Formation and evolution of Galaxy bulges
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The evolution of the Galactic bulge from planetary nebulae

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Abstract. We have used our dataset on the abundances of planetary nebulae (PN) to study the chemical evolution of the Galactic bulge. We have derived several relations involving the chemical abundances and computed three classes of models for the Galactic bulge: (i) one-zone, single-infall models, (ii) one-zone, double-infall models and (iii) multizone, double infall models. We conclude that part of the observational data can be understood in terms of the simpler models, but the full understanding of all observational constraints can only be explained by more complex multizone models.

Keywords. planetary nebulae: general, Galaxy: bulge, Galaxy: abundances

1. Introduction

Planetary nebulae represent the final stage in the evolution of intermediate mass stars, and can be used as observational constraints to model the chemical evolution of a given population, such as the Galactic bulge (Maciel *et al.* 2006; Richer & McCall 2006). In an ongoing project, we are dedicated to the study of all these populations, especially the disk and bulge of the Milky Way and Local Group galaxies (Maciel *et al.* 2006; Costa *et al.* 2004; Escudero *et al.* 2004). In this work, we have considered a large sample of bulge nebulae, for which we have performed spectrophotometric observations and derived chemical abundances of several elements. Using these observational results as constraints, we developed a chemical evolution model for the bulge.

2. Chemical composition of bulge PN

The observations used in this work were carried out in two different telescopes: 1.60 m LNA (Laboratório Nacional de Astrofísica - Brasópolis, Brazil) and 1.52 m ESO (European Southern Observatory - La Silla, Chile). Details on the observational procedures can be seen in Costa *et al.* 2004 and Escudero *et al.* 2004.

The elements O, S, Ar and Ne are probably not produced by the PN progenitor stars, as they are essentially manufactured in the late evolutionary stages of massive stars. Therefore, abundances of these elements as measured in PN should reflect the interstellar composition at the time the progenitor stars were formed. The variation of the ratios S/H, etc. with O/H show a good positive correlation for PN in the Galactic bulge. This can be compared with data from Local Group galaxies from Richer & McCall (2006), and it can be concluded that similar chemical evolution processes occur in these systems. PN are also useful to determine the metallicity distribution, using the abundances of O, S, Ar and Ne. A comparison of the distribution in different systems can be used to infer their average metallicities, with consequences on the star formation rates. The metallicity distribution of PN in the Galactic bulge can also be used as an important tool to constrain Galactic chemical evolution models (Maciel 1999). We have also determined the planetary nebula luminosity function (PNLF) from the $\lambda 5007$Å flux for the Galactic bulge and compared it with data from other Local Group galaxies (Ciardullo 2006).

3. A model for the Galactic bulge

In order to increase the number of observational constraints, in this work we have included as many chemical elements obtained from bulge PN as possible. Three classes of models were developed: (i) one-zone, single-infall, (ii) one-zone, double-infall, and (iii) multizone, double infall models. Concerning one-zone models, we have developed both single and double infall models. For the single infall case, the infall timescale was obtained as 1 Gyr, while for the two infall, one-zone models, timescales of 0.1 and 2.0 Gyr were obtained. The multizone model is based on a mixed scenario for the bulge evolution. To reproduce the abundance distribution and the correlations between elemental abundances, the adopted model has two main phases: the first one is a fast collapse of the primordial gas, essentially responsible for the bulge formation, and the second is a slower infall of enriched gas that forms the disk. The bulge and central region of the Galaxy were divided into two zones, the first one experiencing two gas infall episodes, a 0.1 Gyr collapse and an enriched gas infall lasting 2.0 Gyr, as in the previous models. The results were compared to samples of PN and stars, leading us to the following conclusions (for details see Escudero *et al.* 2007, in preparation): (1) Most abundances can be reproduced assuming a fast initial collapse with a high wind rate; (2) Some peculiarities found in the abundances of PN require the existence of a second infall of material previously enriched by SNII ejecta; (3) Abundance ratios (α/Fe) from stars suggest that, at the beginning of the bulge formation, the IMF was steeper. The best way to describe it is to assume Salpeter's IMF for the initial 0.4 Gyr and Kroupa's for the rest of the evolution.

We have shown that, in spite of the nearly satisfactory results found using simpler models, the best result is achieved using a multizone, double infall model. These results agree with the recent one-zone models developed by Ballero *et al.* (2007), in the sense that a variation in the IMF is necessary depending on the considered environment. Also, a faster star formation of the bulge, as compared to the disk, is in agreement with recent data by Zoccali *et al.* 2006. However, assuming that our PN sample occupies essentially the same region as the stellar samples considered in these works, we find that taking into account a second infall produces a better fit to the data. (Work partially supported by FAPESP and CNPq.)

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