IS THE INTERSTELLAR GAS OF STARBURST GALAXIES WELL MIXED?

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Abstract  
The extent to which the ISM in galaxies is well mixed is not yet settled. Measured metal abundances in the diffuse neutral gas of star–forming gas–rich dwarf galaxies are deficient with respect to that of the ionized gas. The reasons, if real, are not clear and need to be based on firm grounds. Far-UV spectroscopy of giant H\textsc{ii} regions such as NGC604 in the spiral galaxy M33 using \textit{FUSE} allows us to investigate possible systematic errors in the metallicity derivation. We still find underabundances of nitrogen, oxygen, argon, and iron in the neutral phase by a factor of $\sim 6$. This could either be explained by the presence of less chemically evolved gas pockets in the sightlines or by dense clouds out of which H\textsc{ii} regions form. Those could be more metallic than the diffuse medium.

Keywords:  
ISM:abundances - galaxies:starburst - galaxies:ISM - H\textsc{ii} regions

Introduction  
The fate of metals released by massive stars in H\textsc{ii} regions where stars are forming is not yet settled. Kunth & Sargent (1986) have suggested that the H\textsc{ii} gas can enrich itself with metals expelled by supernovæ and stellar winds during the timescale of a starburst. However ionized regions in the LMC and SMC present very little dispersion in their metal content while X-ray studies show that metals reach the halo of galaxies in a hot phase before they could cool down and finally mix within the ISM in a few $10^9$yr. While H\textsc{ii} regions abundances derived from optical emission-lines are usually believed to be representative of the metallicity of extragalactic regions, the derived abundances
would not necessarily reflect the actual abundances of the ISM if H\textsc{ii} regions are self-polluted.

Blue compact dwarf galaxies (BCDs) are prime targets for the study of their neutral gas using far-UV absorption lines. These galaxies are thought to be chemically unevolved and the outskirts of their neutral cloud could still be pristine. The fate of the newly–produced metals in these objects is not clear. A possibility is that, once released by massive stars they remain in a hot phase, being unobservable immediately through optical and UV emission lines (Tenorio-Tagle 1996). On the other hand, Kunth & Sargent (1986) suggested that heavy elements released by supernovae lead to a prompt self–enrichment of H\textsc{ii} regions in the timescale of a star–formation burst. This is supported by Recchi et al. (2001) model by which most of the newly–synthetized metals mix within the cold gas phase in a few $10^6$ years (Myr). Tenorio-Tagle (1996) and Recchi et al. (2001) models differ in the delay between the release and the final mixing, which can reach several $10^9$ years (Gyr) in the first case but only several $10^6$ years (Myr) in the second.

A real surprise came from recent FUSE study of five BCDs, I Zw 18 (Lecavelier et al. 2004 and Aloisi et al. 2003), Markarian 59 (Thuan et al. 2002), I Zw 36 (Lebouteiller et al. 2004), and SBS 0335-052 (Thuan et al. submitted). In these objects, nitrogen is systematically underabundant in the neutral phase as compared with nitrogen abundances derived from the ionized gas (see Fig.1). Oxygen is either identical in both the ionized and neutral phases or deficient in the H\textsc{i} gas. The overall picture brings a new view into the chemical evolution of the ISM in a galaxy. However it is possible that these results suffer from many uncertainties such as ionization corrections, depletion effects or systematic errors due to both multiple sightlines and multiple H\textsc{ii} regions within the slit.

In this context, nearby giant H\textsc{ii} regions provide a much simpler case since only one region falls into the aperture, reducing possible systematic errors. The study of NGC604 presented here is part of a larger project involving several nearby giant H\textsc{ii} regions.

1. **The case of NGC604**

The FUSE observations (LWRS and MDRS apertures) allow us to determine the chemical composition while the HST/STIS spectrum gives the possibility to map the neutral gas inhomogeneities and investigate possible multiple line of sight effects.

**Data analysis**

Data analysis has been performed using the profile fitting procedure Owens developed at the Institut d’Astrophysique de Paris by Martin Lemoine and the
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Figure 1. Comparison of log(X/H) in BCDs (left) and in NGC604 (right) between the neutral gas abundances derived from absorption-lines with FUSE (in grey) with the H\textsc{i} gas abundances derived from optical emission-lines (in black). Errorbars at 2\sigma. References for ionized gas values: Izotov et al. (1997) for BCDs, Esteban et al. (2002) for NGC604. References for neutral gas values: Lecavelier et al. (2004) for IZw18, Lebouteiller et al. (2004) for IZw36, Thuan et al. (2004, in preparation) for SBS0335-052, Thuan et al. (2002) for Markarian 59 and Lebouteiller et al. (2004, in preparation) for NGC604.

\textit{FUSE} French Team. This program returns most likely values of many free parameters such as heliocentric velocities, turbulent velocities, or column densities by a $\chi^2$ minimization of absorption lines profiles. Errors on parameters include uncertainties on all the free parameters, in particular the position and shape of the continuum.

We checked the shape of the adopted continuum by comparing the observed spectrum with a theoretical model of young stellar populations. No significant difference is found between the model and the continuum we adopted for the profile fitting. Moreover, by comparing the data with the model, we find no significant contamination of neutral interstellar lines by stellar atmospheres.

By investigating the two \textit{FUSE} observations, we show that an additional broadening of the lines can account for the spatial distribution of the bright sources within the slit. The column densities we derive account for this extension. For the first time, we could check saturation effects for O\textsc{i} and Fe\textsc{ii} lines by analyzing lines independently. We find no correlation between column densities derived from each line with the oscillator strength, implying that saturated O\textsc{i} and Fe\textsc{ii} lines in those spectra do not give systematic errors.

\textbf{Neutral gas inhomogeneities}

The high spatial resolution of the HST/STIS spectrum of NGC604 gives the possibility to extract spectra towards individual stars of the ionizing cluster (Bruhweiler et al. 2003). So far, we have analyzed three sightlines from which we have measured H\textsc{i} column density using the Lyman $\alpha$ line. We find spatial variations (up to 0.4 dex) suggesting inhomogeneities of the diffuse neutral gas.
This could be a source of systematic errors when determining global column densities from a spectrum of a whole cluster.

We built the global spectrum (i.e. the mean spectrum of all sightlines, weighted by star magnitudes) of the HST/STIS observation to mimic the spectrum of a cluster in order to compare the real mean column density we want to determine with the weighted mean we actually measure. Preliminary results show that we could tend to underestimate the actual column density when analyzing a global spectrum of several sightlines towards clouds having different physical properties.

2. Results and conclusions

Within errorbars, we derive similar column densities with the two FUSE apertures (see Fig. 1). By modelling the ionization structure of the H\textsubscript{II} gas with the photoionization code CLOUDY, we find that N\textsubscript{i} and O\textsubscript{i} are good tracers of the neutral gas, contrary to Ar\textsubscript{i}, Fe\textsubscript{ii}, and Si\textsubscript{ii} which require ionization corrections to obtain final abundances shown in fig. 1.

We find that N, O, Ar, and Fe are underabundant by approximately the same factor ∼6 in the neutral phase of NGC604. Whatever the correct interpretation is, the fact that all specie are equally deficient as compared to that of the H\textsubscript{II} gas regardless their stellar origin (primary or secondary) is not in favor of the self-pollution explanation. These results could alternatively favor the presence of less chemically evolved gas pockets in the sightlines, which would tend to dilute the metallicity measured in front of the H\textsubscript{II} region, or that dense clouds out of which H\textsubscript{II} regions form could be more metallic than the diffuse ISM.

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