PANEL DISCUSSION: THE STATISTICAL ACCURACY OF GLOBAL MOLECULAR GAS MASS DETERMINATIONS FOR SPIRAL GALAXIES

N.A. DEVEREUX and J.S. YOUNG
Department of Physics and Astronomy and
The Five College Radio Astronomy Observatory
University of Massachusetts, Amherst, MA 01003 USA

ABSTRACT. Empirical evidence is presented supporting the use of a constant Galactic CO-H_2 conversion factor to derive global H_2 masses for luminous spirals which are accurate to +/-30%.

1. Discussion

In order to empirically constrain the accuracy of global molecular gas mass determinations for spiral galaxies, we have compared three independently derived quantities, the atomic gas mass [M(HI)] derived from the 21 cm line, the molecular gas mass [M(H_2)] derived from the CO J=1-0 line, and the warm dust mass [M_{dust}] derived from the IRAS 60 and 100 μm flux densities (Devereux and Young 1990). Figure 1 shows the comparison of the inner disk ($R<R_{25}/2$) gas masses and warm dust masses for 58 galaxies included in the FCRAO Extragalactic CO Survey for which HI distributions are reported in the literature. The inner disk HI gas is included in the comparison because the HI-associated dust which is coextensive with the inner disk star forming regions undoubtedly contributes to the warm dust emission detected by IRAS (Boulanger and Perault 1988).

That aspect of Figure 1 which is most important for the present discussion is *not* the correlation itself, but the *scatter* in the correlation. The scatter illustrated in Figure 1 is contributed both by measurement uncertainties for each of the three quantities *and* uncertainties in deriving the gas and dust masses from each of the observed quantities. The small scatter observed in the correlation between the inner disk gas mass and the warm dust mass constitutes the best evidence that the CO-H_2 conversion factor shows little variation among luminous spiral galaxies.

The dispersion in the ratio of inner disk gas to warm dust mass (hereafter referred to as the gas/dust ratio), derived for the galaxies in Figure 1, is +/-0.19 dex. This dispersion could represent a 44% uncertainty in any *one* of the three quantities in the ratio, *or* it could more reasonably represent a +/-30% measurement uncertainty in the molecular gas mass (Kenney and Young 1988), a +/-30% measurement uncertainty in the inner disk HI mass (S. Schneider, private communication), and a +/-10% measurement uncertainty in the dust mass (Rice *et al.* 1988). *It is significant that the small scatter in the gas/dust ratio can be understood in terms of measurement uncertainties.* Thus, all potential contributors to the scatter in the gas/dust ratio, including galaxy

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to galaxy differences in molecular cloud properties, metallicity, and in the fraction of the warm 30 K dust that radiates in the IRAS 60 and 100 μm bands, are presently too small to measure.

In Figure 1, we have differentiated between galaxies which are HI-dominated (filled circles) and those which are H_2-dominated (open circles). It is noteworthy that the dispersion in the gas/dust ratio for galaxies which are HI-dominated is the same as the dispersion in the gas/dust ratio for the galaxies which are H_2-dominated, indicating that the uncertainty in the gas and dust mass determinations is independent of the dominant gas phase. Thus, *gas masses are apparently as equally well determined from the CO J=1-0 emission line as from the 21 cm emission line.* Furthermore, the fact that the gas/dust ratio is similar for the HI-dominated and H_2-dominated galaxies supports the absolute value of the Galactic CO-H_2 conversion factor we have used to derive H_2 masses from the CO J=1-0 emission line. We emphasize however, that the uncertainty in the H_2 mass determinations of low luminosity ($<10^9$ L_o) dwarf systems and the ultraluminous galaxies ($>10^{11}$ L_o) may be higher due to the potential inapplicability of a Galactic CO-H_2 conversion factor.

The individual gas/dust ratios derived for the galaxies in Figure 1 range from 400 to 2400. If the gas to total dust ratio in the external galaxies has a value of 100 like the Milky Way, then the present results indicate that only 4-25% of the total dust mass in galaxies is warm enough to radiate in the IRAS 60 and 100 μm bands. The expectation is that adopting total dust masses will reduce the scatter in the gas/dust ratio even further, allowing a tighter constraint to be placed on the accuracy of global molecular gas mass determinations. In practice, however, the bulk of the dust in galaxies is expected to be cold (10-15 K). The determination of cold dust masses to a level of accuracy which is better than 30% may be difficult using ground based telescopes because it requires complete mapping of galaxies with very high sensitivity at submillimeter wavelengths. Such observations are best performed from space.

Although we find that the *global* CO-H_2 conversion factor has a 1σ variation of only +/-30%, we expect larger variations *within* galaxies, and in the extreme, from one molecular cloud to the next. As pointed out by Dickman *et al.* (1986), the CO-H_2 conversion factor depends on $T/\rho^{0.5}$, where T is the cloud brightness temperature and ρ is the cloud density. But, even within the central 1 kpc of M82, this ratio does not vary by more than a factor of 2 relative to the Galactic value. Thus, apparently the CO J=1-0 line can be used to measure reasonably accurate molecular gas masses even in the center of the most extreme starburst galaxy yet identified.

2. References

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Figure 1. (Left Panel) Correlation between gas masses in the inner disk ($R<R_{25}/2$) and warm dust masses derived from IRAS 60 and 100 μm flux densities (Devereux and Young 1990). The open circles identify galaxies for which the molecular gas constitutes >50% of the gas mass, while filled circles identify spirals for which atomic gas constitutes >50% of the gas mass. The solid line represents gas/dust=100 and the arrows identify spirals with 2σ upper limits, where the upper limits are due to non-detections of H_2. (Right Panel) Histogram illustrating the dispersion in the gas/dust ratio. The shaded portion of the histogram represents the HI-dominated galaxies. The numerical value of the dispersion is indicated by the value of σ, where the limits have been included at the 2σ value.