[CII] and Hydrogen Species in LITTLE THINGS Dwarf Galaxies: The Extremely Metal-Poor Regime

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ABSTRACT

Many FIR studies target systems that have typical or enhanced abundances of heavy elements, but what is the picture for the low-metallicity regime? We present a comparison of HI and [CII] observations for five extremely metal-poor dwarf galaxies from the LITTLE THINGS survey. The galaxies we discuss have 12+log(O/H) = 7.4 - 7.8 (5-13% solar), some of the lowest-metallicity galaxies observed in [CII]. Our galaxies are of particular interest because we probe the regime of normal and typical dwarfs, which exhibit much more moderate star formation than those observed in other Herschel programs. This is important because they represent a much larger fraction of the dwarf population, and because they probe quite different ISM conditions - namely, the combination of extremely low metallicity with reduced ionizing radiation and mechanical agitation from star formation. We note a generally linear relation between HI and [CII] surface brightness in our sample, and we explore avenues of quantifying the molecular species of hydrogen without the aid of CO, which is extremely difficult to detect in faint, metal-poor systems.

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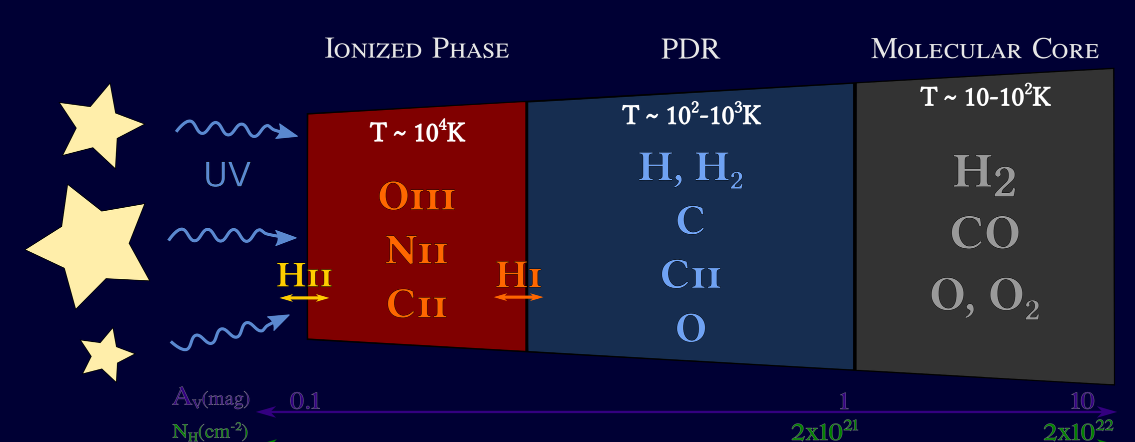
Motivation

The LITTLE THINGS (Local Irregulars That Trace Luminosity Extremes, The HI Nearby Galaxy Survey) project consists of 40 dwarf galaxies within ~ 3 Mpc that span a range of parameters. A suite of HI data and ancillary data have been collected to address the issue of star formation in dwarfs, including Herschel observations of a sample of five dwarfs with very low metallicity. We are particularly interested in eventually quantifying the 'hidden H_2' reservoir - the molecular hydrogen not detected via the usual relation with CO - as well as probing the ISM physics of our galaxies through FIR line ratios. Through PDR models we can use these line ratios to constrain the gas density and say something about the molecular content.



Schematic of a Photodissociation Region (PDR) for $Z_\odot$. CII has a lower ionization potential than H, and can exist with both HI and H_2. Adapted from Hollenbach & Tielens 97, Wolfire+ 2010.

As light is incident upon the clouds, ionizing photons will penetrate to some depth in the PDR (denoted by the blue at left). Carbon has a lower ionization potential than hydrogen; nitrogen has higher. For solar metallicity clouds, this PDR is a relatively thin layer, and H_2 and CII coexist here. The dust keeps a relatively large core of CO and H_2 unionized. For more metal-poor systems, there is less dust to absorb the starlight, and the core becomes smaller in relation to the PDR. The ratio of NII/CII can tell us how far these regions extend.

The figure at right shows several [CII] and HI measurements made in our Galaxy, as well as the I_{C+} predicted from I_{HI}. Each line color represents a different set of choices for (T, n). The dashed lines demonstrate the effect of adding in 'hidden' H_2 . For a given (T, n) line, a higher I_{C+} data point can mean that some (or much) of the [CII] is tracing H_2 instead of HI. Thus, the [CII] excess gives an estimate of the molecular hydrogen in the observed region.

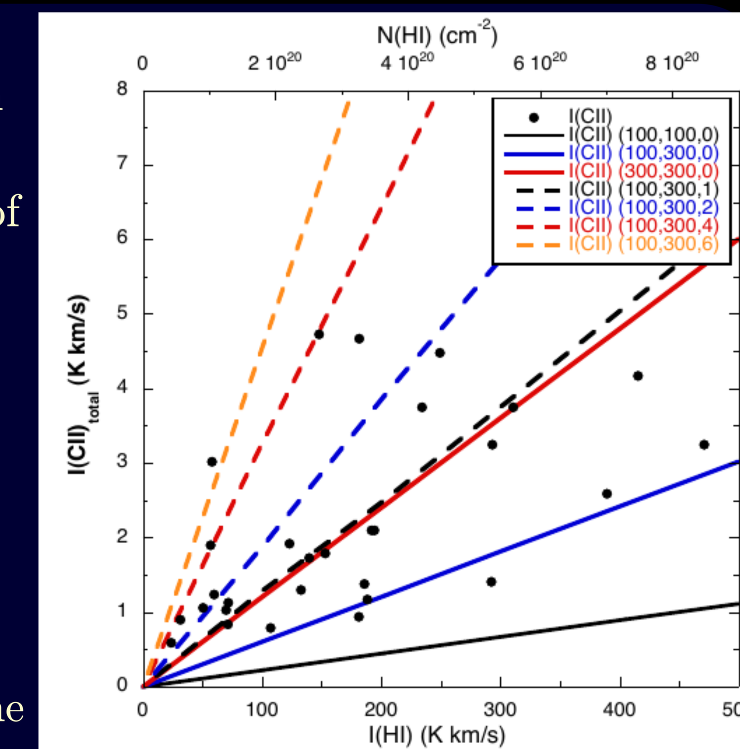
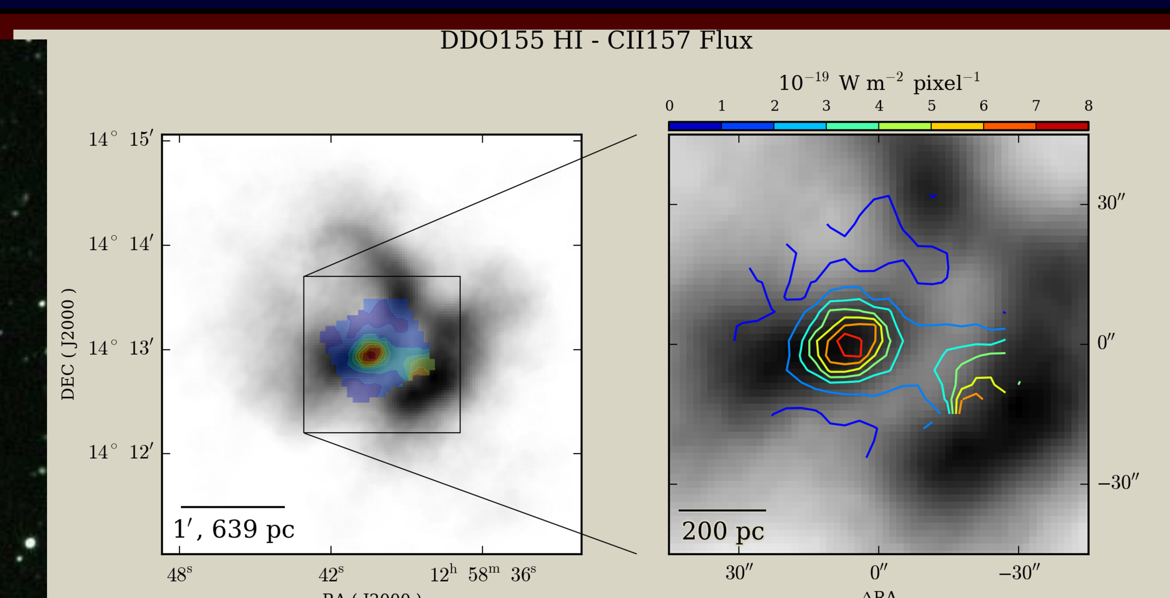
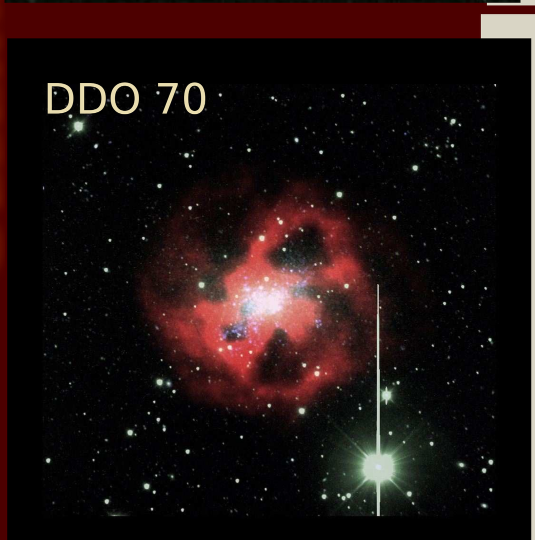
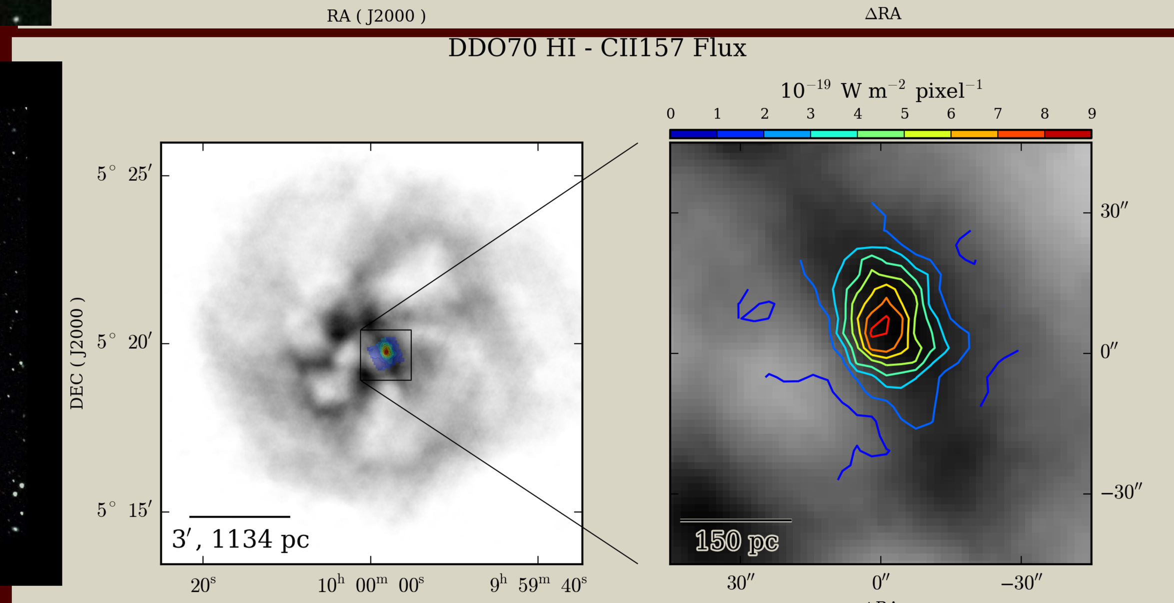


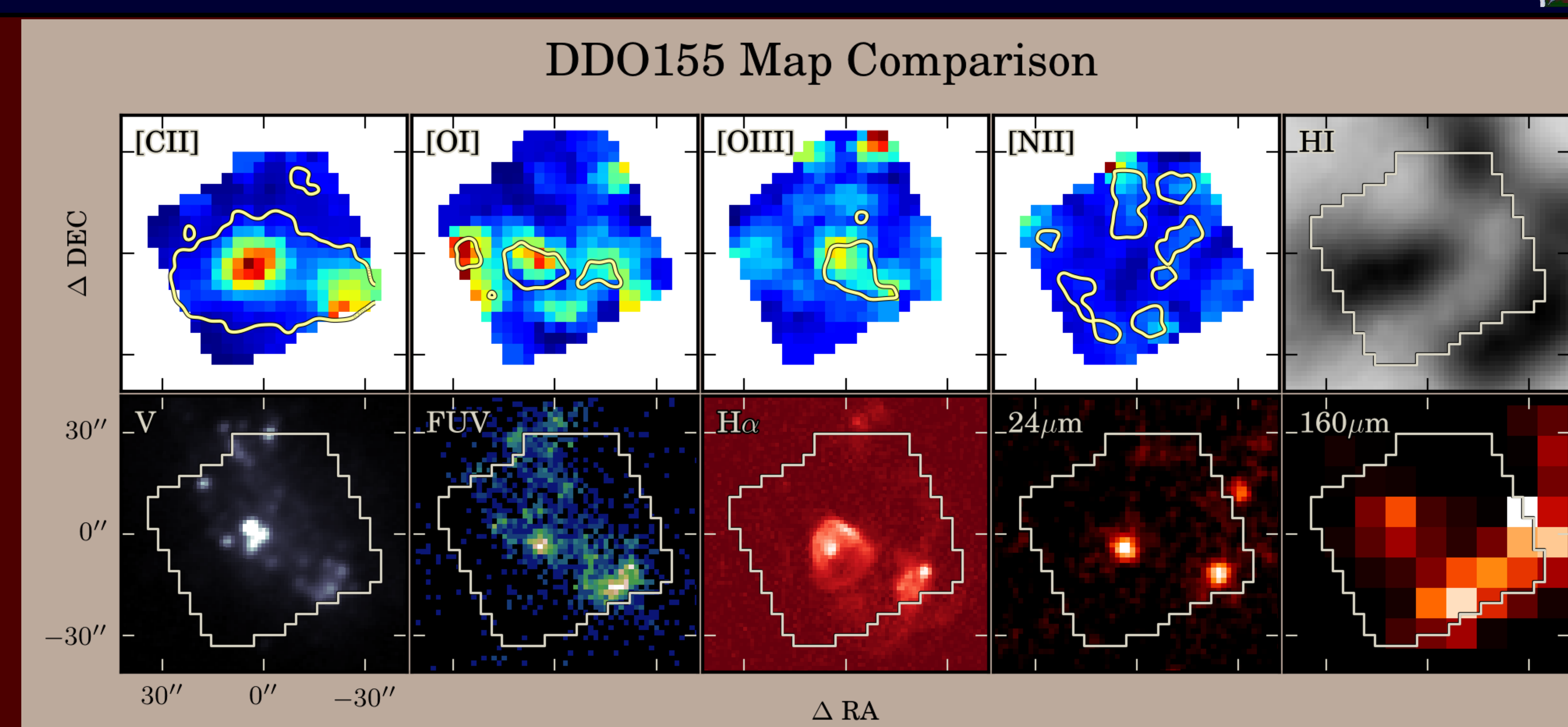
Figure from Langer+2010. Several Galactic cloud measurements and predicted relations.

Observations





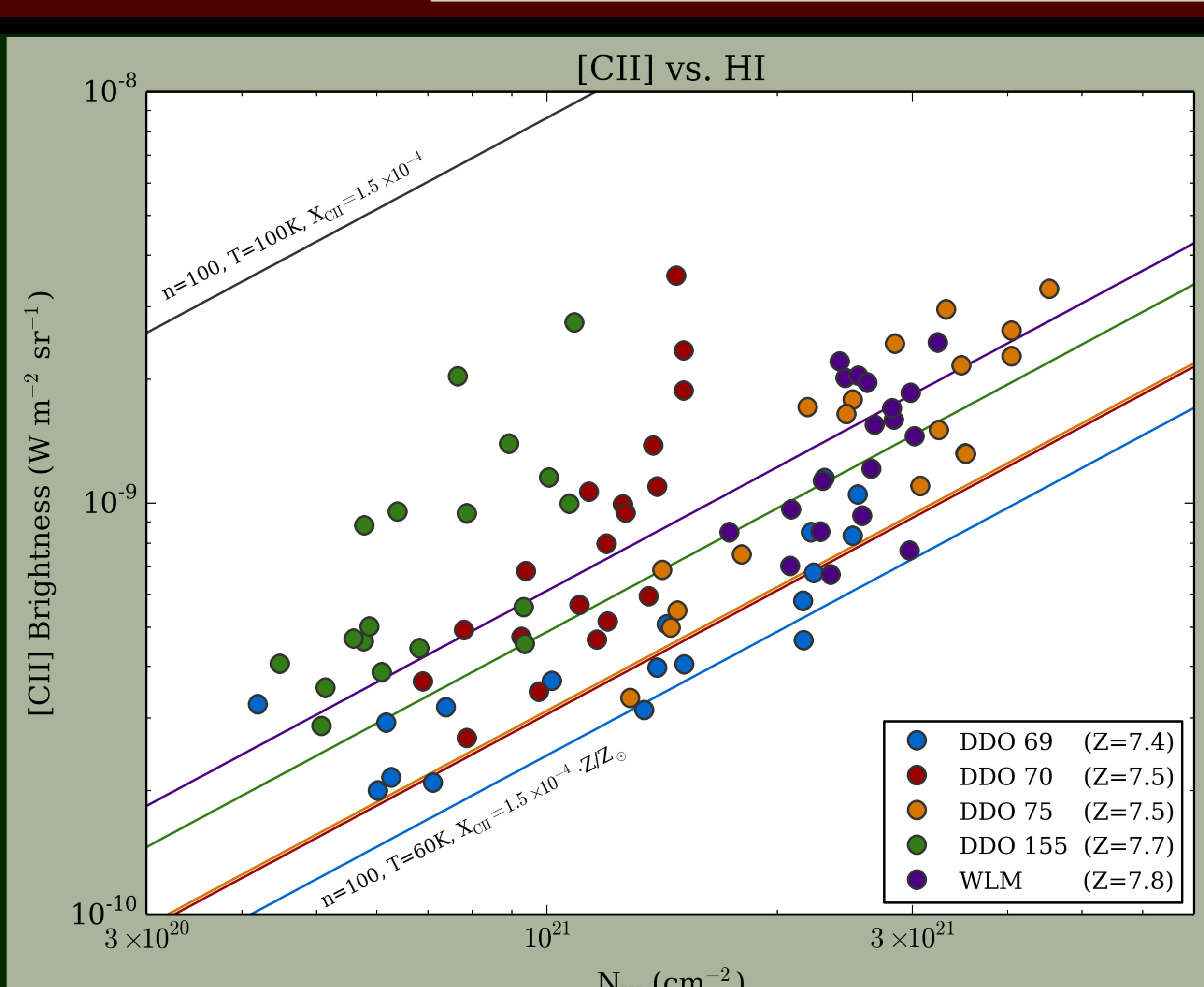




Left: Subsample of 2 LT galaxies - DDO 155 and DDO 70. The composite images show HI in red, optical in yellow, and UV in blue. The zoom plots at right show Herschel [CII] 158 micron overlaid on the HI maps for comparison. Above: Moment-0 maps at several wavelengths of the Herschel observation region for DDO 155. Contours on Herschel maps denote S/N greater than 3.

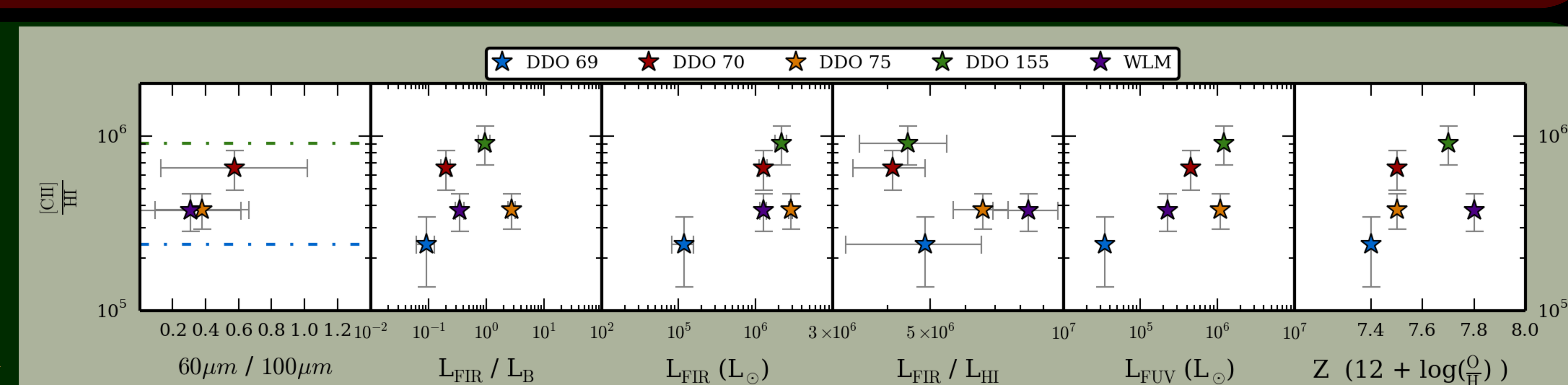
CII qualitatively correlates well with HI peaks. Hα and FUV peaks are generally offset but close to CII peaks.

Analysis



Left: Pixel-by-pixel comparison of CII and HI brightness for our five galaxies. (HI smoothed to CII beam, and each resulting pixel is independent.) We note a positive correlation for each. Regions of enhanced CII/HI emission can be interpreted as CII emission associated with the "dark" H_2. See the PDR cartoon above, and, e.g., Langer+ 2010 & Velusamy+ 2010.

Note on the prediction lines: Predictions assume $N_{CII} = X_{CII}\ N_{HI}$. The colored lines all assume 'typical' cool cloud conditions T~60K, n~100 cm^{-3}. The X_{CII} factor for each line was calculated as the local value 1.5×10^{-4} times the fraction of solar metallicity.



Above: CII/HI line ratios plotted against Several FIR diagnostics. For example, 60/100 is a measure of dust temperature, and FIR/B traces star formation and optical extinction. Horizontal dashed lines were used in the 60/100μm plot to show the vertical positions of our two galaxies that have no IRAS 60 or 100 micron data.

The maps of CII overlaid onto HI show the general correlation of the two species 'by eye', but the plot of integrated values at left shows a clear positive trend in each galaxy. There are slight qualitative differences between the trends in different galaxies. For example, DDO 70 and 155 rise much more sharply than the rest. (In linear space, the difference is more pronounced.) Also, the prediction line for WLM falls above most of the points. This shows the subtlety in choosing the correct T and n values.

We note some potential trends from a preliminary comparison with FIR and other diagnostics. We find quite high ratios of our Hershel lines to FIR (calculated from Spitzer 24,70,160 μm - ask me to show you the ratio plots). The f_{CII}/f_{HI} ratio (averaging ~5×10^5 in our sample) shows a negative trend with FIR/HI, as well as positive relations with L_{FIR}, L_{FUV}, FIR/B, and metallicity.

Discussion

– One application of the positive trend with CII and HI in each galaxy could be the inference of a rough conversion factor. This would be a great aid in studying these systems, as CII observations are much more expensive than HI.

– The predicted CII brightnesses for given HI columns are sensitive to the temperature and number density assumed. We will explore this issue thoroughly to determine the correct levels to use. Each galaxy has roughly the same slope as the prediction line, though the brightest CII points in each tend to be disproportionately higher in CII than in HI.

– There are trends for the line ratios with metallicity, FUV, and FIR - the local environment matters.

– We are interested in eventually quantifying the 'hidden H_2' reservoir - the molecular hydrogen not detected via the usual relation with CO. One method is to compare CII to HI, using the method of Madden+93: 1.) Determine N_{HI} from I_{HI}. 2.) Estimate N_{C+} within the HI/C^+ layer to get $I_{C+,HI}$. 3.) Use $I_{C+,tot} = I_{C+,HI} + I_{C+,H2}$ to infer the component of [CII] emission arising from the H_2 layer (assuming some local temperature and density conditions). 4.) Convert $I_{C+,H2}$ to $N_{C+,H2}$ 5.) Estimate N_{H2} from N_{C+} / $2X_{C+}$. Very preliminary results for DDO 155 give $M_{H2} \approx 10^6 M_\odot$ with this method using the local X_{C+}; using a modified (smaller) X_{C+} gives larger H_2 masses (~$10^7 M_\odot$).

Acknowledgements

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* Suzanne Madden, et al., 1993 ApJ 407, 579
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* Look for the upcoming first papers from the LITTLE THINGS team to learn more! http://www2.lowell.edu/users/dah/littlethings/index.html

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