RADIAL GRADIENTS AND DISC FORMATION IN SPIRAL GALAXIES

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ABSTRACT

Radial abundance gradients are a common feature of spiral galaxies, including the Milky Way and several objects in the Local Group and beyond. These gradients can be observed in HII regions, planetary nebulae (PN) and stars, and are very probably linked to the formation process of the galactic disc. Recent determinations of the gradients for elements such as Fe, O, Ne, Ar and S suggest that there are differences between the gradients derived from younger objects, e.g. HII regions and young stars, and those determined from intermediate and older objects, such as planetary nebulae and open clusters. In this work, we consider the star formation rate (SFR) in the galactic disc as affected by recent determinations of the gradients from intermediate age PN, and compare the results with those derived from other objects. Individual ages are estimated for the PN central stars on the basis of age-metallicity relations as well as using their kinematic properties, so that an independent determination of the SFR can be made. Some conclusions can be obtained regarding the formation of the discs of spiral galaxies, especially concerning the hypothesis of a constant star formation rate in the galactic disc and its radial variation.

1. INTRODUCTION

Radial abundance gradients have long been considered as a key ingredient of the chemical evolution of spiral galaxies, especially when their magnitude, space variations and time variations are taken into account. These gradients are caused essentially by differences in the star formation rate in different regions of the galactic disc, so that they can give valuable information on the star formation process in spiral galaxies. We have presently detailed information on the gradients not only for the Milky Way, but also for several galaxies in the Local Group. Such information comes basically from young objects, namely HII regions, OB stars and associations, and cepheids, as well as from aged objects, such as open clusters and planetary nebulae (PN). In this work we investigate the effects on the star formation rate (SFR) of some recent determinations of the abundance gradients based on young as well as aged objects. Individual ages are determined for a large sample of galactic central stars of planetary nebulae (CSPN), so that an independent investigation of the SFR and its variations can be made.

2. THE CSPN AGE DISTRIBUTION

In recent years, we have made an effort to derive the age distrbution of the CSPN, in view of the fact that this information is essential in the interpretation of the abundance gradients and their time variations. Several methods have been developed based both on age-metallicity relations and on their kinematic properties (cf. Maciel et al. 2010, 2011). The former investigation suggested that most objets studied have ages under 6 Gyr, and the average distribution peaks somewhere between 1 and 3 Gyr, depending on the assumptions made for the relation between the stellar masses and the corresponding ages (Figure 1). This figure shows the probability for the CSPN ages for a sample of well studied objects, based on the mass distributions of their progenitor stars. The two curves refer to different assumptions on the mass-age relation.

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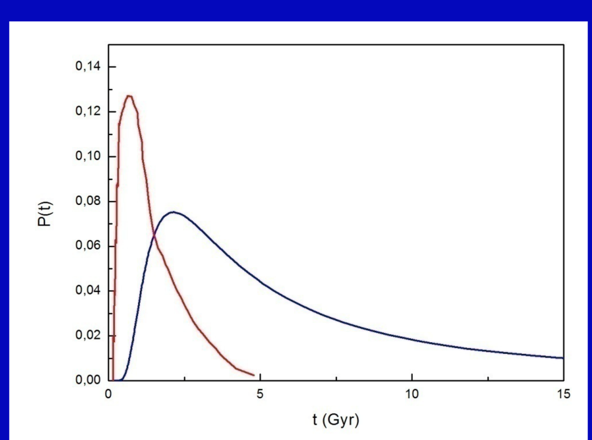

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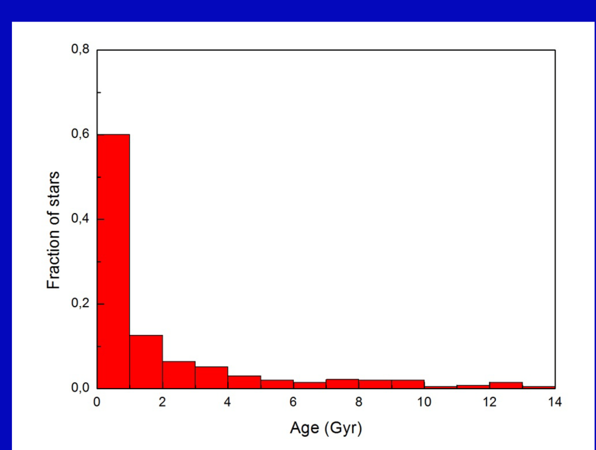


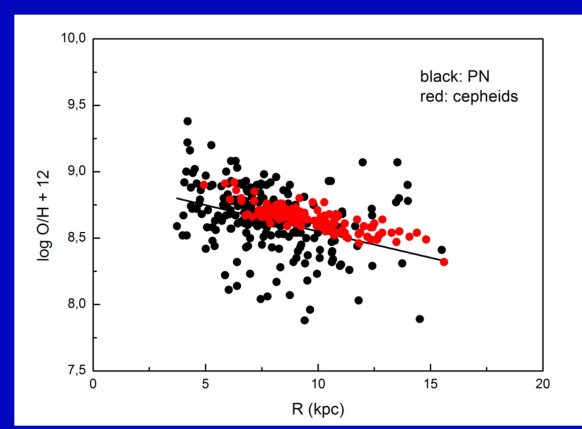
The most recent work (Maciel et al. 2011), based on kinematic ages of the CSPN, confirms the previous results, but suggests generally lower ages for the CSPN compared to the results based on age-metallicity relations. An example of these results is shown in Figure 2. In this case, we show the fraction of stars of a given age for a large sample containing all PN for which accurate radial velocities are known.

3. AVERAGE GRADIENTS IN THE GALACTIC DISC

Gradients from young objects include several chemical elements observed in cepheid variable stars, HII regions, OB stars and associations. There are presently some controversies concerning the behviour of the gradients along the galactocentric radius, but an average gradient of -0.03 to -0.06 dex/kpc is obtained for the Milky Way, with similar values for some of the galaxies in the Local Group. Concerning aged objects, most recent results apply to open clusters and planetary nebulae. The corresponding abundance gradients are also typically in the range -0.03 to -0.06 dex/kpc for elements such as oxygen and sulphur (Maciel et al. 2003, 2005, Henry et al. 2010). For open clusters, recent results suggest gradients similar to those observed in planetary nebulae (Andreuzzi et al. 2011).

A comparison of the oxygen abundances with Fe abundances, which are not well determined in PN, indicates a tight correlation with a slope in the range 1.0 to 1.2 (Maciel 2002). Therefore, the PN gradients are probably slightly larger than the gradients derived from the younger objects, but the difference seems now marginal compared to our previous investigations (Maciel et al. 2005), which may explain the essentially similar gradients measured in PN and HII regions in some Local Group galaxies (Stanghellini et al. 2010, Magrini et al. 2009). Taking into account the uncertainties in the determinations, it can be concluded that the abundance gradients have had a small change in the last 3-4 Gyr, slower than usually assumed.

Figure 3 shows some recent results from planetary nebulae (black dots and line) and cepheids (red dots). The PN sample includes only objects for which the central stars are younger than 3 Gyr according to Maciel et al. (2011), so that the derived gradient is expected to be closer to the cepheid gradient, if the time variation of the gradients is slow. This is in fact observed, as can be seen from Figure 3. Essentially the same results are obtained from the most recent data by Andrievsky and collaborators (Luck et al. 2011). This is shown in Figure 4, where the green and yellow dots and the red line refer to the new cepheid data, which indicates a gradient of -0.037 dex/kpc.



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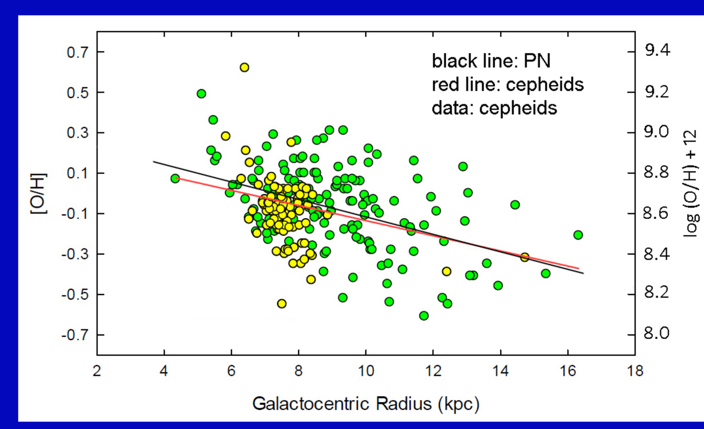

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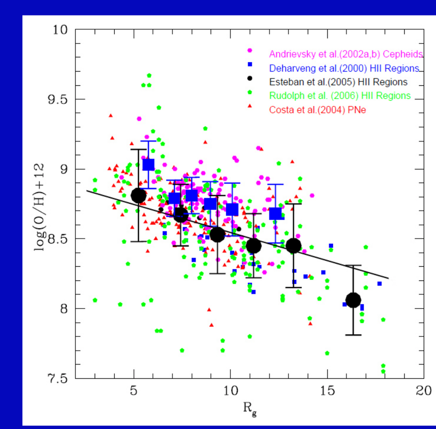

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The black line shows the same PN gradient as in Figure 3. The similarity of the gradients can be better seen in Figure 5 from the compilation by Spitoni and Matteucci (2011). In this figure, gradients of cepheids (pink dots), HII regions (blue squares, black dots, green pentagons) and PN (red triangles) are shown. The large blue squared points are the mean Cepheid values, and the the large black filled circles show the mean values from the HII and PN data.

4. EFFECTS ON THE STAR FORMATION RATE

Recent investigations based on chromospheric ages of dwarf stars in the Milky Way disc suggest that the star formaton rate (SFR) may have suffered time variations, especially in the last 5 or 6 Gyr. In this sense, our Galaxy would have some characteristics resembling starburst galaxies, for which the presence of star formation bursts is well established. On the basis of the age distribution of the CSPN, one can obtain some evidence of galactic bursts, assuming that the birth rate of the planetary nebulae is representative of the star formation rate in these systems. A first examination of the CSPN age distribution would suggest a roughly constant SFR during the last 10 Gyr, approximately, with an enhanced rate a few Gyr ago, depending on the hypotheses on the mass-age relationship, as discussed above. Figure 6 (left panel) shows a comparison of the derived uncorrected SFR from Rocha-Pinto et al. (2000ab) and the results from the present investigation.The black line refers to the original results by Rocha-Pinto et al. (2000b), while the red and blue lines show the average SFR based on the PN age determinations from Maciel et al. (2011, 2010), respectively. It is concluded that the results obtained from the age distribution of the CSPN supports the idea that at least one era of enhanced star formation activity occurred in the MIlky Way in the last few Gyr. The right panel shows the corresponding SFR after applying a correction factor obtained using the initial mass function for the dying stars at each age interval. The peaks are somewhat decreased, but an important enhancement is still observed, especially for the kinematic ages, as shown by the red line.

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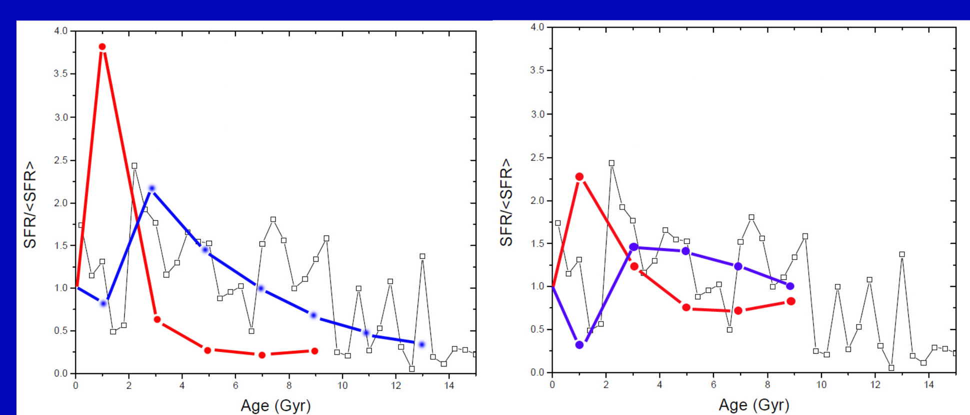

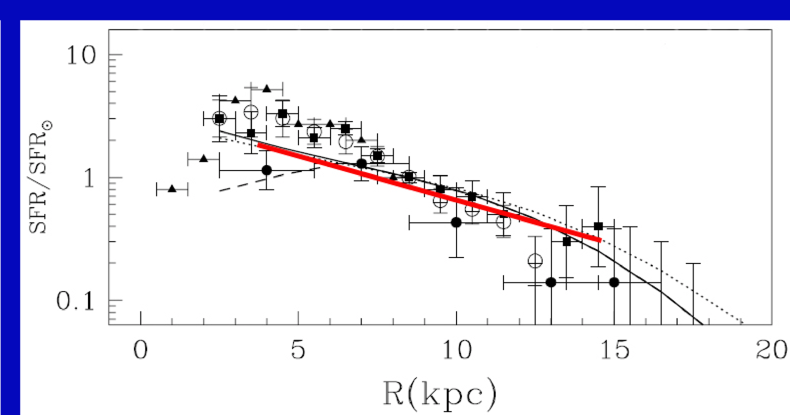

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Concerning the abundance gradients, the similarity of the gradients for young as well aged objects, within the uncertainties, suggest that the average gradients have not changed much, at least during the last 4 to 6 Gyr, approximately, depending on the adopted ages of the CSPN. Therefore, the SFR has probably not changed much as a function of the galactocentric radius during this period. Adopting an average gradient of -0.05 dex/kpc, and assuming that the abundance gradient is directly proportional to the SFR, the difference in the SFR along the galactic disc is about a factor of 4 for in the region where the gradients are best measured, between the galactocentric distances R = 4 kpc and R = 14 kpc. This is in very good agreement with with the radial distribution of the SFR as summarized for example bu Portinari & Chiosi (1999), as shown in Figure 7, where the red line shows the derived SFR on the basis of the abundance gradients.

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