METALS IN THE NEUTRAL INTERSTELLAR MEDIUM OF STARBURST GALAXIES

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Abstract Thanks to their proximity, local starbursts are perfectly suited for high-resolution and sensitivity multiwavelength observations aimed to test our ideas about star formation, evolution of massive stars, physics and chemical evolution of the interstellar medium (ISM). High-resolution UV spectroscopy with FUSE and STIS has recently given the possibility to characterize in great detail the neutral ISM in local starbursts thanks to the presence in this spectral range of many absorption lines from ions of the most common heavy elements. Here we present the results for two nearby starburst galaxies, I Zw 18 and NGC 1705, and show how these results relate to the star-formation (SF) history and evolutionary state of these stellar systems.

1. Introduction

Star-forming galaxies are an important component of both the low- and high-redshift Universe. Star formation is an ongoing phenomenon in nearby spiral and irregular galaxies. Starbursts (strong, intense, and spatially concentrated episodes of SF) are usually seen in local dwarf irregulars and interacting/merging systems. According to the hierarchical scenario for galaxy formation and evolution (e.g., White & Rees, 1978), merging could have been much more frequent in the past. And indeed in the last decade, a population of interacting and star-forming galaxies have been discovered at redshifts $z > 1$ in deep fields (e.g., the HDF-N and -S), the most famous objects of this type being the so-called Lyman Break Galaxies (Steidel et al. 1996).

Thanks to their proximity, local starbursts offer a unique laboratory where to perform high resolution and sensitivity multi-wavelength studies of all those phenomena related to SF, evolution of massive stars, and physics of the ISM (chemical enrichment, gas kinematics, and mixing). These detailed studies
provide a precious tool with which observations of higher redshift star-forming galaxies can be better interpreted (e.g., local systems as templates). They also allow us to better understand the connection between the low- and high-redshift Universe and the processes involved in the origin and evolution of galaxies.

Starbursts are characterized by the presence of a large reservoir of HI which is a fundamental component for the onset of the SF process. Recently, FUSE and STIS have offered the unique possibility to characterize in great detail the neutral ISM in nearby systems by offering access to the plethora of absorption lines arising from the most common heavy elements in the UV. A multi-component fitting technique is usually applied to absorption lines in order to infer the column densities of heavy elements and determine metal abundances. The relative abundances of metals which originate in different types of stars, are like the fossil record of the past SF history of a galaxy, the neutral gas tracing a more ancient past than the ionized gas in the H\textsc{ii} regions due to larger timescales of the mixing processes that come into play. Different abundance patterns in the neutral ISM are thus expected depending on the past SF history of the galaxy.

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 \(~90\) (60) ksec in the LiF (SiC) channels. The LWRS aperture (30"\times30") was used to cover the whole body for a resolution of \(~35\) 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).

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

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
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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 α 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 is the ISM metal abundance. 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 ∼ 21 ksec, a resolution of ∼ 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 ∼ 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 km/s) as inferred by the stellar C III line at 1175 Å, and the second at the velocity of the warm photoionized gas (v = 580 km/s) as detected in absorption through C III or N 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).

Table 2. Interstellar Abundances in NGC 1705

| Element | Ion     | [X/H]_{ISM, total} | [X/H]_{ISM, neutral} | [X/H]_{H\textsc{ii}} |
|---------|---------|--------------------|----------------------|----------------------|
| O       | O\textsc{i} | $-1.19 \pm 0.01$   | ...                  | $-0.48 \pm 0.05$     |
| Ar      | Ar\textsc{i} | $-1.11 \pm 0.04$   | ...                  | $-0.61 \pm 0.10$     |
| Si      | Si\textsc{ii} | $-0.90 \pm 0.01$   | ...                  | ...                  |
| Mg      | Mg\textsc{ii} | $-1.41 \pm 0.12$   | ...                  | ...                  |
| Al      | Al\textsc{ii} | $-1.14 \pm 0.04$   | $-1.36 \pm 0.05$     | ...                  |
| N       | N\textsc{i}   | $-1.79 \pm 0.03$   | $-2.29 \pm 0.06$     | $-1.51 \pm 0.08$     |
| Fe      | Fe\textsc{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 local starburst galaxies is probably one of the unexpected great results of the last 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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