Spectroscopy of PNe in Sextans A, Sextans B, NGC 3109 and Fornax

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Abstract. Planetary nebulae (PNe) and HII regions provide a probe of the chemical enrichment and star formation history of a galaxy from intermediate ages to the present day. Furthermore, observations of HII regions and PNe permit us to measure abundances at different locations, testing the homogeneity with which heavy elements are/were distributed within a galaxy. We present the first results of NTT spectroscopy of HII regions and/or PNe in four nearby dwarf galaxies: Sextans A, Sextans B, NGC 3109, and Fornax. The first three form a small group of galaxies just beyond the Local Group and are gas-rich dwarf irregular galaxies, whereas Fornax is a gas-deficient Local Group dwarf spheroidal that stopped its star formation activity a few hundred million years ago. For all PNe and some of the HII regions in these galaxies we have obtained elemental abundances via the classic Te-method based on the detection of the [OIII] λ4363 line. The oxygen abundances in three HII regions of Sextans A are all consistent within the individual rms uncertainties. The oxygen abundance in the PN of Sextans A is however significantly higher. This PN is even more enriched in nitrogen and helium, implying its classification as a PN of Type I. The presumably unaffected PN abundances of S and Ar are well below those in the HII regions, indicating a lower metallicity at the epoch of the PN progenitor formation. For two HII regions in Sextans B, the oxygen abundances do not differ within the rms uncertainties. The third one is, however, twice as metal-rich, providing evidence for the inhomogeneity of the currentmetallicity distribution in Sextans B. For the PN in Sextans B we measured an O/H that is consistent with that of the low-metallicity HII regions. For NGC 3109 our preliminary results indicate that the oxygen abundances of PNe and HII regions are all within a small range of ±0.15 dex. For the PN in Fornax, Ne, Ar and S abundances suggest that the ISM metallicity was ~0.3 dex lower at the epoch of the PN progenitor’s formation, compared to the O/H value derived for the PN.

1 Introduction

Understanding how the elemental abundances of galaxies have changed over time is an essential issue of galaxy evolution studies. Abundance measurements constrain theoretical models, providing important clues to how galaxies evolve. In particular, combining the data on PNe numbers and on PN and HII region elemental abundances can allow one to derive an approximate enrichment and star formation history of a galaxy from intermediate ages to the present
While HII regions indicate the present-day gas-phase elemental abundances (∼10 Myr), PNe, although they cannot be accurately age-dated, reveal the chemical composition of a galaxy at “intermediate” ages of a few 100 Myr to a few Gyr. Furthermore, if HII regions and PNe at different locations are studied, this permits us to test the homogeneity with which heavy elements are/were distributed within a galaxy. For the Local Group and other nearby galaxies these data can be combined with star formation histories derived from color-magnitude diagrams of resolved stars, thereby yielding deeper insights on galaxy evolution. The goal of our present work was to improve our understanding of metallicities both at the current epoch (from HII regions), and in previous periods of star formation (from PNe) on the basis of new high-quality NTT spectrophotometry for three members of Antlia-Sextans group of dwarf galaxies [27] and for the Fornax dwarf spheroidal galaxy.

2 Observations and Reduction

Spectrophotometric observations of HII regions and PNe in the targeted galaxies were conducted with the NTT at ESO, La Silla, in February 2004. The observations were performed with the Red Arm of the EMMI multipurpose instrument with a long slit of 8′ × 2″. For these observations the CCD rows were binned by a factor of 2, yielding a final spatial sampling of 0.33″ pixel−1. The seeing during the observations was very stable and varied from night to night in the range of 0.4″ to 0.6″. The whole spectral range covered by the two grisms was of 3800 – 8700 Å with the sampling of 1.6 Å pixel−1 for the blue (3800 – 7000 Å) and 1.4 Å pixel−1 for the red part (5750 – 8670 Å) of the spectra. Each galaxy was observed with slit positions which covered several HII regions and also one PN in Sextans A, one PN in Sextans B, four PNe in NGC 3109 and one PN in Fornax. The PNe positions have been taken from [21] for Sextans A, from [20] for Sextans B, from [23] for NGC 3109 and from [4] for Fornax.

All primary reductions were done using the IRAF and MIDAS environments. The method of emission line measurements and the calculation of element abundances was described in detail in [10,11,14–16]. For the majority of PNe and HII regions in these galaxies O, N, S, Ar and He abundances were obtained with the classic $T_e$-method after the detection of the $[\text{OIII}] \lambda 4363$ line.

3 PN abundances vs. HII abundances

HII region metallicities mainly provide information about abundances of $\alpha$-process elements, produced predominantly in short-lived massive stars. In contrast to HII regions, some elemental abundances in PNe are affected by nucleosynthesis in PN progenitors. It is well known that newly synthesized material can be dredged up by convection in the envelope, significantly altering abundances of He, C and N in the surface layers during the evolution of 1–8 M$_\odot$ stars on the giant branch and asymptotic giant branch (AGB) [18,2,9]. In addition, if during the thermally pulsing phase of AGB evolution, convection “overshoots”
Fig. 1. Planetary nebulae in Sextans A and Fornax. The emission-line EMMI/NTT spectra were obtained with grism #5 and cover a wavelength range of 3800 and 7000 Å. The spectra at the bottom of each panel is scaled by 1/10 (top) and 1/30 (bottom) and shifted to show the relative intensities of strong lines.

into the core, significant amounts of $^{16}$O can be mixed into the inter-shell region and may be convected to the surface [8,1]. In combination, these factors mean that surely only Ne, S and Ar abundances, observed in both HII regions and PNe, can be used to probe the enrichment history of galaxies.

4 Sextans A

Sextans A is a dIrr at a distance of 1.32 Mpc for which deep HST images have permitted the measurements of stars to a limiting absolute magnitude of $M_V \sim +1.9$ [5]. The gas abundance of heavy elements for Sextans A was first determined by [24]. This study presented only an empirical estimate of O/H, which has a characteristic rms uncertainty of $\sim 50\%$. While this estimate was successfully used in various statistical studies to combine the data on O/H with the CMD-derived SF history and metallicities, such accuracy is not sufficient.

We have derived an average value of $12+\log(O/H)=7.57$ from three HII regions in Sextans A. The values of N/O, S/O and Ar/O are consistent in all three HII regions to within their rms observational uncertainties and are close to those derived for the subgroup of the most metal-poor HII galaxies [11]. New, high accuracy chemical abundances for HII regions in Sextans A allow us to probe metallicity homogeneity across the body of the galaxy. For the three HII regions observed in Sextans A, the measured abundances show no differences exceeding 0.1 dex. Moreover, these metallicities are in good agreement with those in three A-supergiants in Sextans A [13].
Chemical abundances derived for the PN in Sextans A show that this is a Type I object (see Figure 1), with a highly elevated nitrogen abundance: N/O $\sim$2. Its $12+\log(O/H) = 8.02$ is about a factor of 3 higher than in the HII regions, which implies significant self-pollution by the PN progenitor. Since the abundances of S and Ar should not be altered in a PN progenitor (see discussion above), their values indicate that the ISM metallicity was $\sim$0.5 dex lower at the epoch of the PN progenitor’s formation, compared to the current metallicity in HII regions and A-supergiants.

5 Sextans B

Sextans B is a dIrr at a distance of 1.36 Mpc [12], in which red giants, intermediate-age stars, and young stars are found. As far as its global properties are concerned, Sextans B is considered to be a “twin” to Sextans A, but Sextans B is of particular interest because of a discrepancy in oxygen abundances between the HII measurements of [25,24,22].

We confirmed with good accuracy the low ISM metallicity of Sextans B with $12+\log(O/H) = 7.53 \pm 0.04$ in two HII regions. The element abundance ratios of O, N, S and Ar are well consistent with the respective patterns of very metal-poor HII galaxies. We have found that one HII region is significantly enriched, with an excess of O, N, S and Ar abundances, relative to the mean value of two other HII regions, by a factor of 2.5$\pm$0.5. The elemental abundances of the observed PN in Sextans B are consistent with those of the two HII regions with the low metallicity.

6 NGC 3109

NGC 3109, at a distance of 1.33 Mpc, is the most massive dIrr galaxy in Antlia-Sextans group. Compared to galaxies of similar total luminosity (e.g., the SMC), the optical extent is approximately two times larger. The H I gas, stellar content and star formation history of this galaxy have been studied, e.g., by [3,7]. The underlying old stars are metal-poor ($[\text{Fe/H}] = -1.7$ dex), as measured by [6]. [17] reported an oxygen abundance for one HII region with the $T_e$-method, although the S/N in the [OIII] $\lambda$4363 line was low ($\sim 2.5$). Our preliminary measurement of O/H for this HII region is quite consistent with their value, but with higher S/N=6 for the [OIII] $\lambda$4363 line. We found that oxygen abundances of PNe and HII regions are all in a narrow range near $12+\log(O/H) \sim 7.65 \pm 0.15$.

7 PN in Fornax

The PN in the Fornax dwarf spheroidal galaxy was the only one found by [4], who were the first to observe it spectroscopically. Our data are considerably better (see Figure 1), yielding S/N=25 for the [OIII] $\lambda$4363 line. We have calculated $12+\log(O/H) = 8.28$ for this PN, which is slightly lower than the O/H
value 8.38 from [19] that was calculated on the basis of line intensities from [4]. With our new data we have for first time detected weak [SII] $\lambda\lambda$ 6717,6731 lines ($I(6717+6731) < 0.015 I(H\beta)$) and have determined an electron number density, $N_e$(SII) = 750 cm$^{-3}$. With the newly determined O, N, Ne, Ar and S abundances and knowledge of mean heavy-element abundance ratios for these elements from [11] we have found that the PN is enriched with oxygen and the ISM metallicity was $\sim$0.3 dex lower at the epoch of the PN progenitor formation compared to the value O/H derived for the PN. This result is consistent with the chemical evolution scenario for the Fornax dwarf derived by [26]. The Fornax PN shows a Wolf-Rayet blue bump in the spectrum that provides important constraints on the central star evolutionary status. It is worth noting that both PNe from the Sagittarius dwarf spheroidal galaxy from [28] also show Wolf-Rayet features in their spectra.

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