OH Survey along GOT C+ Sightlines

1 Scientific Justification

Two main spectral line tracers of the mass and column density in the ISM are the 21cm fine structure transition of HI and low-J rotational transitions of CO. Growing observational evidence supports the existence of so-called "CO-dark molecular gas (DMG)", which comprises a substantial fraction of the ISM that is not completely traced by either CO or HI emission. Comparing observed dust optical depths with total gas column densities derived from CO and HI emission, the Planck collaboration (2011) found that the dust opacity is consistently higher in the intermediate extinction range ($A_V \sim 0.37$-2.5). These authors predict that, in ISM regions at a temperature of 80 K similar to the CNM, as much as half of the mass in which hydrogen is molecular may be "CO-dark", i.e. without CO emission. Results from the Energetic Gamma Ray Experiment Telescope (EGRET; Grenier et al. 2005) also show that the CO-dark molecular gas is very common throughout the Galaxy, even in the inner Milky Way. It surrounds all the nearby CO clouds and bridges their dense cores with the surrounding atomic clouds, thus providing a key link in the evolution of interstellar structure.

OH could form quickly in terms of extinction after H_2 becomes self-shielded (van Dishoeck & Black 1988). Subsequently, the formation of OH on grain surfaces could dominate the chemical chain that leads to CO (Wolfire 2010). Fig. 1 shows the schematic distribution OH and C^+. One of the main chemical paths associated with CO after OH formation is:

$$\mathrm{OH} + \mathrm{C}^+ \rightarrow \mathrm{CO}^+ + \mathrm{H}.$$
$$\mathrm{CO}^+ + \mathrm{H}_2 \rightarrow \mathrm{HCO}^+ + \mathrm{H}.$$
$$\mathrm{HCO}^+ + e^- \rightarrow \mathrm{CO} + \mathrm{H}.$$
$$\mathrm{CO} + h\nu \rightarrow \mathrm{C} + \mathrm{O}.$$

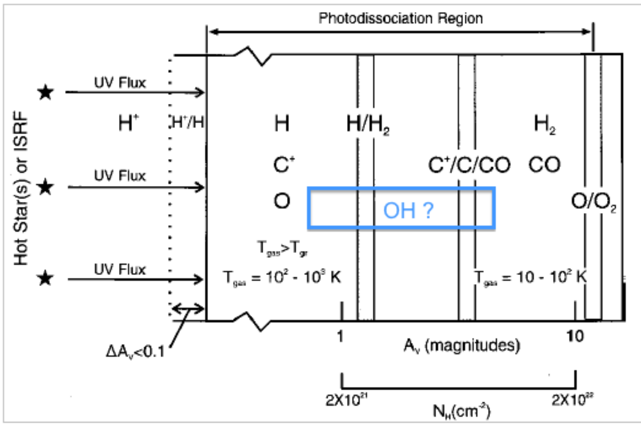

Figure 1: *A schematic view of photo-dissociation region (Tielens 2005). It shows the locations of different transition layers. We add blue pane to show the possible location of OH.*

To build up a large abundance of CO requires protection from UV radiation, which occurs primarily through dust extinction. OH, HCO^+ and C^+ thus seem to be the natural tracers of regions where CO is photodissociated. Regions that show any of these three components but lack CO emission are candidates for DMG.

Previous studies have showed that OH and HCO^+ do reliably trace the DMG even with its harsh UV environment. From Fig.2, the relation of column density of these two tracers $\frac{N(HCO^+)}{N(OH)}$ is exactly 0.03 with small errorbars (Lucas & Liszt 1996)- and the scales are linear! However, the linearity breaks down for $N(OH) \geq 10^{14.5}$ cm^{-2} (which corresponds to $N(H_2) \geq 3 \times 10^{21}$ cm^{-2}). This is expected because OH and HCO^+ participate in additional reactions. *A question is, how about the relation between C^+ and OH or C^+ and HCO^+ ?*

The Galactic Observations of TeraHertz C^+ (GOT C+), a Herschel Key Project, has surveyed 454 C^+ 158μm spectra toward the Galactic plane. Results from C^+ analysis shows: 1) C^+ is an effective tracer of DMG; 2) DMG exists widely in diffuse gas, transition gas and molecular gas (Langer et al. 2010, 2014). Motivated by comparing the relationship (linear correlation, anti-correlation or other) between N(C^+) and N(OH) in tracing DMG which has not been investigated yet, we propose to observe OH spectra along those GOT C^+ sightlines.

1.1 Planned Observations

Along with the C^+ spectra from GOT C+, the proposed Arecibo observation will allow a direct examination of the possible relation between N(OH) and N(C^+) (correlation may not be linear). GOT C^+ project contains 454 sightlines in total along the Galactic Plane. 89 of 454 sightlines which are covered by Arecibo telescope are proposed to be observed. Corresponding HI, ^{12}CO, ^{13}CO and $C^{18}O$ spectra have been already available toward these 89 sightlines. The position distribution of 89 sightlines is plotted in Fig.3.

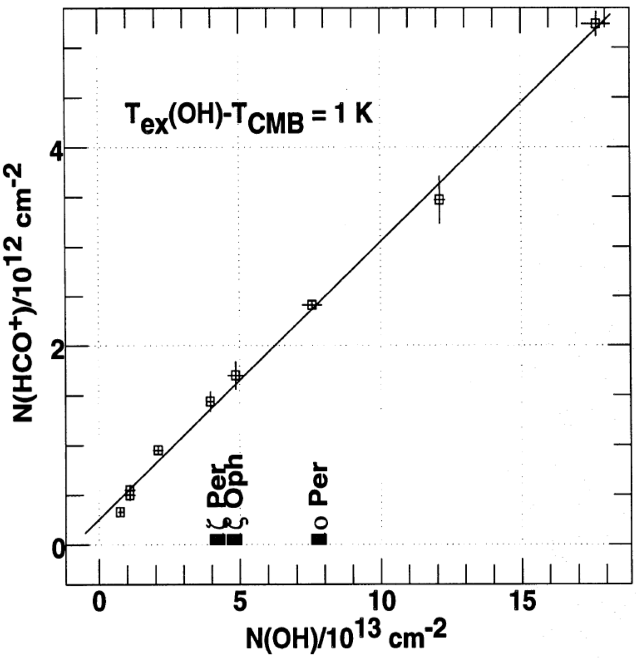

Figure 2: *N(HCO$^+$) vs N(OH). From Lucas & Liszt (1996).*

2 Technical Justification

We plan to do the single pointing OH emission observations of 89 sightlines. Assuming the visual extinction of clouds are 0.5 mag, then column density of the proton is $N_H = 9.4 \times 10^{19}\ cm^{-2}$. We take the OH abundance Z_{OH} in the Galaxy, 2.5×10^{-6} (James & Millar et al. 1991). So OH column density $N_{OH} = N_H Z_{OH} = 2.35 \times 10^{14}\ cm^{-2}$. N_{OH} is also expressed as (1667 MHz) (Li & Goldsmith 2003), $N_{OH} = 2.22 \times 10^{14} \int T_{mb} dv$.

The Full Width at Half Maximum (FWHM) is assumed as 2 km/s, so main beam brightness temperature is about 0.495 K. The antenna temperature $T_A = T_{mb}\eta_{mb} = 0.331\ K$ under the assumption $\eta_{mb} = 0.67$.

When adopting position switching mode, integration time for both polarizations is calculated by

$$t = \frac{1}{\Delta\nu}\left(\frac{\sqrt{2}T_{sys}}{RMS}\right)^2 \quad (1)$$

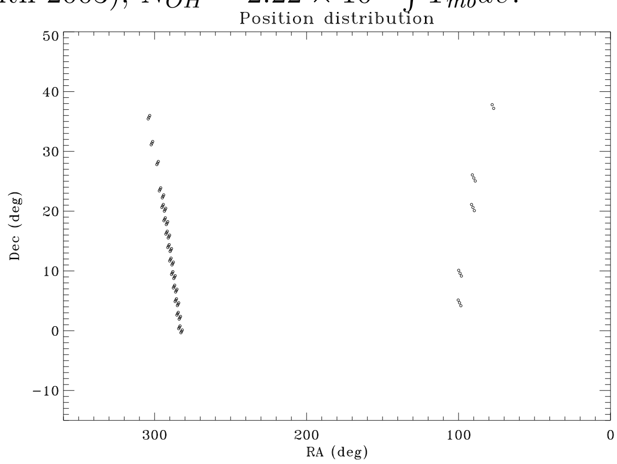

Figure 3: *Position distribution of 89 sightlines. It is showed in Equatorial coordinates (J2000.0).*

The system temperature of Arecibo in L band is 29 K. The required frequency resolution is 1 KHz (velocity resolution, 0.18 km/s). RMS value is taken as 0.05 K, which is used in most Arecibo OH observations and can ensure the signal-to-noise ratio greater than 5 in our case. The integration time for one sightline is

$$t = \frac{1}{1.667 \times 10^9 \frac{0.18}{3\times10^5}}\left(\frac{\sqrt{2}\times 29}{0.05}\right)^2 = 668.8\ s \quad (2)$$

The overheads time is assumed as 30% of the total observation time, thus the total observation time for 89 sightlines is 24 hours (16.55 hours for target observation, 7.45 hours for overheads).

2.1 References

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