HOW TO DETERMINE THE STAR FORMATION HISTORIES IN SPIRAL DISKS

Mercedes Mollá
Dpto. de Física Teórica C-XI, Universidad Autónoma de Madrid, 28049 Madrid, Spain
mercedes.molla@uam.es

Eduardo Hardy∗
NRAO, Casilla 36-D, Santiago, Chile
ehardy@nrao.edu

1. Introduction

With the help of the multiphase chemical evolution model (Mollá, Hardy & Beauchamps 1999) we have derived the evolutionary histories of the galaxies NGC 4303, NGC 4321 y NGC 4535. With these histories and an evolutionary synthesis model, we were able to reproduce their observed radial distributions of the spectral indices Mg2 and Fe5270.

Chemical evolution models however may fit well the present day observational characteristics of galaxies without discriminating among very different star formation histories. Furthermore, the spectral indices Mg2 and Fe5270 exhibit the age-metallicity degeneracy problem, implying that discriminating ages from metallicity with only these indices in single stellar populations might be impossible. Our objective here is to make sure that the implied evolutionary histories represent well these galaxies.

2. The multiphase model

The multiphase scenario begins with a gaseous protogalaxy whose mass is calculated from a rotation curve. The gas collapses onto the equatorial plane, thus forming the disk, at a rate which depends on the total mass: \[
\tau_{0,gal}^{\tau} = \left[ \frac{M_{MWG}}{M_{gal}} \right]^{1/2}
\]

The gas collapses more rapidly in the central regions than in the outer disk, so we assume: \[
\tau_{coll}(R) = \tau_0 \exp \left( (R - R_0) / \lambda_D \right).
\]

Thus, we must select two parameters, \(\tau_0,gal\) and \(\lambda_D\), for a particular galaxy model.

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Stars form in the halo from the primordial gas following a Schmidt law. In the disk, molecular clouds form from the diffuse gas while stars form in a second step as a result of cloud-cloud collisions. Stars also form via the interaction of massive stars with molecular clouds. The former is a local process governed by an efficiency constant valid for all galaxies. The same is valid for the halo star formation efficiency. Thus, for a given galaxy only the two efficiencies, namely $\epsilon_\mu$ and $\epsilon_H$, must be chosen in order to compute a model. They are larger for earlier morphological types than for the later ones, being well represented by a probability function depending on the Hubble Type $T$: $\epsilon_\mu = e^{-T^2/15}$ and $\epsilon_H = e^{-T^2/5}$ (see Mollá, Díaz & Ferrini 2002 for details).

Summarizing, to run a model for a galaxy, i.e. NGC 4303, we need 3 input parameters: 1) The collapse time scale $\tau_0$, determined by the total mass obtained from V(R); 2) The Hubble type $T$, with which we determine the set of efficiencies ($\epsilon_\mu, \epsilon_H$); 3) The scale length $\lambda_D$.

3. The uniqueness problem of models for NGC 4303

The problem is that uncertainties exist in the selection of the above parameters. For the galaxy NGC 4303, the optical and radio rotation curves look different: the maximum rotation velocity is a factor 1.4 larger in the second case. This in turn implies that the collapse time scale may be different than the one selected ($\sim 6$ Gyr) in the first case. It follows that the efficiencies will also have to change in order to fit the present day observational data. Thus, alternative models would seem possible.

We have varied these input parameters within a reasonable range centered around those values selected in Mollá et al. (1999) for NGC 4303. Models with all possible combinations of $\tau_0 = 1, 4, 8, 12$ and 16 Gyr, $\lambda_D = 1, 4, 8, 12, 16$ kpc, and $T$ from 1 to 10 with a variation step of 0.5, that is 20 possible values for the set ($\epsilon_\mu, \epsilon_H$), have been ran, thus doing a total of 500 models. (See details in Mollá & Hardy 2002).

4. The $\chi^2$ method

In order to select the best models out of the above 500, we compare the radial distributions for the oxygen, diffuse and molecular gas, and star formation rate resulting from our models with the observations.

This comparison is performed using the statistical indicator $\chi^2$, which measures the goodness of fit via the differences between the model results and the data, taking into account the measured dispersion of data. We show in Table 1 the characteristics and parameters of models falling within the 97.5 % confidence region (i.e., a 90% of the combined values).
### Table 1. Parameters of the Selected Models (P > 90%)

| Model Number | $\tau$ (Gyr) | $\lambda_D$ (kpc) | $T$ | $\epsilon_\mu$ | $\epsilon_H$ | $P_{\text{OH}}$ | $P_{\text{SFR}}$ | $P_{\text{H}_1}$ | $P_{\text{H}_2}$ | $P_{\text{Mg}_2}$ | $P_{\text{Fe}_52}$ |
|--------------|---------------|-------------------|-----|----------------|-------------|----------------|----------------|----------------|----------------|----------------|----------------|
| * 129        | 4.0           | 4.5               | .259 | .017           | 1.00        | 1.00           | 1.00           | 1.00           | 1.00           | 1.00           | 1.00           |
| * 228        | 8.0           | 4.0               | .344 | .041           | 1.00        | 1.00           | 1.00           | 0.98           | 1.00           | 1.00           | 1.00           |
| * 229        | 8.0           | 4.5               | .259 | .017           | 1.00        | 1.00           | 1.00           | 1.00           | 1.00           | 1.00           | 1.00           |
| 248          | 8.0           | 8.0               | 4.0  | .344           | 0.99        | 0.99           | 1.00           | 0.99           | 0.97           | 1.00           | 1.00           |
| * 249        | 8.0           | 8.0               | 4.5  | .259           | 0.99        | 1.00           | 1.00           | 1.00           | 0.98           | 1.00           | 1.00           |
| * 329        | 12.0          | 4.0               | 4.5  | .259           | 1.00        | 1.00           | 1.00           | 1.00           | 1.00           | 1.00           | 1.00           |
| 348          | 12.0          | 8.0               | 4.0  | .344           | 0.99        | 1.00           | 1.00           | 0.99           | 0.95           | 1.00           | 1.00           |
| * 349        | 12.0          | 8.0               | 4.5  | .259           | 0.99        | 1.00           | 1.00           | 1.00           | 0.98           | 1.00           | 1.00           |
| 368          | 12.0          | 12.0              | 4.0  | .344           | 0.99        | 1.00           | 1.00           | 0.99           | 0.91           | 1.00           | 1.00           |
| 369          | 12.0          | 12.0              | 4.5  | .259           | 0.99        | 1.00           | 1.00           | 0.99           | 0.88           | 1.00           | 1.00           |
| 388          | 12.0          | 16.0              | 4.0  | .344           | 0.99        | 1.00           | 1.00           | 0.99           | 0.88           | 1.00           | 1.00           |
| 389          | 12.0          | 16.0              | 4.5  | .259           | 0.99        | 1.00           | 1.00           | 0.99           | 0.90           | 1.00           | 1.00           |
| 448          | 16.0          | 8.0               | 4.0  | .344           | 0.99        | 1.00           | 1.00           | 0.99           | 0.94           | 1.00           | 1.00           |
| 449          | 16.0          | 8.0               | 4.5  | .259           | 0.99        | 1.00           | 1.00           | 0.99           | 0.83           | 0.90           | 0.90           |
| 450          | 16.0          | 8.0               | 5.0  | .189           | 0.99        | 1.00           | 1.00           | 0.99           | 0.83           | 0.90           | 0.90           |
| 468          | 16.0          | 12.0              | 4.0  | .344           | 0.99        | 1.00           | 1.00           | 0.99           | 0.90           | 1.00           | 1.00           |
| 469          | 16.0          | 12.0              | 4.5  | .259           | 0.99        | 1.00           | 1.00           | 0.99           | 0.93           | 0.99           | 0.99           |
| 488          | 16.0          | 16.0              | 4.0  | .344           | 0.99        | 1.00           | 1.00           | 0.99           | 0.87           | 1.00           | 1.00           |
| 489          | 16.0          | 16.0              | 4.5  | .259           | 0.99        | 1.00           | 1.00           | 0.99           | 0.92           | 0.99           | 0.99           |

We display in column (1) the number identifier for the model. The characteristics collapse time scale, $\tau_0$, and the scale length, $\lambda_D$, are in columns (2) and (3). Column (4) contains the value of $T$. The $\epsilon_\mu$ and $\epsilon_H$ efficiencies are in columns (5) and (6). The probabilities of these distributions to be in a region around the minimum value of $\chi^2$, for each one of our observational constraints, are listed in columns (7) to (10). By selecting the best models as those falling within the 90% confidence region we reduce the number of possible models to 19. All other models have probabilities smaller than this, at least in one of the 4 observational constraints.

### 5. The evolutionary synthesis models

In order to derive integrated stellar abundances, we calculate the integrated mass of all stars created in a given time interval, and the mean abundance reached at that epoch by the gas out of which they form. We consider the stellar populations residing at every galactocentric region as the superposition of a set of single stellar populations or generations each one defined by its age and its metallicity. Spectral index features...
are calculated with the same method described in Mollá & García-Vargas (2000) by using the Padova group isochrones. The fitting functions from Worthey (1994) and from Idiart et al (1997), for assigning the index Fe52 and Mg2, respectively, to each star are used. We obtain this way the radial distributions of these spectral indices for the 19 models of Table 1.

As before, we compute the $\chi^2$, by comparing these two radial distributions with the observations (Beauchamp & Hardy 1997; Mollá et al. 1999). The resulting probabilities are given in Columns (11) and (12) of Table 1. Only 6 of the 19 models, marked with an * in this same table, fit these new constraints with probabilities larger than 97.5%.

6. Conclusions

We have computed 500 models for the galaxy NGC 4303 with different input parameters. By using the usual goodness-of-fit chi-square parameter we select those reproducing the present-day data within a confidence level of 90%, and we constrain the possible number to 19. However, these models do not reproduce equally well the spectral index radial distributions. Out of these 19 models, only 6 are also able to reproduce the radial distributions of spectral indices.

It seems that the uniqueness problem associated to chemical evolution models is not strong: possible models reduce to 5% of the initial ones using only the present day data as constraints. When we also use the spectrophotometric indices, we limit even more the possible evolutionary histories, by reducing to a 1% the possible models out of the initial 500.

We conclude that this technique combining chemical evolution with evolutionary synthesis is a very powerful tool to discriminate among evolutionary scenarios in galaxies with continuous star formation. We propose more observational campaigns in order to obtain the present as well as other spectral indices in spiral and irregular galaxies.

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