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Characterizing the Transition From Diffuse Atomic to Dense Molecular Clouds in The Magellanic Clouds with [CII], [CI], and CO

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[CII], [CI], and CO emission in the Magellanic Clouds

We present and analyze deep Herschel/HIFI observations of the [CII] 158μm, [CI] 609μm, and [CI] 370μm lines towards 54 lines-of-sight (LOS) in the Large and Small Magellanic clouds. These LOSs represent different stages of interstellar cloud evolution and have been chosen to study the formation and evolution of molecular clouds in metal poor galaxies. We complemented these observations with CO, Hα, and dust continuum data to determine the physical conditions of the line-emitting gas, which we use to study the transition from atomic to molecular gas and from C^+ to C^0 to CO in the low metallicity environments of the LMC and SMC.

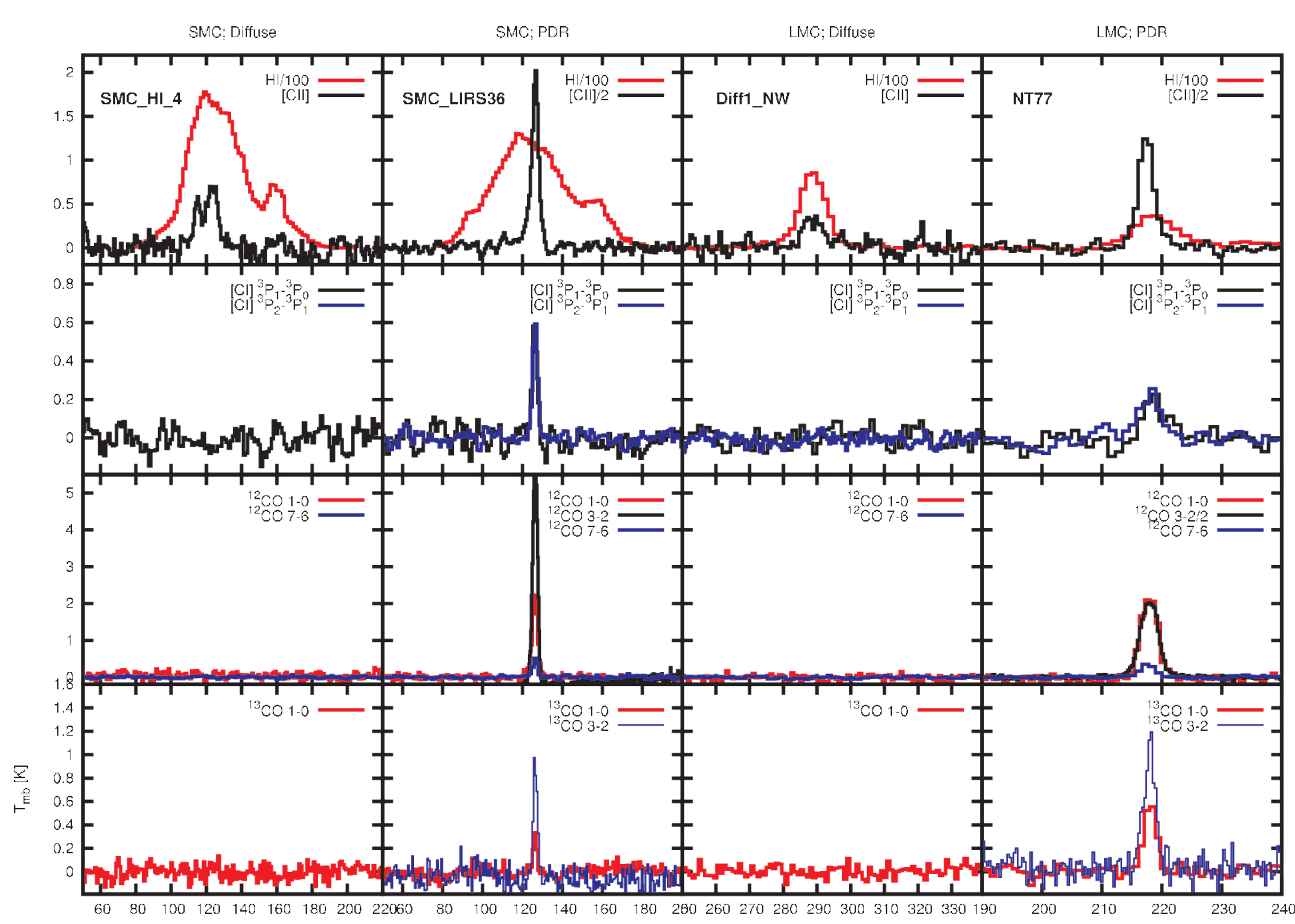

Figure 1: Sample spectra of ionic, atomic, and molecular species in the Large and Small Magellanic Clouds. We show examples of diffuse regions as well as of dense photon dominated regions.

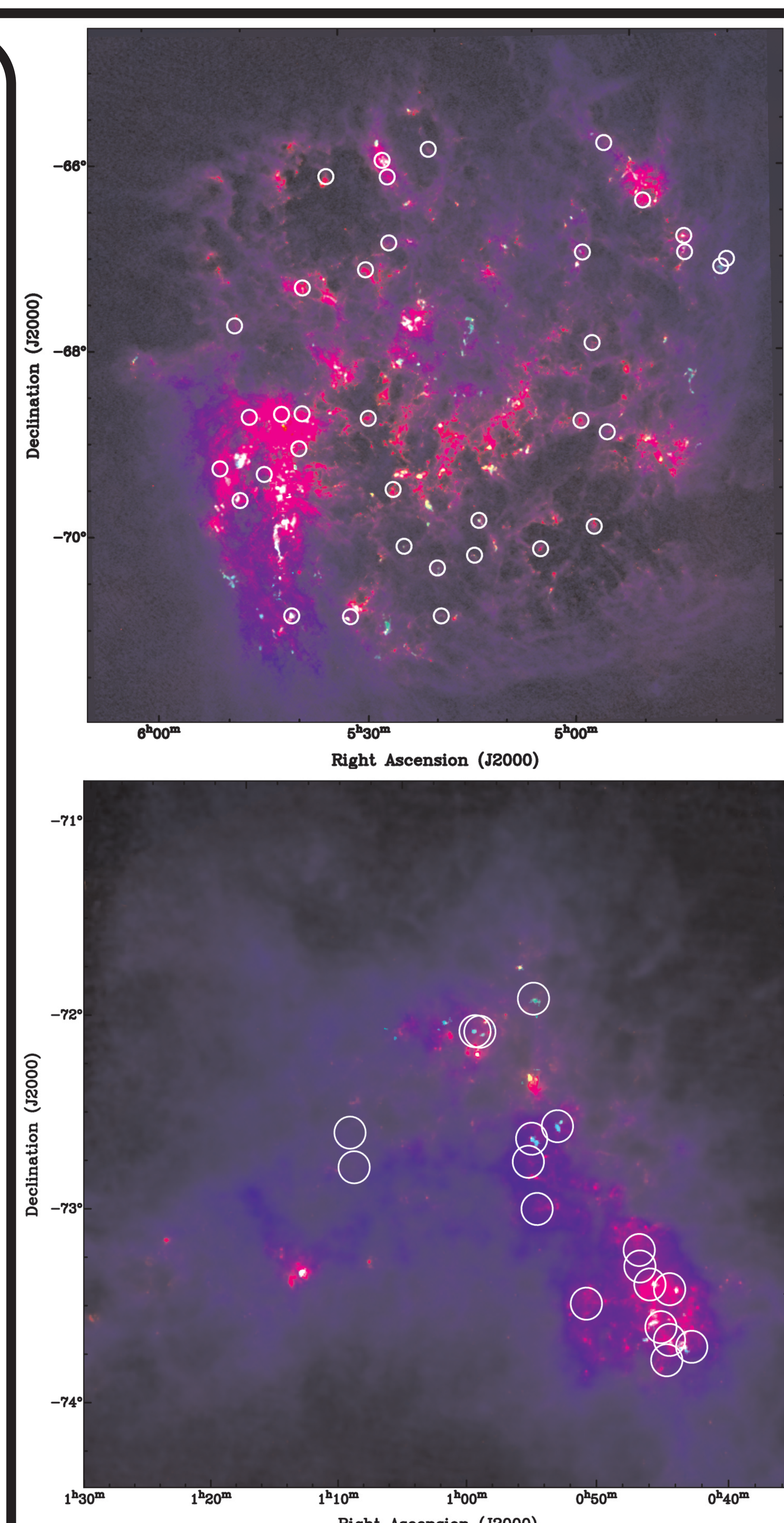

Figure 2: Images showing HI column density map, Herschel 160 μm continuum emission, and MAGMA CO line emission in the Large (top) and Small (bottom) Magellanic clouds. The white circles denote the positions studied in this poster.

Thermal Pressures of the Diffuse ISM in the LMC and SMC

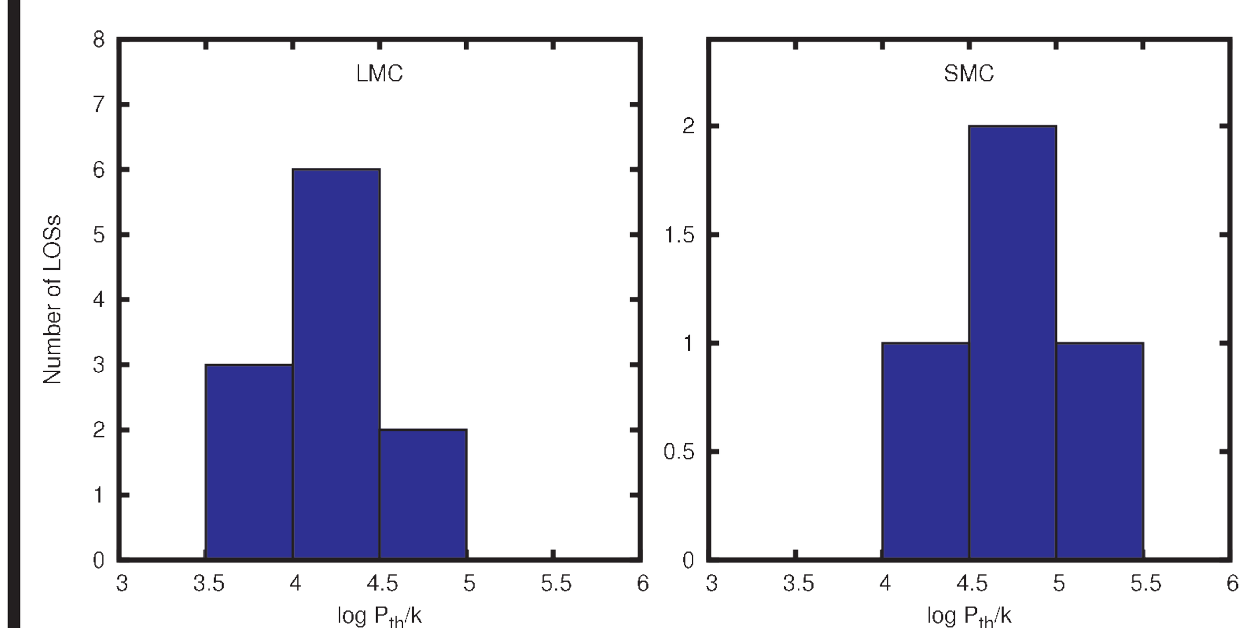

Figure 3: Histograms of the thermal pressure of the diffuse interstellar medium of the LMC and SMC.

Using lines-of-sight where only HI and [CII] emission were detected, and using a derivation of the visual extinction from dust continuum emission, we determine the thermal pressure of the diffuse ISM in the Magellanic Clouds. We show in Figure 3 histograms of the derived thermal pressures in the LMC and SMC.

We find the average thermal pressures of the diffuse ISM to be P_{th}/k_B=2.5x10^4 K cm^{-3} in the LMC and 8x10^4 K cm^{-3} in the SMC.

These thermal pressures are larger than those found in the Solar Neighboorhood (~3x10^3 K cm^{-3}; Jenkins et al. 2011) due to the enhanced FUV fields and lower dust abundances in the Magellanic clouds affecting the thermal balance.

The Origin of [CII] in our sample in the Magellanic Clouds

The observed [CII] emission arises from gas associated with hydrogen in the form of HI, H_2 , and H^+. We first modeled the HI and Hα emission in our sample to estimate the contribution from atomic and ionized gas to the observed [CII] emission. We often find [CII] residual emission which originates from molecular gas (CO-dark H_2). We used the association of [CII] with [CI] and/or CO emission to distinguish whether the [CII] emission originates from diffuse H_2 (CO-dark H_2) or from warm and dense H_2 (PDRs).

In LOSs associated with warm and dense PDRs, the [CII] emission from this ISM component tends to dominate. The contribution from CO–dark H_2 to the observed [CII] shows a large scatter, ranging from □10% to □80%. This large scatter could be a reflection of clouds at different stages of evolution, with different clouds having varying CO–dark H_2 fractions. We find that ionized and atomic gas have typically smaller contributions to the observed [CII] emission.

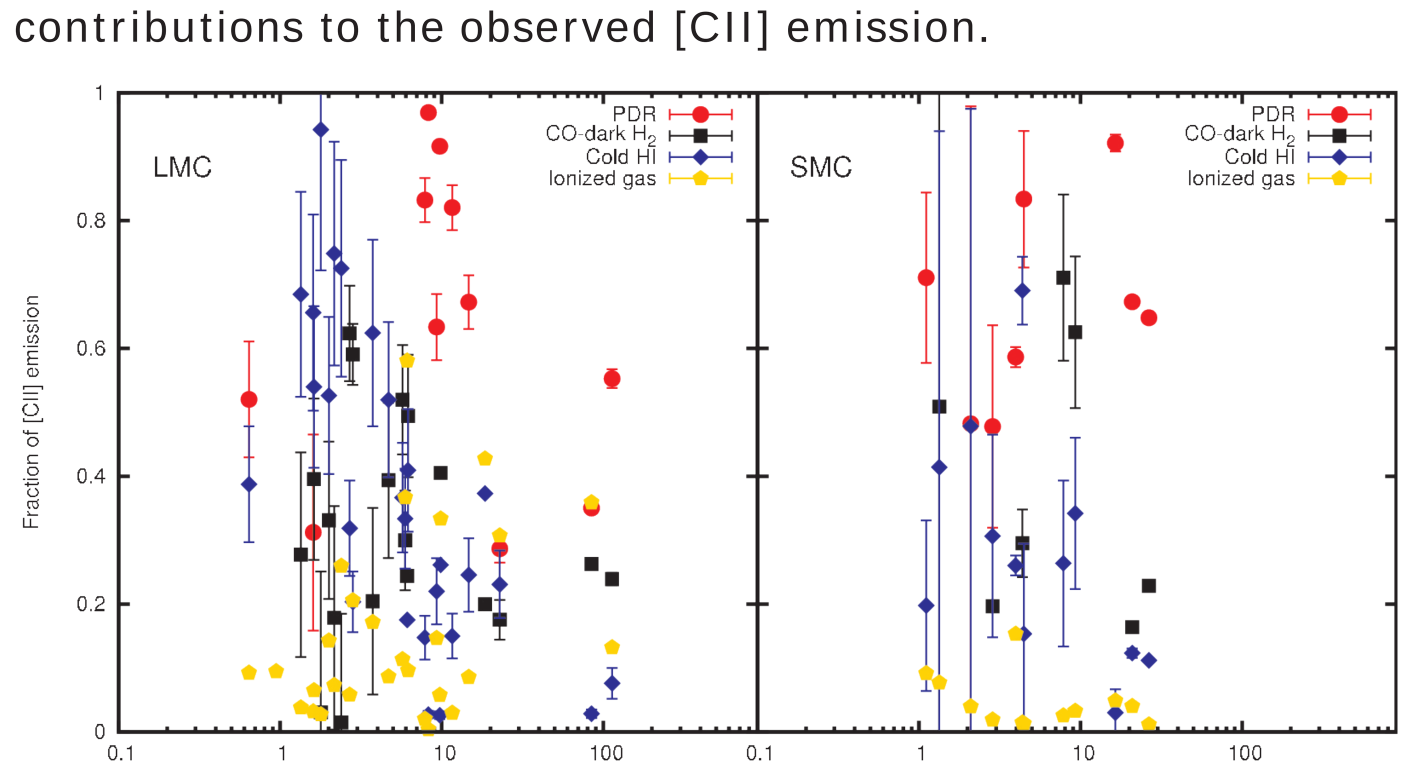

Figure 4: The fraction of the [CII] emission that we estimate arises from ionized gas, cold atomic gas, CO-dark H_2 , and photon dominated regions (PDRs) as a function of the observed [CII] emission in the LMC and SMC.

The H to H_2 Transition

We study the transition between atomic and molecular gas in the LMC and SMC by comparing the H_2 column densities of CO-dark H_2 and CO-traced H_2 with the total hydrogen, N(HI)+2N(H_2), column density. We show that the CO-dark H_2 represents an intermediate stage in cloud evolution between the diffuse H_2 detected with UV absorption and H_2 arising from well shielded regions (Figure 5).

With [CII] observations we can trace molecular gas with molecular fractions (f_{H2}=2N(H_2)/(N(HI)+2N(H_2)) in the range 0.1<f_{H2}<1, between those in the diffuse H_2 gas detected by UV absorption (f_{H2}<0.2) and well shielded regions in which hydrogen is essentially completely molecular (Figure 6). The [CI] and/or CO are only detected in regions with molecular fractions f(H_2)>0.5.

In Figures 5 and 6 we compare our data with predictions from the models of Sternberg et al. (2014) and McKee & Krumholz (2010) for Z'=0.26 and χ_0=1 for the LMC and Z'=0.1 and χ_0=2.8 for the SMC. We find that Sternberg et al. 2014 theoretical model is in better agreement with our observations than the Mckee & Krumholz (2010) model. The difference is mostly due to the influence of FUV absorption from dust associated with H_2 gas that is only considered in the Sternberg et al. (2014) model.

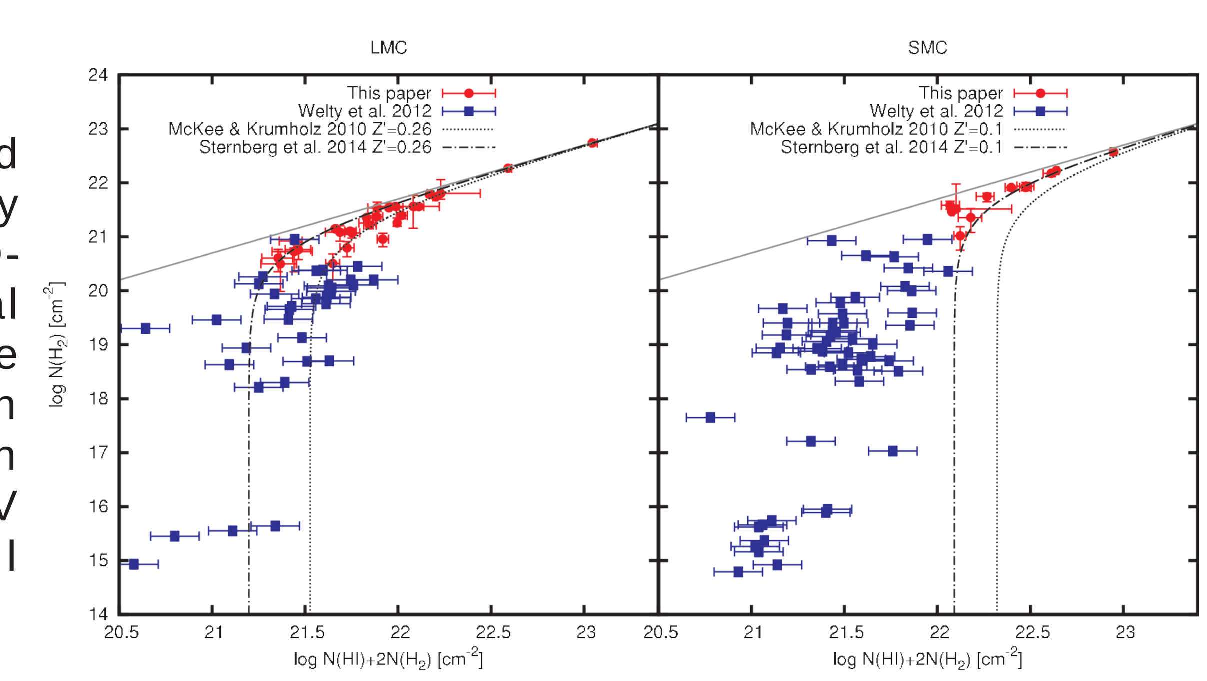

Figure 5: The column density of molecular hydrogen as a function of the total hydrogen column density, N(HI)+2N(H_2), for the values derived here and those observed in absorption in the FUV for H_2 and in the optical for HI compiled by Welty et al. 2012. The straight line represents a molecular fraction of f(H_2)=1.

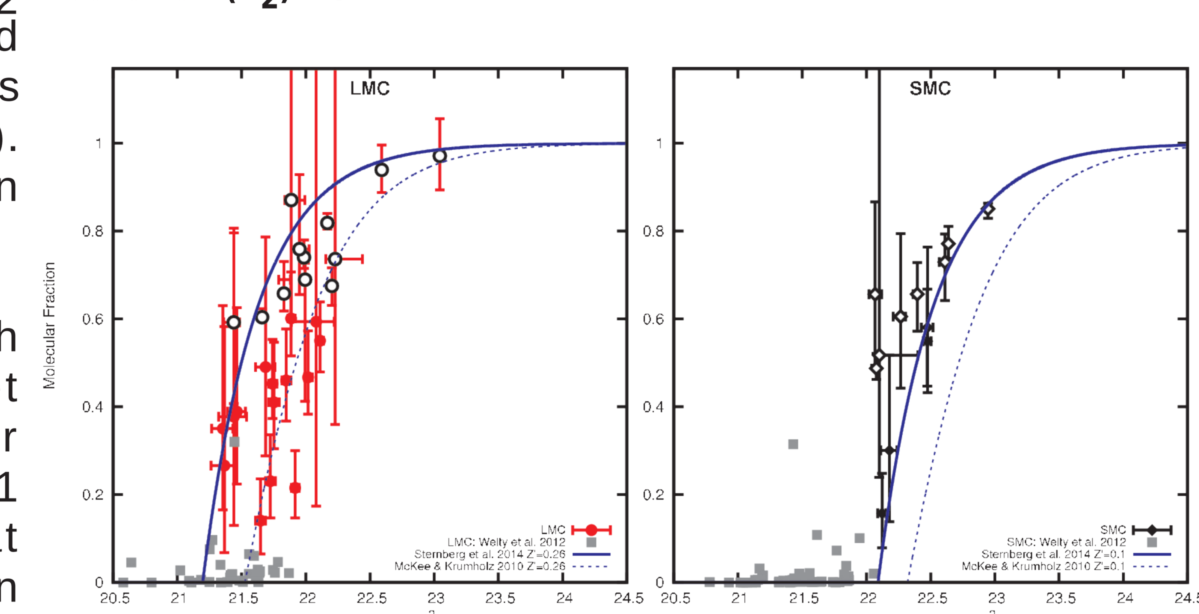

Figure 6: Molecular fraction as a function of the total hydrogen for the LMC and SMC. The filled circles and squares correspond to lines-of-sight where only [CII] is detected while the open circles and squares represent LOSs where [CI] and/or CO are detected. We also include molecular fractions calculated from the sample of column densities observed in absorption in the FUV for H_2 and in the optical for HI compiled by Welty et al 2012.

References

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For details see:
Pineda, J.L. 2016, ApJ, submitted

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