Ubiquity of “Dark Gas” as traced by OH

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ABSTRACT

Is it worth spending time surveying the sky for diffuse OH for its ability to trace “Dark Gas”? And if so, how ubiquitous is this Dark Gas? We use the Millennium survey data to illuminate these questions in a statistically unbiased manner. We find: (1) yes, it is worth doing; and (2) OH absorption against continuum sources is an essential feature of a practical survey.

1. Introduction

I became intrigued by the possible ubiquity of transucent molecular clouds by the work of Liszt & Lucas (several papers mainly in 1990’s) and Ron Allen’s recent OH results, which were presented at the Berkeley ‘Trio’ meeting (Fall 2012, in honor of Chris McKee, Dave Hollenbach, and Frank Shu). In particular, Ron’s results imply that OH is detectable in lots of directions in which there is no obvious molecular cloud as revealed by CO. However, we should not rely too much on his results, because they are confined to a small area (~ 25 deg^2) centered on a molecular cloud L1204 (near $(l, b) = (108^\circ, 5^\circ)$). The same is true for other similar studies, such as Cotton & Magnani (2012). How to get more data with an economical use of telescope time?

At the FAST meeting in late October 2012, I presented this and suggested quite strongly that, as part of an all-sky HI survey with FAST, OH should also be included in order to obtain a more complete picture of the ISM—not only purely atomic gas, but also molecular hydrogen in structures where CO emission was absent. In other words, use OH as a tracer of translucent molecular clouds for which CO emission is undetectable.

In conversations with Di Li and Josh Peek during the meeting, we realized the need for more data to illuminate this issue. Josh suggested looking at fairly low Galactic latitudes where long lines of sight would increase the sampling volume without using more telescope time. I subsequently realized that we have data that come close to this: the Millinnium survey (Heiles & Troland, several papers in early 2000’s). That survey was done for HI, but we simultaneously observed the two OH main lines. So we have emission/absorption data for OH as well as H in the direction of roughly 70 sources. Here we present those data for some of the sources; others are not included for obscure reasons, and if we ever make a public version of this paper we should include those and use the full source sample.

2. Does OH exist when CO does not?

Here, we ask whether OH exists when CO does not. Or, in other words, "Does OH trace H_2 in regions where CO is undetectable?" (This alternative question assumes that no molecules, like OH, can exist unless the H is molecular). Look at Figure 1. Stars show sources with detected OH absorption. Red circles show sources with detected CO emission and green circles show no CO emission. Therefore, sources with both stars and green circles have OH absorption but no CO emission, so these show "Dark Gas". (Blue circles have no CO data). CO data are from Dame's compilation (`http://www.cfa.harvard.edu/rtdc/CO/`).

There are eight sources with OH but no CO, showing Dark Gas. There are 7 sources showing both OH and CO. Thus *Dark Molecular Gas (with no CO) is as common as Undark Molecular Gas (with CO).* Or, in other words, OH does exist when CO does not, and quite commonly.

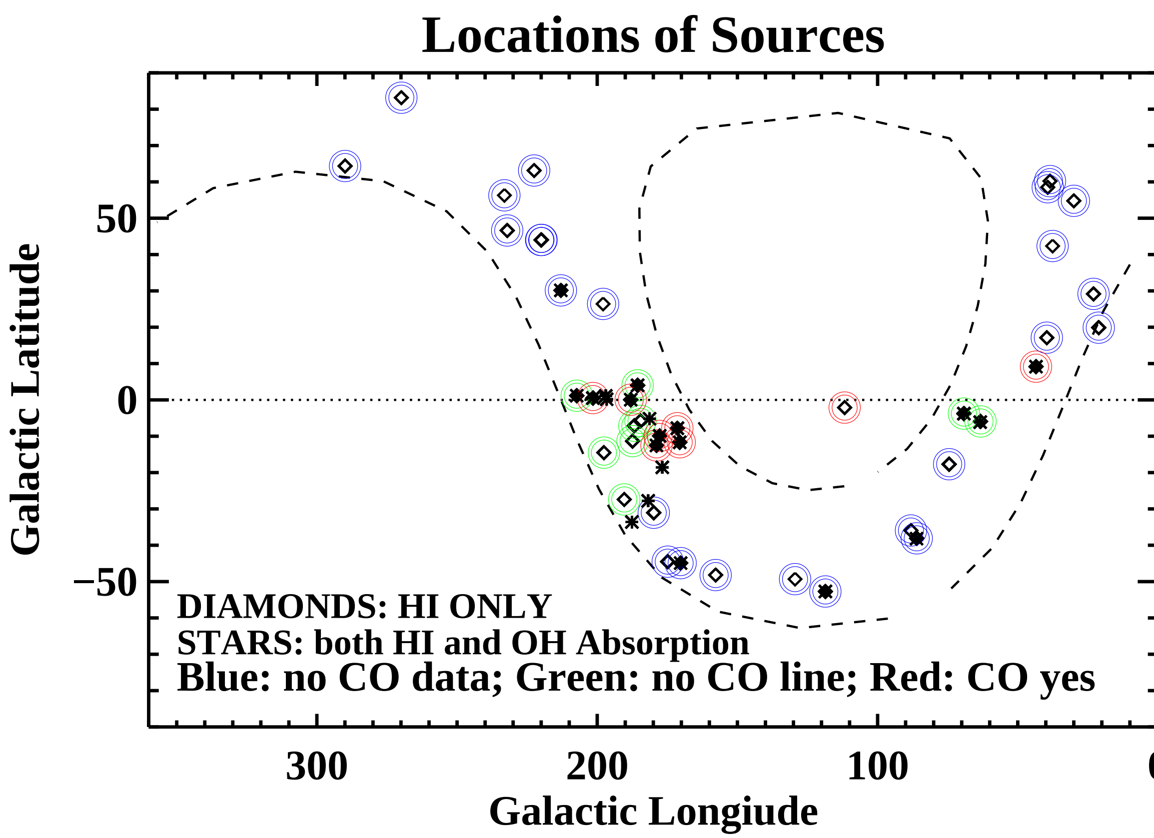

Fig. 1.— Map of sources observed in the Millennium survey. Diamonds are sources showing HI absorption only. Stars show both HI and OH absorption. Blue circles show sources having no CO data. Green circlees show sources having CO data, but no detected CO line. Red circles show sources having detected CO line.

3. Detecting OH in absorption

Our primary detection scheme was OH in absorption against the background continuum sources used in the Millennium survey. These sources typically had $S \gtrsim 2$ Jy, so produced antenna temperatures in excess of about 20 K at Arecibo. Figure 2 exhibits the histogram of detected optical depths of the OH components. To make this figure, we decomposed all OH lines into Gaussian components and made the histogram of the peak optical depth for each component.

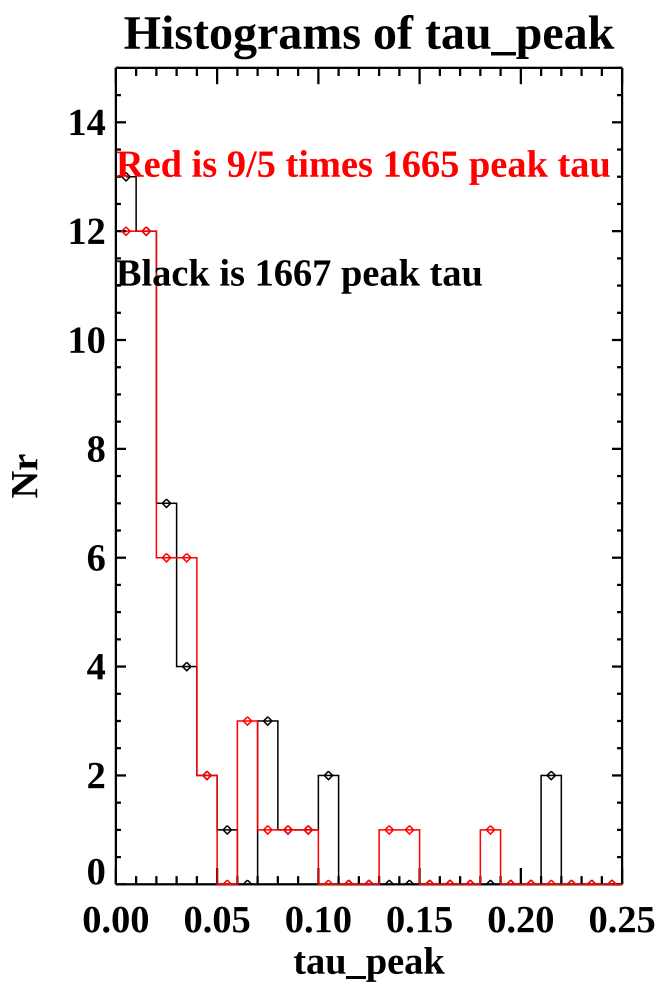

Fig. 2.— Histogram of peak optical depth for the Gaussian components. Black shows 1667 and red shows 9/5 times the peak optical depth for 1665.

For 1665, the histogram is for 9/5 the peak optical depth; this makes it identical in scale to 1667 so there is no funny business in the excitation. The histograms for 1665 and 1667 do, indeed, look similar. The histograms keep rising toward low optical depths with no turnover, implying that our OH detectability is sensitivity limited. This bears examination with more sensitive data! Anyway, even with a peak optical depth of 0.01, the absorption line intensity for a 2 Jy source is about 0.2 K—fairly easy to detect.

4. Detecting OH in emission

It was very clear in examining the data that the OH lines were much stronger in absorption than in emission. This is easy to understand when considering the excitation temperature. For a frequency-switched emission spectrum of a single OH feature having peak optical depth τ seen against a continuum background brightness temperature T_C, the observed antenna temperature T_A is

$$\Delta T_A = [T_x - T_C]\,[1 - \exp(-\tau)] \tag{1}$$

where T_x is the OH line excitation temperature. T_C includes the CBR and also the Galactic synchrotron background, which we obtained from the Haslam et al. 408 MHz map and scaled in frequency with spectral index 2.8. Owing to our OH line measurements in both absorption and emission, we derive T_x. Figure 3 shows histograms of the two T_x and also T_C. T_C is typically about 3.5 K, while the T_x's range from 2 to 15 K—but they peak at low temperatures. Since $T_A \propto (T_x - T_C)$, the emission line intensities are significantly reduced.

Figure 4 shows the histogram of emission antenna temperatures for the Gaussian components. Again, the histograms rise toward low values, implying sensitivity-limited. The low-temp peak is at about 20 mK, and we expect more lines to be even weaker. The OH is hard to see in emission; much easier to see in absorption!

The typical spacing for sources having $S > 0.5$ Jy is about 2.4 degrees. The Fast telescope will produce an antenna temperature $\gtrsim 10$ K for such sources, makking the OH fairly easy to detect. Probably the best way to survey OH is to first find contiinuum sources against which OH is dettectable in absorption, and then to map it in emission in the vicinity.

5. HI and CO on a component-by-component basis

You might think that the probability of OH would increase with the column density of HI. To check this, Figure 5 plots OH column densities derived from the emission/absorption data versus HI column desities, both on a Gaussisan component-by-component basis.

To do this requires associating OH components with HI components. This is not so easy. HI components are always wider than OH ones, and the central velocities never line up. Usually there are several OH components for each HI component. So the OH column densities in Figure 5 are

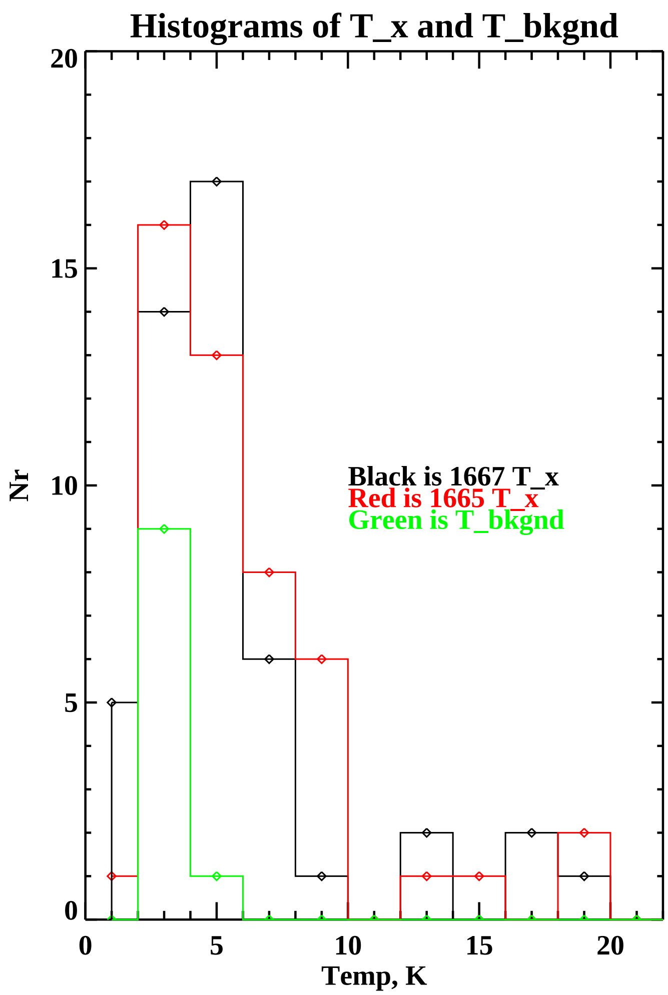

Fig. 3.— Histograms of excitation temperature T_x for the two OH lines; and the background continuum temperature T_C in equation 1.

the sum of all OH components associated with a single HI component.

The row of red points at “zero” on the vertical axis shows that there are lots of HI components without OH. $N(OH)$ does not increase monotonically with $N(HI)$. However, one needs to look at this more carefully—to what extent are the HI components breakable down into smaller subcomponents?

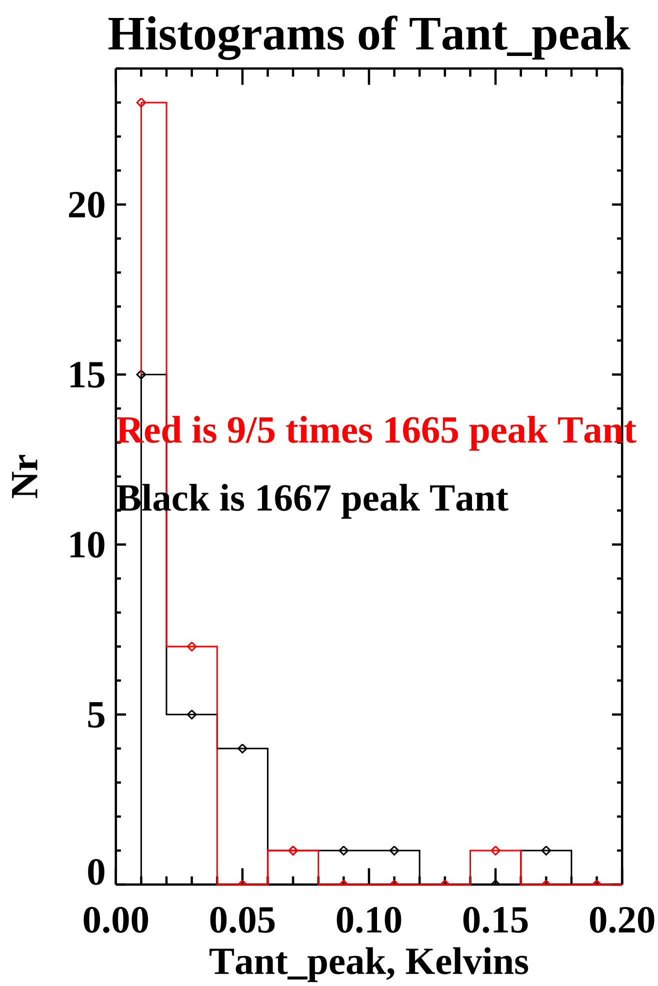

Fig. 4.— Histograms of antenna temperature for the OH components in emission.

6. More to do

I've run out of time. If I had more time, I'd compare the CO velocities with the OH and HI velocities and compare integrated line intensities, or column densities, on a Gaussian component-by-component basis. I'd search for correlations between the presence of OH or CO an HI properties such as excitation temperature, line width, and magnetic field strength. There is a pretty nice paper that could be written on the basis of these data. If you guys (Di and Josh) want to pursue this, please go ahead!

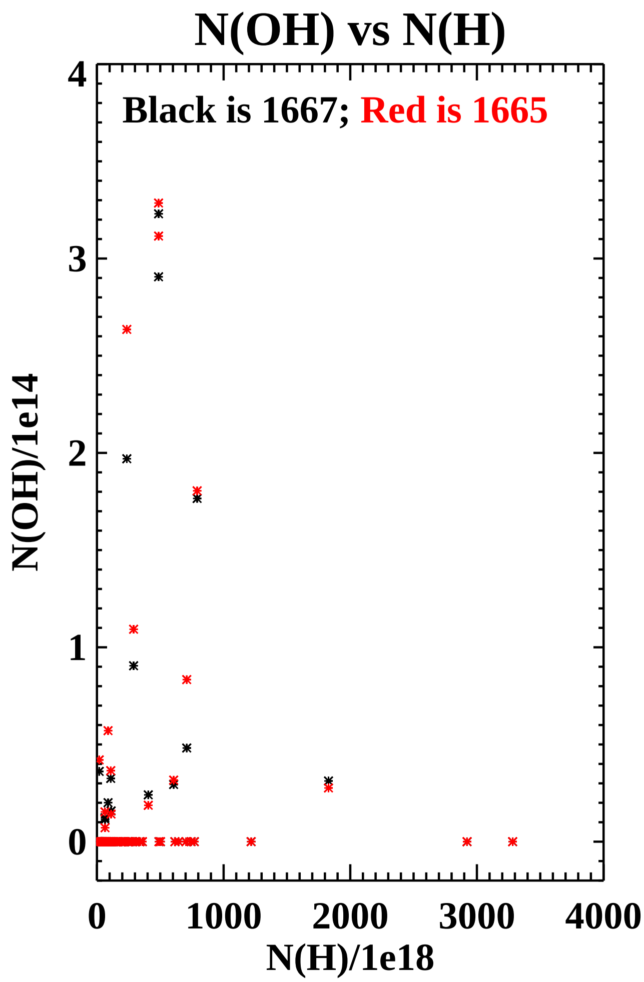

Fig. 5.— Histogram of peak optical depth for the Gaussian components. Black shows 1667 and red shows 9/5 times the peak optical depth for 1665.