Where is the CO in Dwarf Galaxies?

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1 Introduction

A primary goal of extragalactic astronomy is understanding galaxy evolution. To this end, studying the molecular gas content is vital; galaxy evolution is driven by the evolution of the stellar populations, and those stars are formed from the molecular ISM. For dwarf galaxies, however, observations of the molecular ISM have been problematic, as the primary tracer of molecular gas, CO, is hard to detect in dwarfs. This had been ascribed to a genuine lack of molecular gas in dwarf galaxies, but the fact that many dwarf irregulars and blue compact dwarf galaxies exhibit relatively high rates of star formation suggests otherwise. It is now more common to argue the low metal abundance of dwarfs is behind their low detection rate in CO emission; with less C and O available, they have less CO per mass of H_2 than metal rich systems.

2 Recent Work on CO in Dwarfs

In recent years there has been a revival of interest in molecular gas in dwarfs (e.g. Taylor et al. 1998, Petitpas & Wilson 1998, Walter & Heithausen 1999, Taylor et al. 1999, Barone et al. 2000). Taylor et al. (1998) found evidence that the integrated CO intensity in dwarf galaxies depends upon their metal abundance (measured by oxygen abundance). They also found that below a certain metallicity, $\sim 12 + \log(O/H) = 8.0$ (about 0.1 solar), CO (1-0) emission is no longer detected in dwarfs, despite very deep integrations (Figure 1). These data are consistent with a metallicity dependent CO-H_2 conversion factor.

Norman & Spaans (1997) modeled the formation of H_2 in young galaxies, finding that CO emission is not expected at very low metallicities. They argued CO emission will not be detected until the metallicity reaches somewhere between 0.03 to 0.1 of solar metallicity, when there exist enough species like C, O, and CO for the ISM can cool to temperatures < 300 K. The metallicity of this transition corresponds closely to that of the observed cutoff of Taylor et al. (1998).

In the cases where CO emission is detected with single dishes, observations with interferometers reveal a wealth of structure (e.g. Walter et al. 2001, Taylor et al. 1999). For the most nearby galaxies the current interferometers offer high enough spatial resolution to resolve individual giant molecular clouds (GMCs) (e.g. Wilson 1995, 1994; Wilson & Reid 1991; Ohta 1992). In such cases it is possible to use the virial theorem to estimate the CO-H_2 conversion factor (see the contribution of Hüttemeister in this volume for more on the perils of this calculation).

An example of what can be done is presented in Figure 2: the integrated intensity map of CO (1-0) emission from Plateau de Bure observations of the nearby dwarf galaxy NGC 1569 (Taylor et al. 1999). The CO contours are superposed over an HST WFPC image. Five GMCs are resolved (the southern clump resolves into distinct clouds in velocity). The lack of a correlation between the optical and molecular components in the galaxy is interesting; neither the two super star clusters,

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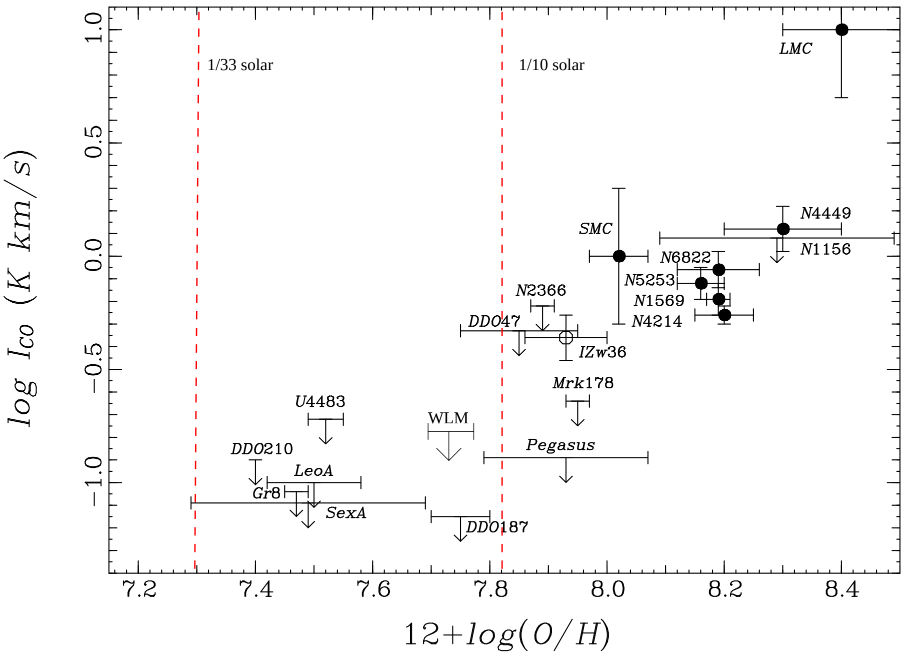

Figure 1: *From Taylor et al. 1998:* Log $I_{\rm CO}$ vs. oxygen abundance for gas rich dwarfs within 10 Mpc that have both CO and oxygen abundance measurements. The filled circles denote detections of greater than 4σ significance. The vertical lines show the range predicted by Norman & Spaans (1997) for the lower limit in metallicity at which the ISM can cool down to below 300 K and CO emission might be detected. This range corresponds closely to the the lower limit in metallicity at which Taylor et al. (1998) no longer detect CO in dwarf galaxies.

nor most of the HII regions correlate spatially with the GMCs. The HI is also not well correlated with the CO – Israel & van Driel (1990) report a small hole in the HI distribution centered on SSC A, about 200 pc in diameter. The CO emission is outside this hole and not part of any swept up material. It is also not associated with the peaks in the HI column density.

A similar case is that of the star bursting dwarf galaxy NGC 4214. OVRO observations by Walter et al. (2001; see also Walter in this volume) found CO emission associated with a strong central starburst, and with a younger star forming region. However, a third CO emitting region contains no young stars at all. This third region does coincide with a secondary peak in the HI column density, but there are several such peaks which appear to have no CO emission. By the "standard" criteria for searching for CO emission, this third region would have been missed, as it has no nearby star formation, nor is it near the global peak of the HI column density.

This behavior is observed in another dwarf galaxy, Local Group member IC10. In a multi-transition study of CO emission, Taylor et al. (2001, in prep.) have found CO emission from a area devoid of star forming regions. The HI column density at this location is only half that of the main starburst region. Furthermore, an additional CO emitting region was discovered to be very strong in the (3-2) line observed at the Heinrich Hertz Telescope, but was not found at all in a map of the (1-0) emission obtained at the FCRAO 14m telescope. Targeted interferometer observations (Walter & Taylor 2001, in prep.) revealed that there is in fact quite strong CO (1-0) emission at this location, only on size scales so small that the 44″ beam at FCRAO suffered considerable beam dilution. The resolution at the HHT in the (3-2) line is more than a factor of two better, and so suffered much less beam dilution.

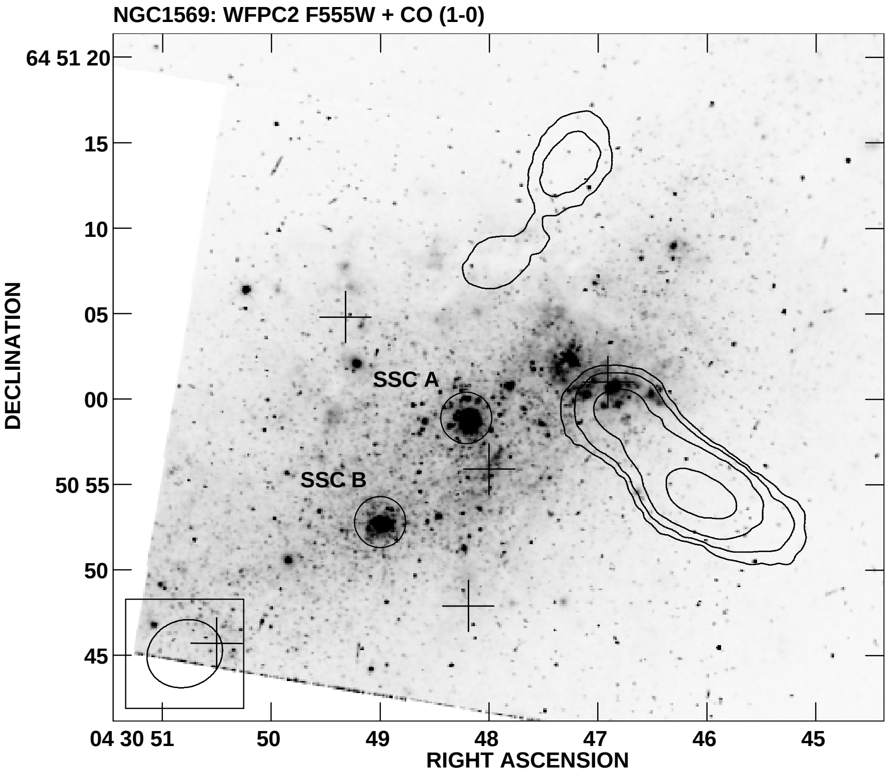

Figure 2: *From Taylor et al. 1999:* The CO (1-0) emission in NGC 1569 observed with the IRAM interferometer, superposed over an HST WFPC image. The circles show the location of super star clusters, and the crosses indicate HII regions.

3 Where is the CO in Dwarf Galaxies?

The results from NGC 4214 and IC 10 suggest additional complications in efforts to observe CO emission in dwarf irregular galaxies:

- The CO emission may not be where people tend to point their telescopes. Because the signals are expected to be weak, mapping large areas is expensive in telescope time, thus many observations are limited to a few positions within a galaxy. But because these dwarf systems are *irregular* it is difficult to predict based upon the optical appearance (or even the HI distribution) of the galaxy where the CO emission may be.

- Beam dilution in the large beams may hide CO emission. Because of their lower metallicities, the size of CO emitting zones in GMCs of dwarf galaxies will be smaller than in GMCs in spirals. In addition, dwarfs will have fewer GMCs than spirals, so it is easy to see how a telescope beam placed on a dwarf galaxy could contain fewer GMCs that are smaller in size than for a comparable observation of a spiral galaxy.

To address these issues, observations of Holmberg II, a dwarf irregular in the M81 group, have been undertaken using the SEQUOIA focal plane array on the FCRAO 14m telescope. SEQUOIA offers a $6' \times 6'$ field of view, so there is no question of biasing the observations towards only a few lines of sight in a galaxy. Figure 3 shows the area mapped in CO(1-0) using SEQUOIA. Holmberg II was chosen because it is nearby ($\sim$ 3 Mpc), more metal rich than IC 10, and has plenty of star formation ($\sim$ 0.2 to 0.5 times that of IC 10). It ought to be detectable in CO, but never has been (Brouillet 1999, priv. comm.). We have made two tentative detections, in locations distant from the star forming regions near the galaxy center. These tentative detections are at different velocities from the HI at these locations, so they may not be real. If they are not real, then we are left with the question of why such a metal rich system actively forming stars has no detectable CO emission? The answer may be that the emission is present, but on such small scales that beam dilution renders it undetectable. To put this idea to the test, a mosaiced map with a millimeter interferometer is necessary.

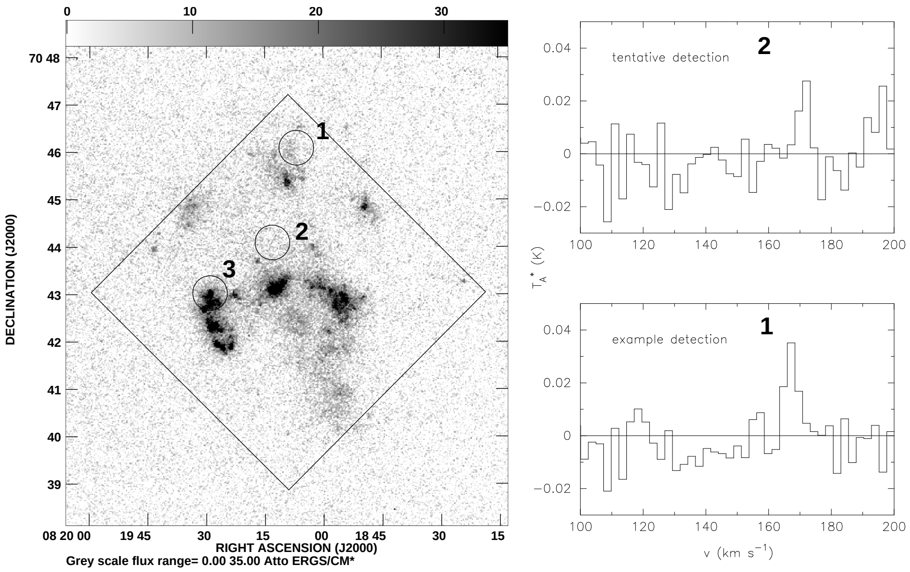

Figure 3: *Left:* A far UV image of Holmberg II from Stewart et al. (2000) with the $6' \times 6'$FOV of SEQUOIA superposed. The circles labeled 1 and 2 show the locations of tentative CO detections. *Right:* CO(1-0) spectra from the locations of the tentative detections.

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