

The chemical evolution of spiral galaxies: the Galaxy, M 31, M 33, M 83 and M 101

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Summary. We investigate a certain class of numerical chemical evolution models characterized by different combinations of the two parameters: star formation rate and infall of gas, with the aim of reproducing the observed oxygen abundances throughout the discs of the Galaxy and four other spirals: M 31, M 33, M 83 and M 101. Good agreement between models and observations is attained for all galaxies, except M 33, by adopting oxygen yields corresponding to stellar evolution models with mass loss. The best fit parameters to the observed oxygen gradients in their discs imply a star formation rate which is almost constant for all the galaxies except M 101, for which it seems to be rapidly decreasing with time. The infall of gas, assumed uniform and constant, should be in the range $0-5 \times 10^{-3} M_{\odot} \text{ kpc}^{-2} \text{ yr}^{-1}$.

1 Introduction

The information on the abundance gradients in the Milky Way and in external galaxies is continuously improving both for the reliability of the data and for the number of observed objects. As frequently stressed in the literature (for a review see Pagel & Edmunds 1981), these results are extremely important, among other reasons, for a better understanding of the chemical evolution of galaxies.

Some authors have already computed models of galactic chemical evolution based on the observed abundance gradients both for external galaxies and the Milky Way (e.g. Alloin *et al.* 1979; Talbot 1980). As for the Galaxy, the quality and the quantity of the data on the chemical composition of objects at different galactocentric distances are probably good enough to provide reliable constraints on the models. In fact, it has been possible (Tosi 1982; hereinafter Paper I) to reproduce, with relatively simple models, not only the abundance gradients observed in the disc, but also the age–metallicity relation found in the solar neighbourhood and some of the isotopic ratios observed in molecular clouds.

We have improved these chemical evolution models by including new results on stellar nucleosynthesis for low and intermediate mass stars (Renzini & Voli 1981) in addition to

Chiosi & Caimmi's (1979) yields for high mass stars and we have applied them to the case of some spiral galaxies in order to compare the principal chemical evolution parameters (initial mass function (IMF), star formation rate (SFR), infall of gas, etc. ...) in the Milky Way and their corresponding values in other galaxies.

The need for high quality data for the observed mass distributions and metal abundance restricts the number of external galaxies for which reliable results can be obtained. Quite often, in fact, data for the same galaxy as derived with different methods and/or by different authors are vastly inconsistent with each other. The four external spirals presented here are probably the best studied in the literature and allow for reliable application of the chemical evolution models with the possible exception of M33, for which there is still some discrepancy among different mass distributions (see Section 4).

Sections 2 and 3 of this work contain the description of the observational data and the theoretical models respectively. The results are presented in Section 4, and discussed in Section 5.

2 General description of the data

2.1 H II-REGION DATA

Spectrophotometric data relative to H II regions in the discs of the galaxies in our study have been selected from the most recent literature. Only the H II regions whose spectra include the lines $\lambda\lambda 3727-29$ of [O II] and $\lambda\lambda 4959-5007$ of [O III] have been used, giving high weight to those observations obtained using equipments of high photometric performance (IDS, IIDS, IPCS, etc. ...). The effective resolutions in all cases range from 5 to 18 Å.

For each H II region the reddening was determined by standard procedures (Whitford 1958; Brocklehurst 1971).

Although the set of data assembled in this way is somewhat heterogeneous, the oxygen abundances have been deduced from the reddening-free line intensity ratios in a homogeneous manner. In the cases in which the electron temperature could be deduced from suitable line ratios, abundances were calculated following standard methods (e.g. Saraph & Seaton 1970; Brocklehurst 1971; Seaton 1975; Pradhan 1976). In the other cases an empirical calibration of oxygen abundance against the ratio $([\text{O II}] + [\text{O III}])/\text{H}\beta$ (Pagel, Edmunds & Smith 1980) has been used. This calibration has recently been revised by McCall (1982) who proposes a new one based on more recent photo-ionization models. For normal and high excitation H II regions this revision leads, in most cases, to values of the electron temperature which are inconsistent with the ones deduced directly from the measurement. McCall attributes this discrepancy to a systematic overestimate of the temperatures, and subsequently an underestimate of the abundances, as derived from measurements of the [O II] $\lambda 4363$ line due to poor signal-to-noise and possible Hg I $\lambda 4358$ night sky line contamination. However, Shaver *et al.* (1983) find a tight correlation between the radio-determined temperatures and the optical-line ratios $([\text{O II}] + [\text{O III}])/\text{H}\beta$ for galactic H II regions, agreeing well with Pagel, Edmunds & Smith (1980) correlation, and therefore indicating a close agreement between the temperatures derived from radio and optical measurements. Thus, we have no reason to reject the abundances obtained in this latter way. On the other hand, the low excitation end of the original Pagel *et al.* (1980) calibration was mainly based on the abundance models constructed by Dufour *et al.* (1980) for M83, which in turn were determined by extrapolation of the model S5 in M101 (Shields & Searle, 1978). Since then, more sophisticated photo-ionization models have been made available. In particular those computed by McCall provide an excellent fit to this last H II region. In this work we have adopted the original Pagel *et al.* (1980) calibration slightly modified by the inclusion of the ne

Table 1. Adopted parameters for each galaxy.

Galaxy	Morphological type	Adopted distance (Mpc)	Effective radius (kpc)	$\Delta (\log O/H)/\Delta R$ (kpc ⁻¹)	c.c.	References
MWG	SAB bc II	—	6.19	-0.07 ± 0.02	-0.77	1, 2
M 31	SA b I-II	0.65	7.37	-0.03 ± 0.01	-0.76	3, 4
M 33	SA cd II-III	0.72	2.55	-0.08 ± 0.02	-0.79	5, 6
M 83	SAB c I-II	3.75	4.32	-0.09 ± 0.02	-0.93	7
M 101	SAB cd I	7.20	6.91	-0.04 ± 0.01	-0.89	6, 8, 9

References for the table:

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|---------------------------------|---------------------------------|
| 1. Peimbert (1979). | 6. McCall (1982). |
| 2. Shaver <i>et al.</i> (1983). | 7. Dufour <i>et al.</i> (1980). |
| 3. Dennefeld & Kunth (1981). | 8. Shields & Searle (1978). |
| 4. Blair <i>et al.</i> (1982). | 9. Rayo <i>et al.</i> (1982). |
| 5. Kwitter & Aller (1981). | |

results by McCall for $12 + \log (O/H) > 9.0$.^{*} Typical errors of the abundances calculated in this way are of the order of 0.2 dex (Pagel *et al.* 1980).

Finally, for every galaxy, the logarithmic oxygen abundance gradient has been calculated by performing a least square fitting to the H II region data. In Table 1 we list the resulting values of these gradients and the correlation coefficients of the fits. Also given in the table are the adopted distance in Mpc, the effective radius of the disc (the radius containing half of the light of the disc) in kpc and the references for the data.

In order to make the oxygen abundances as derived from H II regions directly comparable with those calculated from chemical evolution models we must allow for the effect of oxygen depletion from the interstellar gas. If dust grains consist mainly of oxides and silicates (Savage & Mathis 1979) a certain amount of oxygen must be locked up into dust. However, only a small fraction of the oxygen (20 per cent) can be bound in dust grains if no ice coatings are present and, since the time-scale for destruction of ice grains in an H II region is extremely short compared to its dynamical time scale (Barlow 1978), we can take this fraction to be an upper limit for the depletion of oxygen from the gas phase. This corresponds to a maximum rise by 0.08 dex in the logarithmic scale.

2.2 TOTAL GAS AND MASS SURFACE DENSITY DATA

To interpret the abundance gradients in spiral galaxies in terms of astration, as it is done in chemical evolution models, we need to know the present distribution of gas to mass ratio along their discs. These distributions have been deduced from existing data in the following way:

(i) The total mass density has been obtained by applying Monnet & Simien's (1977) method of fitting a two-component model (an exponential disc and a spheroid following an $r^{-1/4}$ law) to the rotation curve of the galaxy, assuming a constant mass to light ratio. The limitations of this approach are recognized; blue and infrared brightness profiles (Elmegreen & Elmegreen 1983) are similar for a number of early-type (Sb) galaxies, supporting this assumption, but in the Scd galaxies M 33 and M 101 the infrared brightness profiles appear to be steeper. On the other hand, since the effect of total mass density on the abundance is

^{*} Only the high metal abundance H II regions in M 83 are affected by this modification, and uncertainties in the calibration should be taken into account when examining the results for this galaxy.

approximately logarithmic, we do not regard this problem as one of the major sources of uncertainty compared with the gas surface density.

(ii) The total gas density has been obtained from the neutral and molecular hydrogen distributions according to the expression:

$$\Sigma g = 1.41 [\Sigma (H I) + \Sigma (H_2)] \tag{1}$$

where the symbol Σ is used to indicate surface densities in units of $M_\odot \text{ pc}^{-2}$. The factor 1.41 takes into account the helium contribution under the assumption that $N(\text{He})/N(\text{H}) = 0.1$ (e.g. Talbot 1980). Except in the case of the Galaxy and M 83 for which we have adopted the data provided by Talbot (1980), the molecular hydrogen distribution, H_2 , has been

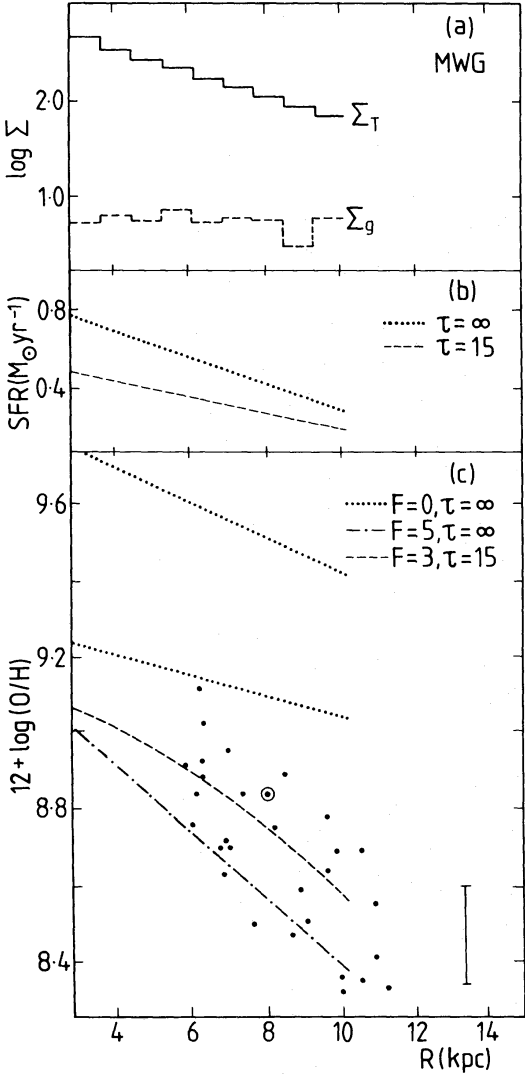


Figure 1. For the Milky Way: (a) Total mass and gas density distributions with galactocentric distance (b) Present star formation rates as resulting from the indicated models. (c) Radial variation of the oxygen abundance as derived from the indicated models computed with Chiosi & Caimmi's (1979) yields; the upper dotted line represents the simple model with Arnett's yields. The infall rate is expressed in $10^{-3} M_\odot \text{ kpc}^{-2} \text{ yr}^{-1}$ and the star formation e-folding time τ in Gyr. The dots represent the observed abundance referenced in the text. The solar oxygen abundance is indicated by the usual sun symbol. The average error bar is shown in the lower right corner. The total mass and gas density distributions are derived from Talbot (1980).

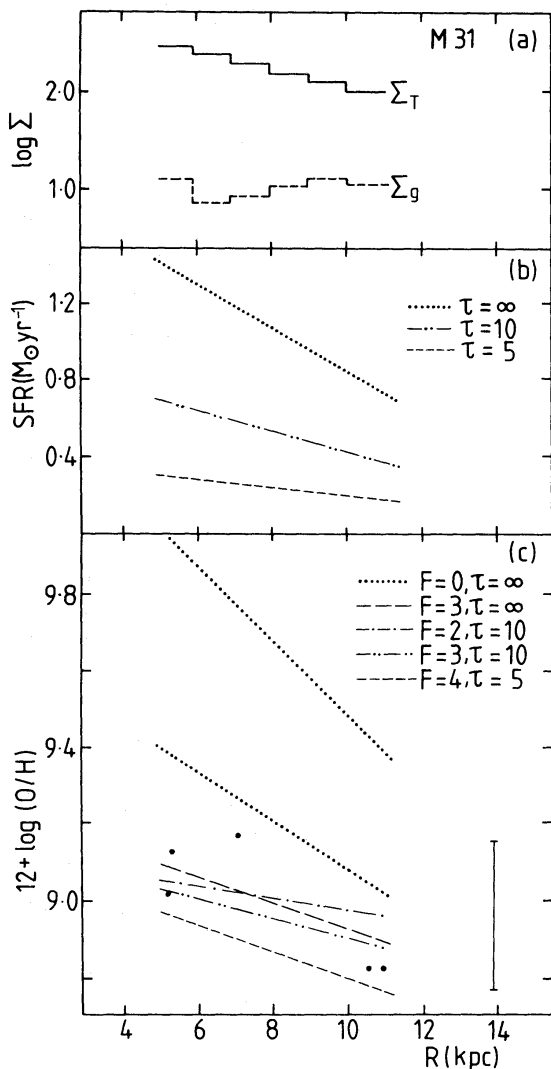


Figure 2. Same as Fig. 1, but for M31. The total mass and gas density distributions are derived from Combes *et al.* (1977a, b), Unwin (1980) and McCall (1982).

derived from the CO distribution assuming a value of $N(\text{CO})/N(\text{H}) = 4 \times 10^{-5}$ (Gordon & Burton, 1976; Encenaz *et al.* 1979) constant through the disc.

CO distributions along the galactic discs exist for all but one of the galaxies of this study: M33. However, recent observations of the radial distributions of CO in the two Scd galaxies IC 342 and NGC 6946 (Young & Scoville, 1982a) indicate that in these galaxies the CO distributions follow the exponential blue luminosity profiles. We have derived the CO distribution for M101 following this assumption and using the only positive CO detection reported by Blitz *et al.* (1981) for normalization. This distribution has later been checked against the recent observations made by Solomon *et al.* (1983). Both distributions agree within the errors. We have then used this method to derive the CO distribution for M33 using the blue luminosity profile given by Gordon (1971) and the nuclear CO detection reported by Young & Scoville (1982b) for normalization purposes. All these factors taken into account make the total gas distribution be the major source of uncertainty in our investigation.

Figs 1a–5a show, for each galaxy, the adopted present distributions of gas and total mass densities along the disc.

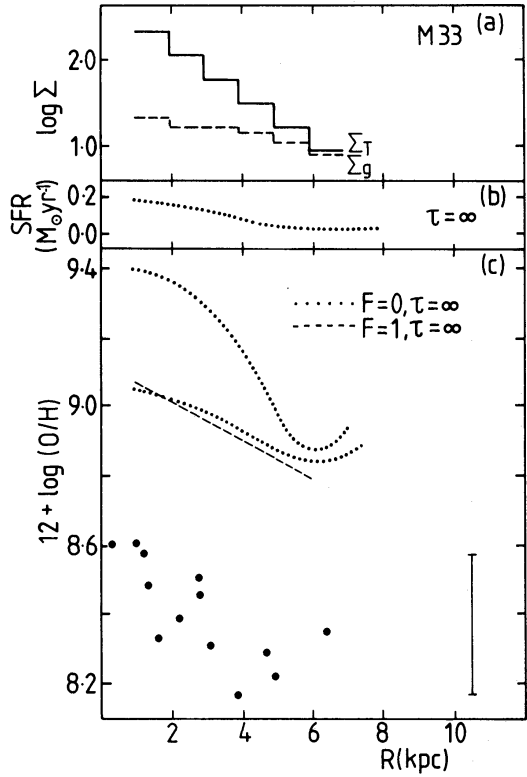


Figure 3. Same as Fig. 1, but for M33. The total mass and gas density distributions are derived from Newton (1980), McCall (1982) and Young & Scoville (1982b).

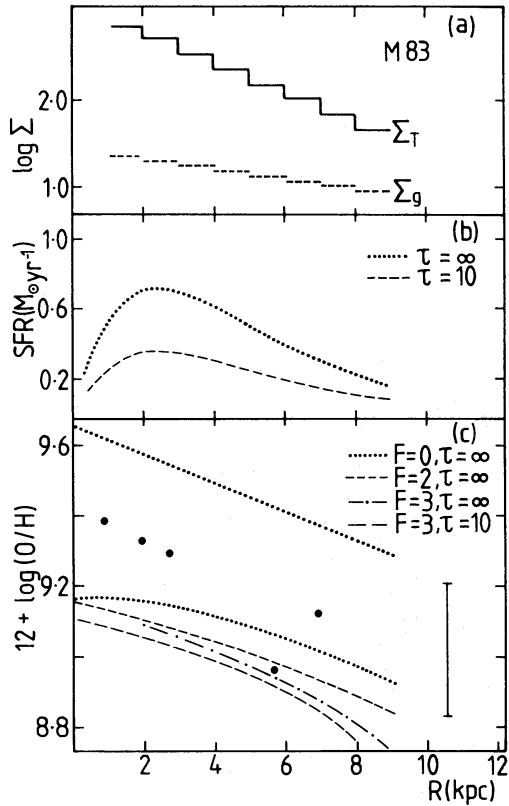


Figure 4. Same as Fig. 1, but for M83. The total mass and gas density distributions are derived from Talbot (1980).

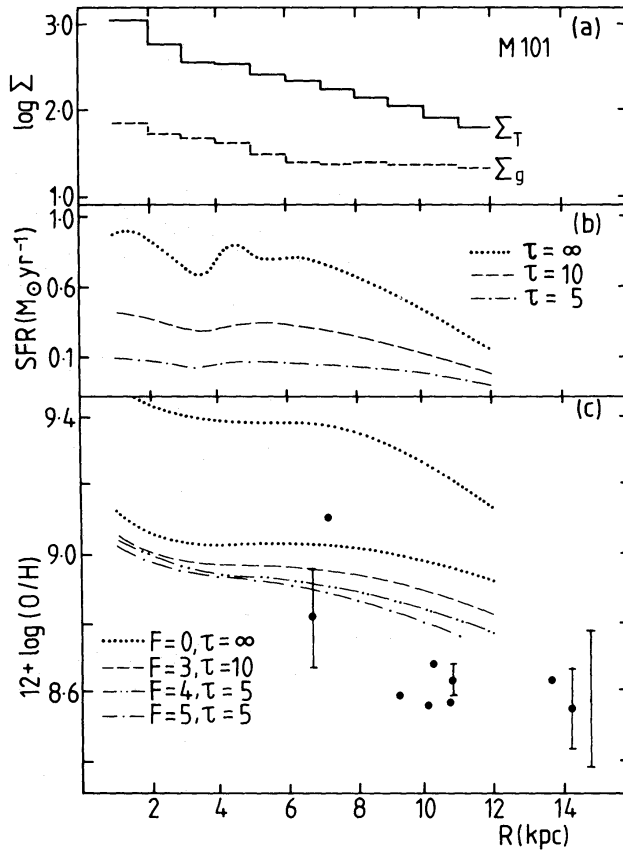


Figure 5. Same as Fig. 1, but for M101. Individual error bars are as quoted by Shields & Searle (1978) and Rayo *et al.* (1982). The total mass and gas density distributions are derived from Bosma *et al.* (1981) and Solomon *et al.* (1983).

3 Theoretical models

The chemical evolution of each galaxy has been analysed by means of numerical models as described in Paper I.

Since we have no reliable indication about the initial mass function (IMF) in external galaxies, we have assumed it to be the same as the one derived by Tinsley (1980) for the solar neighbourhood.

The disc of each spiral has been divided in concentric rings 1 kpc wide (except in the case of the Milky Way in which the rings are 0.8 kpc wide for consistency with Paper I), for which the present gas and total mass have been derived from the literature as described in Section 2.2).

We have assumed all discs to be as old as the Milky Way, i.e. 13×10^9 yr (Twarog, 1980); anyway, the age does not affect much the resulting O-abundances since a variation of T is compensated through equation (3) by an opposite variation of the SFR. For each disc we have computed models corresponding to all possible combinations of the two free parameters: infall (F) and star formation (ψ) rates. Star formation laws proportional to some power of the gas density (Schmidt laws) when combined with monotonic star formation rates, have been shown not to be compatible with observational constraints in the Galaxy (e.g. Miller & Scalo 1979; Tinsley 1980; Twarog 1980; and Paper I), and do not seem to be consistent with recent studies of star formation in external galaxies (Kennicutt 1983), therefore, for each ring, j , of the Galaxy and the other spirals, we have computed only models

with SFR laws of the type

$$\psi_j(t) = \psi_j(0) \exp(-t/\tau) M_\odot \text{ yr}^{-1} \quad (2)$$

where $\psi_j(0)$ denotes the initial star formation rate (SFR) and τ is a free parameter, reasonably ranging from 1 Gyr to ∞ (i.e. constant star formation). This simple mathematical expression still relates the SFR to the gas and total mass density of each ring through $\psi_j(0)$ which is analytically derived, in the instantaneous recycling approximation, by means of equations (1) and (2) of Paper I:

$$\psi_j(0) = [M_j(T) - G_j(T)] / [(1-R)\tau [1 - \exp(-T/\tau)]] M_\odot \text{ yr}^{-1} \quad (3)$$

where $R \approx 0.2$ (e.g. Tinsley 1980) is the returned fraction.

For the infall rate (assumed for simplicity to be constant and uniform) all values could be possible *a priori*, but values consistent with the observed total masses came out to be limited to the range

$$0 \leq F \leq 5 \times 10^{-3} M_\odot \text{ kpc}^{-2} \text{ yr}^{-1}$$

In fact, once a pair of values for F and τ is chosen, the initial total mass, $M_j(0)$, for each ring is uniquely derived from its present mass, $M_j(T)$, by

$$M_j(0) = M_j(T) - f \times T$$

where

$$f = \pi (r_{\max}^2 - r_{\min}^2) \times F$$

is the infall rate in each ring, $T = 13 \times 10^9 \text{ yr}$ is the present time, and r_{\max} and r_{\min} are the limiting galactocentric radii of the ring. Therefore, values of F so high as to imply negative initial mass for a ring have to be rejected.

The abundance by mass of any primary element i (^{16}O in our case) is given, at any time step, t , by

$$X_i = {}^{t-1}X_i \left[1 - \sum_m \alpha_m - f \times t/G_j(t) \right] + \sum_m ({}^{t-1}X_i + X_i^m) \alpha_m \quad (4)$$

where ${}^{t-1}X_i$ is the element abundance at the previous time step of the numerical procedure, $G_j(t)$ is the gas mass at time t , α_m is the gas fraction which has been through stars of mass m (see equation (5) in Paper I) and

$$X_i^m = \frac{\int_m X_i^{ej,m} m \phi(m) dm}{\int_m m \phi(m) dm}$$

with $X_i^{ej,m}$ being the abundance of newly formed X_i ejected by stars of mass m and $\phi(m)$ Tinsley's IMF. In practice the last term on the right-hand side of equation (4) gives the abundance of element i in the gas just added to the interstellar medium by stars dead in the time interval $[t-1, t]$, and the first term represents the abundance of the remaining medium including the infalling gas which is assumed to contain no metals.

For the yields from high mass stars, we have used alternatively the values derived by Arnett (1978) for constant mass evolution, and the values derived by Chiosi & Caimmi

(1979) from stellar evolution models taking mass loss into account; with the IMF law assumed by both sets of authors, we will show in next section that the latter give results which are more consistent with observation.

For intermediate mass stars, we have adopted the yields given by Renzini & Voli (1981), choosing those corresponding to mixing length $l/H_p = 2$ and a mass loss parameter $\eta = 0.33$. The initial oxygen abundance given by Renzini & Voli (1981) is scaled to that derived for the Sun, i.e. $X_{16}^{\odot} = 7.5 \times 10^{-3}$ for stars of total metal abundance $Z = 0.02$. Most of these yields are actually negative: in fact, intermediate mass stars burn rather than produce oxygen.

We have computed for each ring of our spirals the present abundance by mass of ^{16}O as derived from all choices of the SFR and the infall rate and then converted it to the corresponding $\log(\text{O}/\text{H})$ values by number, which are directly comparable with the abundances observed in H II regions.

4 Results

The model results can be interpreted with the help of Figs 1–5 which show, for each galaxy, (a) the adopted present distributions of total gas and mass along the disc, (b) the resulting present SFR for the principal models, and (c) the oxygen abundances as resulting from each of those models and as observed in H II regions. All models shown in Figs 1c–5c correspond to abundances computed adopting Chiosi & Caimmi's (1979) yields from high mass stars. Only the upper dotted line shows the oxygen abundances resulting from the 'simple' model (in Tinsley's (1980) definition, i.e. a model with constant star formation rate and no infall) when Arnett's (1978) yields are adopted. It is evident that stars evolving without mass loss are able to contribute more metals to the ISM at the end of their life: the comparison of the two dotted lines of the bottom panel of each figure gives the difference in ISM enrichment resulting in each galaxy from the assumption about mass loss. For all galaxies the O values computed without mass loss come out systematically over abundant with respect to measurements on H II regions. In order to shift them down to the observed oxygen abundance, we should adopt higher values for the infall rate, but this would be against the unremovable constraint of initial positive mass for all galaxies, mentioned in the previous section. Alternatively, all yields can of course be scaled by making the corresponding alterations in the initial mass function.

In the following we will analyse each galaxy separately.

The Galaxy

A perfect agreement between numerical results and observations is reached for models with constant or almost constant SFR ($\tau = 15$ Gyr) and high infall ($3 \leq F \leq 5 \times 10^{-3} M_{\odot} \text{ kpc}^{-2} \text{ yr}^{-1}$). These values for the infall are also expected on the basis of observational (e.g. Oort 1970) and theoretical (e.g. Larson 1972) considerations. Since the model with $F = 3 \times 10^{-3} M_{\odot} \text{ kpc}^{-2} \text{ yr}^{-1}$ and $\tau = 15$ Gyr not only best fits the H II region abundances, but also matches very well Twarog's (1980) age–metallicity relation and the observed global metallicity gradients (Mayor 1976; Panagia & Tosi 1981), we can argue that it fairly represents the actual evolution of our Galaxy. In this case the SFR would have changed by a factor of 2.36 over the lifetime of the disc.

M31

For M31 we have computed the models in the radius interval in which the CO distribution has been measured, i.e. from $R = 5$ to $R = 11$ kpc. A very good agreement with observations

is attained (Fig. 2c) for models with intermediate infall rates ($F = 3 \times 10^{-3} M_{\odot} \text{ kpc}^{-2} \text{ yr}^{-1}$). No definite indication can be reached for the star formation, whose e-folding time could range between $10 \leq \tau \leq \infty \text{ Gyr}$; in any case it has changed by less than a factor of 4 in these 13 Gyr.

M33

It is apparent from Fig. 3c that our models cannot reproduce the observed oxygen distribution. Even if we removed the constraint on the upper limit to the infall mentioned in Section 2, and adopted $F > 1 \times 10^{-3} M_{\odot} \text{ kpc}^{-2} \text{ yr}^{-1}$, we would not match the observations.

We should mention, however, that there are some discrepancies among the various determinations of the distributions of gas and total mass available in the literature and that even a small difference in the adopted gas and/or total mass can lead to strong variations in the SFR and, therefore, in the resulting abundances. For example, in the outer rings ($R > 5 \text{ kpc}$) of M 33, passing from the adopted Newton's (1980) mass values to Gordon's (1971) implies an increase of the gas/total mass ratio by a factor of 6, which reflects in a decrease of the SFR by almost two orders of magnitude. In addition to that, the adopted H_2 distribution is derived by Young & Scoville's (1982b) method, normalizing the light curve in order to reproduce the CO values obtained by them in the central part of the Galaxy, but not necessarily demanding that these values be consistent with the CO distribution in the rest of the disc (see e.g. Talbot (1980) for the H_2 in the Galaxy). Clearly, no improvement can be achieved for the models until the basic input data are better defined.

M83

In the case of M 83, the indication is toward a constant star formation and a low infall, but all models in Fig. 4c give oxygen abundances lower than the values adopted for the inner H II regions. However, as has been mentioned in Section 2, caution must be used when dealing with absolute values of the oxygen abundance due to possible uncertainties in the adopted calibration.

M101

The abundances derived from the models are slightly higher than, but still consistent with, the observed ones. Fig. 5c shows that, in order to fulfil the constraint of positive initial mass, the infall rate cannot be higher than $4 \times 10^{-3} M_{\odot} \text{ kpc}^{-2} \text{ yr}^{-1}$, but probably not much lower than this, and that the SFR must be rapidly decreasing with time (i.e. $\tau \approx 5 \text{ Gyr}$), showing a reduction factor of almost 14 from its initial value.

5 Discussion

The oxygen abundance gradients for five nearby spirals, including our own, have been analysed with the help of numerical chemical evolution models. It is found that, although the abundance distributions in the galactic discs are different from galaxy to galaxy and the uncertainties on gas and total mass data are rather high, their variation with galactocentric distance can be described relatively well with the same class of models with a suitable choice of only two free parameters: the infall flux and the star formation rate.

Since the star formation rate depends on the gas and total mass densities, its absolute values and radial distributions are different from one galaxy to another (the lowest values being in M 33 and the highest in M 31 as shown in Figs 1b–5b), but its time behaviour is

fairly similar for all the galaxies. In fact, four of them appear to evolve with an almost constant or slowly decreasing rate; only M101 should have a rather short e-folding time ($\tau \approx 5$ Gyr) of the SFR.

The required infall of gas from outside the disc does not seem to vary much from galaxy to galaxy, ranging from $F = 0$ to $F = 5 \times 10^{-3} M_{\odot} \text{ kpc}^{-2} \text{ yr}^{-1}$. From the observational point of view, the existence in our Galaxy of high velocity clouds which have been known for more than 15 years (Oort 1967) might indicate the presence of an infall of gas from outside the disc, and the rate deduced from these data is in agreement with that required by our models to match the H II region abundances.

As far as the stellar yields are concerned, the present study shows that stellar evolution models taking mass loss into account can lead to chemical evolution results in agreement with observations. In particular, the combination of Renzini & Voli's (1981) yields for intermediate mass stars, and Chiosi & Caimmi's (1979) for high mass stars give present oxygen abundances well reproducing those observed in H II regions of the best studied galaxies, i.e. MWG and M 31.

On the other hand, Maeder (1981) argues that mass loss and the related effects of stellar winds, mixing of matter in the envelope, variations of the helium core mass, etc., should not sensibly affect the yields. Therefore, models of mass losing stars should predict an amount of newly formed elements similar to that predicted by models of constant mass stars. In this case (see curves corresponding to Arnett's yields in Figs 1c–5c), in order to get a better agreement between the absolute values of computed and observed abundances, we would require a large reduction of the upper mass limit and/or the fraction of high mass stars in the IMF of all the galaxies in our sample. Vice versa, if Chiosi & Caimmi's yields are correct, it is not necessary to assume an IMF different from the one assumed by previous authors for the solar neighbourhood for most of our galaxies.

There have also been suggestions that, even in the Milky Way, the IMF might be variable. However, the situation is far from being clear. For example, both Burki (1977) and Garmany, Conti & Chiosi (1982) claim that the initial mass function depends on the galactocentric distance; while the former concludes that there are fewer high mass stars towards the centre, the latter reaches the opposite conclusion. In any evolution model, the adoption of such radially varying IMFs would flatten or steepen, respectively, the computed oxygen gradient, since this element is mainly produced by massive stars. However, our results show that for all these five galaxies the observed slopes of the gradient can be adequately reproduced adopting a uniform initial mass function.

This is also true for the gradient in M 33, although in this case no combination of the free parameters (star formation and infall rates) could reproduce the absolute values of the observed abundances. For this galaxy, a reduction in the contribution of massive stars to the IMF appears to be necessary. The fact that this galaxy has a very low surface brightness gives some support to this possibility. Moreover, we recall that the quoted high uncertainty on the gas and total mass distributions available for M 33 leads to even larger uncertainties on the model results. These two arguments together could account for the present disagreement between theory and observations.

The previous discussion shows the importance of obtaining reliable information about the initial mass function in external galaxies. This information is presently lacking and we should probably wait for the Space Telescope to collect complete samples of various mass stars and derive direct indications on the IMF in nearby galaxies.

In any case, the agreement attained in this work between a fairly simple and non *ad hoc* set of chemical evolution models and the gradients and absolute values of oxygen abundances observed both in our own and in external galaxies, should be stimulating for further studies

of more spiral galaxies. In particular, high quality data both on extragalactic H II regions and on mass distributions in several galaxies are needed to extend our analysis to a significant sample of spirals of each morphological type and try to better understand the Hubble sequence from the point of view of chemical evolution.

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