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Extended Carbon Emission in the Galaxy: Dark Gas along the G328 Sightline

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Abstract. We present spectral data cubes of the [CI] 809 GHz, ^{12}CO 115 GHz, ^{13}CO 110 GHz and HI 1.4 GHz line emission from a $\sim 1^\circ$ region along the $l = 328^\circ$ (G328) sightline in the Galactic Plane. The [CI] data comes from the High Elevation Antarctic Terahertz telescope at Ridge A on the summit of the Antarctic plateau, where the extremely low levels of precipitable water vapour open atmospheric windows for THz observations. The CO data comes from the Southern Galactic Plane Survey being conducted with the Mopra telescope. Emission arises principally from gas in three spiral arm crossings along the sight line. The distribution of the emission in the CO and [CI] lines is found to be similar, with the [CI] slightly more extended, and both are enveloped in extensive HI. Spectral line ratios are similar across the entire extent of the Galaxy. However, towards the edges of the molecular clouds the [CI]/^{13}CO and ^{12}CO/^{13}CO line ratios rise by $\sim 50\%$, and the [CI]/HI ratio falls by $\sim 10\%$. We attribute this to sightlines passing predominantly through the surfaces of photodissociation regions (PDRs), where the carbon is found mainly as C or C^+ rather than CO, while the gas is mostly molecular. This is the signature of dark molecular gas.

1. Summary

We have presented data cubes (see Fig. 1) in Burton *et al.*(2013, 2014, 2015) & Braiding *et al.*(2015) showing the distribution of the [CI] 2–1, ^{12}CO, ^{13}CO and C^{18}O 1–0, and HI line emission, over a $\sim 1^\circ$ region of the Galactic plane along a sightline towards G328, with angular and spectral resolutions of $\sim 1'$ and ~ 1 km/s. The [CI] data comes from a new telescope, HEAT, sited on the summit of the Antarctic plateau; the CO data was taken with Mopra, and the HI with Parkes and ATCA, in Australia.

Complex morphology is evident in all species, with the [CI] and CO line emission extending over 120 km/s in extent, and arising principally from molecular cloud complexes in three spiral arm crossings along the sight line. The distribution in these atomic and molecular species is very similar in both angular and spectral dimensions, and is encompassed by more extensive HI line emission. However close examination of the [CI] and CO emission shows the former to be slightly more extended spatially. At the edges of the emission features the [CI]/^{13}CO and ^{12}CO/^{13}CO ratios are typically found to be 50% larger, with [CI]/HI ratios around 10% lower (see Fig.2). This is attributed to relatively more C than CO at the edges of molecular clouds, with the ^{13}CO intensity providing the best measure for the column of CO, rather than the optically thick ^{12}CO. On the other hand, the relative amount of atomic gas is seen to rise at the edges of the clouds.

PDR models were constructed for molecular gas exposed to average interstellar radiation fields to explore the behaviour of these lines with increasing depth into molecular clouds. Charge exchange reactions between C^+ and both S and PAHs were also found to be important to match the data, and require significant depletions of the S and PAHs. The models then reproduce the broad behaviour seen in the data, in particular the line fluxes and the increased line ratios for [CI]/^{13}CO and ^{12}CO/^{13}CO in the surface layers, i.e. when $A_V < 2$ mags. The ^{13}CO and [CI] lines remain marginally optically thin through the PDR, and so provide direct probes of the amount of CO and C present, respectively. Roughly one-third of the molecular gas along the sightline is estimated by these models to be associated with dark molecular gas.

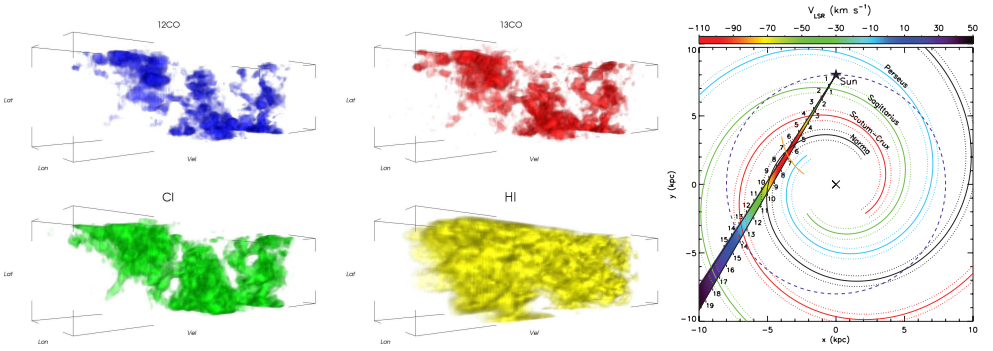

Figure 1. Left: Renderings of the G328 data cubes for ^{12}CO (blue), ^{13}CO (red), [CI] (green) and HI (yellow). Galactic longitude and latitude are along the short axes, with velocity along the long axis. The three spiral arm crossings are Norma near-, Norma far- and Scutum-Crux near-, from left to right. The relative extent of the atomic and molecular gas can be gauged, with the atomic hydrogen enveloping both the carbon and carbon monoxide emitting-gas. Right: Schematic of a four-arm model of the Galaxy using parameters from Vallée (2014). Spiral arms are shown by colour lines: Perseus (turquoise), Sagittarius (green), Scutum-Crux (red) and Norma (black). The G328 sightline is indicated by the wedge, with colour shading for the radial velocity and the orange arc for tangent points. The spatial scale is in kpc.

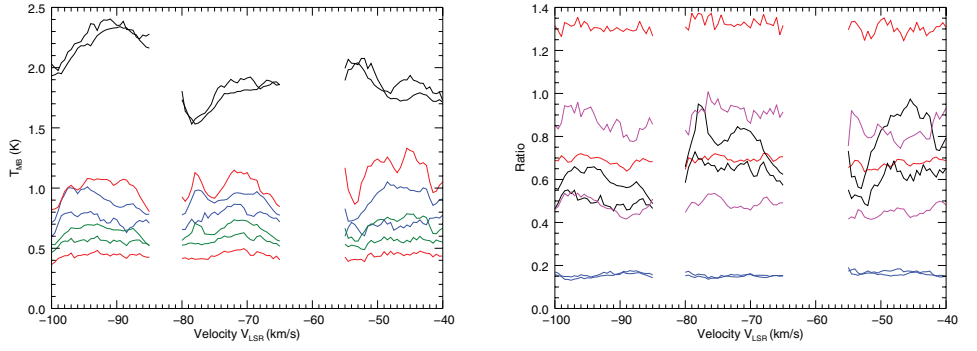

Figure 2. Left: averaged line profiles for ^{12}CO/5 (blue), ^{13}CO (red), [CI] (green) and HI/150 (black). Solid curves are for voxels where [CI]/^{13}CO < 1 and dotted where [CI]/^{13}CO > 1 (and meet a flux threshold). Right: averaged line ratios for [CI]/^{13}CO (red), [CI]/^{12}CO (blue), ^{12}CO/^{13}CO /10 (magenta) and [CI]/HI $\times$100 (black). When [CI]/^{13}CO > 1 the [CI]/^{13}CO and ^{12}CO/^{13}CO ratios nearly double, [CI]/^{12}CO is unchanged and [CI]/HI decreases by $\sim 10\%$.

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