Nucleosynthesis of intermediate mass stars: inferences from the observed abundances in photoionized nebulae of the Local Group

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Abstract. Photoionized nebulae, comprising HII regions and planetary nebulae, are excellent laboratories to investigate the nucleosynthesis and chemical evolution of several elements in the Galaxy and other galaxies of the Local Group. Our purpose in this investigation is threefold: (i) to compare the abundances of HII regions and planetary nebulae in each system in order to investigate the differences derived from the age and origin of these objects, (ii) to compare the chemical evolution in different systems, such as the Milky Way, the Magellanic Clouds, and other galaxies of the Local Group, and (iii) to investigate to what extent the nucleosynthesis contributions from the progenitor stars affect the observed abundances in planetary nebulae, especially for oxygen and neon, which places constraints on the amount of these elements that can be produced by intermediate mass stars.

1. Introduction

Planetary nebulae (PN) have strong emission lines of H, He, O, N, Ne, S, Ar, etc., including forbidden lines and recombination lines. The analysis of these lines gives abundances accurate to about 0.2 dex or better. The abundances include elements that are probably not significantly produced by the progenitor stars (O, S, Ne, Ar), and therefore contribute to the study of the chemical evolution of the host galaxies. They also provide accurate abundances of elements that are produced by the progenitor stars (He, N, C), so that they are also useful to study nucleosynthesis processes in intermediate mass stars. Some of these elements are difficult to study in stars, and better observed in photoionized nebulae, which comprise PN and HII regions. Blue Compact Galaxies (BCG) and Emission Line Galaxies (ELG) can also be included as low metallicity HII regions. In this work, we compare the observed abundances of these elements in PN and HII regions in several galaxies in the Local Group.

2. The data

The data used in this investigation include a large sample of PN and HII regions in the following galaxies: The Milky Way (MW), the Large Magellanic Cloud (LMC), the Small Magellanic Cloud (SMC), M31, M32, M33, M51, M81, M101, NGC 185, NGC 105, NGC 300, NGC 628, NGC 3109, NGC 5194, and the Sextans galaxy. The total PN sample includes about 1200 objects, while the HII region sample has about 500 objects, so that a reasonably large sample of Local Group objects is considered. The data sources are given by Maciel et al. (2014) [1], with recent data by Stanghellini et al. (2014) [2], Reyes et al. (2015) [3], Berg et al. (2015) [4], and Croxall et al. (2015) [5].

3. Results

3.1 Elements produced by the PN progenitor stars

In this work, we have stressed the elements that are not expected to be substantially produced by the PN progenitor stars, so that we will present a general outline of the elements that are affected by the progenitor star evolution, such as He and N. The abundances of these elements are particularly changed by the dredge-up processes that occur in the intermediate mass stars.

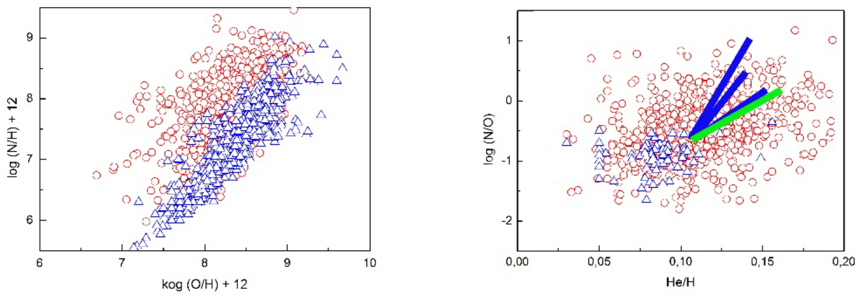

Figure 1. Nitrogen and helium abundances

Figure 1 shows the N/H and N/O ratios as functions of O/H and He/H, respectively, where the empty red circles refer to PN, and the blue triangles are HII regions in the Local Group. As expected, PN show an increase in both N and He compared to most HII regions in the sample. It can be seen that for these elements some dispersion is observed even for HII regions, so that part of the nitrogen is probably secondary. The excess nitrogen in PN is essentially produced by their progenitor stars, in a strong contrast with the remaining elements studied here, as we will see in the next section. The green and blue lines in the second plot are from theoretical models by Marigo et al. (2003) [6] with Z = 0.019, and Karakas (2010) [7], with Z = 0.02, 0.004, 0.008, respectively. These are synthetic evolutionary models for thermally-pulsing AGB stars with initial masses of 1 to 6 solar masses, in which up to three dredge-up episodes occur, apart from hot-bottom processes (HBB) for the most massive objects. According to these models, progenitors having 0.9 to 4 solar masses and solar composition can explain the "normal" abundances, He/H < 0.15, while for objects with higher enhancements (He/H > 0.15), masses of 4 to 5 solar masses are needed, plus an efficient HBB. For intermediate mass stars, agreement with theoretical models is fair, but abundance determinations should be improved and expanded.

3.2 Elements not produced by the PN progenitor stars

The abundances of the elements O, Ne, S, and Ar are probably not significantly affected by the evolution of the PN progenitor stars, and the observed correlations are much better determined. The measured abundances therefore reflect the interstellar abundances at the time the progenitor stars were born. Oxygen can be used as a metallicity proxy, and an accurate relation between O and Fe can be determined (see for example Ramirez et al. 2013) [8]. This is important, since in photoionized nebulae Fe is mostly locked up in grains. The average slope of the Fe – O correlation is $\delta = 1.11$ (thin disk) and $\delta = 1.31$ (thick disk). Here we concentrate on distance-independent correlations, to avoid distance determination problems, which affect processes such as the abundance gradients observed in the Milky Way and other spirals.

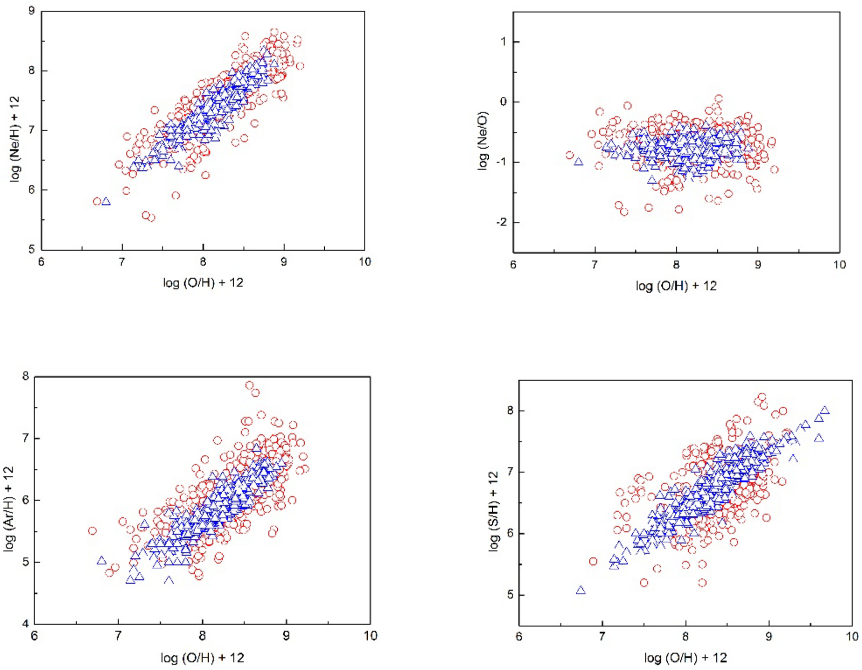

Figure 2. Abundances of Ne, Ar, and S

The main results are shown in Figure 2 for Neon, Argon, and Sulphur. Again, the empty red circles are Local Group PN, while the blue triangles represent HII regions and BCG. PN abundances of O, Ne, S, and Ar show good correlations, indicating that Ne, S, and Ar vary in lockstep with O. The most accurate result is for neon (figure 2a), which does not suggest any important contribution from the progenitor stars, as the PN data dispersion is essentially constant at all metallicities. The abundances relative to oxygen are essentially constant, which can be seen in figure 2b for neon. Argon presents similar results as neon, with a somewhat higher dispersion, probably due to the weakness of the Ar lines (figure 2c). Sulphur abundances in PN may present the "sulphur anomaly", that is, lower abundances than expected at a given metallicity. This is probably due to incorrect ICFs (ionization correction factors), but is not apparent in the bulk of Local Group objects, as can be seen from figure 2d, where a particularly extended metallicity range can be observed. All correlations for HII regions show smaller dispersions, as expected, a result that is not affected by the inclusion of either BCG or ELG. The same trends are observed in both types of photoionized nebulae. The dispersion observed in PN is probably real, and reflects the different ages of the progenitor stars, but it should be noted that part of the dispersion may be due to the different abundance sources considered.

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