X_{CO} as a function of metallicity:

a physically motivated three-step approach

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Lee+15, MNRAS, 450, 2708
Lee+, in prep

1. Motivation

- Astronomers use CO to trace molecular hydrogen (H_2)
  1. H_2 not directly observable in typical molecular cloud conditions
  2. CO is the second most abundant molecule after H_2
  3. Its rotational transitions are fairly strong and observationally accessible from the ground

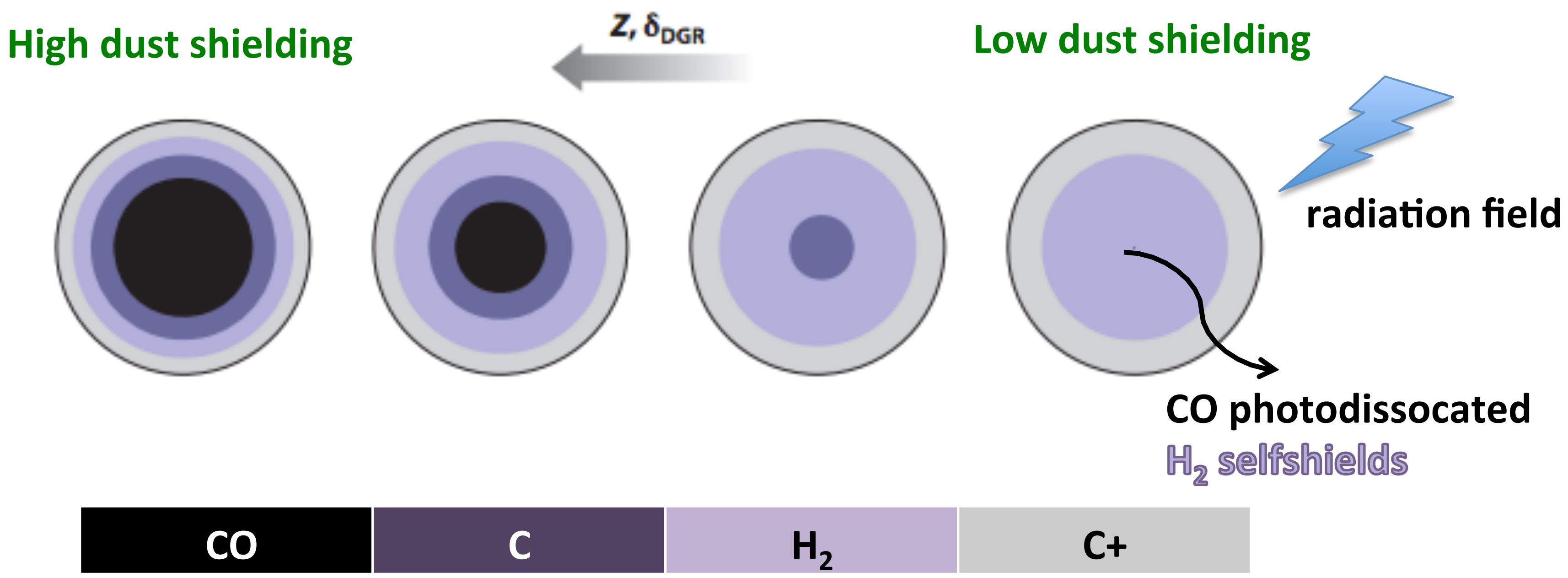
- X_{CO} is the conversion factor between the observed CO emission intensity (I_{CO}) and the column density of molecular hydrogen (H_2)

$$X_{\mathrm{CO}} = \frac{N(\mathrm{H}_2)}{I_{\mathrm{CO}}}$$

averaged over a large part of galaxies

1. Motivation

- Simple PDR model suggests that CO emission tracks dust shielding
- H_2 less sensitive to dust shielding thanks to self-shielding
- ➢ Mismatch between H_2 and CO in low metallicity systems



Bolatto+13

1. Motivation

- We would like to understand X_{CO} as a function of metallicity because…

- Small galaxies and high redshift galaxies tend to have low metallicities and we care about e.g.
  1. Their molecular gas content and star formation
  2. The time evolution of $\Omega(H_2)$

because these galaxies are important targets for galaxy evolution

Need for physical, quantitative prescription for X_{CO} (Z)

2. Physical prescription for X_{CO} (Z)

- In Lee+15, we divide the problem into three observationally tractable parts:

1. I_{CO} is a function of A_V in approximately universal way
   - i.e. CO tracks dust shileding

   Lombardi+06
   Pineda+08
   Wolfire+10
   Glover+11

2. Molecular cloud has some gas column density distribution, PDF(N_H)

   Kainulainen+09,+14
   Lombardi+15

3. A_V distribution is a product of dust-to-gas ratio and PDF(N_H)

   Remy-Ruyer+14

Each part is an active topic of research that can be constrained by observations and combined to provide X_{CO} (Z)

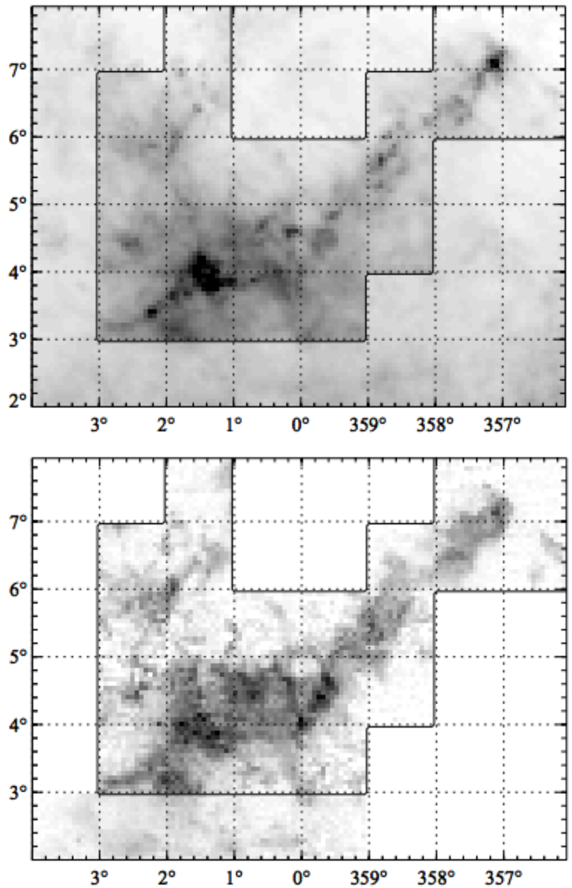
3. I_{CO}-A_V in the Local Group

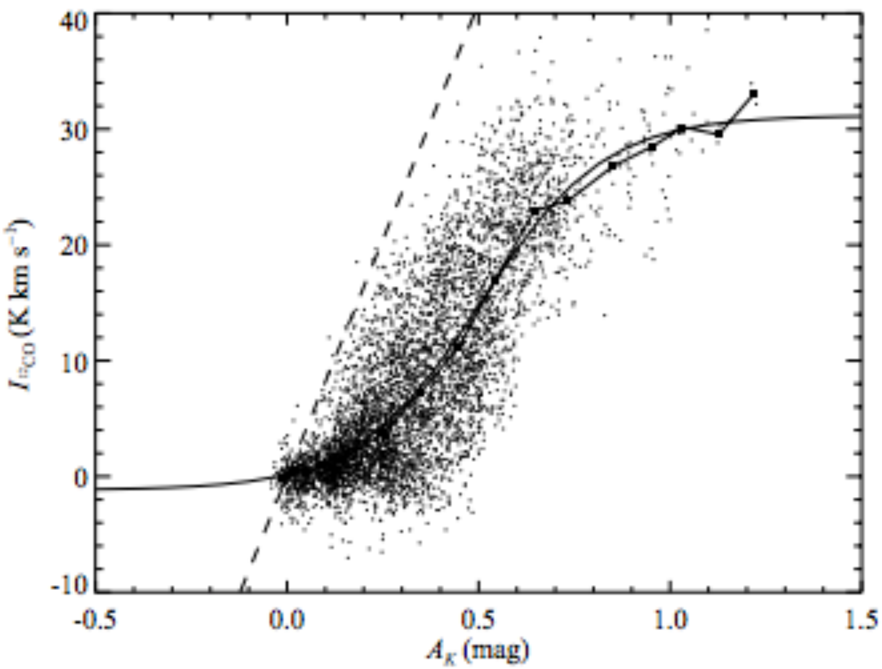
- In the Milky Way, CO tracks dust shielding nicely

1. I_{CO} is a function of A_V in a universal way

Dust

CO

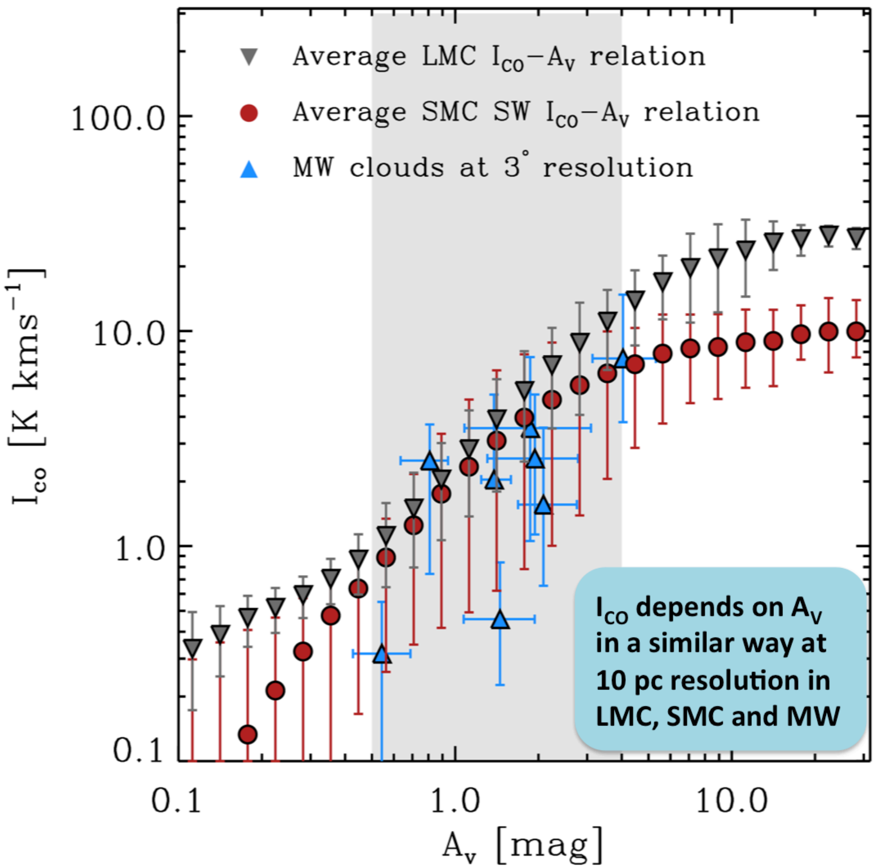




Lombardi+06
See also Pineda+08, Pineda+10

3. I_{CO}-A_V in the Local Group

- Do we actually observe similar CO emission for a given dust shielding in different metallicity systems? (Lee+15)



MW : 1.0 Solar metallicity

LMC : 0.5 Solar metallicity

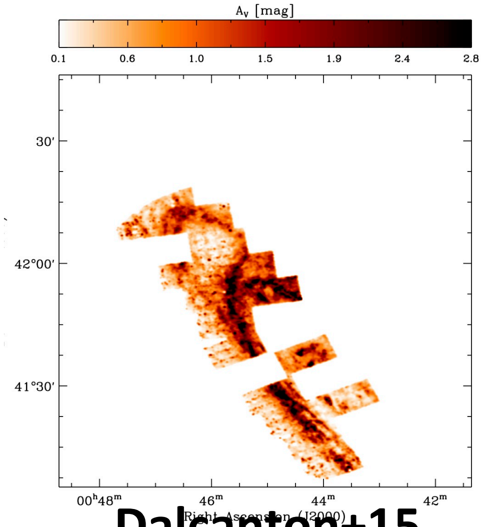
SMC : 0.3 Solar metallicity

Yes, in the gray area where most of the data are distributed

3. I_{CO}-A_V in the Local Group

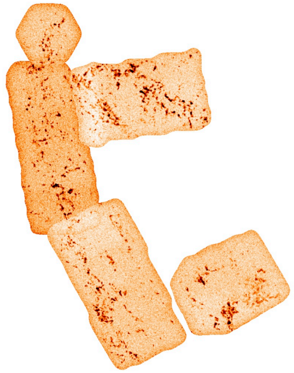
- Andromeda, in collaboration with HST and CARMA (Lee, Schruba+, in prep)

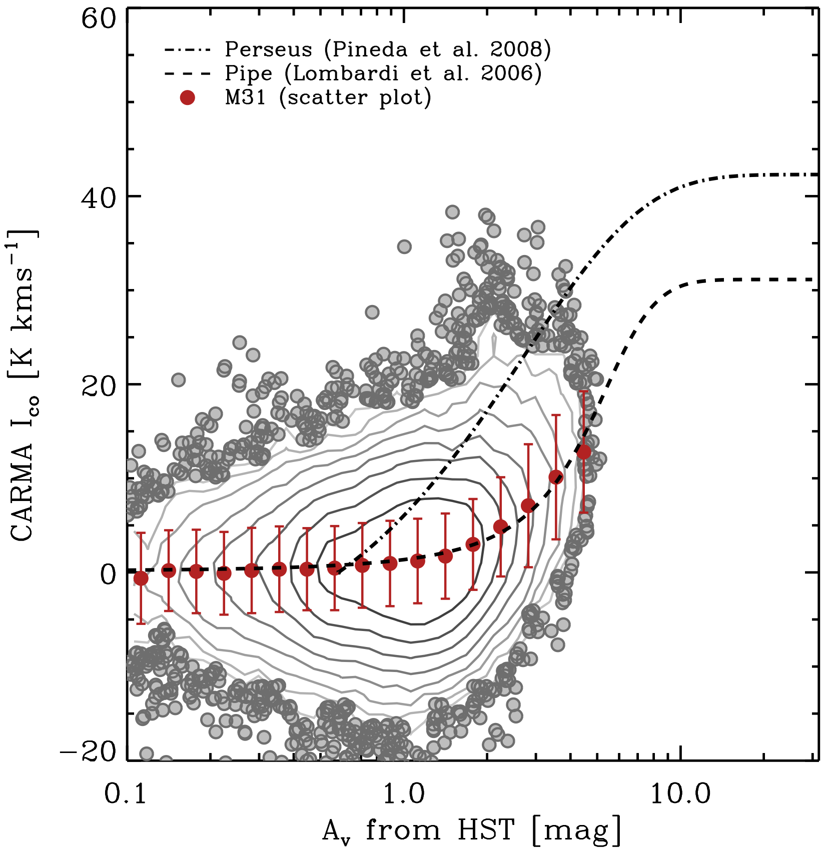
Dust



Dalcanton+15

CO

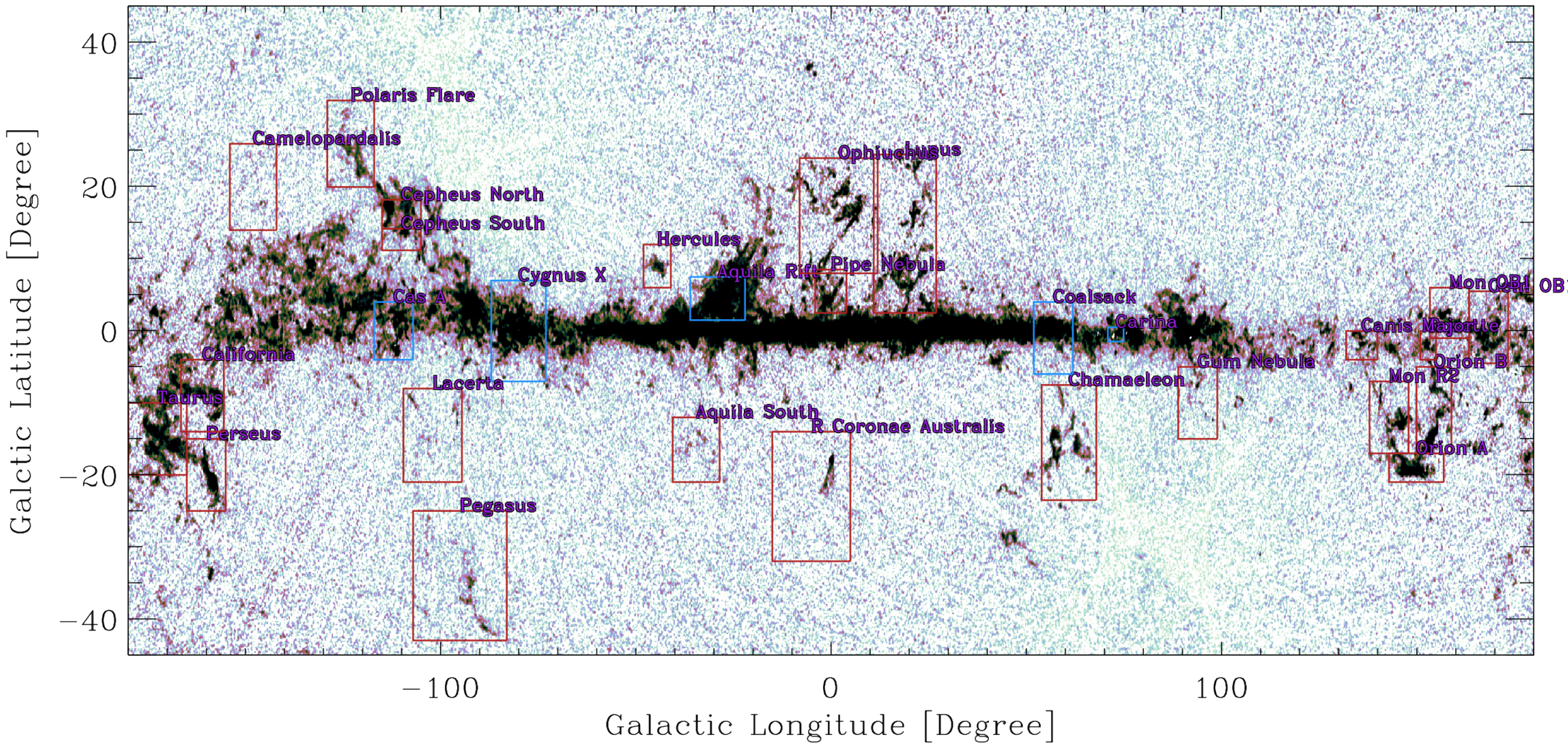




Schruba+, in prep : See Andreas Schruba talk

4. Parsec scale I_{CO}-A_V in the Milky Way

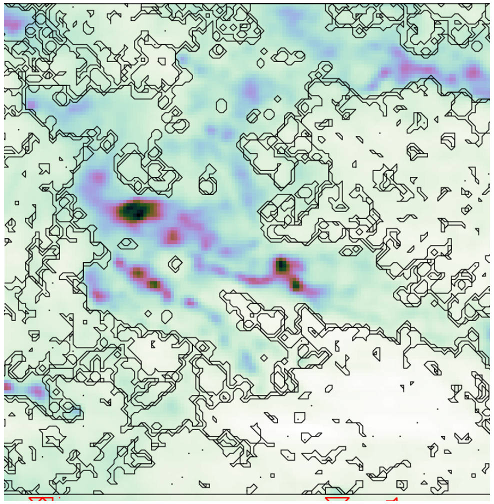
- Highly resolved (sub-pc resolution) Milky Way clouds using *Planck* data
  : An ongoing effort to extend the work by Lombardi+06, Pineda+08, Pineda+10



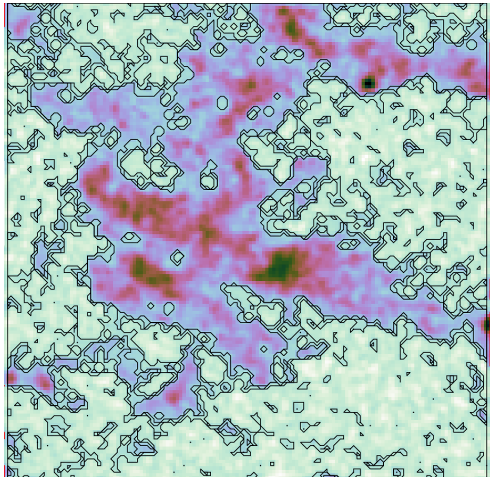
4. Parsec scale I_{CO}-A_V in the Milky Way

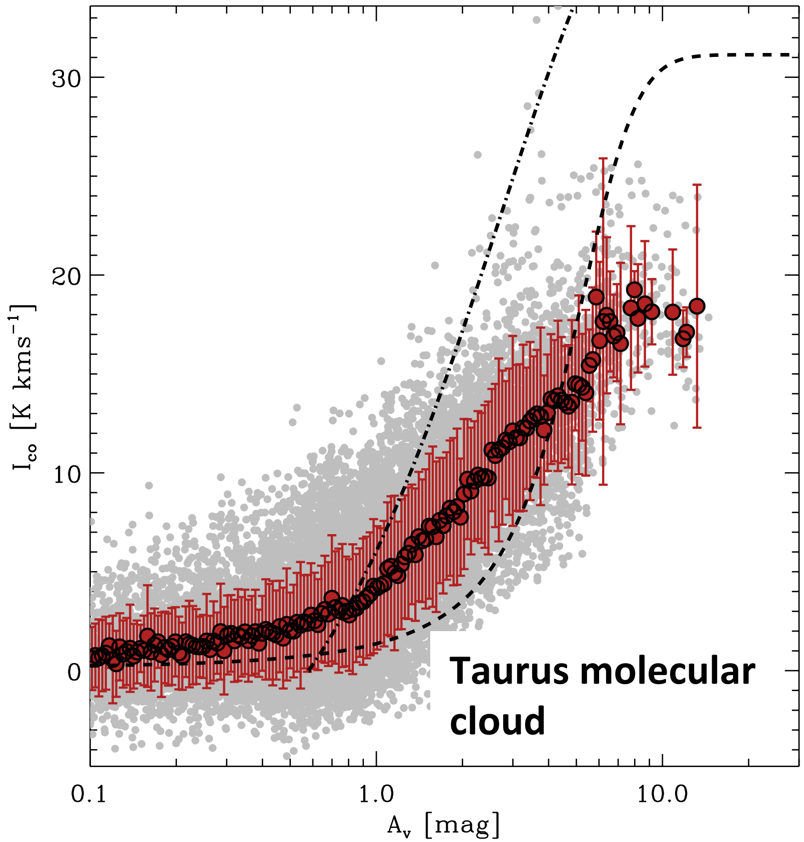
- An example of Taurus molecular cloud at pc resolution

Dust



CO

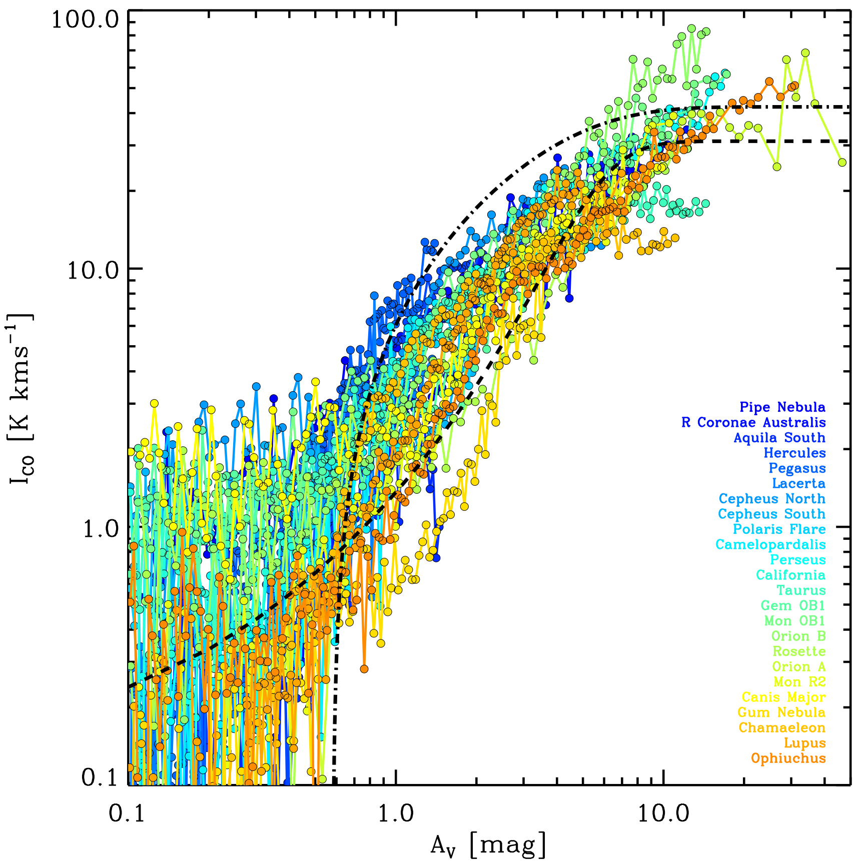


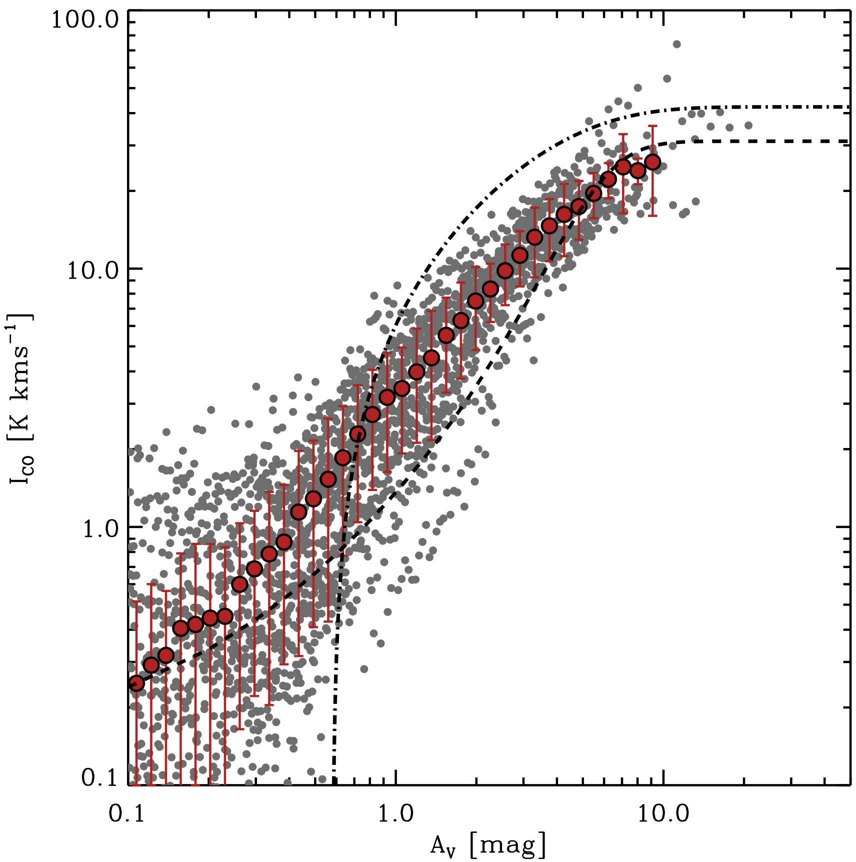


Lee+, in prep
(extending Lombardi+06, Pineda+08, Pineda+10)

4. Parsec scale I_{CO}-A_V in the Milky Way

- Average I_{CO}-A_V profiles of approx 20 individual clouds at pc resolution
- Provides better statistics and captures spreads between clouds

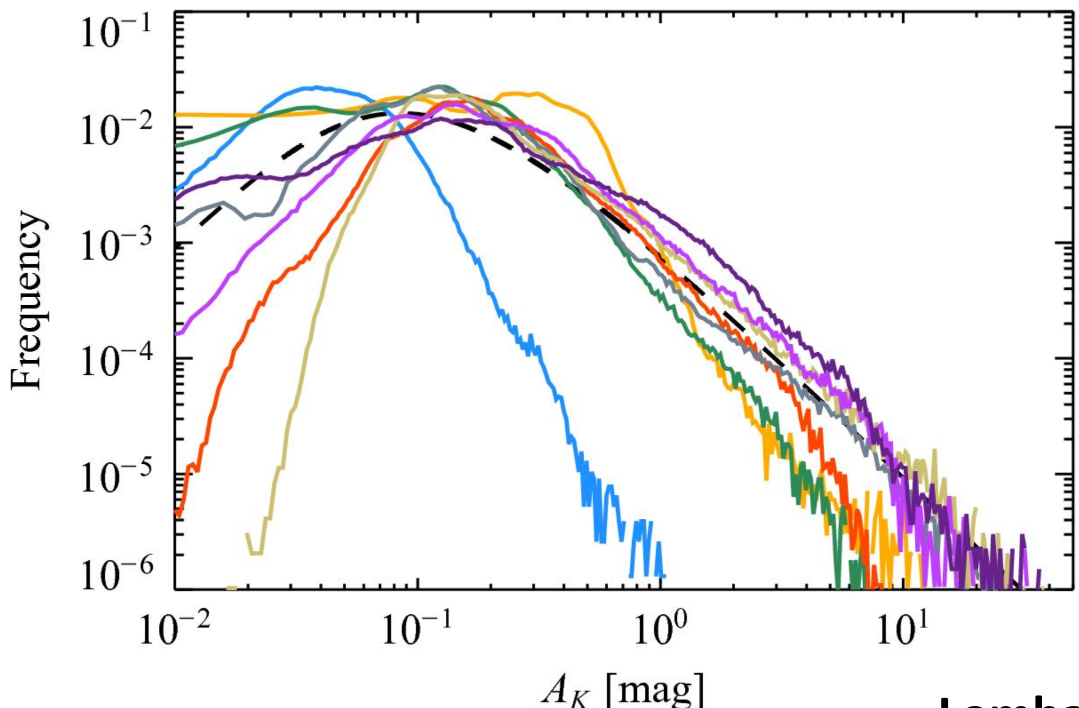




5. Calculation of X_{CO} (Z)

- We take a modern view of realistic molecular cloud structure

2. Molecular cloud has some gas column density distribution, PDF(N_H)

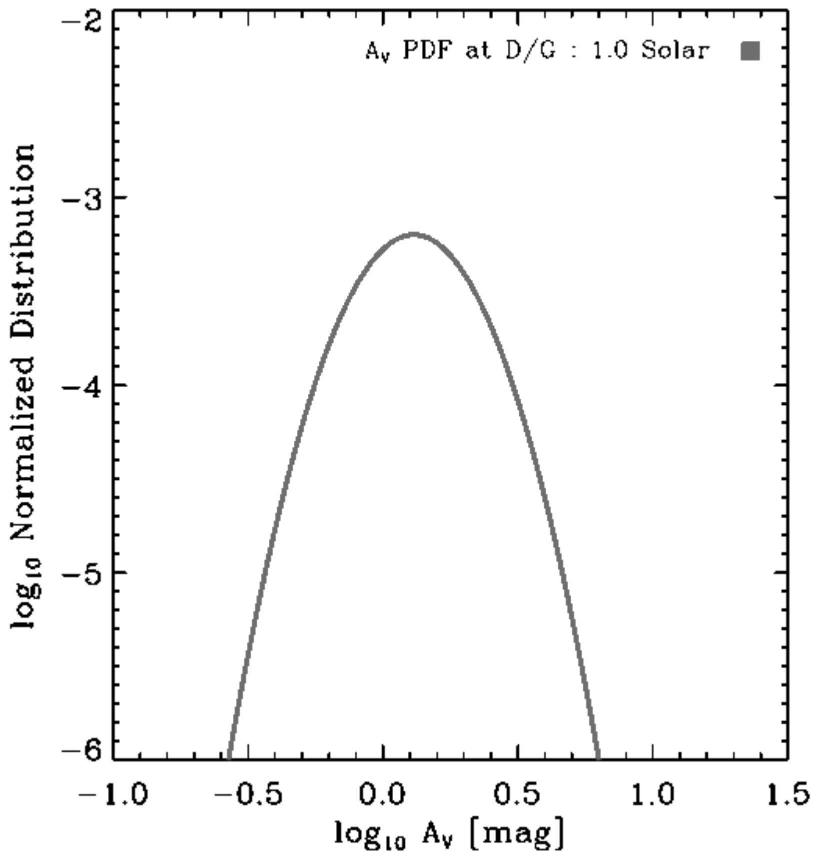


Lombardi+15
See also Kainulainen+09,+14
Schneider+15

5. Calculation of X_{CO} (Z)

- Imagine a cloud like Taurus moved to low metallicity (and dust-to-gas) system!

3. A_V distribution is a product of dust-to-gas ratio and PDF(N_H)

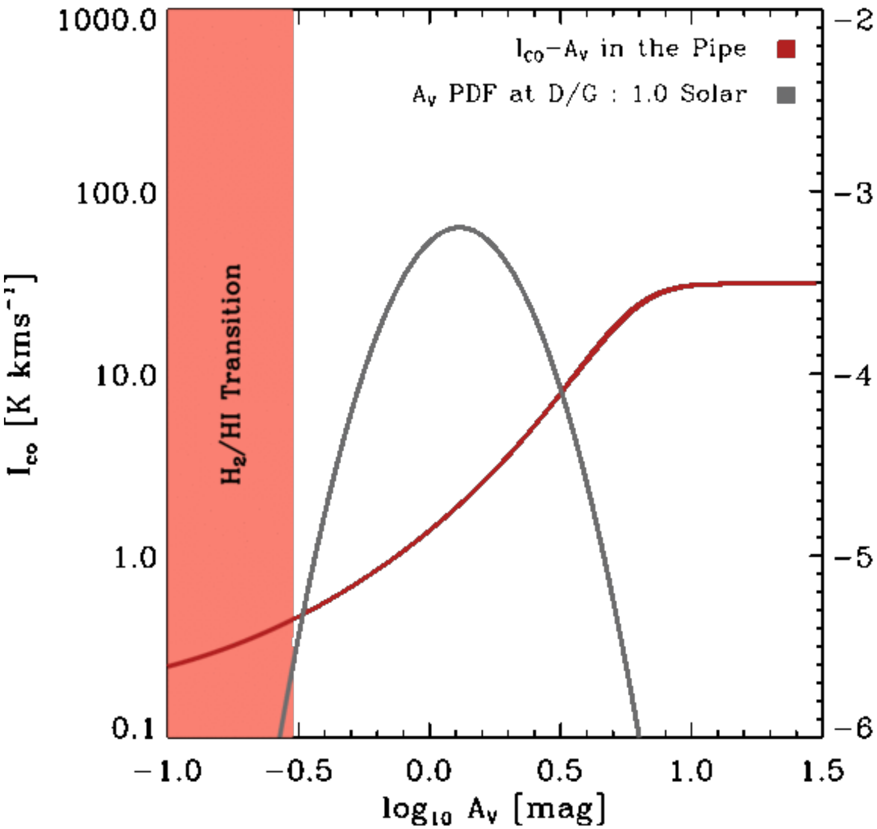


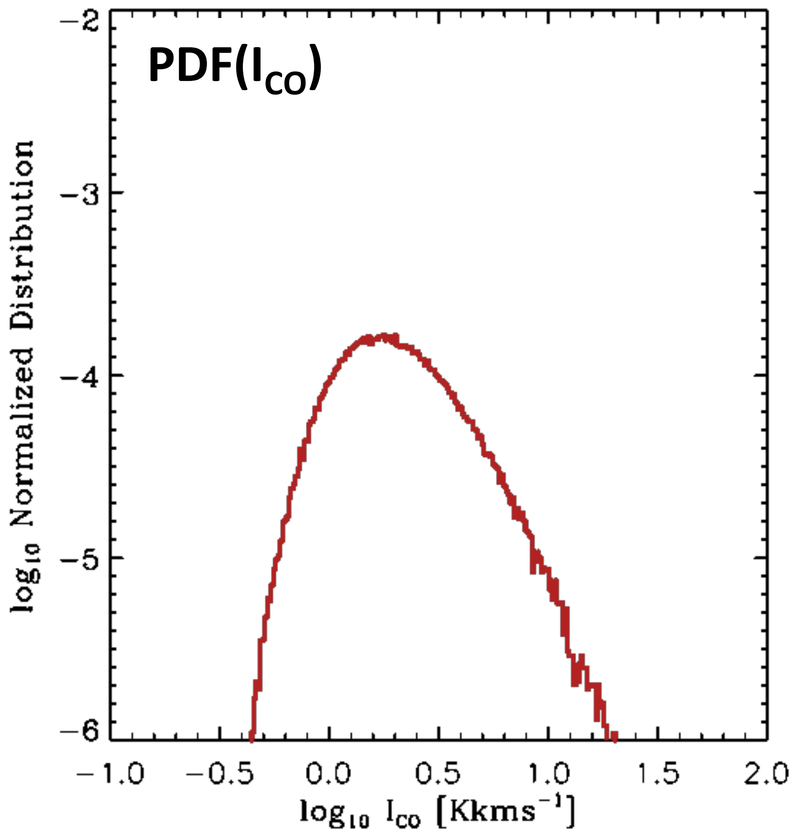
PDF(A_V) = DGR*PDF(N_H)

Assuming DGR ≈ Z

5. Calculation of X_{CO} (Z)

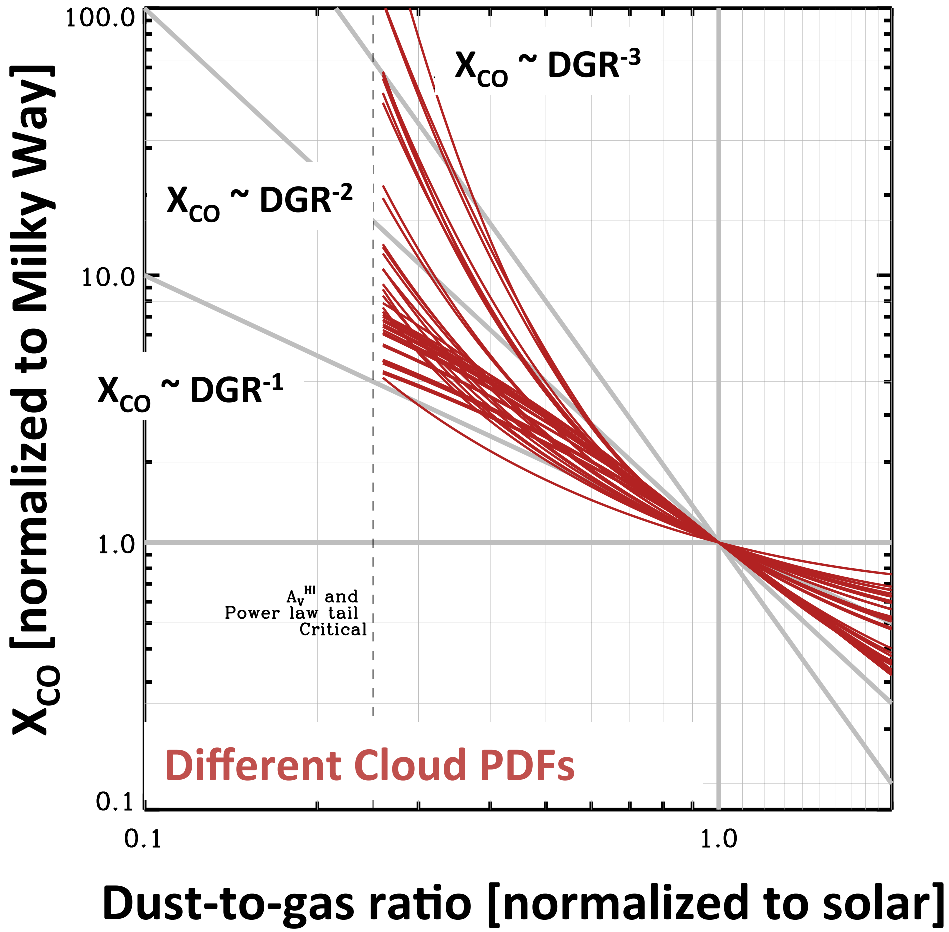
- Convolution of PDF(A_V) with I_{CO}-A_V curve gives us PDF(I_{CO}) as a function of Z
- PDF(N_{H2}) can be estimated from PDF(N_H)





5. Calculation of X_{CO} (Z)

- X_{CO} varies nonlinearly as you change the metallicity (Lee+15)



6. Summary

- Physically motivated prescription for Z dependence of X_{CO} (Lee+15)

1. We divide the problem into three separate parts that can be observationally constrained in the Local group

2. I_{CO}-A_V relationship, Gas PDF, DGR

3. In the Local group galaxies, I_{CO} at a given A_V similar across the environments

4. X_{CO} goes as Z^{-1} - Z^{-3} as you decrease the metallicity; Trend for super solar metallicity also interesting

5. The utility of CO emission to trace H_2 very uncertain even at SMC like metallicity