

# Chemical evolution of low mass disc galaxies

Mercedes Mollá and Jean-René Roy

Département de Physique and Observatoire du mont Mégantic, Université Laval,  
Québec, G1K 7P4 Qc, Canada

**Abstract.** We show that the multiphase chemical evolution model reproduces the correlations obtained along the spiral sequence, dwarf galaxies included. However the apparent spatial chemical uniformity observed in some irregular galaxies cannot be reproduced with it. An evolutionary model has been developed and tested to explain flat gradients. Preliminary results, obtained with a new code including supernova winds and radial flows, suggest that radial flows are probably responsible for this uniformity.

## 1 The multiphase model: summary and generic results

The multiphase model has already been used for the solar neighborhood (Ferrini et al. 1992), for both the Galactic bulge and disc (Ferrini et al. 1994; Mollá & Ferrini, 1995) and for some nearby spiral galaxies (Mollá, Ferrini, & Díaz, 1996, hereinafter MFD96). The model starts with a sphere of primordial gas whose total mass  $M_{tot}$  is calculated using rotation curves. This mass collapses onto an equatorial plane on a timescale  $\tau_0$ . The sphere is divided into concentric cylindrical regions, each of which having a halo and a disc zone. The star formation rate in the disc is considered a two step process: First, the diffuse gas forms molecular clouds at a rate which depends on the efficiency  $\epsilon_\mu$ . Then stars form from cloud-cloud collisions with efficiency  $\epsilon_h$ , or by the interactions of massive stars with molecular gas clouds with efficiency  $\epsilon_a$ .

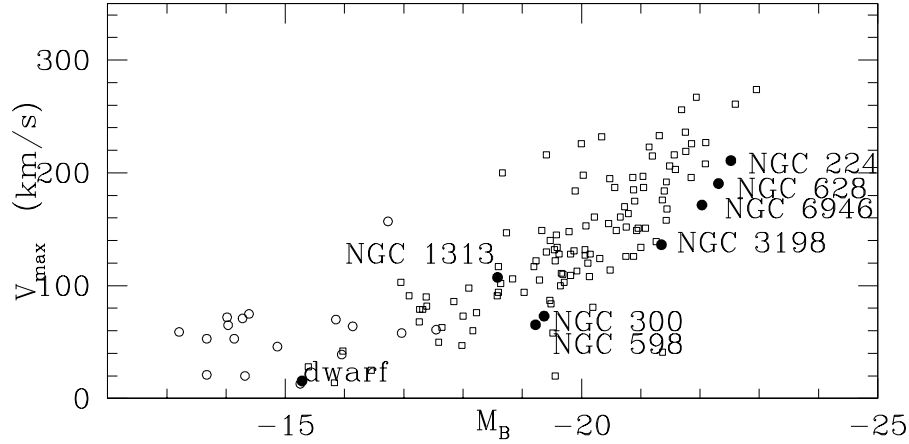
When applied to different spiral galaxies (MFD96), the characteristic values of  $\tau_0$  and efficiencies  $\epsilon_h$  and  $\epsilon_\mu$  change, depending on the total mass of the galaxy, the Arm Class and the Hubble type respectively. Radial distributions of oxygen abundance, atomic and molecular gas surface densities and star formation rates, which are used as constraints for the models, are reproduced with larger  $\tau_0$  values for less massive galaxies and efficiencies  $\epsilon_\mu$ , and smaller  $\epsilon_h$  values for later type galaxies. Thus star formation histories differ from galaxy to galaxy and from region to region in a given galaxy. Generic trends are consistent with observed correlations for large spirals (Vila-Costas & Edmunds, 1992; Zaritsky, Kennicutt & Huchra 1994; Oey & Kennicutt 1994).

## 2 The model for the low-mass end of the spiral sequence

Recently obtained data on low-mass and dwarf galaxies show that these trends are maintained: low-mass irregular galaxies and large spirals fall on the same

sequence (Hoffmann et al. 1996 – HOF96, Broeils & Mc Rhee 1997 – BR97, McGaugh & de Block 1997 – GB97).

Wishing to see if the multiphase model reproduce these correlations, we simulated dwarf galaxies as unevolved systems: low in luminosity and irregular in their optical appearance, a star formation rate which does not follow the spiral wave but with recent bursts, low metallicities, blue colors and high gas fractions. We chose smaller values of  $\epsilon_\mu$  and  $\epsilon_h$  than those used for NGC 598 and NGC 300, the latest type galaxies modeled by MFD96. For low-mass galaxies,  $\tau_0$  is larger due to the smaller total mass.



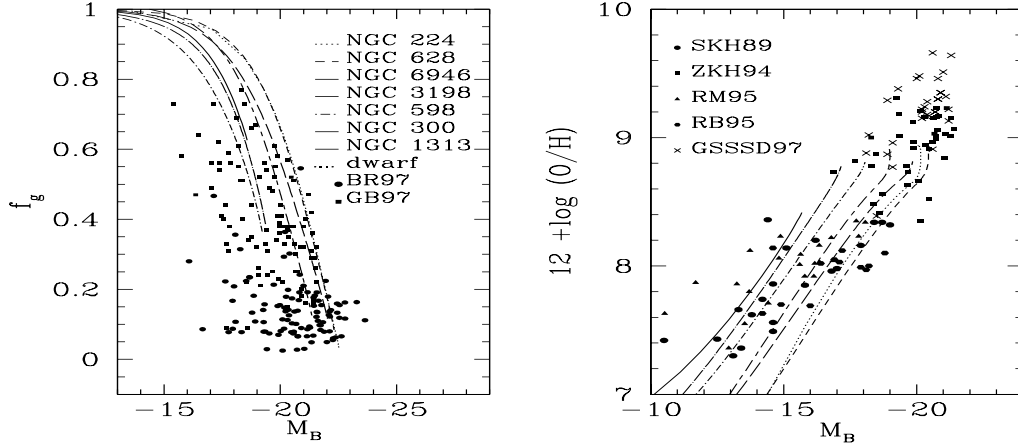
**Fig. 1.** The maximum rotation velocity  $V_{max}$  vs.  $M_B$ . Open symbols are the data taken from HOF96 and from BR97. Filled circles are the multiphase model results.

Using these models, we investigated the behavior along the whole spiral sequence. Dynamical masses have larger values for outer disc regions. The ratio  $M_{\text{dark}}/M_{\text{lum}}$  is higher for low-mass galaxies than for large spirals, and it increases with radius. These effects are reflected by the multiphase model in leading to longer  $\tau_0$  when the total mass is lower; this timescale is assumed to be increasing with radius. The correlation observed between the maximum rotation velocity  $V_{max}$  and the total magnitude  $M_B$  is reproduced by the multiphase models (Figure 1). The model results represent a range of galaxy types, from the earlier type galaxy NGC 224 ( $T = 3$ ) to the intermediate type galaxies NGC 628 and NGC 6946 ( $T = 5, 6$ ), the later type galaxies, NGC 598 and NGC 300 ( $T = 6, 7$ ) and finally the magellanic irregular galaxy NGC 1313 ( $T \geq 8$ ).

Other correlations refer to gas quantities and total magnitudes or luminosities. The relation between the gas fraction  $f_B$  and  $M_B$  is shown in Figure 2a. While being less massive, galaxies with lower luminosities have lower absolute gas mass, but have the largest gas mass fraction. Spiral galaxies with lower luminosities are also those with later morphological types. It results in a correlation between  $f_B$  and the Hubble type  $T$ .

The characteristic oxygen abundance  $12 + \log (\text{O}/\text{H})$  is related to  $M_B$  for

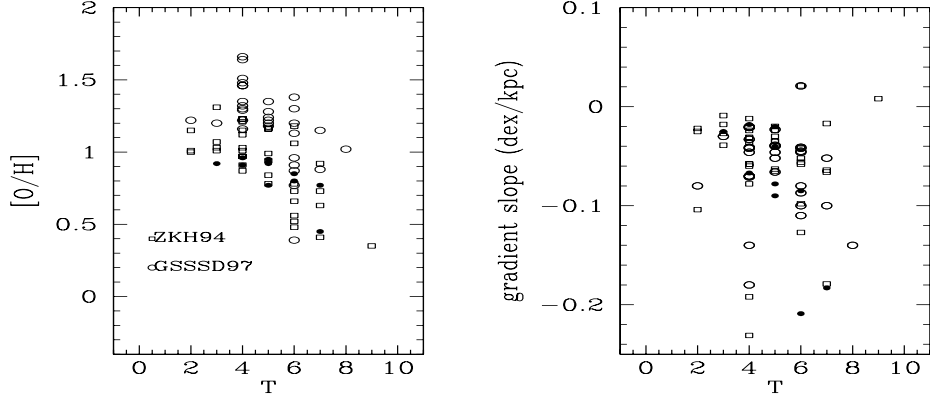
spiral galaxies: the more luminous ones have higher abundances (Skillman, Kennicutt & Hodge 1989 – SZH89; Zaritsky, Kennicutt & Huchra 1994 – ZKH94; Ritcher & McCall 1995 – RMC95; Rönnbavk & Bergvall 1995 – RB95; Garnett et al. 1997 – GSSSD97). The same trend is valid for the luminosity range  $M_B = -10$  to  $M_B = -20$ . Models reproduce this (Figure 2b).



**Fig. 2.** a) The gas fraction  $f_B$  vs.  $M_B$  for spiral galaxies. Symbols are the data taken from BR97 and from GB98. b) The relation of  $[O/H]$  vs.  $M_B$ . Data are from SKH89, ZKH94, RMC95, RB95 and GSSSD97. Lines correspond to our models for each type of galaxies.

There are two other known facts: 1) early type galaxies have higher abundances in their discs than later type ones; 2) radial gradients are steeper in late-type galaxies than in early-type ones. Both results are reproduced by models in Figure 3: Fig. 3a shows the characteristic O/H abundances (open symbols) versus  $T$ ; in Fig. 3b, radial gradients are plotted against  $T$ . A trend of steeper radial gradients with less evolved and later type galaxies is obvious.

Therefore, most of the characteristics of low-mass irregular and normal large spirals are reproduced by the multiphase model based on rather simple physical assumptions. For example, the total mass of a galaxy defines the rate of collapse and disc formation. The star formation rate depends on the gas mass fraction in the disc, and also on the arm class or morphological type. The more massive galaxies evolve more rapidly and reach higher abundances quickly. The less massive galaxies take longer to form the disc and some of them are just now reaching their peak star formation in their centers; this leads to a steep radial gradient of abundances due to the production of oxygen in this region. It is also possible to have two galaxies with similar total masses but different types of spiral density wave, allowing different star formation histories. This could explain the large dispersion of the data in most of the correlations.



**Fig. 3.** a). Oxygen abundance  $[O/H]$  vs. Hubble type  $T$ . b). Radial gradient for  $[O/H]$ . Open symbols correspond to data from ZKH94 and from GSSSD97. Filled circles are the multiphase model results.

### 3 The abundance uniformity in dwarf galaxies.

However, radial gradients disappear when spiral structures no longer exists (Edmunds & Roy, 1993). While in normal galaxies radial gradients steepen for later type galaxies, the low mass irregular galaxies show a large uniformity of abundances over their discs. This is difficult to understand especially because a burst of star formation is generally occurring in their centers (Skillman, Dohm-Palmer & Kobulnicky 1998 and references therein).

For example, the galaxy NGC 1313, considered as a galaxy in transition between a magellanic type and a normal spiral such as the Sc galaxies NGC 598 (M 33) or NGC 300, and similar to both in total mass, shows a flat radial gradient of oxygen abundance (Walsh & Roy 1997). By choosing efficiencies smaller than those chosen for NGC 598 and NGC 300 and a similar collapse timescale, the multiphase model (see Mollá & Roy 1999 for details) produces a steep radial gradient contrary to what is observed. If we assume a constant  $\epsilon_{\mu}(R)$  to take into account that it is an irregular galaxy without a strong spiral wave system, a flat radial gradient is obtained but the theoretical star formation radial profile  $\Psi(R)$  is much flatter than observed. The only way to reproduce the observed  $\Psi(R)$  is to have a burst of star formation in the center of the galaxy. But then,  $[O/H]$  is higher than observed and the radial gradient steepens.

This is a well known problem and some solutions have been suggested (see Kobulnicky & Skillman 1996) to explain why the heavy elements may not be observed in regions with young massive stars. The global star formation conspiracy is not valid with a maximum for  $\Psi(R)$  in the center. We have developed a new version of the multiphase chemical evolution model which allows mass loss by supernova (SN) explosion winds and the possibility of mass exchanges between regions. As a first test, we simulated selective mass loss: the oxygen goes to a hot phase and remains there for a time (the hidden ejecta hypothe-

sis), or it is expelled into the halo at large galactocentric distances to fall back later onto other disc regions following Charlton & Salpeter (1996). Preliminary results indicate that this scenario does not work: the star formation increases in the center (without increasing  $[O/H]$ ) but only for early epochs. Moreover, the  $\Psi(R)$  profile has the same shape than before and the gas density ends up lower than observed.

Until now, the multiphase model has not included the effect of radial flows induced by central bars. Barred galaxies have flatter radial abundance gradients than normal spirals (see Roy 1996) and there is a direct relation between the bar strength and the radial gradient amplitude. When a bar appears, radial flows of gas are produced by the non-axisymmetric gravitational potential. These flows mix the interstellar medium and flatten the radial gradient over a timescale of 1 Gyr (Friedli, Benz & Kennicutt 1994; Edmunds & Greenhow, 1995). Therefore, irregular and magellanic type galaxies may have or have had a bar. For NGC 1313, this possibility is appropriate to explain the flat gradient and the star formation with a maximum in the center: the gradient can become flat, assuming a radial flow of gas with a mean effective velocity of  $\sim 20$  km/s lasting a few Gyr (2-3 Gyr) and having started about 5 Gyr ago, when the galaxy was 8 Gyr old. We are now exploring this scenario with a new model which allows the exchange of matter between radial zones.

## References

- Broeils, A. H., & Rhee, M.-H. 1997, *A&A*, 324, 877 (BR97)  
 Charlton, J. C., & Salpeter, E. E. 1989, 346, 101  
 Edmunds, M. G., & Greenhow, R. M. 1995, *MNRAS*, 272, 264  
 Edmunds, M. G., & Roy, J.-R. 1993, *MNRAS*, 261, L17  
 Ferrini, F., Matteucci, F., Pardi, C., & Penco, U. 1992 *ApJ*, 387, 138  
 Ferrini, F., Mollá, M., Pardi, C., & Díaz, A. I. 1994, *ApJ*, 427, 745  
 Friedli, D., Benz, W., & Kennicutt, R. 1994, *ApJ*, 430, L105  
 Garnett, D. R., Shields, G. A., Skillman, E. D., Sagan, S. P., & Dufour, R. J. 1997, *ApJ*, 489, 63 (GSSSD)  
 Kobulnicky, H. A., & Skillman, E. D. 1996, *ApJ*, 471, 211  
 Hoffman, G.L., Salpeter, E.E., Farhat, B., Roos, T., William, S.H., & Helou, G. 1996, *ApJSS*, 105, 269  
 McGaugh, S. S., & de Block, W. J. G. 1997, *ApJ*, 481, 689 (GB97)  
 Mollá, M., & Ferrini, F., 1995, *ApJ*, 454, 726 (MF)  
 Mollá, M., & Roy, J.-R., 1999, *ApJ*, to be published in April 1st issue.  
 Mollá, M., Ferrini, F., & Díaz, A. I. 1996, *ApJ*, 466, 668 (MFD96)  
 Oey, M. S., & Kennicutt, R. C. 1993, *ApJ*, 411, 137  
 Ritcher M. G. & McCall M. 1995, *ApJ*, 445, 642 (RMC95)  
 Rönnebark J. & Bergvall, N. 1995, *A&A*, 302, 353 (RB95)  
 Roy, J.-R. 1996, in *IAU Coll. no 157, Barred Galaxies*, ed. R. Buta, D. A. Crocker, & B. Elmegreen (San Francisco: ASP), 63  
 Skillman, E. D., Kennicutt, R.C. & Hodge, P.W. 1989, *ApJ*, 347, 875 (SKH89)

- Skillman, E. D., Dohm-Palmer, R. C., & Kobulnicky, H. A. 1998, in ASP Conf. Proc. 147, *Abundance Profiles: Diagnostic Tools for Galaxy History*, ed. D. Friedli, M. Edmunds, L. Drissen, & C. Robert (San Francisco: ASP), 133
- Vila-Costas, B., & Edmunds, M. G. 1992, MNRAS, 259, 121
- Walsh, J.-R., & Roy J.-R. 1997, MNRAS, 288, 726
- Zaritsky, D., Kennicutt, R. C., & Huchra, J. P. 1994, ApJ, 420, 87