THE ^{12}CO(1-0) TO H_2 CONVERSION FACTOR IN NORMAL LATE-TYPE GALAXIES

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Abstract

The molecular gas mass in nearby galaxies is generally estimated using ^{12}CO(1-0) line intensities and assuming the X conversion factor between I(CO) and N(H_2) measured in the solar neighborhood. It is however known that this X conversion factor is not universal since it changes with metallicity, cosmic ray density and UV radiation field. Far-IR data in the spectral range 100-1000 μm can be used to estimate the molecular gas content of late-type galaxies in an independent way of CO line measurements once a constant dust to gas ratio is assumed, allowing a direct estimate of X. This exercise is presented here for a large sample of galaxies with available multifrequency data using ISOPHOT and IRAS far-IR data. This analysis, which is extremely useful to study the properties of the ISM of galaxies spanning a large range in luminosity and morphological type, is however limited by the lack of photometric data in the range 100 μm $\leq \lambda \leq$ 1000 μm, the spectral domain observed by FIRST.

Key words: Galaxies: ISM – Stars: formation – Missions: FIRST

1. Introduction

The importance of the molecular gas in the process of star formation resides in the fact that the atomic hydrogen has to condensate into molecular clouds to form stars. It is thus necessary to know the molecular gas content and distribution to study the activity of star formation in normal galaxies. Since the H_2 is not directly observable, indirect methods must be used. The molecular hydrogen content of galaxies is generally estimated:

- using the virial theorem in resolved molecular clouds; this method can be applied only in nearby, resolved galaxies where molecular clouds are spatially resolved. In the assumption that clouds are in virial equilibrium, the *total* (HI+H_2) mass of the cloud can be estimated from the virial theorem.
- in UV bright sources the molecular gas content can be measured from H_2 absorption lines in the far-UV, these being available for few galaxies thanks to FUSE observations.
- form ^{12}CO(1-0) line measurements using a *standard* X=N(H_2)/I(CO) conversion factor calibrated in the solar vicinity.

The first method is generally used to calibrate, in the solar neighborhood or in nearby galaxies, the CO to H_2 conversion factor. The assumption underlying a universal ratio X = N(H_2)/I(CO) between the intensity I(CO) of the ^{12}CO(1–0) line and the column density of molecular hydrogen N(H_2) is that CO and H_2 are contained in optically thick molecular clouds with a similar brightness in the ^{12}CO(1–0) line (Dickman et al. 1986). The distribution of the molecular gas over the disc of galaxies is however non uniform; the molecular gas might have a fractal distribution, where the density of the gas is significantly higher in the core than in the outer parts of the giant molecular clouds, and even higher than in the diffuse medium. The ^{12}CO(1-0) line being optically thick, the X = N(H_2)/I(CO) conversion factor can significantly change with the density of the molecular gas. This is confirmed by the measure of X in the Milky Way. Polk et al. (1988) have found a X=0.5 10^{20} mol cm^{-2} (K km s $^{-1}$) in the diffuse medium, and X=4.2 10^{20} mol cm^{-2} (K km s^{-1}) in the core of molecular clouds. The diffuse molecular gas is in fact dissociated by strong UV radiation fields (both CO and H_2 but with a variable ratio due to a more efficient self shielding of the molecular hydrogen with respect to CO), typical of low metallicity environments such as the ISM of dwarf irregular galaxies (Lequeux et al. 1994). Figure 1 shows the dependence of the X, determined from the virial theorem or other methods for few nearby galaxies, on the UV radiation field (as traced by the Hα E.W.), or the metallicity (12 +log O/H). Figure 1 shows how the X conversion factor in galaxies with intense UV radiation fields and low metallicities is on average a factor of 10 higher than in quiescent objects with solar metallicities such as the Milky Way or M31.

2. An alternative method

The determination of the molecular gas mass in galaxies of different type and luminosity using ^{12}CO(1-0) data and a constant value of X can introduce strong systematic errors. An alternative method has to be applied. Let us assume a metallicity dependent gas to dust ratio, calibrated on the Milky Way and on the Magellanic clouds. If we

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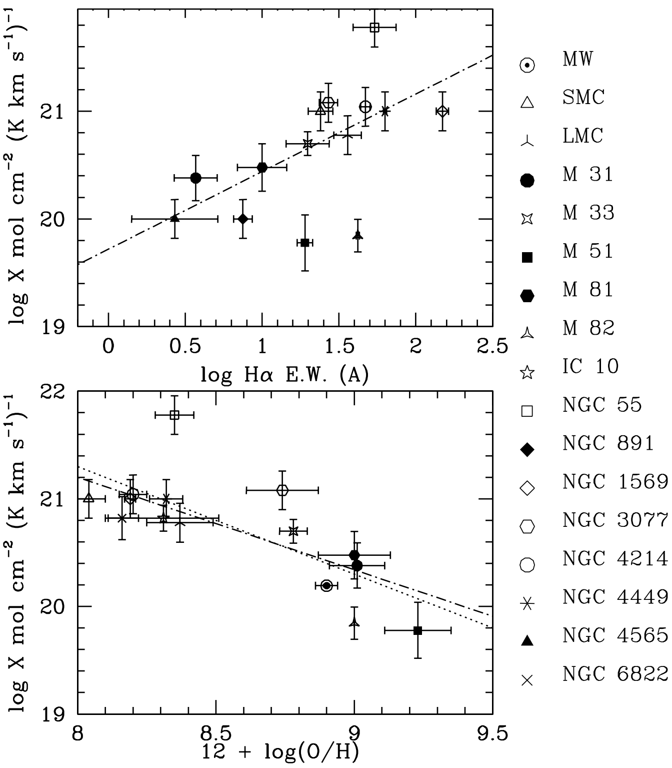

Figure 1. The relationship between the X conversion factor and the Hα+[N II]E.W. (top) and the metallicity index 12 + log(O/H) (bottom) for the sample of nearby galaxies. The dotted-dashed line is the best fit to the data; the dotted line is the best fit given by Arimoto et al. (1996).

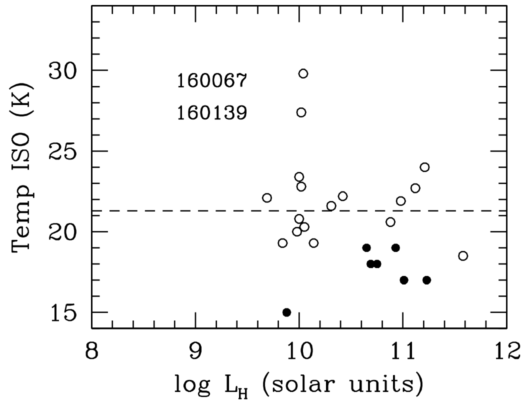

Figure 2. The relationship between dust temperature, as estimated from the ISOPHOT data at 100-200 μm and the H luminosity for the sample of galaxies observed by Contursi et al. (open dots) and Alton et al. (filled dots). The dashed line indicates the average value of T_{dust} (21.3 K)

know the HI column density, and we can estimate the cold dust mass using far-IR (100-1000 μm) data, the molecular gas mass can be derived assuming that the difference between the expected total gas to dust ratio and the measured HI to dust ratio is due to molecular hydrogen. This method has been succesfully applied to M51, NGC 891 and NGC 4565 (Guélin et al. 1993, 1995; Neininger et al. 1996)

Unfortunately far-IR data covering the whole spectral range 100-1000 μm are now only available for a few galaxies. Since the peak of the far-IR emission of normal galaxies is ~ 200 μm, data at $\lambda > 100$ μm are necessary to constraint the cold dust temperature, fundamental parameter in the determination of the cold dust mass. Some galaxies have been recently observed at 200 μm by ISOPHOT. The dust temperature of the normal galaxies observed by Alton et al. (1998) and Contursi et al. (2000) seems fairly constant in galaxies of different luminosity (Fig 2).

If we assume a constant cold dust temperature, T_{dust}=21 K, with dust distributed along a disc of comparable size than the optical disc we can estimate the total dust mass for thousands of objects observed by IRAS. This exercice is here done for 266 normal galaxies in the Coma/A1367 supercluster region and in the Virgo cluster with data available at other wavelengths (IRAS, HI, CO, Hα, metallicity, H band (1.65 μm); Boselli et al. 2001).

The dependence of X, as measured for our sample of 266 galaxies, on the UV radiation field (traced by the Hα E.W.) and the metallicity (12 +log O/H) is compared in Fig. 3 to that observed for the sample of nearby galaxies. Since lower metallicities and higher UV radiation fields are typical of dwarf galaxies, this implies a relationship between X and the H band luminosity and/or the B absolute magnitude (Fig. 4).

The relationships between X and the Hα E.W., the metallicity, the H band luminosity and the absolute B magnitude observed in the sample of nearby galaxies are valid, at least at the first order, also for the 266 objects in the Coma/A1367 supercluster and in the Virgo cluster. Since most of the nearby galaxies observed in CO do not have Hα and/or metallicity measurements, Fig. 4 can be used to universally calibrate X as a function of the absolute B magnitude and the H band luminosity, these last observables being available for most of the objects. This empirical calibration is useful to remove any first order systematic effect in the determination of the total molecular hydrogen mass of galaxies using CO line measurements.

The determination of the molecular hydrogen content using a constant gas to dust ratio can be done only once

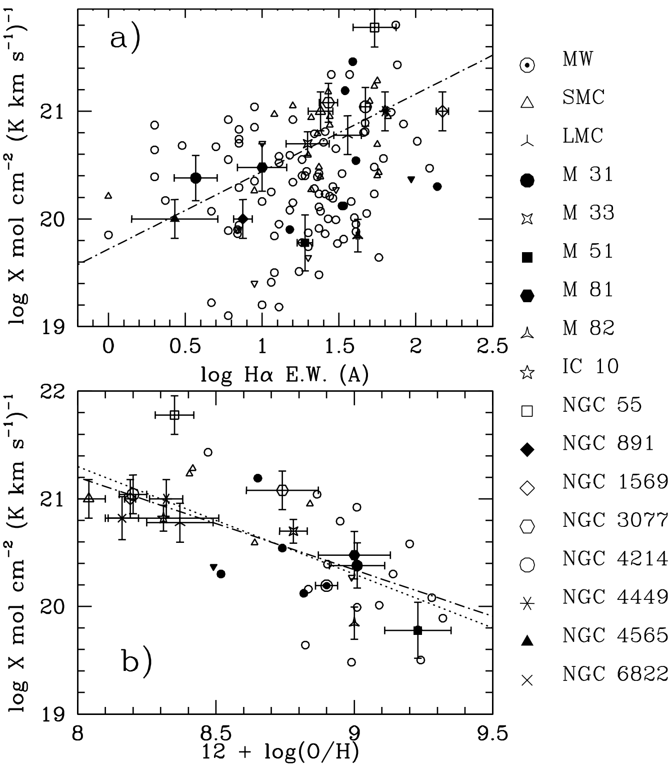

Figure 3. The relationship between the X conversion factor and a) the Hα+[N II]E.W., b) the metallicity index 12 + log(O/H) for the sample of galaxies in the Coma/A1367 supercluster and in the Virgo cluster (small symbols) compared to that observed for the sample of nearby galaxies.

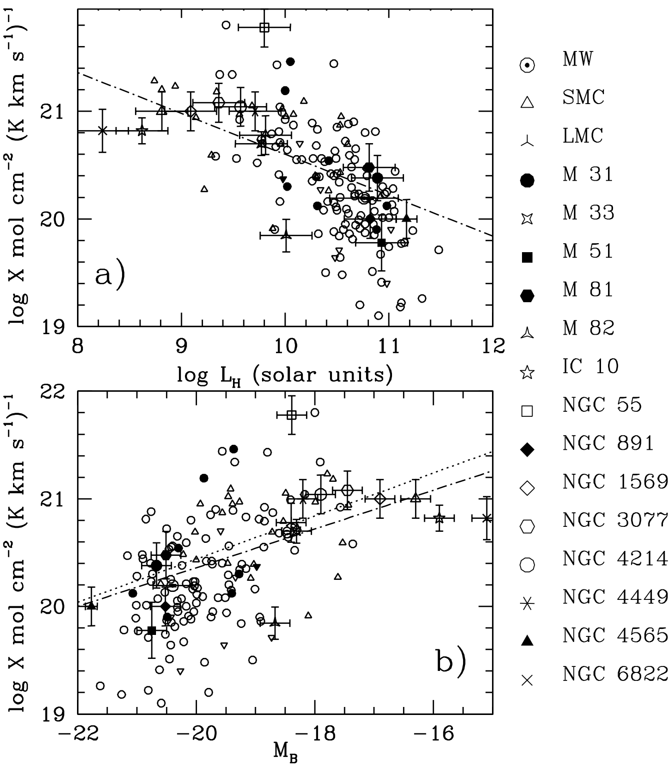

Figure 4. The relationship between the X conversion factor and a) the H band luminosity and b) the absolute magnitude for the sample of galaxies in the Coma/A1367 supercluster and in the Virgo cluster (small symbols) compared to that observed for the sample of nearby galaxies.

the total dust mass is accurately estimated. The dust mass strongly depends on the dust temperature T_{dust}, thus T_{dust} must be measured with high accuracy. Since in normal galaxies the peak of the dust emission is at ∼ 200 μm a full coverage of the 100-1000 μm spectral range is needed for an accurate determination of T_{dust}. Furthermore the dust column density can be exactly measured only once the dust distribution along the disc is known. Data at higher spatial and spectral resolution are thus needed to accurately characterise the physical properties (dust temperature, spatial distribution) in different types of galaxies.

This exercice, which looks very promising once far-IR data from future generation facilities such as FIRST will be available, is at present limited by the large uncertainty on the total dust mass determination from IRAS data. However, it can already be conclude that molecular hydrogen masses measured from CO data can be underestimated by a factor of ∼ 10 in low mass galaxies if a constand CO to H_2 conversion factor is used.

2.1. The contribution of FIRST

The FIRST satellite will provide a unique opportunity for studying the properties of the ISM of external, nearby galaxies. Joint PACS and SPIRE observations of large samples of nearby galaxies with available multifrequency data will allow to:

- accurately measure the SED in the wavelength range 100-1000 μm, thus correctly estimate T_{dust} and M_{dust} in hundreds of galaxies.
- see the dust distribution along spiral discs in resolved objects, and thus properly determine the dust column density.
- accurately estimate X in a statistical significant sample and to see using a multifrequency statistical analysis, how X changes with the physical properties of the ISM such as the UV radiation field and metallicity.
- see the radial variation of X on galactic discs, predicted from the metallicity and star formation gradients observed in spiral galaxies.

Altogether multifrequency data, including UV, optical, mid- and far-IR, radio continuum as well as single line measurements (Hα, CO, HI,...) will be useful to accurately characterize, on scales of ∼1 kpc, the physical properties of the ISM of a large sample of nearby galaxies spanning a large range in morphological type and luminosity. The statistical analysis of this large database will allow to put strong observational constraints on model of galaxy formation and evolution.

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