Metals in the Neutral Interstellar Medium of Dwarf Star-Forming Galaxies

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Abstract. The determination of the metal abundances in the neutral interstellar medium (ISM) of dwarf star-forming galaxies is a key step in understanding their physical and chemical evolution. This type of investigation has been possible in the last 5 years thanks to FUSE. We will give a flavor of the issues involved by presenting the work that we are performing in this astrophysical field.

1. Introduction

Dwarf galaxies are the most common type of galaxies in the local Universe and may have also played an important role in the past as building blocks from which larger systems formed by merging. Present-day dwarfs are the leftovers of this building process, and as such they could have had a completely different evolutionary path compared to their high-redshift counterparts. However, local star-forming dwarfs are particularly interesting from a cosmological point of view. They are chemically poorly evolved systems which are undergoing star formation (SF), thus the closest analogue to primeval galaxies. They are also perfect targets for FUSE, since SF means hot young and massive stars that emit the bulk of their energy in the rest-frame UV rich in transitions of the most abundant ions. These galaxies are characterized by a large reservoir of H\textsc{ii}. FUSE is thus particularly suited to study the physics, chemistry and kinematics of their ISM.

2. FUSE Spectra of I Zw 18

I Zw 18 is the star-forming galaxy with the lowest metallicity known and has always been regarded as the best candidate for a truly “young” galaxy in the local universe. It has been observed with FUSE for a total of \( \sim 90 \) (60) ksec in the LiF (SiC) channels. The LWRS aperture (30\textquotesingle\texttimes30\textquotesingle) was used to cover the whole body for a resolution of \( \sim 35 \) km/s and a S/N of 7-18 (Aloisi et al. 2003). A multi-component fitting technique was applied to infer the column densities of the most common heavy elements and determine metal abundances in the neutral gas. Our results are reported in Table 1 together with the metal abundances in the H\textsc{ii} regions (Izotov et al. 1999; Izotov & Thuan 1999).
Table 1. Interstellar Abundances in I Zw 18

| Element | Ion   | [X/H]_{ISM}   | [X/H]_{HII}   |
|---------|-------|---------------|---------------|
| O       | O     | -2.06 ± 0.28  | -1.51 ± 0.04  |
| Ar      | Ar    | -2.27 ± 0.13  | -1.51 ± 0.07  |
| Si      | Si    | -2.09 ± 0.12  | -1.90 ± 0.33  |
| N       | N     | -2.88 ± 0.11  | -2.36 ± 0.07  |
| Fe      | Fe    | -1.76 ± 0.12  | -1.96 ± 0.09  |

It is clear that the neutral gas in I Zw 18 has already been enriched in heavy elements, and is not primordial in nature. The $\alpha$ elements are several times lower in the H I than in the H II gas, while Fe is the same. The Fe behavior suggests that some old SF is required for the metal enrichment of the H I (Fe is mostly produced by SNe Ia on time scales $> 1$ Gyr). The relative metal content in $\alpha$ elements (produced by SNe II on time scales $< 50$ Myr) and N (released on timescales $> 300$ Myr) between neutral and ionized gas suggests that the H II regions have been additionally enriched by more recent SF.

3. FUSE and STIS Spectra of NGC 1705

There are some caveats to address in order to be sure that what we really measure are the ISM metal abundances. First of all, there is saturation, especially for O I. Hidden saturation of unresolved multiple components can also bring to erroneous estimates of the column density. Ionization constitutes another type of uncertainty. Abundances are derived by assuming that the primary ionization state in the neutral gas is representative of the total amount of a certain element and this is probably the case in ISM studies. However, we can have contamination by ionized gas laying along the line of sight. Furthermore, Ar I and N I should be well coupled with H I and O I due to similar ionization potentials. However, they could be found in higher percentage in their ionized state due to larger cross-sections for photoionization. Finally, depletion is important. Some elements could be more easily locked into dust grains than others (e.g., Fe compared to O), thus altering the relative abundances produced by a certain SF history.

A wonderful dataset where to address all these issues is represented by the FUSE and STIS Echelle spectra (900-3100 Å) of NGC 1705, one of the brightest dwarf starburst galaxies in the nearby Universe. The FUSE data were taken by centering the SSC in the LWRS aperture for a total of $\sim 21$ ksec, a resolution of $\sim 30$ km/s and a S/N of 10-16 (Heckman et al. 2001). The STIS echelle data were taken with the 0.2" × 0.2" aperture centered on the SSC for a total of 10 HST orbits, a resolution of $\sim 15$ km/s, and a S/N of 10-20 (Vázquez et al. 2004). We measured the column density of many ions in the FUSE and STIS spectra of NGC 1705 with the line-profile fitting and inferred the ISM metal abundances. We found consistency in the measurements performed on those ions detected in both spectra. Thus, the FUV light is dominated by the SSC. The low-ionization absorption lines have a mean radial velocity of about 590 km/s. However, two
components were detected for selected ions in the higher-resolution STIS data. One component is at the same radial velocity of the stars in the SSC \((v = 618\ \text{km/s})\) as inferred by the stellar C\textsc{iii} line at 1175 Å, and the second at the velocity of the warm photoionized gas \((v = 580\ \text{km/s})\) as detected in absorption through C\textsc{iii} or N\textsc{ii} and confirmed by nebular emission lines in the optical. The use of the abundances from the total (neutral + ionized) absorbing gas would thus be misleading for the derivation of the metal content in the neutral ISM of NGC 1705. In Table 2 we report the abundances as inferred by both the total column densities of the ions (column 3) and the column densities of the absorbing component at rest with the stars in the SSC (column 4). The latter have to be compared with the H\textsc{ii} region abundances (Lee & Skillman 2004).

| Element | Ion | [X/H]_{ISM, total} | [X/H]_{ISM, neutral} | [X/H]_{HII} |
|---------|-----|--------------------|----------------------|------------|
| O       | O i | \(-1.19 \pm 0.01\) | ...                  | \(-0.48 \pm 0.05\) |
| Ar      | Ar i| \(-1.11 \pm 0.04\) | ...                  | \(-0.61 \pm 0.10\) |
| Si      | Si ii | \(-0.90 \pm 0.01\) | ...                  | ...        |
| Mg      | Mg ii | \(-1.41 \pm 0.12\) | ...                  | ...        |
| Al      | Al ii | \(-1.14 \pm 0.04\) | \(-1.36 \pm 0.05\) | ...        |
| N       | N i | \(-1.79 \pm 0.03\) | \(-2.29 \pm 0.06\) | \(-1.51 \pm 0.08\) |
| Fe      | Fe ii | \(-0.86 \pm 0.03\) | \(-1.29 \pm 0.03\) | ...        |

4. Conclusions

The offset in metal content between neutral ISM and H\textsc{ii} regions in dwarf star-forming galaxies is probably one of the unexpected great results of FUSE in the past five years. However, this area of research is still pretty new and many unknowns and uncertainties still affect the interpretation of the data. It is thus premature to draw conclusions and more targets with a data quality similar to that of NGC 1705, still need to be investigated before having all the pieces of this intriguing puzzle put together.

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