IV. RELATION WITH CHEMICAL EVOLUTION OF GALAXIES AND COSMOLOGY

RELATIONS BETWEEN THE GALACTIC EVOLUTION AND THE STELLAR EVOLUTION

Jean AUDOUZE
Institut d'Astrophysique du CNRS, Paris-France
and Laboratoire René Bernas, Orsay-France.

1. INTRODUCTION

The question which has been raised in many chapters of this book is about the existence of constraints on stellar evolution coming from related topics like cosmology or in the case of the present chapter the chemical evolution of the galaxies. As it will be seen in this contribution it seems wiser to consider that chemical evolution of galaxies is indeed related to the problem of stellar evolution discussed here but is not going to provide as many constraints on it as one would expect. The purpose of this presentation is therefore to outline the principal relations between these two fields and to discuss the impact of some recent works on them.
After a quick definition of the galactic evolution and a summary of the basic ingredients (namely the abundances of the chemical elements observed in different astrophysical sites), the parameters directly related to the stellar evolution which govern the galactic evolution are outlined. They are the rates of star formation, the initial mass functions and the various nucleosynthetic yields. The "classical" models of chemical evolution of galaxies are then briefly recalled. Finally, the emphasis is made in three recent contributions interesting both the galactic evolution and the stellar evolution. They are (i) some prediction of the rate of star formation for low mass stars made from the planetary nebula abundance distribution (ii) the chemical evolution of C, O and Fe and (iii) some very recent work dealing with the chemical evolution of the galactic interstellar medium performed by Gusten and Mezger, 1983.

2. GALACTIC EVOLUTION : DEFINITION AND INGREDIENTS

In models of galactic evolution one tries to understand the variations and the evolution with the location and the time t of the functions $N_A(r,t)$ where N_A designates the observed abundances of the element A. In all the subsequent discussion it is assumed that the Universe has been formed about 15×10^9 years ago through primordial hot and dense phases (the Big Bang model).

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From the simple definition of the models of galactic evolution one can realize already that the relation with stellar evolution is very important since all elements with atomic mass ≥ 12 come from stellar nucleosynthesis.

The ingredients of any model of galactic evolution are therefore the abundances of the different chemical species which can be observed in old objects (halo stars, globular clusters), in the population I stars of various ages, in the interstellar medium which characterizes the composition of the most recently formed material. It is well known that the solar system composition of age $4.55\ 10^9$ years is of invaluable value in building up such models.

Further ingredients directly related to these abundances like the photometry in different colors of many stars (see eg. Twarog 1980) the age metallicity relations, the stellar metallicity distributions, the determination of isotopic ratios in many locations or the discovery of abundance gradients along the disks of spiral galaxies play also an important role in the selection of galactic models.

3. THE THREE MOST IMPORTANT PARAMETERS OF THE GALACTIC EVOLUTION

The three major parameters governing the chemical evolution of galaxies are

(i) the initial mass function of stars (IMF) generally described by a relation similar to that designed by Salpeter

$$\Phi(m) = \varphi(m)\,dm \;\alpha\; m^{-(1+x)}\,dm$$

where m is the mass of stars in unit of solar mass and the exponent x taken as equal to 1.35 is deduced from stellar population analysis (see eg. Tinsley 1980 for a recent review of this topic).

(ii) the rate of stellar formation (SFR) given by a relation similar to that sketched by Schmidt :

$$\psi\,(t)\,\chi \sim \mu^n$$

where $\psi\,(t)$ is the rate of stellar formation as a function of time; μ is the gas density of the considered galactic region ($\mu = m_{gas}/m_{tot}$ and n is an exponent the value of which ranges from 1 to 2.

(iii) the nucleosynthetic yields y_i which represent the amounts of any given nuclear species i which are released by stars and evaluated per unit of mass locked into stars

$$y_i = \frac{\sum_{i\neq j} X_j \int_{m_L}^{m_U} Q_{ij}(m)\,\varphi(m)\,dm}{1-\sum_{j} X_j \int_{m_L}^{m_U} Q_{ij}(m)\,\varphi(m)\,dm}$$

In this expression, the X_j terms are the mass fractions of the elements j and the $Q_{ij}(m)$ are the mass fractions of the stars m which are transformed from j to i.

One should recall now the important distinction between primary and secondary elements. Primary elements are those which can be produced in principle in a pure hydrogen stars (examples: C, O, Fe...). For those elements the yields are simply proportional to their observed abundances.By contrast, the secondary elements can only be synthetized from primary elements (examples: ^{13}C, part of ^{14}N, the s process elements) their yield is proportional to the metallicity deduced from the abundances of the primary elements.
These yields are also related to the constraints coming from the nucleosynthesis. Some of them are for instance :
(i) the depletion of D during the galactic evolution by factors at least equal to 2,
(ii) the significant enrichment into ^{7}Li consequence of the recent determinations of the Li abundance concerning halo stars performed by Spite and Spite (1982),
(iii) the differences in the evolution of C, N, O and Fe which will be discussed later
(iv) an interesting difference between the behaviour of the abundance of the s process elements (like Ba) and that of the r process elements (like Eu) as noticed by Spite and Spite (1978): the [Ba/Fe] ratio is proportional to [Fe/H] which shows that the s process elements are of secondary origin or that they should be formed mainly in low mass stars. By contrast [Eu/Fe] is in first approximation independant of [Fe/H] which would mean that the r process elements are primary (which is an astonishing conclusion since the seed for their formation is Fe itself) or that they are only formed in very massive stars.

4. THE MODELS OF GALACTIC EVOLUTION.

The classical models dealing with the chemical evolution of galaxies have been reviewed in many articles (Pagel and Patchett 1975, Audouze and Tinsley 1976, Tinsley 1980). It might be sufficient here to remind the reader with the main features of the so called "simple" model and show how the model builders circumvent the drawbacks of this approach.

4.1. The features of the "simple" model and its drawbacks.

In the so called "simple" models which attempt to sketch the chemical evolution of one closed galactic zone, one adopts the following hypothesis
(i) the considered zone is well mixed and closed which means that there is no further addition (or ablation) of gas by infall, inflow or sweeping mechanisms,
(ii) at time t=0 there are no metals and no stars, the gas density is $\mu=1$ (only gas),
(iii) the rate of star formation follows the Schmidt low i.e. $dS/dt= \mu^{n}$ with $1 \leqslant n \leqslant 2$
(iv) the initial function is assumed to be constant with respect to time and follow the Salpeter law $\varphi(m)dm=\zeta(x-1)\ m^{-x}\ dm$
(v) the stars are assumed to evolve more rapidly than the galactic

zone itself. This hypothesis is called the instantaneous recycling approximation. Another way to express it is to say that the individual stellar lifetimes are assumed to be negligible which is not the case for low mass stars which last also very long.
In these conditions, the metallicity Z evolves with time according to the relation $Z=p \ln(\frac{1}{\mu})$ where p is the yield and μ is related to time t either in $e^{-t/\tau}$ for n=1 or in $1/(1+t/\tau_o)$ for n=2.
The simple model presents two major difficulties
(i) the metallicity increases too much with time while the observations show a plateau for the metallicity of disk stars,
(ii) it predicts too many stars of low metallicity

4.2. In order to alleviate these two difficulties, many proposals have been advanced,
(i) the assumption of infall and/or inflow of external material which leads to a plateau in the metallicity
(ii) a varying initial mass function either by assuming that the initial mass function is more devoided in high mass stars now than in the past. Another way to express the same assumption is to speculate about the existence of a first generation of massive stars which leads to a prompt initial enrichment of metals. (No star with a zero metallicity has ever been observed so far). With J.L.Puget and G. Malinie , we are currently investigating models in which the upper and lower limit of the initial mass function may vary with time. It is assumed that the upper limit of the IMF may decrease (by being inversely proportional to the metallicity) while the lower limit could have been as high as $2M_\odot$ when the metallicity was very low and decrease quickly after the release of some metals by the first generation stars.
All these approaches solve effectively the two difficulties outlined before which are suffered by the "simple" model.
At this point one should be easily convinced that many relations exist obviously between the galactic evolution and the stellar evolution. Stars are responsible for the metal enrichment of the interstellar gas; their mass govern not only their evolution but also the evolution of the galactic zone to which they belong.

5. A FEW SPECIFIC PROOFS OF THE CLOSE RELATION BETWEEN GALACTIC AND STELLAR EVOLUTION.

Many contributions would deserve to be mentioned to show the strong relation between the galactic and the stellar evolution. I have selected here three recent works dealing respectively with an attempt to deduce the stellar formation rate of low mass stars from planetary nebulae, with the relative production and chemical evolution of C, O and Fe and with a very recent model concerning the chemical evolution of the interstellar medium.

5.1. Star formation rates deduced from planetary nebulae

This is an attempt proposed by G. Malinie, myself and M. Dennefeld to deduce this parameter from the abundance distribution of a sample of several planetary nebulae. Planetary nebulae possess two interesting

features : they are numerous,they are bright and they have low mass progenitors. The procedure that we propose is the following:
(i) given a good sample of planetary nebulae construct the histogram N(Z) here Z is taken as the oxygen abundance,
(ii) use a Z(t) distribution like the one determined by Twarog (1980)
(iii) deduce N(t) and from that the fraction of planetary nebulae with progenitors of age larger than t

$$F(t) = \frac{\int_{T}^{t_G} \varphi(m_t)\ \psi\ (t)\ dm_t/dt \quad dt}{\int_{t}^{t_G} \varphi(m_t)\ \psi\ (t)\ dm_t/dt \quad dt}$$

where t_G is the age of the galaxy, ψ (t) is the stellar formation rate = $\varphi_{\odot} \exp(\psi t/\tau)$, $\varphi(m) \sim m^{(1+x)}$ and the lifetime of stars is $t=m_t^{\,b}$ with b=3

$$F(t) = \frac{\int_{T}^{t_G} t^{\,x/b\,-\,1}\, e^{t/\tau}\ dt}{\int_{t_{min}}^{t_G} t^{\,x/b\,-\,1}\, e^{t/\tau}\ dt}$$

From the PN samples studied so far $\tau = 4^{+2}_{-1}\ 10^{9}$ years, which means a fairly significant decrease of the stellar formation rate with time if this method is found to be applicable.

5.2. The relative production and chemical evolution of C, O and Fe.

Clegg, Lambert and Tomkin (1981) have observed a sample of about 20 F and G main sequence stars with a high resolution reticon and for which 0.9 < [Fe/H] +0.4. They found :

[C/H] = (0.84 ± 0.08) [Fe/H] - (0.02 ± 0.03)
[N/H] = (1.31 ± 0.25) [Fe/H] + 0.07 (±0.07)
[O/H] = (0.52 ± 0.07) [Fe/H] + (0.03 ± 0.03)
[S/H] = [Fe/H]

Clegg _et al_ (1981) interpret their results by arguing that O is less deficient than Fe in metal poor stars because it might be produced by heavier stars.
Two other analyses of this observational set of data have been proposed:
Twarog and Wheeler (1982) have proposed a model of chemical evolution (the simple model with infall) adopting the nucleosynthetic prescriptions of Arnett (1978) with constant IMF and yields. With a production rate of 2.4 Fe$_{\odot}$ pc^{-2} Gyr^{-1}, they overproduce O, C, Ne and Mg relative to Fe. In order to solve this overproduction, they propose a change in the IMF slope and a upper limit in the IMF fairly low at 25-40M$_{\odot}$.
Chiosi and Matteucci (1984) have very recently proposed an alternative and argue that the nucleosynthetic yields may vary during the galactic evolution.
Their nucleosynthetic prescriptions are the following: for stars with 1 < m < 9 they adopt those of Renzini and Voli (1981): they assume

that these stars are important sources of He, ^{12}C, and primary N. The stars with masses from 9 to 120 $M_\odot$ produce C, O and Fe while the heavier stars would produce only O <u>but not Fe</u>.
In their galactic model, they therefore make use of varying nucleosynthetic yields and possible significant stellar mass loss rates during the stellar evolution. With those assumptions they manage to explain the difference of behaviour of the O and Fe abundances.

5.3. A very recent model of the chemical evolution of the interstellar medium

Güsten and Mezger (1983) have made a very interesting proposal to solve the difficulties encountered by the simple model. They propose (i)a continuous infall of unprocessed material,
(ii) a bimodal star formation. They assume that in the galactic arms and the galactic interarms the star formation is different. They quantify this effect by assuming that the lower limit of the IMF in the arms is 2 $M_\odot$ while it is 0.1 Mo in the interarms. This assumption is fairly similar to that of Malinie, Puget and I quoted above.The net result of this last assumption is to increase the yield in the arms.
As a result their model provides a good account of the age metallicity relation like that of Twarog (1980); it also reproduces well the gradients of abundances observed along the galactic disk from the external up to the central regions. Finally since the yields increase for a given star formation rate, these rates can be lower and reproduce well the Lyman continuum photon production rate.

6. FINAL REMARKS.

From the above developments , the reader can easily be convinced that models of chemical evolution of galaxies are constrained by stellar evolution models. <u>The reverse is highly debatable</u> because there are too many free parameters for the present amount of relevant observations. In any case progress made in one of these fields benefits eventually to the other.

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DISCUSSION

G. Cayrel: Could the introduction of initial mass function in the models of evolutionary scenarios avoid the formation of too many stars of low metallicity?

Audouze: There are many scenarios which have been proposed so far to avoid the formation of too many stars of low metallicity: they all belong to the family of models assuming that the initial mass function varies with time: In all these scenarios one assumes that when the metallicity was lower more massive stars were formed. They all succeed in solving the so-called F-G dwarf problem.

Schatzman: Source of information for the observed abundance of Europium? It should be noticed that Europium abundance is very sensitive to radiation pressure and mixing (or non-mixing). Did you include these effects in your discussion?

Audouze: (i) The observed abundances of Europium discussed here have been determined by Spite M. and Spite F. (Astron. Astrophys. 67, 23, 1978). (ii) In this discussion the only effects which have been taken into account are the nucleosynthetic ones, i.e. the fact that Europium is an r-process element.

Renzini: Concerning the use of PNe as tracers of the past SFR, one should be aware that the PN lifetime is likely to be a rather sensitive function of the mass of the precursor. So this should produce a systematic error in the estimated SFR.

Audouze: I would agree with you that this is a possible problem in the type of analysis we try to propose although it is not proved at all that such an effect (the sensitivity of the PN lifetime with the mass of precursor) does really exist. Moreover, one could, as an exercice, solve this problem if it exists by making the most reasonable assumption that the PN lifetime is a decreasing function of the mass of the precursor.

Vanbeveren: Is the last model you proposed, where it is suggested that more massive stars are formed when the metallicity is low, not somewhere conflicting with the observations of R. Humphreys presented Wednesday? I have the impression that the lack of massive stars in the SMC could suggest that the lower the metallicity, the lower the probability that more massive stars are formed!

Audouze: The apparent difficulty which worries you can be in fact easily alleviated by noticing that the stars observed by Roberta Humphreys and other participants like Peter Conti are much more massive (~30-40 $M_\odot$) than those which are needed to solve the problem of the lack of low metallicity stars (a few $M_\odot$). For instance J. Silk argues that when the metallicity is very low the lower limit of the IMF might be 2 $M_\odot$ instead of .01 $M_\odot$ (or so) when the metallicity is normal.

Weidemann: If the new initial-final mass relation which I presented (Weidemann and Koester, Astron. Astrophys. 121, 77, 1983) is correct, the amount of mass locked up and the yield becomes very different in the important mass range 3 to 8 $M_\odot$, with supernova production only beyond 8 $M_\odot$, and much more unprocessed material returned to the ISM.

Maeder: The initial mass limit for black hole formation is also a critical one in this context as above this limit the stars contribute to the galactic enrichment only by their winds, while most of their remaining mass is removed from our visible universe. We do not know where this limit lies and this may affect considerably the models of galactic chemical evolution.