1996RMxAC...4...51D

RevMexAA (Serie de Conferencias), **4**, 51–54 (1996)

CHEMICAL EVOLUTION OF ELLIPTICAL GALAXIES: ABUNDANCE DETERMINATION FROM POPULATION SYNTHESIS

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RESUMEN

Se presenta una calibración basada en los índices de Lick (Fe52, Fe53, Mg_2, NaD) para sistemas estelares constituidos por una mezcla de poblaciones. Se obtuvieron empíricamente funciones que dan la variación de los índices con parámetros estelares y se computó la contribución de luz de las diferentes etapas de la evolución por medio de trayectos evolutivos teóricos. Se computaron modelos multi-población usando el modelo de población singular de Borges et al. (1995). La calibración resultante (aún preliminar) se aplicó a una muestra de galaxias elípticas, indicando una media [Fe/H] apenas sobre la solar. La media de la muestra para la abundancia del magnesio es [Mg/Fe]=0.47, confirmando la sospecha que las galaxias E tienen abundancias no-solares y que su consumo de gas ocurrió en una escala de tiempo menor que 2×10^9 años.

ABSTRACT

A calibration based on the Lick indices (Fe52, Fe53, Mg_2, NaD) is presented for stellar systems constituted by a population mix. Functions giving the variation of the indices with stellar parameters were obtained empirically, and the light contribution from the different evolutionary stages were computed using theoretical tracks. Multi-population models were computed using the single-population models by Borges et al. (1995). The resulting calibration (still preliminary) was applied to a sample of ellipticals, indicating a mean [Fe/H] just above solar. The sample mean for the magnesium abundance is [Mg/Fe]=0.47, confirming the suspicion that E's have non solar abundances, and that their gas consumption occurred in a timescale less than 2 Gyr.

Key words: **GALAXIES–ELLIPTICAL AND LENTICULAR, CD — GALAXIES–STELLAR CONTENT**

1. INTRODUCTION

The study of the chemical evolution of distant objects is a rather complex problem, since theoretical results must be compared with observed integrated properties derived from their spectra. The information concerning the chemical composition of stellar systems like ellipticals and bulges comes essentially from the strength of absorption features. These features represent the light contribution of stars belonging to different populations, introducing effects of spread in age and metallicity, which are strongly coupled.

The interpretation of spectra under these conditions require necessarily evolutionary models. Pioneering works on this line were those by Tinsley (1972), Bruzual (1983), Arimoto & Yoshii (1986), among others. Spectral synthesis calculations can be handled by distinct procedures. First, a complete theoretical approach can be adopted: the number of stars at different evolutionary stages as well as their spectra are derived from models. The difficulty is that a library of spectra as a function of spectral type, [Fe/H] and relative abundances is not yet available in the literature. Secondly, a solution of compromise may be adopted: the number of stars is still obtained from models but the spectral library is obtained from observations. In fact, if one addresses to the specific question of chemical abundances, then it is preferable to synthesize absorption indices as, for instance, those defined by the Lick group (Faber et al. 1985). However, an important point should be emphasized: if the equations relating the indices and stellar parameters are derived empirically, one should be aware that the chemical history of our Galaxy may influence the results. In fact, stars with near-solar metallicity, in general, belong to the disc and have near-solar abundance ratios whereas metal-poor stars, in general belonging to the halo, have a different abundance pattern. Therefore it is necessary that the calibration of the different indices

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take into account the relative abundances of the relevant elements. This question was considered by Barbuy (1994), who calibrated the Mg_2 index using synthetic spectra and, more recently by Borges et al. (1995). The latter authors have adopted an empirical procedure, using stars with known abundances. Moreover, they have also derived the calibration of several integrated indices for single stellar populations.

2. SINGLE STELLAR POPULATIONS

The calibration of metallicity indices for single stellar populations (SSP) is certainly the first step required to model systems with a population mix. The integrated index for a SSP is given by

$$W_{SP}(\tau,[Fe/H] = \sum_i f_i W_i(p_j) \ , \tag{1}$$

where τ is the population age and f_i is the light fraction at the relevant wavelength due to the contribution of the evolutionary stage i (f_i is calculated fixing the initial mass spectrum and using theoretical evolutionary tracks); the $p_j's$ stand for the different stellar parameters like effective temperature, gravity, metallicity and relative abundance. Explicit formulas for the $W_i's$ can be found in Idiart & Freitas Pacheco (1995) and Borges et al. (1995). In the latter, integrated indices derived from a grid of models as a function of age, metallicity and relative abundances can be found, and these results were used in the present computations.

The comparison of those SSP models with globular cluster data as well as with the computations by Barbuy (1994), has ensured that those formulas are rather satisfactory. Thus, the natural next step was the development of models with a population mix.

3. MULTI-POPULATION MODELS

The integrated index for a given stellar population mix can be written as

$$W_{MP} = \int \Psi([Fe/H]) W_{SP}([Fe/H],\tau) d[Fe/H] \ , \tag{2}$$

where W_{SP} was defined in the previous section and $\Psi([Fe/H])$ is the integrated luminosity function per metallicity interval of the system.

The equation above represents an important result, since it shows that the integrated index of a population mix can be derived from the integrated index of SSP. However, solution of such an equation requires: a) the knowledge of the luminosity function; b) the age vs. metallicity relation, which reflects the chemical history of the system.

In order to obtain those needs, a simple evolutionary model was envisaged, as a first approximation. Thus, the "one-zone" model was adopted, and the star formation rate was assumed to be proportional to the available gas mass. The efficiency parameter (related directly to the mean population age) was considered as a free parameter. In all the models, the onset of the star formation activity was assumed to be 16 Gyr ago.

The computation of the chemical history of the system requires also the knowledge of the frequency of the different supernova types., Type II poses no large problems, since they are originated from single massive stars. However the situation is not so clear concerning type Ia events. Presently, the best candidates of type Ia progenitors are accreting white dwarfs in close binary systems, and different scenarios have been proposed to describe their evolution from the beginning of the mass transfer phase up to the thermonuclear explosion (see, for instance, Yoshii et al. 1996). Face to the present difficulties for a realistic evaluation of the evolutionary timescale, an empirical approach was followed to handle this problem. Observations of halo stars show that objects with $[Fe/H] < -1.0$ have an abundance pattern compatible with a chemical enrichment due to type II supernovae only. This suggests that there is a minimal time τ_0 for a given binary system to evolve and become a supernova. On the other hand, type Ia events are the only class observed today in elliptical galaxies. Since the star formation activity is rather low or practically ceased in these objects, binaries with quite long evolutionary timescales must also exist. We assume that the distribution probability of a given binary system explodes as a supernova in a time τ after formation is given by

$$\varphi(\tau) = A(\frac{\tau_0}{\tau})^n \ , \tag{3}$$

where A is a normalization constant and the exponent n is a free parameter.

Under these conditions, if F(t) is the star formation rate in $M_\odot \cdot yr^{-1}$, the type Ia supernova frequency is

$$\nu_{Ia}(t) = \lambda_{Ia} \int_0^{(t-\tau_0)} F(t')\varphi(t-t')dt' \ . \tag{4}$$

The factor λ_{Ia} takes into account that only a fraction (by mass) of the formed stars results into binaries able to explode. Since in our scenario, the star formation rate is proportional to the gas mass, equation (4) can be written as

$$\nu_{Ia}(t) = \lambda_{Ia} \cdot k \cdot (n-1) \cdot M_0 \cdot G(t,\tau_0) \ , \tag{5}$$

where k is the star formation efficiency, M_0 is the total mass of the system and $G(t,\tau_0)$ represents the convolution of the star formation rate with the distribution probability for a binary system evolves into a type Ia supernova, after a timescale τ. The parameter λ_{Ia} was estimated by imposing that the calculated frequency be equal to the observed one. We have adopted the observed average value $0.36h^2$ SNu (van den Bergh 1991), where the "reduced" Hubble parameter is h = $H_0/(100$ km s^{-1} Mpc$^{-1})$. Table 1 shows the resulting values of λ_{Ia} for different values of the evolutionary timescale τ_0 and the star formation efficiency k, representative of models for elliptical galaxies. In these computations, it was assumed that T = 16 Gyr and n = 1.5.

TABLE 1

MASS FRACTION OF TYPE IA PROGENITORS

k (Gyr^{-1})	$\tau_0(Gyr)$	$G(T,\tau_0)$	λ_{Ia}
1.66	2.0	0.0196	6.9×10^{-4}
1.25	2.0	0.0271	6.6×10^{-4}
0.42	2.0	0.1185	4.6×10^{-4}
1.66	1.0	0.0136	9.9×10^{-4}
1.25	1.0	0.0189	9.5×10^{-4}
0.42	1.0	0.0911	5.9×10^{-4}

From Table 1 we notice that λ_{Ia} varies as much as 25% within the considered range of the parameters. We have adopted $\lambda_{Ia} = 7.2 \times 10^{-4} M_\odot^{-1}$ as a representative value in all present model computations.

4. RESULTS

We have calculated a grid of 60 evolutionary models, assuming a Salpeter's law for the initial mass function. The supernova yields are those of Arnett (1990) for type II and those of model W7 by Nomoto et al. (1984) for type Ia. For each model the indices $H\beta$, $< Fe >$, Mg_2, NaD and the color $(B-V)$ were synthesized. Then, adequate fitting formulae were obtained, from which mean values of metallicity, abundance ratios and population age can be estimated. For models with $\tau_0 = 1.0$ Gyr, the mean [Mg/Fe] ratio is given by

$$[Mg/Fe] = -0.0414 - 0.2000(Mg_2) - 0.06283 < Fe > +7.727r_1 \ , \tag{6}$$

and the mean [Na/Fe] ratio

$$[Na/Fe] = -0.6178 - 0.0825(NaD) + 0.0587 < Fe > +1.0292r_2 \ , \tag{7}$$

where r_1 and r_2 are respectively the ratios between the indices $Mg_2/< Fe >$ and NaD/$< Fe >$. Notice that the abundance ratios in those formulae are derived from observational quantities. Once the mean value [Mg/Fe] is known, the average age of the population can be estimated from the the relation

$$< \tau > = -0.361 + 53.55[Mg/Fe] - 43.39([Mg/Fe])^2 \ Gyr \ , \tag{8}$$

and the mean metallicity from the equation

$$[Fe/H] = -1.8743 + 1.2510 < Fe > -0.1250(< Fe >)^2 - 0.2210 \cdot ln < \tau > \tag{9}$$

(Notice also that in this equation **ln** stands for natural log).

These equations have been applied for a sample of galaxies with measured indices (Worthey et al. 1992). For a set of 37 E's the mean metallicity is [Fe/H]=0.10±0.16 and the mean abundance ratio of the α-elements, here represented by magnesium is [Mg/Fe]=0.47±0.07. These results demonstrate that E's in spite of having metallicities just above solar, have abundance ratios (at least for the α-elements) comparable to those found in galactic halo stars. Moreover, the bulk of the stellar population has a mean age of about 15 Gyr, indicating a quite fast gas consumption due to an efficient star formation process. In agreement with a previous study (Freitas Pacheco 1996), no ellipticals were found with metallicities higher than 2.0 – 2.5 times the solar value. Similar results were found for a set of 16 S0's, namely, mean metallicity [Fe/H] = 0.14 ± 0.18 and mean abundance ratio [Mg/Fe] = 0.41 ± 0.06. The comparison of the predicted $(B-V)$ colour with data indicates that our models are, on the average, redder by 0.06 mag. This point will still require additional studies.

The mean metallicity of E's is correlated with the central velocity dispersion, a well known result. However a stronger correlation is obtained if the magnesium abundance is included. In this case, one obtains a bivariate function of the form

$$\sigma = -84 + 302[Fe/H] + 515[Mg/Fe] \text{ km/s} . \tag{10}$$

This result suggests that the more massive galaxies are the more metal rich and they have also, in general, higher abundance ratios. This could be an indication that massive galaxies have a star formation efficiency higher than low luminosity objects.

We emphasize that these results are still preliminary. The behavior of other elements like Ca, Na must be studied, and it remains to be verified if a consistent scenario is still obtained.

REFERENCES

Arimoto, N., & Yoshii, Y. 1986, A&A 164, 260
Arnett, W.D. 1990, in Chemical and Dynamical Evolution of Galaxies, eds. F.Ferrini, F.Matteucci (ETS Editrice, Pisa), p. 410
Barbuy, B. 1994, ApJ 430, 218
Borges, A.C., Idiart, T.P., de Freitas Pacheco, J.A., & Thevenin, F. 1995, AJ 110, 2408
Bruzual, G.A. 1983, ApJ 273, 105
de Freitas Pacheco, J.A. 1996, MNRAS 218, 841
Faber, S.M., Friel, E.D., Burstein, D., & Gaskell, C.M. 1985, ApJS 57, 711
Idiart, T.P., & de Freitas Pacheco, J.A. 1985, AJ 109, 2218
Nomoto, K., Thielemann, F.K., & Yokoi, K. 1984, ApJ 286, 644
Tinsley, B.M. 1972, A&A 20,383
van den Bergh, S. 1991, Phys.Rep. 204, 385
Yoshii, Y., Tsujimoto, T., & Nomoto, K. 1996, ApJ in press
Worthey, G., Faber, S.M., & Gonzalez, J.J. 1992, ApJ 398, 69