Comparison of CS with ^{13}CO Emission

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Abstract

As a part of the Boston University-Five College Radio Astronomy Observatory Galactic Ring Survey, we have mapped both ^{13}CO(1-0) and CS(2-1) emission over two square degrees ($44.25° \leq l \leq 46.25°$, $-0.5° \leq b \leq 0.5°$). Because CS has a higher critical density than ^{13}CO, the CS to ^{13}CO brightness ratio is sensitive to volume density. The GRS offers an unbiased, high-resolution dataset to examine the CS/^{13}CO ratio toward a variety of objects, ranging from dense, star-forming regions to diffuse clouds. We find that this ratio varies by factors of $\sim$7 between star-forming cores and diffuse clouds, and that this variation most likely reflects density changes. We also find that ^{13}CO data alone are sufficient to identify star forming cores.

Why Survey in CS?

Figure 1 shows maps of two square degrees of sky in CS and ^{13}CO. There is a striking similarity in these two maps; with few exceptions, the CS map resembles a noisy version of the ^{13}CO map. The CS(2-1) line is commonly observed as a dense gas tracer. With a high critical density, $n_{crit} \approx 10^5$ cm^{-3}, this line is thermalized in the dense gas of star-forming cores. This has led many (including the GRS team) to observe in CS as a method of finding dense, star-forming (SF) cores. The observing strategy of the GRS was to survey in two transitions, one a column density tracer (^{13}CO) and the other a volume density tracer (CS), in the hope that each would provide a unique, yet complimentary view of the galactic ring.

As Figure 1 shows, CS does not give a significantly different view of SF cores from that of ^{13}CO. Any peak in CS emission is seen clearly as a peak in ^{13}CO. *The advantages of observing a high volume density tracer are countered by dense cores having a large column density, as well.* We easily find star-forming cores in the optically thin line of ^{13}CO. For these reasons, and due to the intrinsic faintness of CS, the GRS has decided to halt surveying in CS.

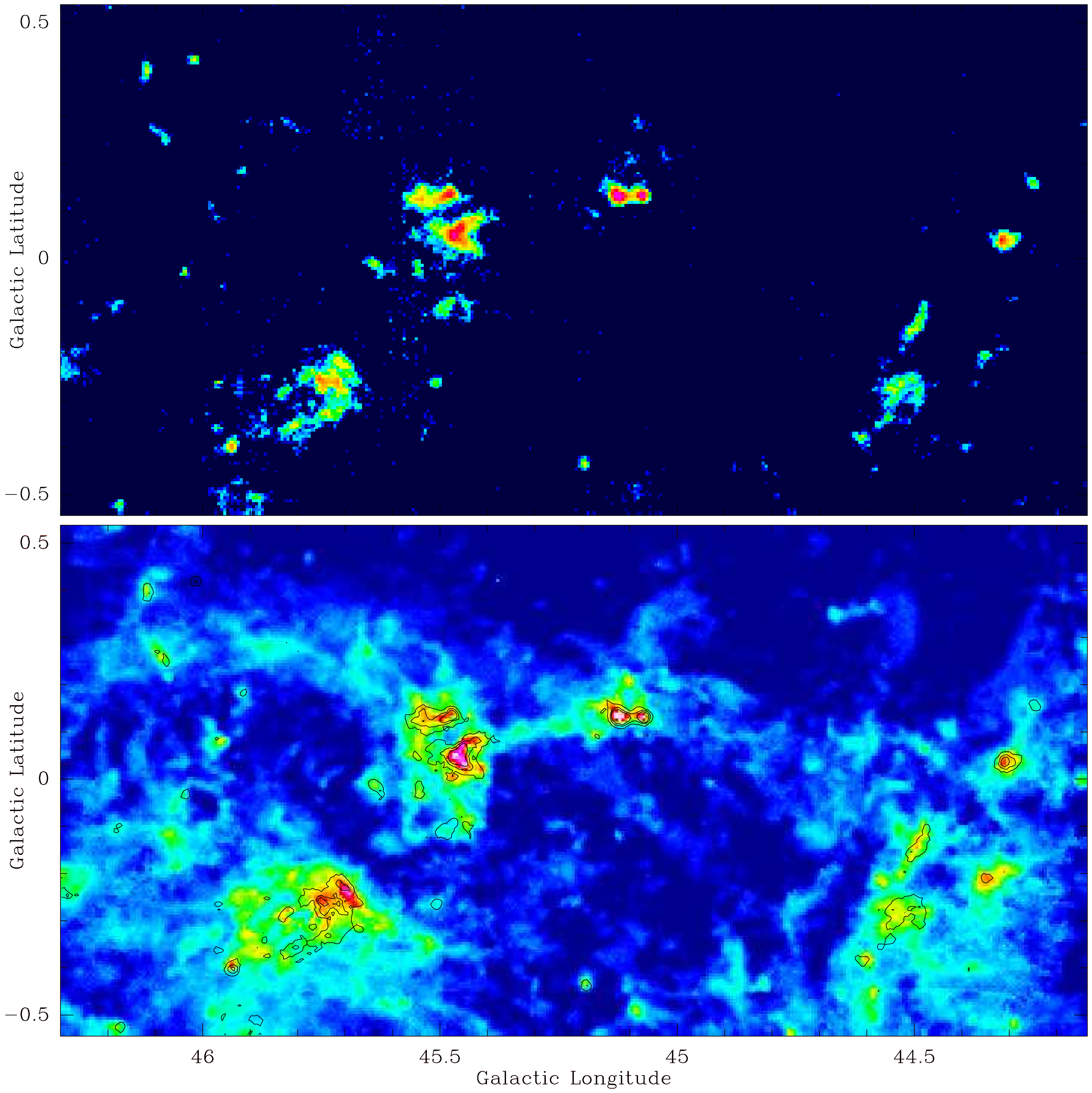

Figure 1: *Is CS the best star-formation tracer? The top image is a map of the integrated intensity of CS(2-1) emission for the V_{LSR} range −5 to 80 km/s. The bottom image shows the same region, where the color image now shows the integrated intensity of ^{13}CO(1-0) emission and the contours are the CS(2-1) data. We find that ^{13}CO distinguishes star-forming cores as easily as CS.*

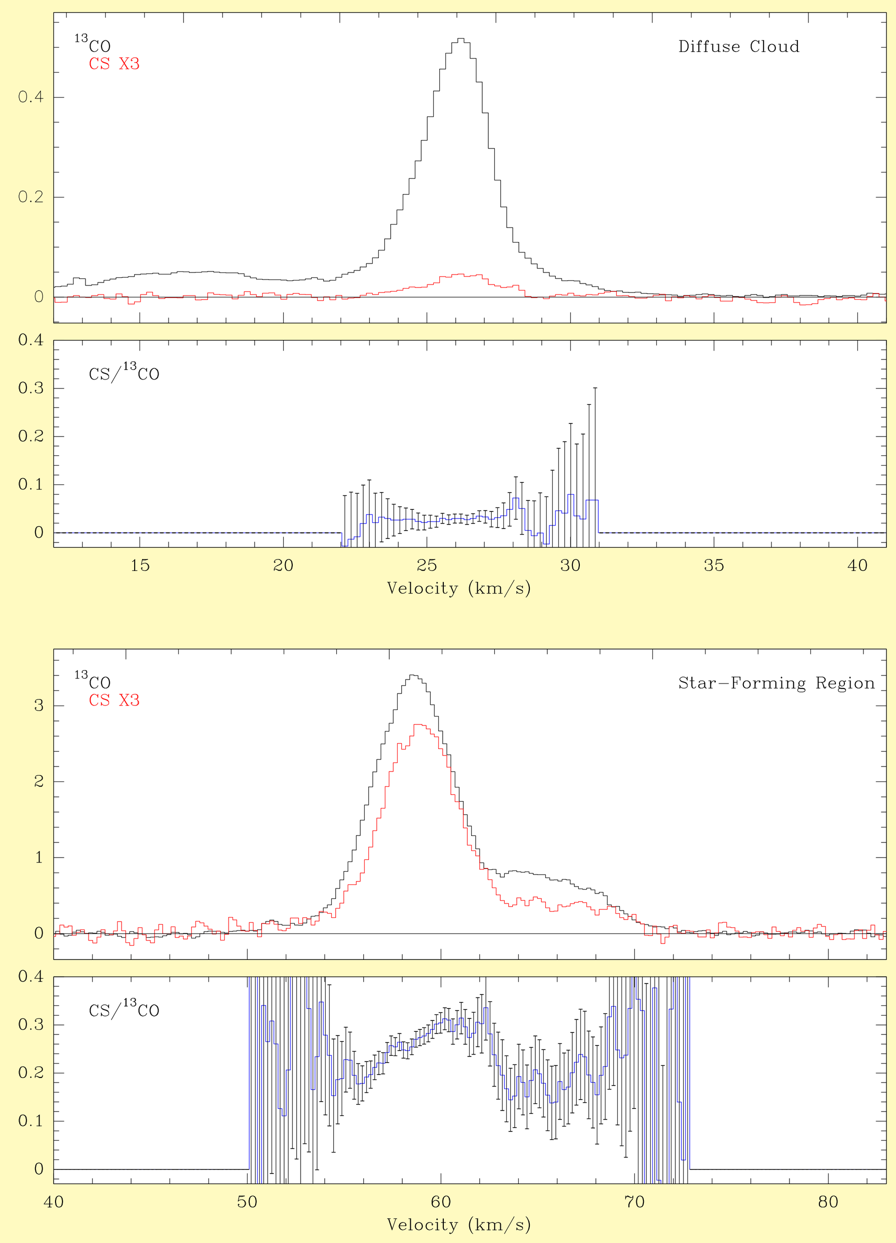

Figure 2: Shown are CS and ^{13}CO spectra together with their CS/^{13}CO intensity ratio, for two regions in the Figure 1 image. The top set is the average of all spectra of an expansive, diffuse cloud, the "25 km/s Filament" ($45.5° \leq l \leq 46°$, $0.1° \leq b \leq 0.5°$). The bottom set is the average of all spectra of the core of an intense, star-forming region in a portion of the "Klingon Warbird" ($l \sim 45.1°$, $b \sim 0.1°$). The errorbars refer to two standard deviation ($\pm 2\sigma$). The large intensity ratio seen in the SF region is due to its high volume density.

We use the UMass-Stony Brook ^{12}CO survey (Sanders et al., 1986, ApJS, 60, 1) to estimate the kinetic temperature of gas in the two square degrees studied here. The ^{12}CO line is typically thermalized and optically thick, providing a direct measure of gas kinetic temperature. The two regions represented in figure 2 span the range of conditions seen in the ISM: calm and diffuse to active and dense. We find typical kinetic temperatures in these two regions to be roughly equal (T_K from 8 to 15 K). If we assume that the CS and ^{13}CO emission in these regions is optically thin, then the ratio of their intensities is most sensitive to the H_2 volume density (Helfer & Blitz, 1997, ApJ, 478, 233). With these assumptions, we use the CS to ^{13}CO brightness ratio as a measure of volume density.

Figure 3 shows the dependance of this intensity ratio on ^{13}CO intensity. Future work will use excitation models to quantify the densities implied by these ratios. Here we note that densities of molecular clouds range from diffuse ($n \sim 10^2$ cm^{-3}, where CS is subthermal) to dense ($n \sim 10^5$ cm^{-3}, CS beginning to be thermalized). Figure 4 shows CS and ^{13}CO spectra, as well as the CS/^{13}CO intensity ratio for the average of all spectra. The mean value of the intensity ratio for this "whole field" spectrum is similar to the ratio seen in diffuse clouds. This suggests that most of the CS emission comes from faint, somewhat diffuse, subthermally excited gas (Liszt, 1995, ApJ, 443, 163).

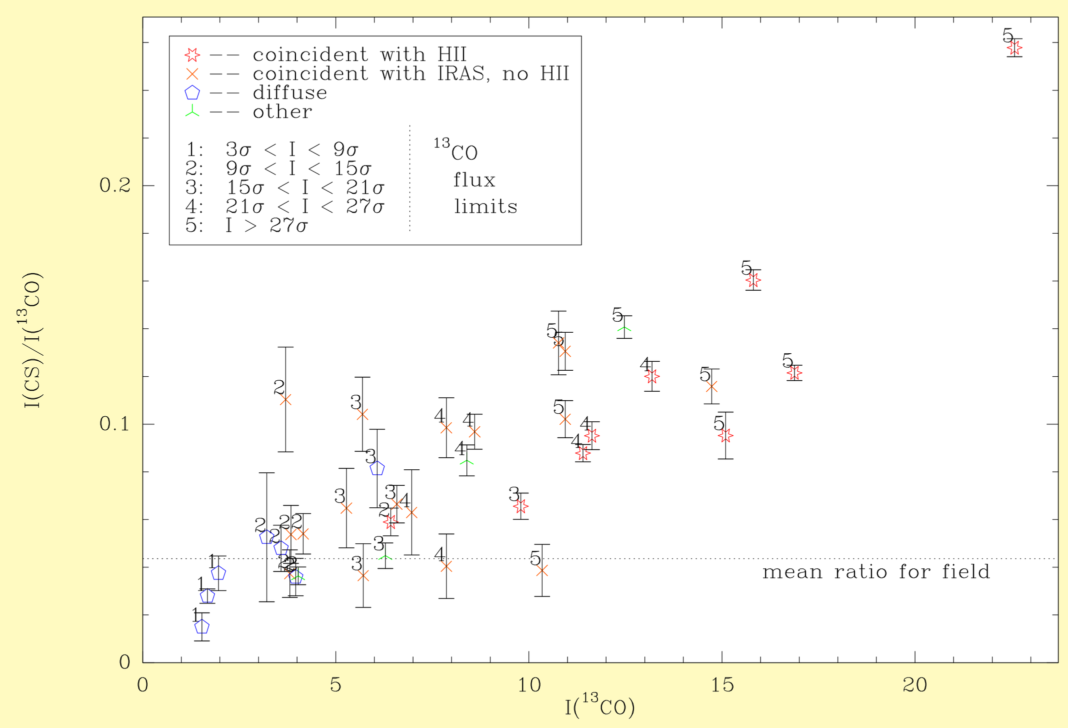

Figure 3: Ratio of CS and ^{13}CO emission intensity as a function of I(^{13}CO) for selected objects and flux ranges.

Each point in figure 3 is calculated for a unique set of spectra selected by (1) association with a previously defined object, and (2) flux limits. HII regions by Lockman (1989), and "diffuse" objects are defined by general morphology. The values of the intensity ratio ($r \equiv$ CS/^{13}CO) range from $r = 0.037 \pm 0.007$ in the faint ($3\sigma \leq I \leq 9\sigma$) emission of a diffuse cloud, to $r = 0.257 \pm 0.004$ in the intense ($I \geq 27\sigma$) emission in the core of a SF (HII) region. The dotted line shows the intensity ratio calculated for *all* spectra from V_{LSR} : −5 to 80 km/s. This velocity range covers all emission seen in the survey. The ratio calculated over the whole field is $r = 0.0436 \pm 0.0008$. This value for the intensity ratio is similar to the ratio seen in diffuse regions, suggesting that CS is typically subthermally excited.

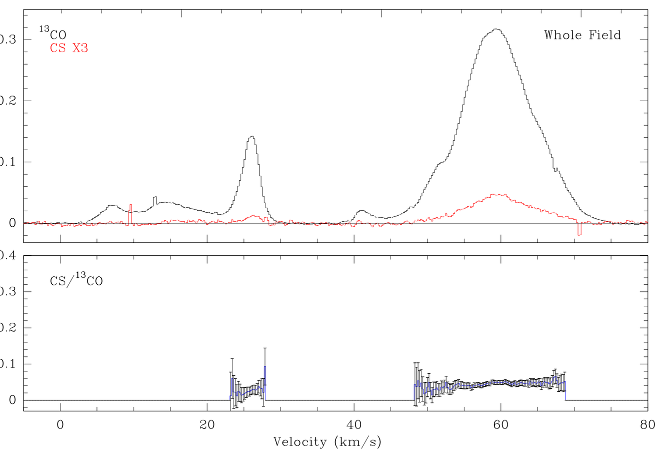

Figure 4: The average spectra and intensity ratio for the entire figure 1 field. The intensity ratio suggests that most CS emission is subthermally excited.

Conclusions

We have mapped two square degrees of the galactic plane in CS(2-1) and ^{13}CO(1-0), with high spatial and velocity resolution on a fully-sampled grid. We have compared the maps of these two species and found the following:

- ^{13}CO is as useful as CS at finding star-forming cores. In terms of efficiency, ^{13}CO is *more* useful than CS, since its line is typically $\sim$ 20 times brighter.
- CS emission is not restricted to the densest regions of the ISM. The average CS emission observed by the GRS is subthermally excited from widespread, diffuse gas.

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