OVRO Observations of Molecular Gas in Dwarf Galaxies

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Abstract

Although dwarf galaxies have proven to be difficult to observe in the CO(1–0) line emission, high–resolution follow–up observations of the ones detected in single dish studies are enlightening: the distribution of molecular gas can be compared to the neutral as well as the ionized phase of the interstellar medium (ISM) at similar resolution, allowing to study the interplay of violent star formation with its surroundings. In addition, high velocity as well as spatial resolution observations can be used to determine the 'infamous' conversion ('X')–factor in low–metallicity dwarf galaxies which relates the total molecular mass to the observed CO intensity. E.g., a possible dependence of the conversion factor on metallicity would have important consequences for deriving molecular gas masses of young galaxies at high redshift. We present new, high–resolution CO(1–0) observations of nearby dwarf galaxies obtained with the OVRO millimeter interferometer. Based on our recent OVRO observations we show that the X–factor can not be a strong function of metallicity only. The OVRO maps also reveal an unexpected structural wealth when compared to observations at other wavelengths, stressing the irregular nature of dwarf galaxies.

1 The Crux with CO and $X_{\rm CO}$ in Dwarfs

The CO to H_2 conversion factor ($X_{\rm CO}$) is widely used to derive molecular masses from observed CO intensities, even in galaxies so distant that the masses of individual giant molecular clouds cannot be determined independently (using, e.g. the virial theorem). In recent years, evidence has accumulated that '$X_{\rm CO}$' as derived for our Galaxy (e.g. Strong et al. 1988), may not be generally applicable to other galaxies: it may be influenced by a number of properties such as density, the radiation field, or metallicity. Applying the Galactic value of $X_{\rm CO}$ may therefore result in erroneous estimates of the molecular gas mass, especially for metal poor systems (e.g. dwarf galaxies or galaxies at high redshift) or for galaxies where the average excitation conditions are different from those of the Milky Way (e.g. starburst systems). Regarding a possible change of $X_{\rm CO}$ with radiation field or metallicity, a few trends became apparent over the past few years: e.g., based on a study of a few Local Group galaxies, Wilson (1995) showed evidence for a relationship between the conversion factor and galaxy's metallicity. Taylor et al. (1998) have shown that dwarf galaxies with metallicities below 15% solar have not been detected so far in single dish studies. However, these trends have to be taken with caution since they are only based on a few galaxies. To shed more light on the possible dependence of $X_{\rm CO}$ with metallicity, and to reveal the spatial distribution of molecular gas in dwarf galaxies, we have observed a carefully chosen sample of nearby dwarf galaxies with the OVRO millimeter interferometer.

"Dwarf Galaxies and their Environment"; Bad Honnef, Germany, 23-27 January 2001; Eds. K.S. de Boer, R.-J.Dettmar, U. Klein; Shaker Verlag

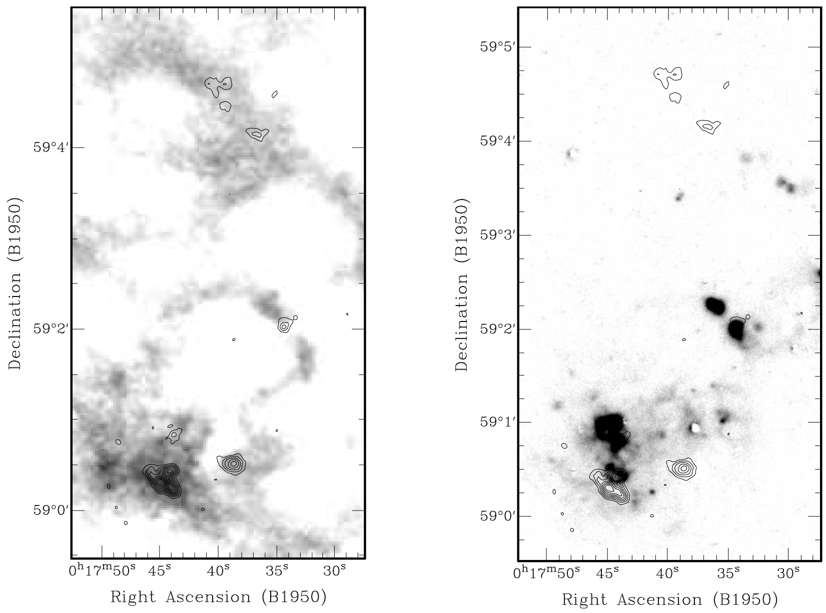

Figure 1: The nearby 'benchmark' dwarf galaxy IC 10. The left hand panel shows the distribution of neutral gas (H I, Wilcots & Miller 1998) overlaid with the CO contours of our OVRO observations (5 pointing mosaic). The right hand panel displays the OVRO CO contours overlaid on an Hα image of IC 10. Note the presence of CO emission in the north, far off any ongoing star formation.

1.1 Sample selection

Unfortunately, there are only very few dwarf galaxies which are strong enough in CO(1–0) to be followed up with current interferometers (see Walter et al. 2001 for a 'complete' list). It should be stressed that, if one is interested in determining the X–factor to a reasonable degree of confidence one should at least be able to resolve giant molecular cloud comlexes (GMCs). These clouds have typical sizes of 50 pc and a reasonable resolution which can be reached with today's interferometers at 115 GHz in weak systems is of order $2''$. I.e., the galaxy under study should be closer than $\sim$4 Mpc to resolve the complexes. It is also important that, in order to resolve these GMCs with typical velocity widths of 2-7 km s^{-1}, a velocity resolution of least 1.2 km s^{-1} is needed. It should be also noted that a linear resolution of $\sim 2''$ is ideally suited for a detailed comparison of the position of the molecular gas with the neutral and ionized phases as traced by H I as well as Hα observations. In our ongoing program at OVRO we focus on 5 nearby dwarf galaxies: IC 10, a member of the Local Group (metallicity, 1/5 solar, D $\sim$0.7 Mpc), NGC 3077 and M 82, both members of the M 81 triplet (D $\sim$3.2 Mpc), NGC 3077–Phoenix (a molecular cloud comlex in the tidal arms of the M 81 triplet, Walter & Heithausen 1999) and NGC 4214 (metallicity: 1/5 solar, D $\sim$4.2 Mpc). For the sake of brevity, only the preliminary results for IC 10 and NGC 4214 are presented here.

2 The Targets

2.1 IC 10

Figure 1 shows the result of our recent 5–pointing OVRO mapping of IC 10 (velocity resolution: 0.6 km s^{-1}, linear resolution: $\sim$12 pc). The greyscale in the right panel is a representation of the Hα emission in this galaxy – the contours indicate the distribution of CO as revealed with the interferometer. The left panel shows the distribution of neutral hydrogen (HI) in the same region

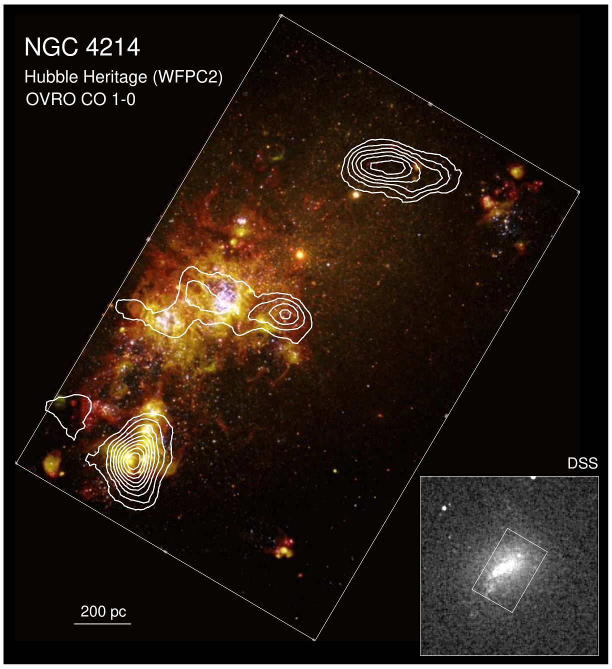

Figure 2: WFPC2 mosaic (HST) of NGC 4214. The inset in the lower right is an optical image of NGC 4214 from the digitized sky survey (DSS). The contours indicate the CO emission from our OVRO mosaic observations. Note that strong CO emission is associated with the southern star forming region. Only diffuse CO emission is found in the central, more evolved starburst. Strikingly, the northern molecular complex is not associated with any star formation.

(greyscale, see Wilcots & Miller 1998), the contours are again the OVRO observations.

The prominent southern molecular complex coincides with a major starburst region (and hence a strong radiation field). In clear contrast, the northern molecular complex is far away from any star formation. IC 10 therefore is a very nice target to study individual molecular clouds *within* one galaxy (at roughly the same metallicity and the same distance) under different environments (e.g., radiation fields). We discuss our preliminary determination of the X–factor in IC 10 below.

2.2 NGC 4214

NGC 4214 is a prototypical dwarf starburst galaxy. Figure 2 shows an overlay of the CO contours as observed with OVRO (3 pointings) on top of a multi–color WFPC2 mosaic obtained with HST. Interestingly, molecular gas is found to be associated with a young star forming region towards the south; diffuse CO emission is found near the central, more evolved star forming region. Strong CO emission is also found in the north where no signs of strong star formation are apparent. In that sense the situation is similar to IC 10: CO is not necessarily found near regions of ongoing star formation (see Walter et al. 2001a for the full description of these observations).

3 Conclusions / Some Surprises

Our preliminary analysis of the virial masses of individual molecular complexes in these metal–poor systems shows that the conversion factor is less than what one would expect based on previous studies. In Figure 3 we plot our newly derived X–factors as well as upper limits on top of a plot

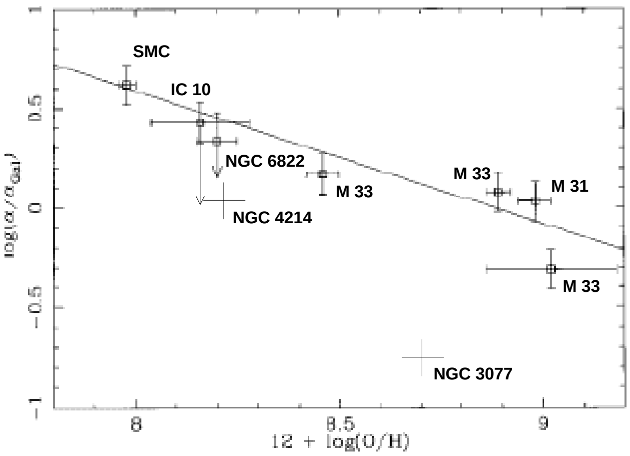

Figure 3: The conversion factor X (=α, α_0=Galactic value) as a function of metallicity (oxygen abundance) plotted for a few dwarf galaxies (adopted from Wilson 1995). The new values derived from our virial mass analysis in NGC 3077, NGC 4214 and IC 10 are added. A clear relationship between the conversion factor and the metallicity is not apparent from this plot.

previously presented in Wilson (1995). Based on the new data points, it seems obvious that the previously indicated relation between the conversion factor and the metallicity is not strong. It is clear that the conversion factor apparently changes from galaxy to galaxy, however the different metallicities can not be the only cause.

In summary, our high–resolution OVRO observations of molecular gas in metal–poor dwarf galaxies reveal a rather unexpected structural wealth and give important insights to the irregular nature of dwarf galaxies – they serve as a good excuse to map similar low–metallicity systems with interferometers in the future. A larger sample of interferometric observations of dwarf galaxies will also help to derive a possible dependence (or non–dependence) of the conversion factor with metallicity to a higher degree of certainty.

Acknowledgements

I would like to thank Nick Scoville and Anneila Sargent for their continous support and acknowledge NSF grant AST96–13717. This work would not have been possible without the contributions by C. Taylor, A. Weiss, C. Martin, N. Scoville, S. Hüttemeister, V. McIntyre and B. Miller.

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