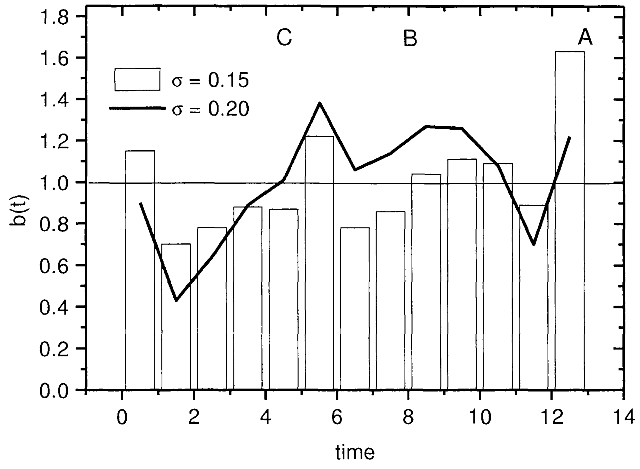

Figure 4. Comparison of the results using the AMR of Edvardsson et al. (1993) and different values for the cosmic abundance scatter.

Table 1. Mean SFR history for the local disc.

t (Gyr)	$b(t)$
0 to 1	1.14 ± 0.20
1 to 2	0.79 ± 0.15
2 to 3	1.09 ± 0.15
3 to 4	1.26 ± 0.22
4 to 5	1.64 ± 0.39
5 to 6	1.42 ± 0.10
6 to 7	1.14 ± 0.24
7 to 8	0.95 ± 0.08
8 to 9	0.78 ± 0.13
9 to 10	0.61 ± 0.25
10 to 11	0.54 ± 0.28
11 to 12	0.39 ± 0.25
(12 to 13	1.28 ± 0.22)

Several remarks can be made on the recovered histories. First, we will consider the histories derived from the AMR relations by Meusinger et al. (1991), Twarog (1980) and Rana (1991), which show good agreement with each other. In general, these histories show the occurrence of an extended enhanced star formation era 6 to 10 Gyr ago. We can also see a 'lull' between 1 and 3 Gyr ago, when the star formation activity decreased considerably. The results also indicate the occurrence of an intense burst at $t = T_G$. However, from the discussion in the previous section, we expect most of this burst to be produced by our method. It should also be noted that the history from Rana's AMR cannot be taken independently of that derived from Twarog's AMR, as the parametrization presented by Rana (1991) is based on the data of Twarog (1980).

The large star formation event present in these histories at 4 to 5 Gyr (8 to 9 Gyr ago) clearly corresponds to burst C (Majewski 1993). There is also an indication of another star formation enhancement at 7 to 8 Gyr (5 to 6 Gyr ago), corresponding to burst B (Majewski 1993). This feature is very similar to the result of our simulations shown in Fig. 1(e), where the occurrence of a less intense burst close to the main burst is recovered as a small bump.

The history derived from the AMR by Carlberg et al. (1985) shows an essentially flat SFR, apart from strong events at $t = 0$ and $t = 13$ Gyr. We should recall that the AMR of Carlberg et al. (1985) predicts a high initial metallicity for the disc. By analogy with the problem at T_G, the method also assumes that all stars with [Fe/H] $\leq$[Fe/H]$_{t=0}$ were born at $t = 0$. As long as [Fe/H]$_{t=0}$ is very high in this AMR, it can be understood why this SFR history has so many stars at $t = 0$. In view of the fact that the AMR of Carlberg et al. (1985) is probably biased, we decided to disregard the corresponding SFR history.

A more complex situation occurs with the AMR by Edvardsson et al. (1993). From the results of Fig. 3, the history derived from this AMR seems to indicate a nearly constant SFR over the disc lifetime, except that some remnants of the star formation events shown in the other histories are still visible at about 5 and 10 Gyr. A more detailed analysis of this SFR history is shown in Fig. 4, where we compare the results using two different values for the cosmic scatter, namely $\sigma = 0.15$ and 0.20. In this figure, it can be seen more clearly that some star formation enhancements are present, which approximately correspond to bursts B and C (Majewski 1993). Therefore the results derived from the AMR by Edvardsson et al. (1993) do not contradict the results derived from the remaining AMRs, namely those by Twarog (1980), Meusinger et al. (1991), and Rana (1991), although the derived SFR enhancements are considerably smaller.

We obtained an average SFR history using the derived histories, excluding that derived from the data of Carlberg et al., as shown in Table 1 and Fig. 5. The formal errors are shown, and the last temporal bin is given within parentheses, owing to the limitations of our method.

Fig. 5 also shows a comparison of our average SFR history and some previous determinations in the literature: Twarog (1980) and Barry (1988), as presented by Noh & Scalo (1990); Meusinger (1991a), after transforming to relative SFR; and Soderblom et al. (1991), after corrections by Rana & Basu (1992). Note that the main events found in our SFR history are also present in the other determinations. In particular, we note a large star formation era from 3 to 9 Gyr, and a considerable decrease in the star formation activity between 10 and 12 Gyr.

The second burst at 8 Gyr, suggested by Fig. 4, which corresponds to Majewski's burst B, is not reproduced in the SFR mean history, as it is not present in the histories derived from Meusinger et

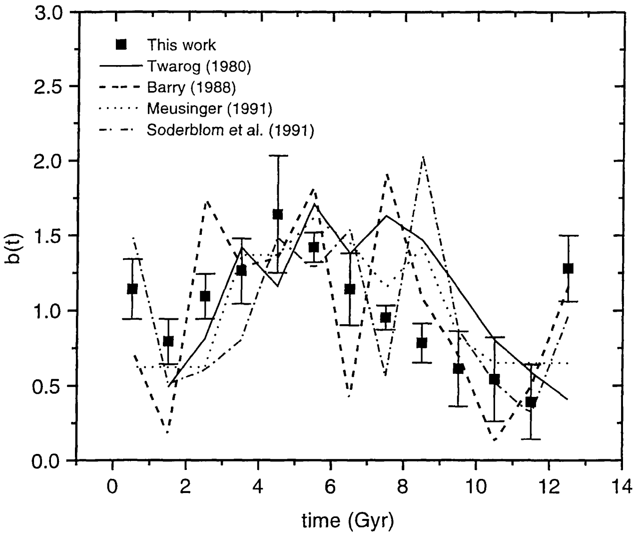

Figure 5. Comparison of our mean SFR history and previous determinations in the literature.

al. (1991) and Twarog (1980). However, we do not discard the possibility of its occurrence, as long as all other histories in Fig. 5 seem to support it. It is possible that this burst is not so intense as to be resolved by our method.

4.3 Concluding remarks

Our results are in very good agreement with some previous determinations of the star formation history. However, it must be stressed that the mean history we have obtained, as well as the other histories presented in Fig. 5, reflects the history of the star formation amongst late-type dwarfs. We have not made any assumptions regarding possible variations of the initial mass function (IMF) during the star formation bursts. If the IMF favoured massive stars during the bursts (Mezger 1987), we would expect the global SFR history to be very different from that we have recovered. As long as there is little evidence concerning variations in the IMF in these environments (Scalo 1986, 1987; Larson 1992), we believe that the history we have recovered is representative of the global SFR activity.

There is much independent evidence for the occurrence of star formation bursts in the solar neighbourhood. As long as the stars presently observed in our vicinity are likely to have been born at different galactocentric distances, the bursts that we find among solar neighbourhood stars could have occurred over a large part of the disc (Meusinger 1991b).

Majewski (1993) gives a scenario for the evolution of our Galaxy including these bursts. He suggests that the burst occurs during a certain time after which the global gas heating, due to supernova explosions, inhibits further star formation. During an interval of a few Gyr, the hot gas is efficiently mixed, so that the next stellar generation (characterized by the next burst) has a greater mean metallicity and a smaller abundance scatter. This scenario can satisfactorily explain the chemical properties of the stars that define bursts A, B and C (Majewski 1993). Majewski also presents some similarities between his stellar population scheme as discrete burst populations and the classification system proposed by Roman (1950, 1952). In this classification, the disc late-type dwarfs are subdivided into a spectral sequence composed of the weak CN, weak-line and strong-line groups. The existence of these discrete stellar groups is more easily explained by the assumption that the building of the disc was not a continuous process. In fact, Majewski points out that the chemical and kinematical properties of the stars in the weak CN, weak-line and strong-line groups (Yoss 1992) are in remarkable agreement with the properties of the stars that define bursts C, B and A, respectively.

A previous explanation for the occurrence of bursts in the disc was given by Scalo (1987). He remarked that the similarities between the ages of the bursts in the disc and those in the Magellanic Clouds may suggest that the bursts could be the result of past interactions between the Clouds and our Galaxy. In fact, it is well known that close encounters between galaxies can trigger star formation bursts (Combes 1987). This hypothesis also seems very attractive because orbital calculations show that the Clouds are presently near perigalacticon (Lin, Jones & Klemola 1995), which could have triggered burst A.

A usual criticism with respect to the occurrence of star formation bursts in the local disc comes from the traditional view that our Galaxy is a typical spiral galaxy, where the SFR has been constant or slightly decreasing over its lifetime. In fact, the Galaxy is probably not a typical object, and should not be considered as such. The existence of nearby satellite galaxies (the Magellanic Clouds) and the warp in the disc at great galactocentric distances indicate that our Galaxy is rather an interacting galaxy, subject to bursts and other phenomena that occur in such galaxies.

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REFERENCES

Bahcall J. N., Piran T., 1983, ApJ, 267, L77
Barry D. C., 1988, ApJ, 334, 446
Basu S., Rana N. C., 1992, Ap&SS, 196, 1
Carlberg R. G., Dawson P. C., Hsu T., Vandenberg D. A., 1985, ApJ, 294, 674
Combes F., 1987, in Thuan T. X., Montmerle T., Tran Thanh Van, eds, Starbursts and Galaxy Evolution. Editions Frontières, Gif sur Yvette, p. 313
Díaz-Pinto A., García-Berro E., Hernanz M., Isern J., Mochkovitch R., 1994, A&A, 282, 86
Edvardsson B., Anderson J., Gustafsson B., Lambert D. L., Nissen P. E., Tomkin J., 1993, A&A, 275, 101
Gómez A. E., Delhaye J., Grenier S., Jaschek C., Arenou F., Jaschek M., 1990, A&A, 236, 95
Henry T. J., Soderblom D. R., Donahue R. A., Baliunas S. L., 1996, AJ, 111, 439
Larson R. B., 1992, in Tenorio-Tagle G., Prieto M., Sánchez F., eds, Star Formation in Stellar Systems. Cambridge Univ. Press, Cambridge, p. 125
Lin D. N. C., Jones B. F., Klemola A. R., 1995, ApJ, 439, 652
Majewski S. R., 1993, ARA&A, 31, 575
Marsakov V. A., Shevelev Yu. G., Suchkov A. A., 1990, Ap&SS, 172, 51
Meusinger H., 1991a, Ap&SS, 182, 19
Meusinger H., 1991b, Astron. Nachr., 312, 231
Meusinger H., Reimann H.-G., Stecklum B., 1991, A&A, 245, 57
Mezger, 1987, in Thuan T.X., Montmerle T., Tran Thanh Van, eds, Starbursts and Galaxy Evolution. Editions Frontières, Gif sur Yvette, p. 3
Miller G. E., Scalo J. M., 1979, ApJS, 41, 513

Noh H.-R., Scalo J., 1990, ApJ, 352, 605
Pagel B. E. J., Patchett B. E., 1975, MNRAS, 172, 13
Rana N. C., 1991, ARA&A, 29, 129
Rana N. C., Basu S., 1992, A&A, 265, 499
Rocha-Pinto H. J., Maciel W. J., 1996, MNRAS, 279, 447
Roman N. G., 1950, ApJ, 112, 554
Roman N. G., 1952, ApJ, 116, 122
Scalo J. M., 1986, Fundam. Cosmic Phys., 11, 1
Scalo J. M., 1987, in Thuan T.X., Montmerle T., Tran Thanh Van, eds, Starbursts and Galaxy Evolution. Editions Frontières, Gif sur Yvette, p. 445
Soderblom D. R., Duncan D. K., Johnson D. R. H., 1991, ApJ, 375, 722
Sommer-Larsen J., 1991, MNRAS, 249, 368
Strobel A., 1991, A&A, 247, 35
Tinsley B. M., 1975, ApJ, 197, 159
Tinsley B. M., 1980, Fundam. Cosmic Phys., 5, 287
Twarog B. A., 1980, ApJ, 242, 242
Vaughan A. H., Preston G. W., 1980, PASP, 92, 385
Yoss K. M., 1992, AJ, 104, 327

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