The BU-FCRAO Milky Way Galactic Ring Survey (GRS)

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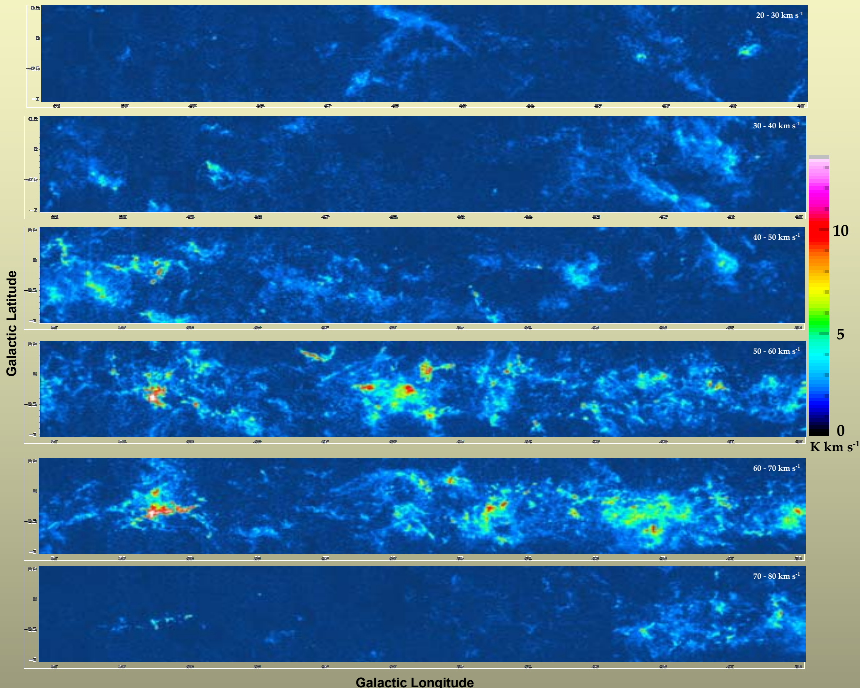
The Milky Way Galactic Ring Survey (GRS) continues to map *J=1-0* ^{13}CO emission in the First Galactic Quadrant with an excellent combination of sensitivity (0.2 K), angular resolution (45") and sampling (22"), and spectral resolution (0.2 km s^{-1}) with the Five-Colleges Radio Astronomy Observatory 14m. Here we present the channel maps of our Second Release data, covering 16 square degrees from ***l=40° to 51°***, ***b=-1° to 0.5°***, and ***V_{lsr}=20 to 80 km s^{-1}***. We also display maps of the ^{12}CO/^{13}CO intensity ratio using the UMASS-Stony Brook (UMSB) ^{12}CO survey. In addition to confirming the widely accepted I(^{12}CO)/I(^{13}CO) intensity ratio for the CO isotopes of 5-6 for the bulk of the Galactic emission seen from molecular clouds, we also find a significantly lower value of I(^{12}CO)/I(^{13}CO)=3 toward infrared-dark clouds (IRDCs) identified by Simon et al. Such low values suggest very large CO opacities and molecular column densities for the IRDCs.

^{13}CO Channel maps

Figure 1: The channel maps are in units of K km s^{-1} (color scale on the right) integrated over 10 km s^{-1} from V_{lsr}=20 to 80 km/s. Velocity ranges are given in the top right corner. Specific sources are discussed in posters by *Simon et al. (112.21), Flynn et al. (112.20),* and *Johnson et al. (112.19).*



I(^{12}CO)/I(^{13}CO) Intensity Ratio

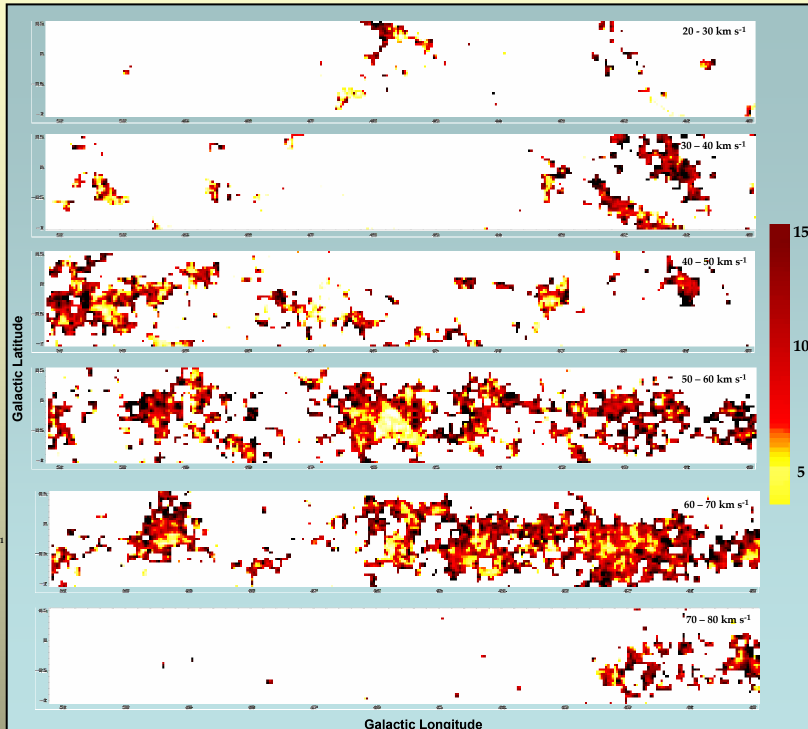


Figure 2: We use the UMSB ^{12}CO survey (**Sanders *et al.* 1986, *ApJ. S.*, 60, 1; Clemens *et al.* 1986, *ApJ. S.*, 60, 297**) to generate channelmaps of the I(^{12}CO)/I(^{13}CO) intensity ratio. The ratio is presented in the same velocity bins as the ^{13}CO channel maps. It is determined by taking the ratio of pixels in both surveys with at least 0.5 K intensity (5σ for UMSB and 20σ for GRS). The limiting factor in choosing the clip level is the poorer sampling and sensitivity in the UMSB data set. The intensity ratio scale to the right of the images is unitless. Though the range of the intensity ratio is rather small (1 to 20 with a median of 5.5), the channel maps reveal significant spatial and velocity structure.

The I(^{12}CO)/I(^{13}CO) ratio has traditionally been used as an estimate of the τ(^{12}CO) along equivalent lines of sight, assuming homogeneous, well-mixed distributions and equal excitation temperatures for both isotopes. Important effects which contribute to the interpretation of the observed structure -- and, therefore our interpretation of optical depth variations -- include CO self-shielding, external heating, and clumping.

Figure 3
I(^{12}CO)/I(^{13}CO) and ^{12}CO emissivity [J_ν(^{12}CO)] as a function of Galactocentric Radius

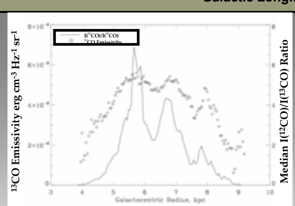
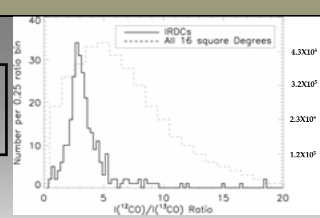


Figure 4
Infrared Dark Cloud I(^{12}CO)/I(^{13}CO) intensity ratio



A significant advantage of large angular scale surveys of the Milky Way like the GRS is the ability to track galactocentric radial dependencies of astrophysically significant quantities. In ***figure 3*** we provide the galactocentric radial distribution of the median I(^{12}CO)/I(^{13}CO) ratio (solid line) in 0.05 kpc bins. We also plot the radial ^{12}CO emissivity, J_ν(^{12}CO) (diamonds). For both distributions, we assume a flat rotation curve with R_0=8.5 kpc and Θ_0=220 km/s. For well-mixed, homogeneous gas (the simplest assumption), peaks of the isotope ratio as a function of radius correspond to low ^{12}CO optical depth clouds. For similar circumstances, peaks of the ^{12}CO emissivity correspond to high optical depth gas. Interestingly enough, we find similar radial trends for I(^{12}CO)/I(^{13}CO) and J_ν(^{12}CO), which suggest *opposite* trends in CO opacity. A high external temperature, ^{12}CO self shielding (i.e. photodestruction of ^{13}CO while ^{12}CO remains abundant; **Bally & Langer, 1982, *ApJ*, 255, 143**), and/or different clumping between ^{12}CO and ^{13}CO can explain this effect. High external temperatures induced by UV heating from stars and massive star forming regions will tend to heat the more spatially extended ^{12}CO, thus increasing I(^{12}CO) relative to I(^{13}CO) in a given radial bin. Self-shielding selectively reduces abudances of isotopic species of carbon monoxide *not* made of ^{12}C^{16}O. Thus, higher abundances of the standard CO isotope lead to larger observed intensity ratios than if no selective destruction took place. Clumping lowers the observed brightness temperature of ^{13}CO with respect to ^{12}CO by the ratio of the filling factor of the clumps.

Figure 4 plots the ^{12}CO/^{13}CO values towards the Infrared Dark Clouds identified by Simon et al. (see 122.21). The values plotted are determined by choosing the nearest peak position in both the GRS and the UMSB surveys. The distribution strongly peaks at 3, a factor of 1.7 smaller than typically observed and indicative of the high ^{12}CO column density (N[^{12}CO]>10^{14} cm^{-2}) of this population of sources.

Summary

(1)We present 420,000+ positions of the ^{13}CO Galactic Ring Survey. The data are fully sampled with excellent sensitivity (T_{mb}=0.1 K in 0.25 km s^{-1} channels), covering *l=40° to 51°* and *b=-1° to 0.5°*. We are in the process of completing the survey from *l=15° to 54°* and *b=-1° to 1°* with the FCRAO 14m.

(2) We find significant spatial and velocity variation in the I(^{12}CO)/I(^{13}CO) ratio across this region. Preliminary analysis finds the puzzling association of high median I(^{12}CO)/I(^{13}CO) ratios with large ^{12}CO emissivities as a function of galactocentric radius. For homogeneous, well-mixed gas, these two trends indicate opposing values for optical depth: high I(^{12}CO)/I(^{13}CO) means low optical depth while high J_ν(^{12}CO) means high optical depth. This suggests that CO self-shielding, external UV heating, and or clumping will play an important role in our analysis of the large scale variations of CO.

(3) Infrared Dark Clouds (IRDCs), as defined by Simon et al. (2003, in preparation; see poster 122.21), show I(^{12}CO)/I(^{13}CO)=3, a factor of 1.7 smaller than is typically found in the Galaxy. This is consistent with the high molecular column densities necessary to make objects opaque in the mid-IR.

For more information and available data, visit the GRS web page at *www.bu.edu/grs*

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