OH as a Tracer for "CO-Dark H_2" in the Galaxy

A progress report on a blind mini-survey for OH emission with the Green Bank Telescope

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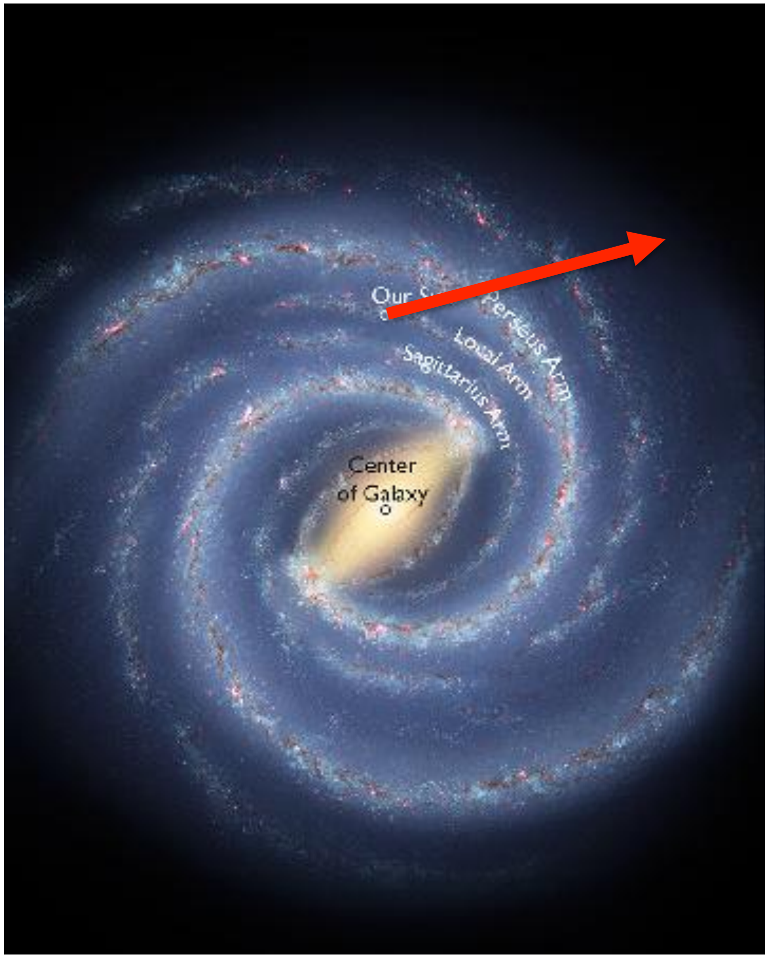
Why is this interesting?

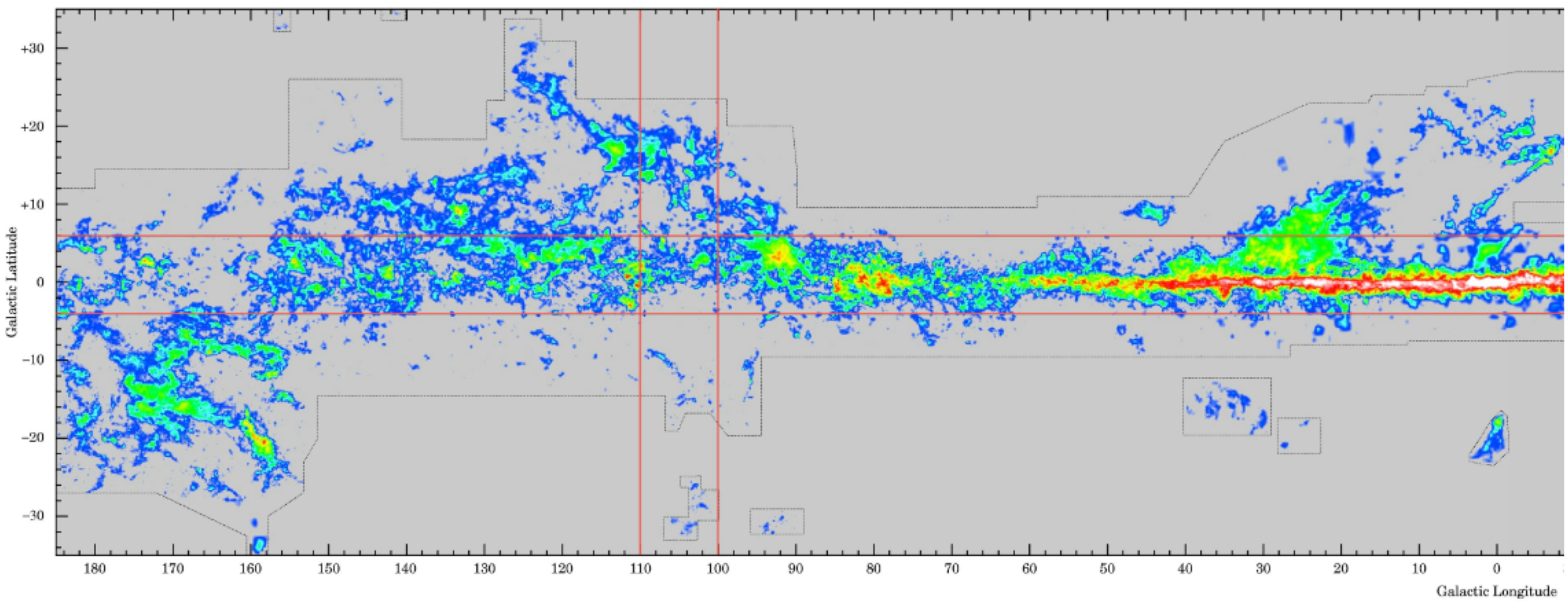
- The problem: tracing the amount, distribution, and motions of the interstellar gas in galaxies on various scales in galaxies.
  - understanding the condition for star formation
  - studying the kinematics and dynamics of spiral structure
- Tracers for neutral gas:
  - HI - traced by the 21-cm line
    - pretty well understood, but often over-simplified with the assumption of low optical depth.
  - H_2 - traced with surrogates
    - CO(1-0) dominates the field for lack of alternatives, but questions of the reliability of quantitative H_2 determinations from it remain.
- Developing a viable alternative to CO would at least provide a useful "second opinion" and could possibly reveal new results.

GBT OH Pilot program 2013

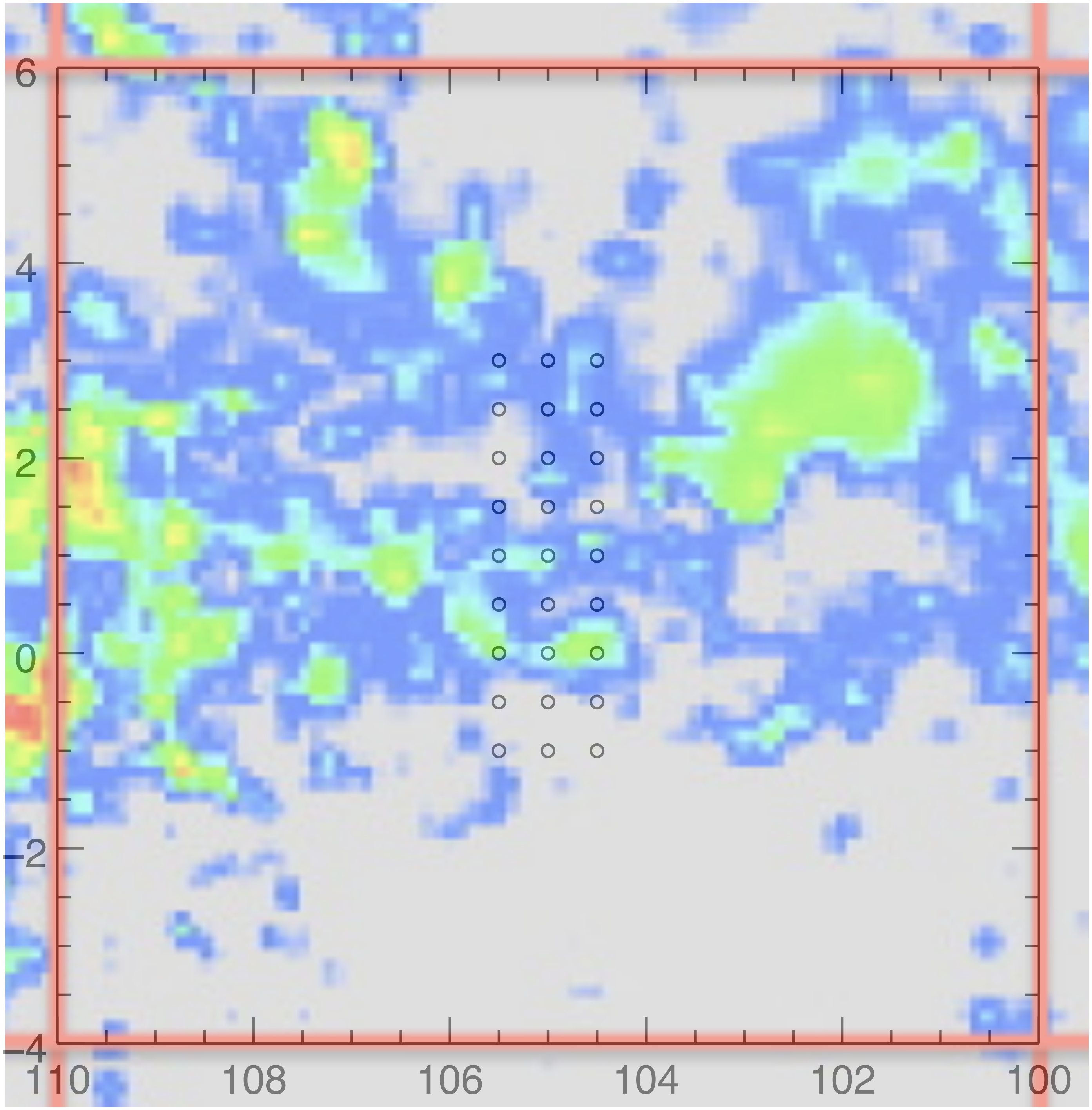
3 X 9 grid centered at:
L = 105.0°, B = +1.0°
ΔL = ΔB = 0.5°



Area of our Blind OH Survey on the CO(1-0) All-Sky Map ...



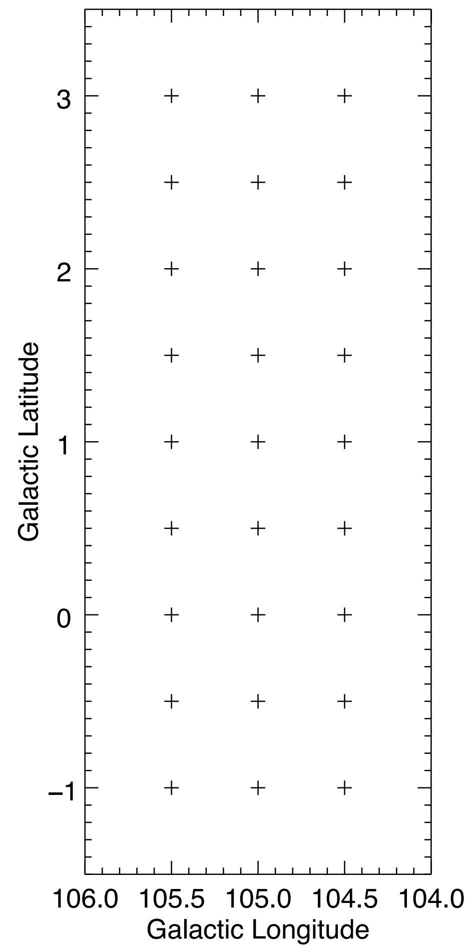
Dame, Hartmann, & Thaddeus 2001



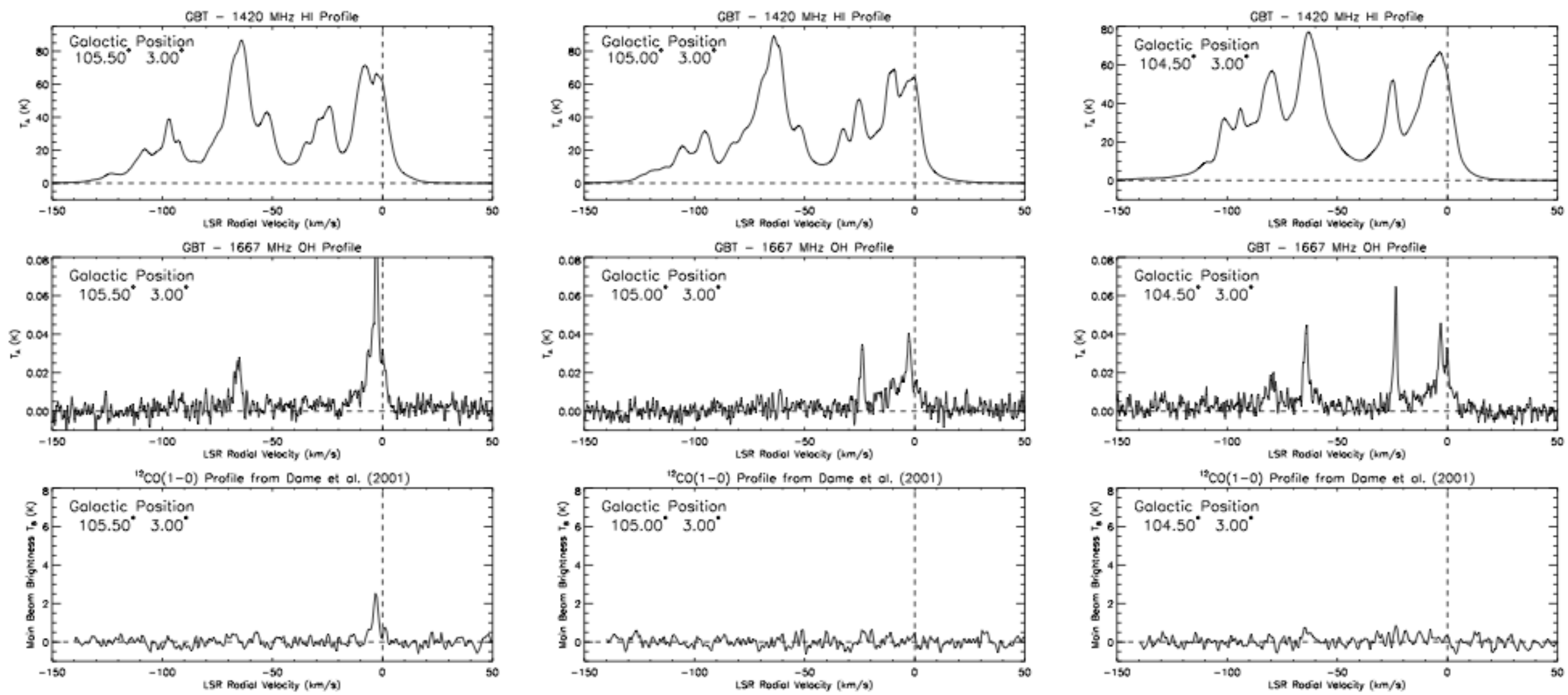
6
4
2
0
-2
-4
110
108
106
104
102
100

What did we do?

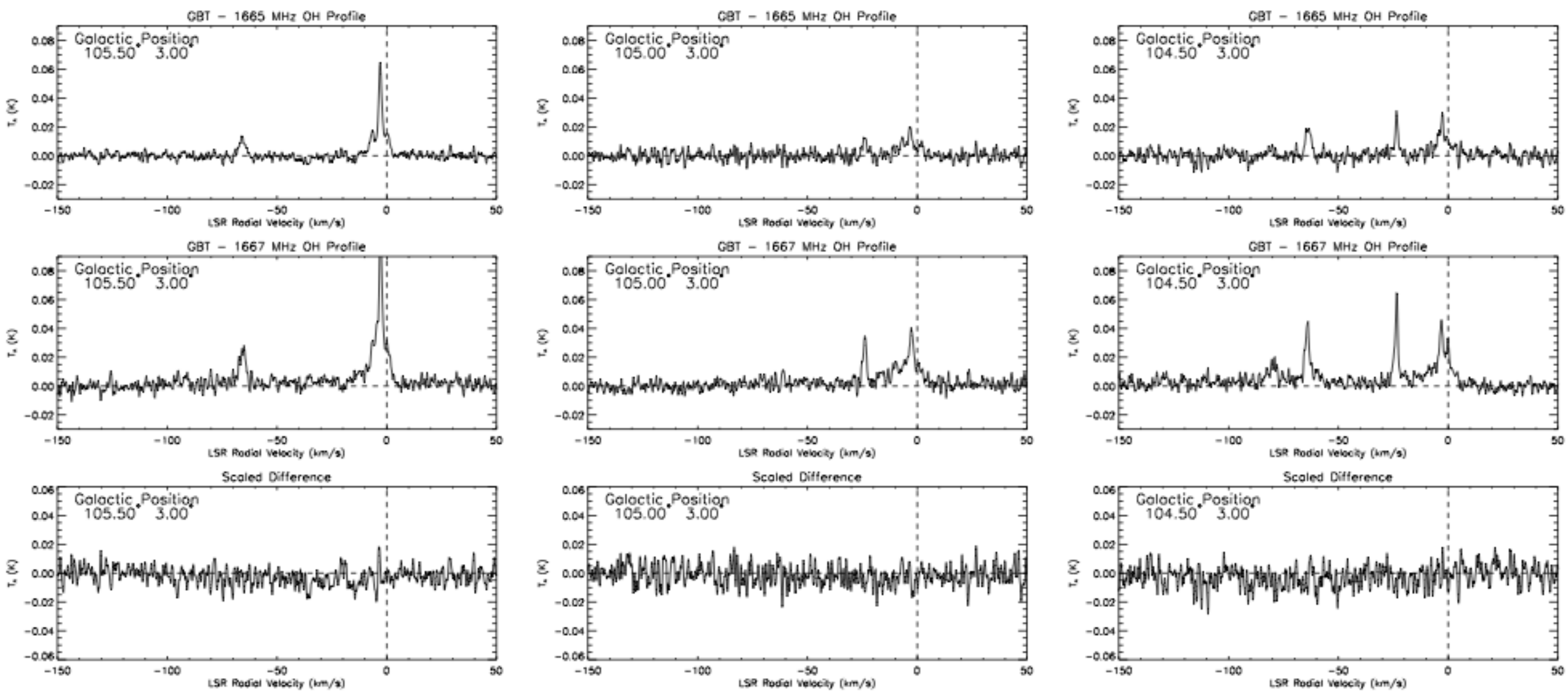
- 3 X 9 grid of GBT pointings near L=105, B=+1, on 0.5° spacing, straddling the Galactic Plane.
  - 66 hours requested.
  - L-band: 1420/1665/1667/1720 MHz
  - frequency-switching mode
  - 2-hour integrations at OH, final sensitivity of ≤ 3.5 mK rms in 0.55 km/s
  - 5-min integrations at HI
  - GBT FWHM: 8.9' at HI, 7.6' at OH
- CO data available at 8.4' FWHM
  - CfA archives – Dame et al. 2001
  - observe at same pointing positions
  - region chosen to be faint in CO



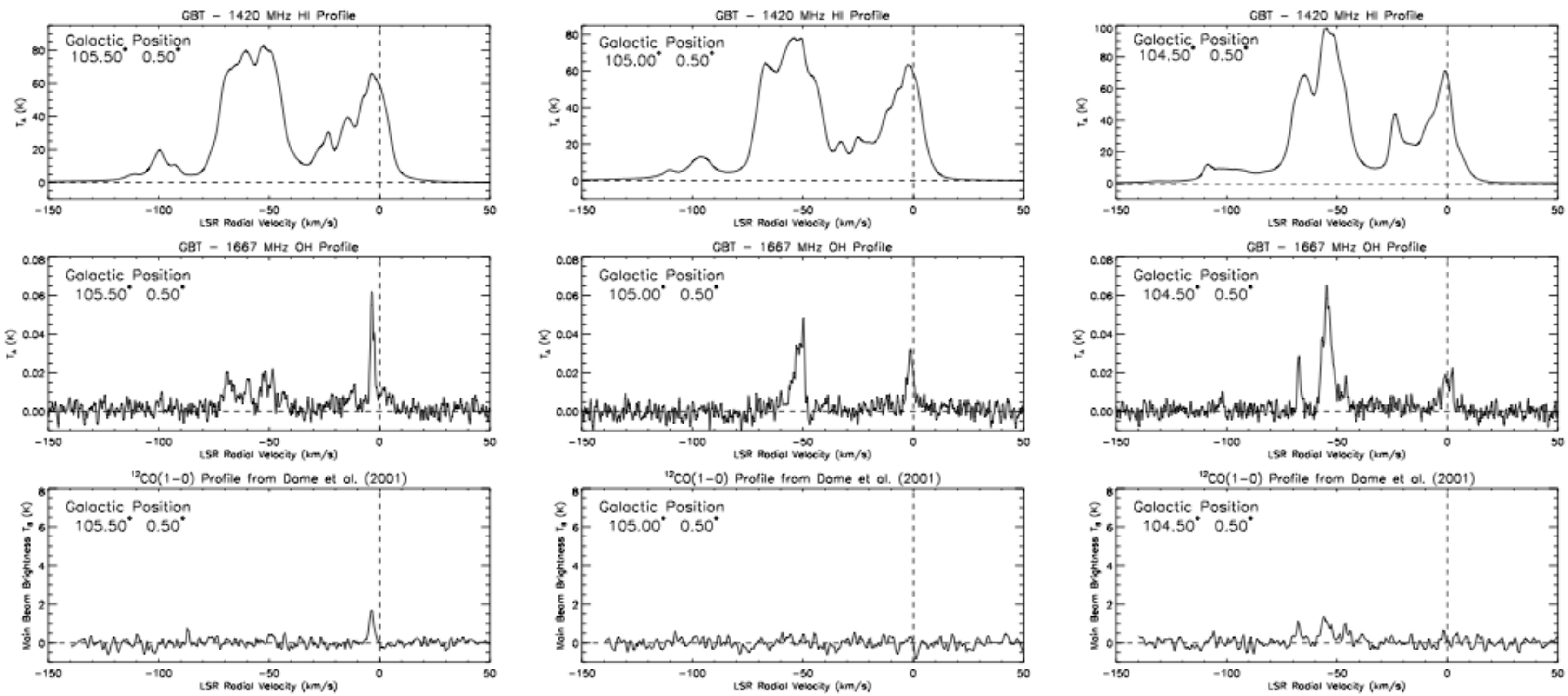
HI, OH 1667, and CO Profiles



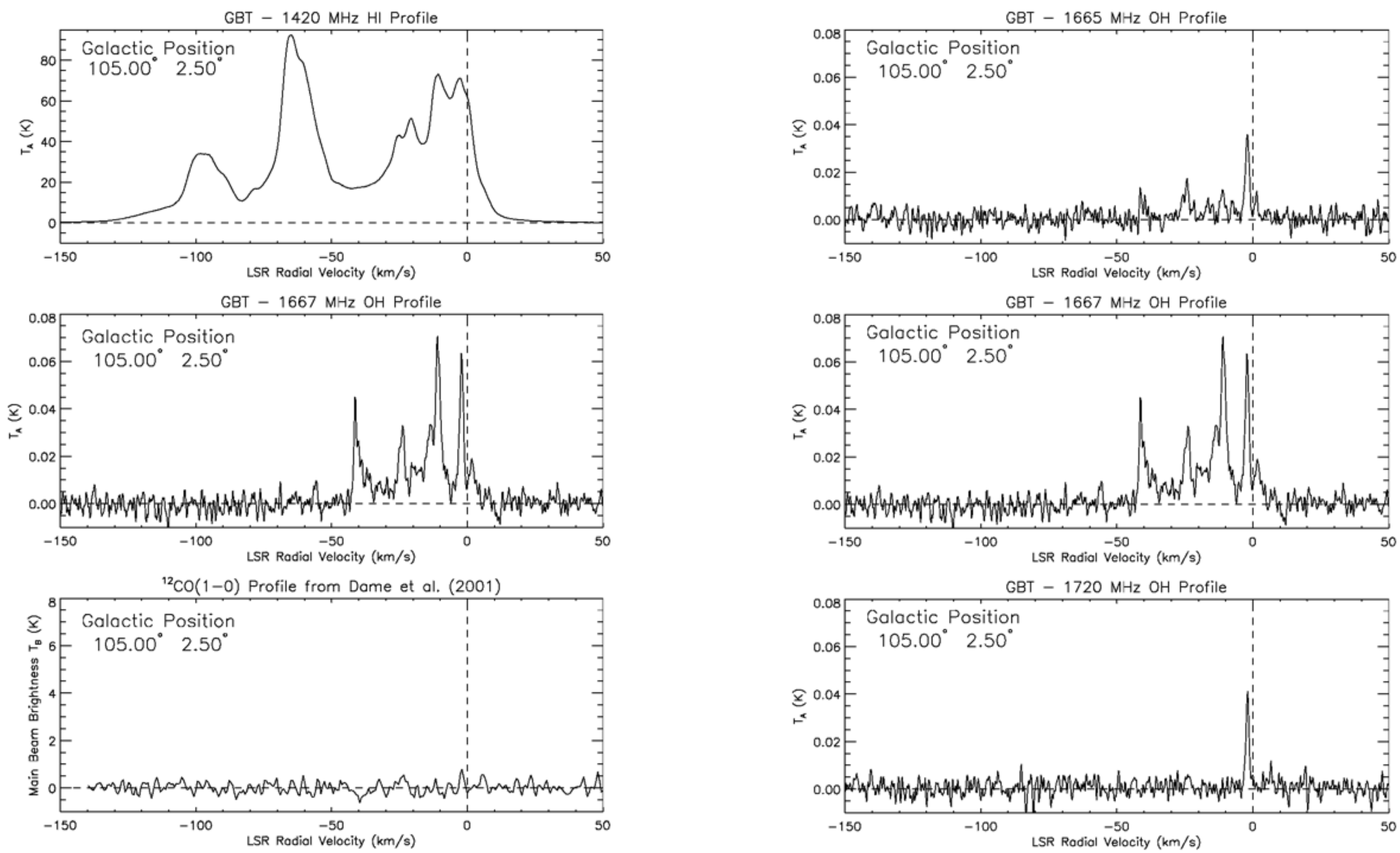
Main line ratios are 5/9



Spatial structure varies strongly ...



A few profiles show (familiar!) anomalies ...



What did we find? - I

- We have confirmed the ubiquity of faint OH emission in the Galaxy, as found in an earlier, more limited blind survey at Onsala (Allen et al 2013, 2014).
  - OH identified in more than 23 of the total of 27 pointings.
  - 55 separate OH features found, corresponding with familiar features of Galactic structure such as Gould's Belt, the Local Arm, and the Perseus Arm.
  - (almost) all 1667 MHz OH features correspond with peaks in the HI profiles at the same positions.
  - not every peak on an HI profile shows up in OH (sensitivity?)
- CO is generally faint or absent in the survey region.
  - this was by design, but the contrast is striking; less than 1/3 of the 55 OH features show detectable CO emission in the CfA data.

What did we find? - II

- Confirmed that the main OH lines are not generally anomalously excited.
  - the scaled difference profiles (1667 – 1.80 X 1665) generally show just noise.
  - Identified a small number of anomalous features:
    - One survey position is by chance near a known OH-IR star
    - a narrow feature the appears both in the main OH lines and at 1720 MHz may be a large-scale shock
- Neighboring profiles show spatial variations at angular scales less than our survey grid spacing.
  - this is especially obvious for features in the Perseus Arm

What did we find? - III

- No absorption features were found in the area of our "blind" survey.
  - consistent with the low levels of Galactic continuum emission in this direction towards the Outer Galaxy.
- Contrasts with the recent results from the SPLASH survey at Parkes (Dawson et al 2014)
  - these authors generally see OH in absorption, probably because of the brighter Galactic continuum emission in the southern sky.
  - Proximity of OH excitation temperatures to that ambient continuum emission compromises detection of faint emission.
    - Dawson et al (2014) generally do not find OH without CO.

H_2 column density from CO …

- $N(H_2)$ from 3-mm CO emission:
  - $N_{CO}(H_2) \approx 2 \times 10^{20}\ T_{MB}\,(CO)\ \Delta V$ K•km/s
  - This uses the "X Factor" for CO(1-0)
    - based on a simple "counting" model for optically-thick clouds and the Virial Theorem.
    - the accuracy is uncertain. Many papers have discussed this, but questions persist and are often resolvable only with ad hoc corrections (e.g. metallicity correction).

H_2 column density from OH …

- Usual method is to get N(OH) from the line integral of $T_{MB}(OH)\Delta V$ and use an assumed abundance of OH to H_2 to infer $N(H_2)$.
- Absorption-line spectroscopy of UV-bright stars in the solar neighborhood may eventually allow a more direct method:
  - Copernicus and FUSE results for $N(H_2)$
  - UVES results for N(OH)
    - e.g. Weselak et al 2009, A&A 499, 783

The OH – H_2 correlation …

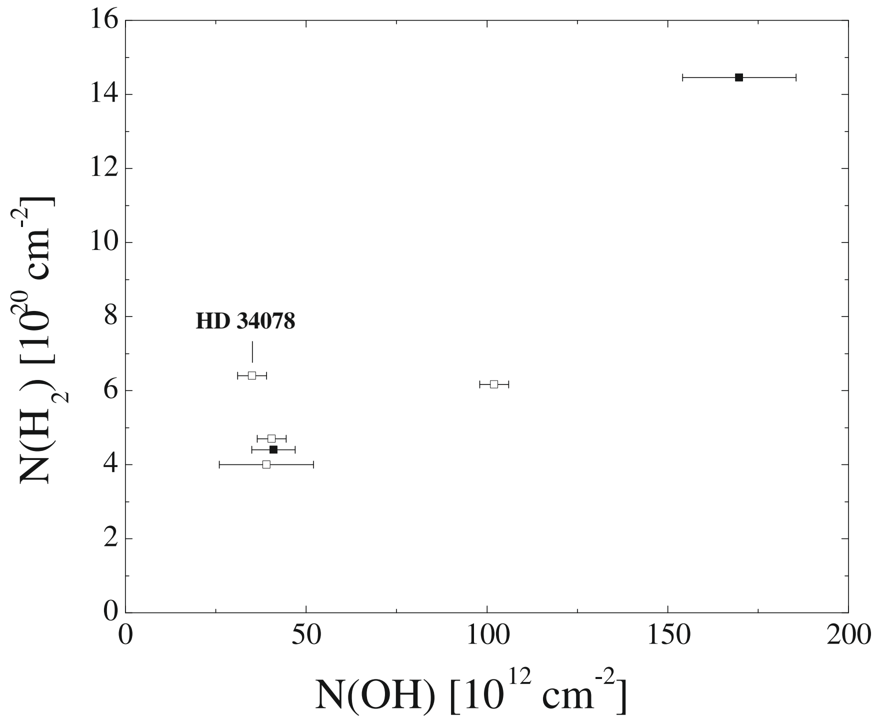
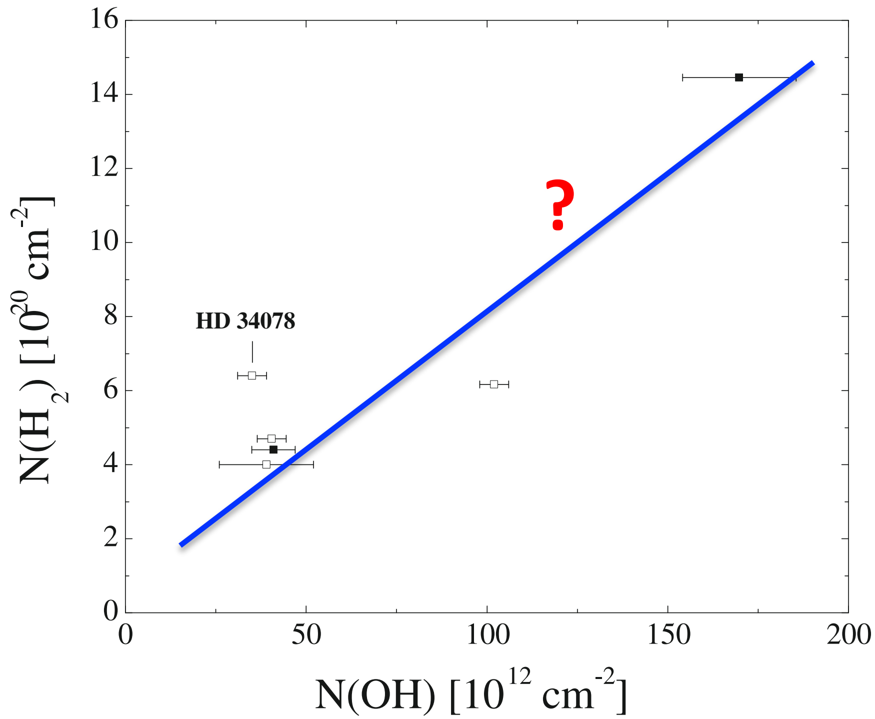


Fig. 5. Interstellar H_2 column density (from the literature) vs. that of OH. Filled squares – our measurements; open squares – the literature data. Note HD 34078 – the object probably also lies outside the relation between column densities of H_2 and OH.

Weselak et al 2009

The OH – H_2 correlation …



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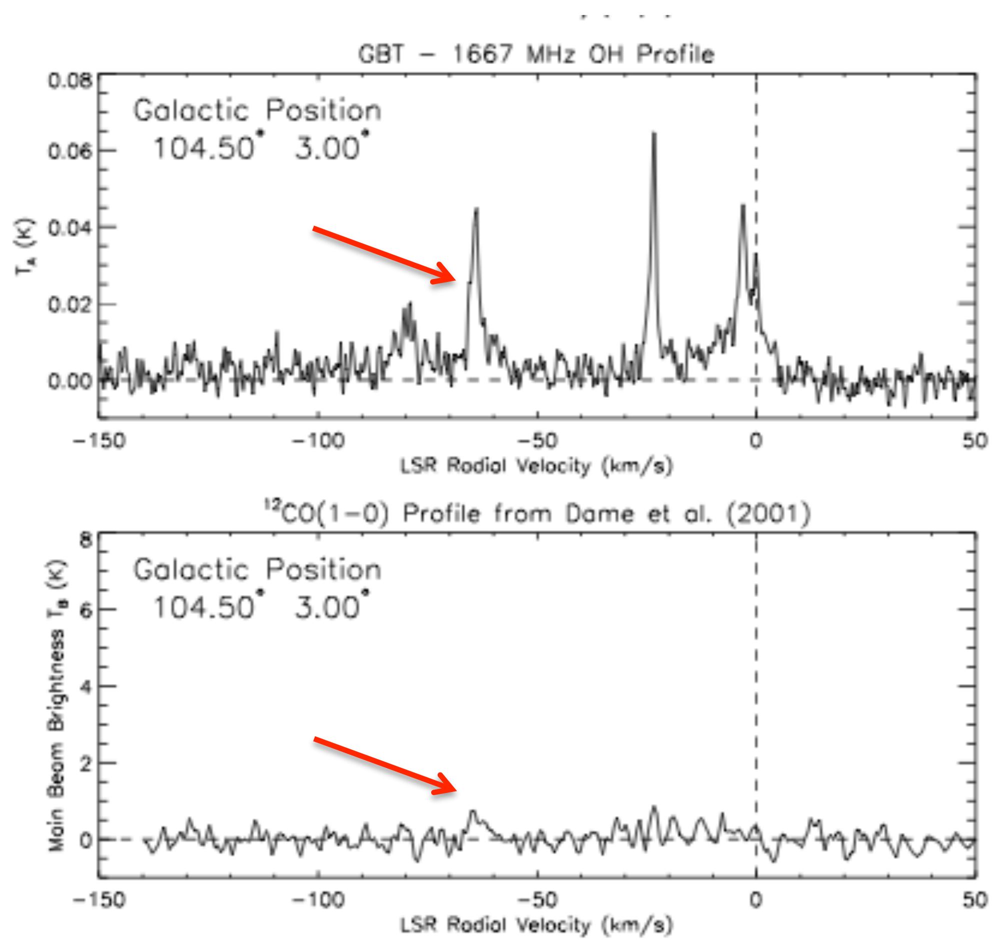
Weselak et al 2009

H_2 column density from OH

- The data are clearly still a bit sparse, but tantalizing, and more needs to be done.
- If this correlation proves robust, then we have a direct measure of $N(H_2)$ from 18-cm thermal OH line emission which numerically resembles the X(CO)-Factor. It is:
  - $N_{OH}(H_2) \approx 34 \times 10^{20}\ T_B(OH)\ \Delta V$ K•km/s
    - this is quite close to the old “abundance” argument, but now is linked to a direct measurement.
    - $T_{exc} \approx 10$K here; If it is less, the inferred $N_{OH}(H_2)$ is larger.

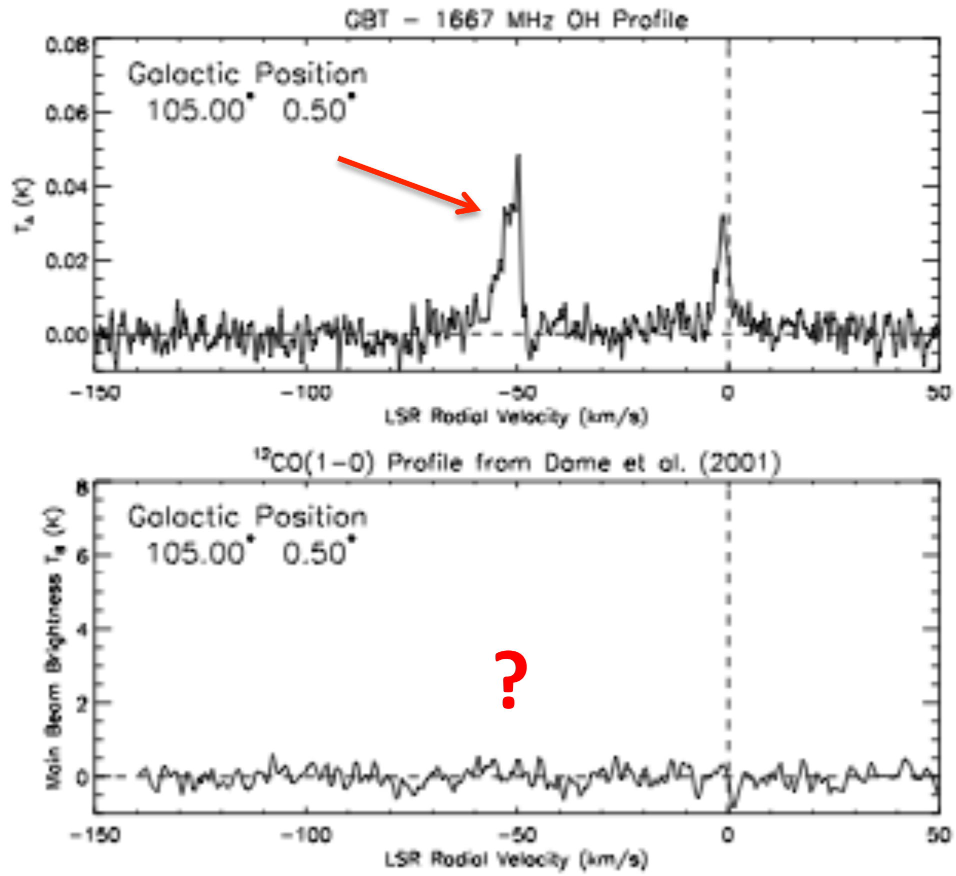
Sample calculation #1 ...



Typical H_2 column densities in specific Perseus Arm "features" …

Feature	Tb(OH)	Tmb(CO)	ΔV	NH2(OH)/ 10^20	NH2(CO)/ 10^20
1	40 mK	≤0.5 K	4 km/s	5.4	≤4.0

Sample calculation #2 ...



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Feature	Tb(OH)	Tmb(CO)	ΔV	NH2(OH)/ 10^20	NH2(CO)/ 10^20
1	40 mK	0.5 K	4 km/s	5.4	4.0
2	35	< 0.3	5	6.0	< 3

The bottom line ...

- OH appears to be a promising complement/alternative to CO as a large-scale tracer for H_2 in the ISM.
  - It is more sensitive to low-density regions than CO
    - $n_{crit}(CO) \approx 50$ to $1000\ cm^{-3}$ depending on opacity
    - $n_{crit}(OH) \approx 2\ cm^{-3}$
  - It is revealing H_2 even in CO-poor regions, and is likely to lead to and increase the mass of H_2 in the Galaxy
  - Keep OH emission in mind when thinking about new instruments.
    - High sensitivity, stability, and low interference levels are required.
- Some important issues need to be addressed:
  - What is a good value to use for T_{ex} ?
  - Can we reach to larger distances in the Outer Galaxy?
  - The N(OH) – N(H_2) relation needs more attention.