The Structure of Dark Molecular Gas in the Galaxy

I - A Pilot Survey for 18-cm OH Emission near L ≈ 105°, B ≈ +1°

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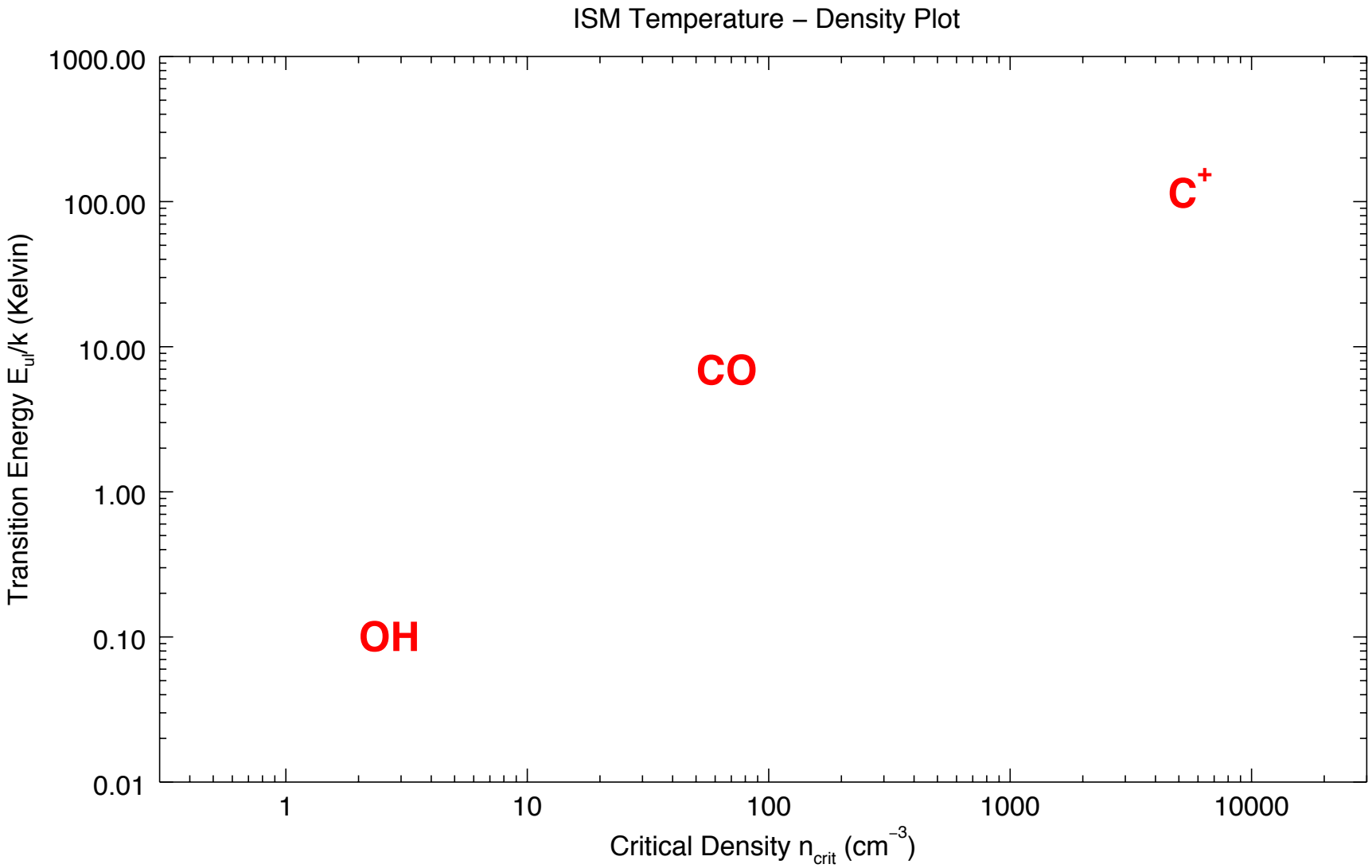
Introduction

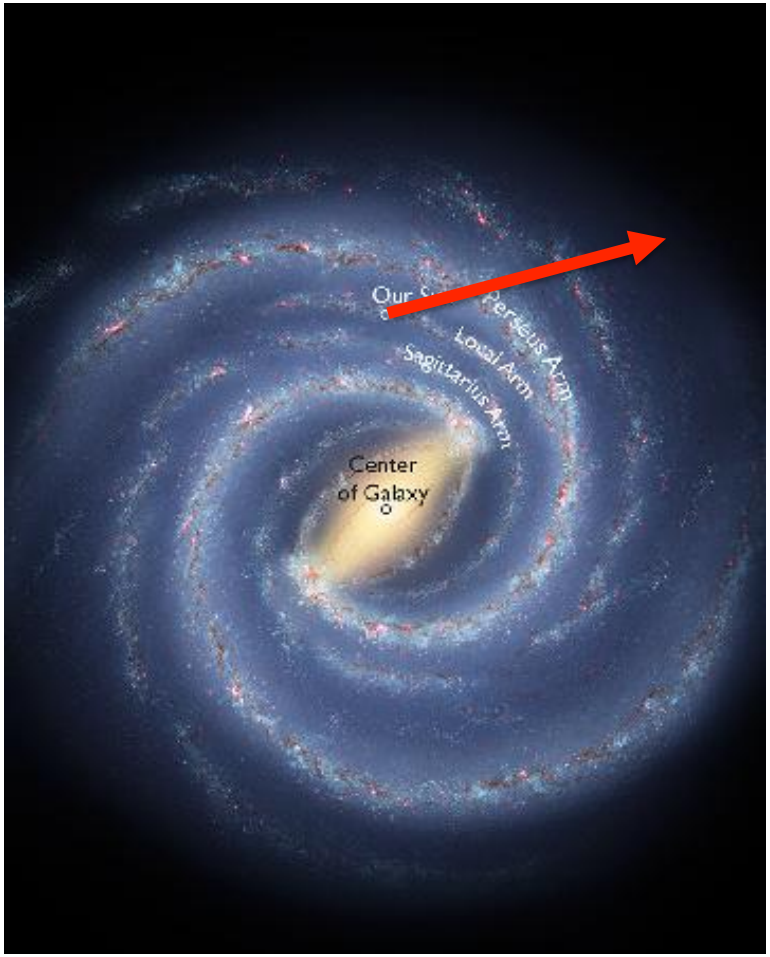
- Some personal history.
- Why is this interesting?
- Where do we look?
- What tracer do we use?
- What did we do?
- What did we find?
- What are we doing next?


ISM Temperature – Density Plot
1000.00
100.00
10.00
1.00
0.10
0.01
Transition Energy E_{ul}/k (Kelvin)
1
10
100
1000
10000
Critical Density n_{crit} (cm^{-3})
C^+
CO
OH

GBT OH Pilot program 2013

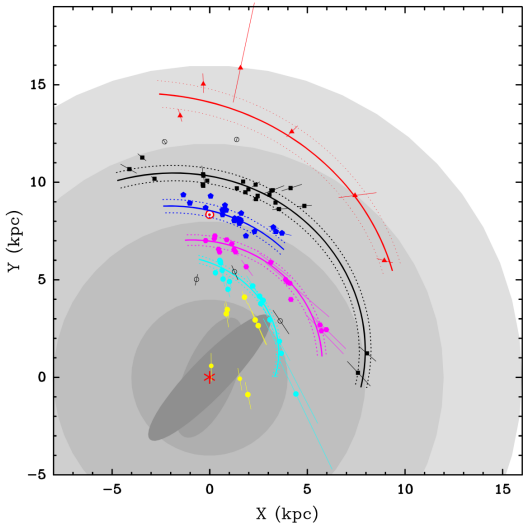
3 X 9 grid centered at:
L = 105.0°, B = +1.0°
ΔL = ΔB = 0.5°
(undersampled -
GBT FWHM ≈ 8’ @ 18 cm)
1’ ≈ 1 pc at Perseus Arm

NRAO
Green Bank Telescope



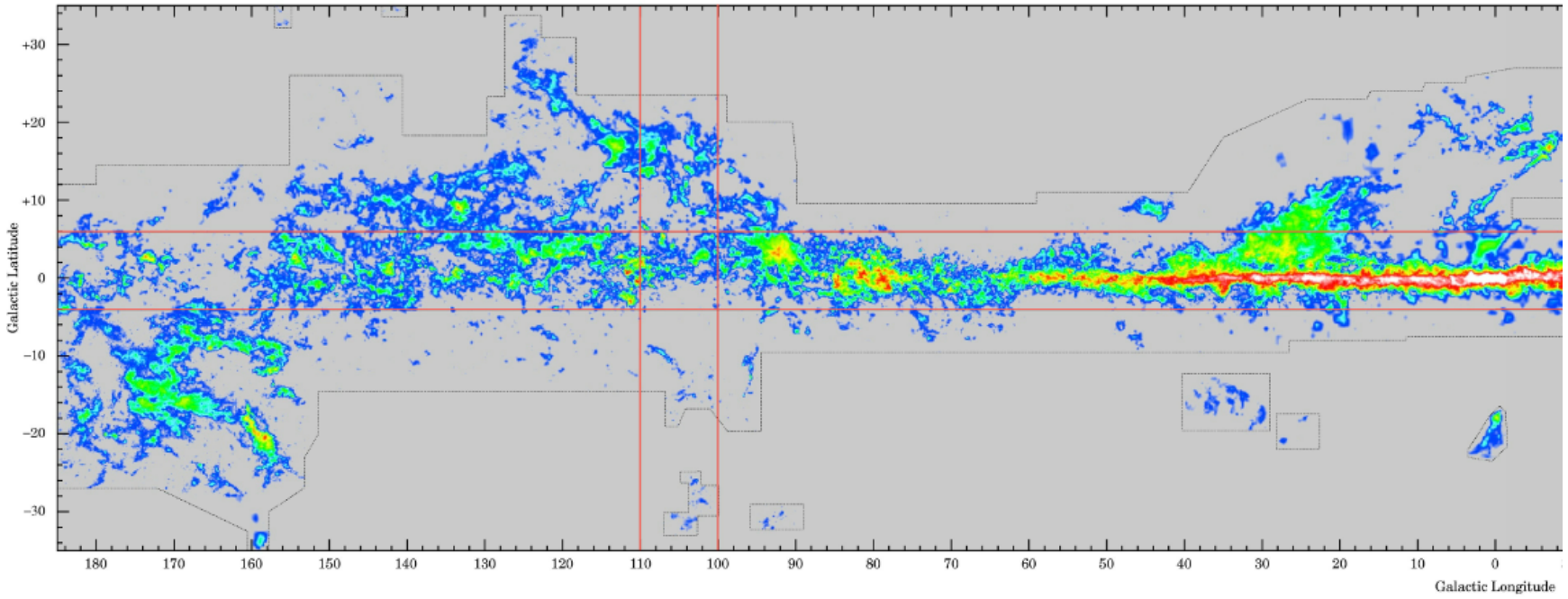
Galactic rotation separates features in V along the LOS:
- Local gas: $V_{LSR} \approx 0$ km/s
- Perseus: $V_{LSR} \approx -65$ km/s
- Outer: $V_{LSR} \approx -100$ km/s

Distances along LOS known in parsec by triangulation:

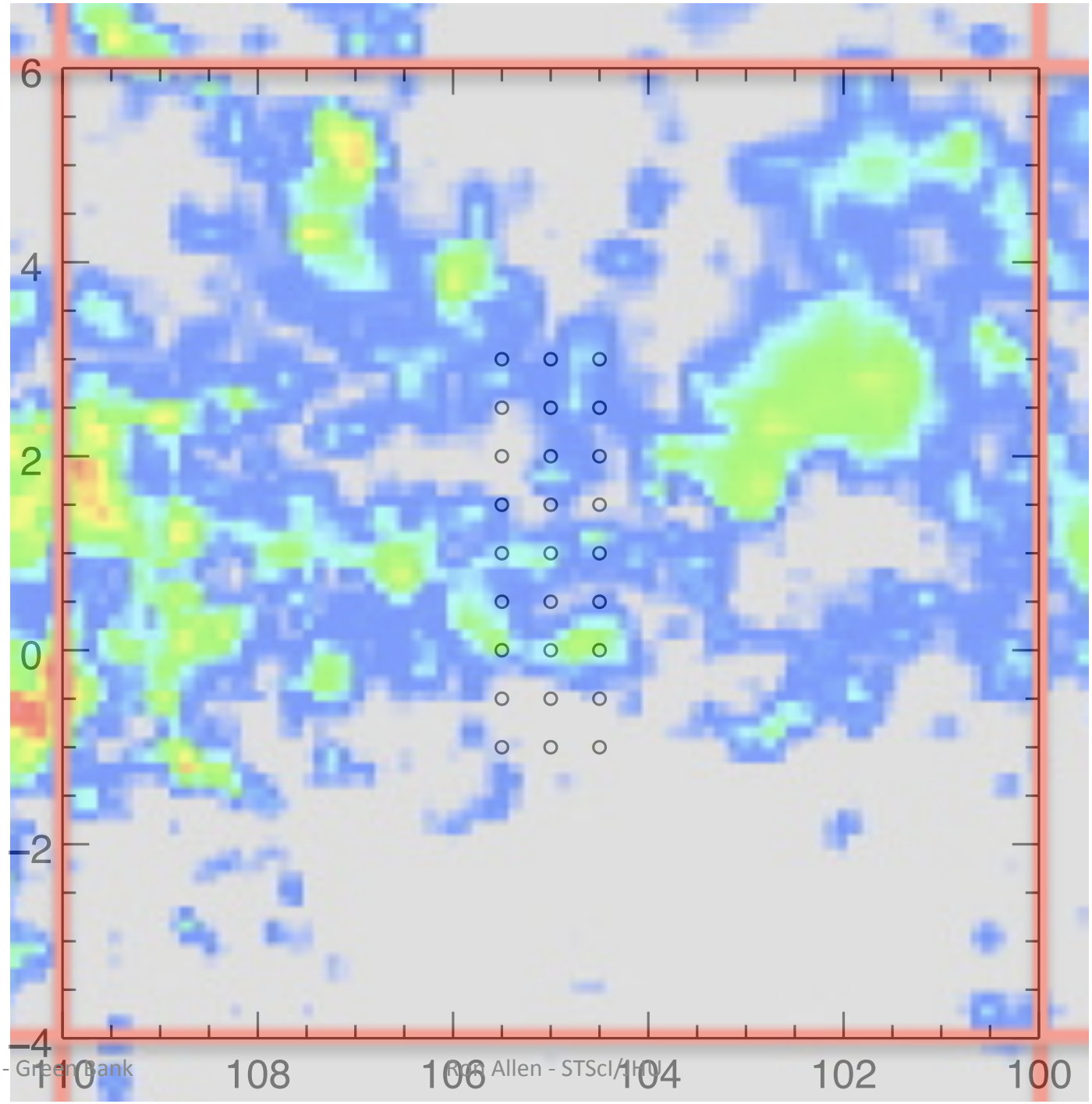


Reid et al 2014, ApJ 783, 130

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

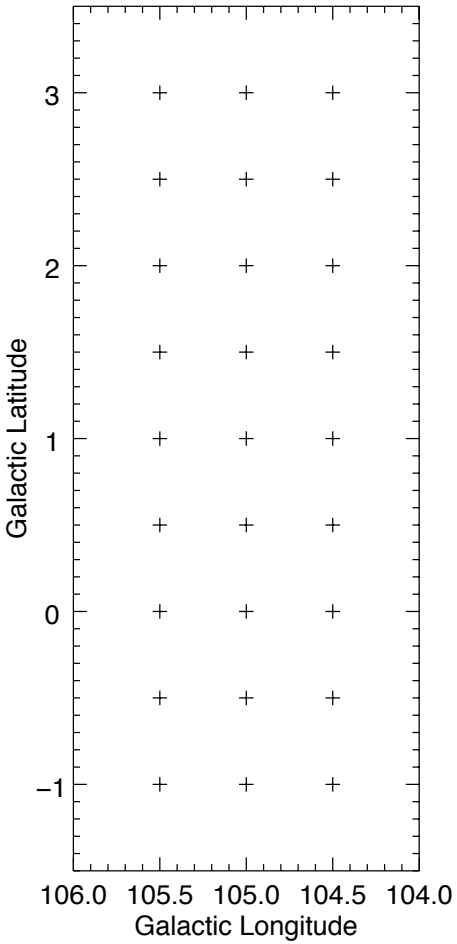


Dame, Hartmann, & Thaddeus 2001


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 channels
  - 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



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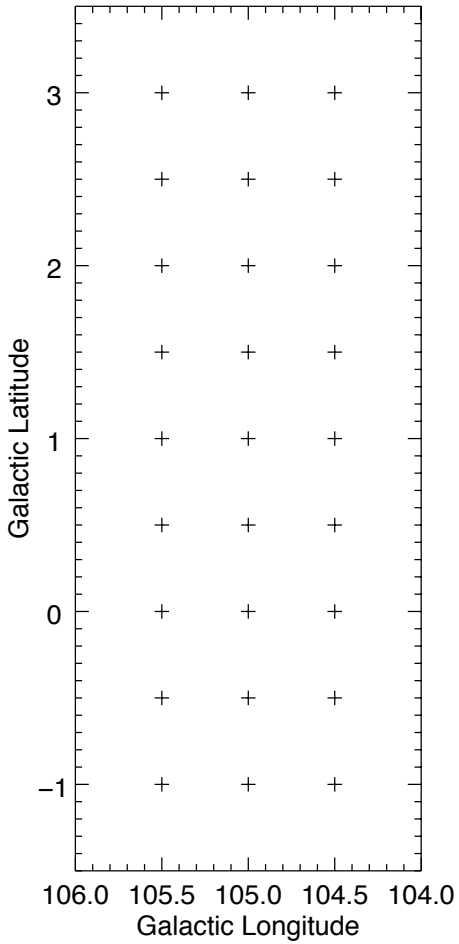

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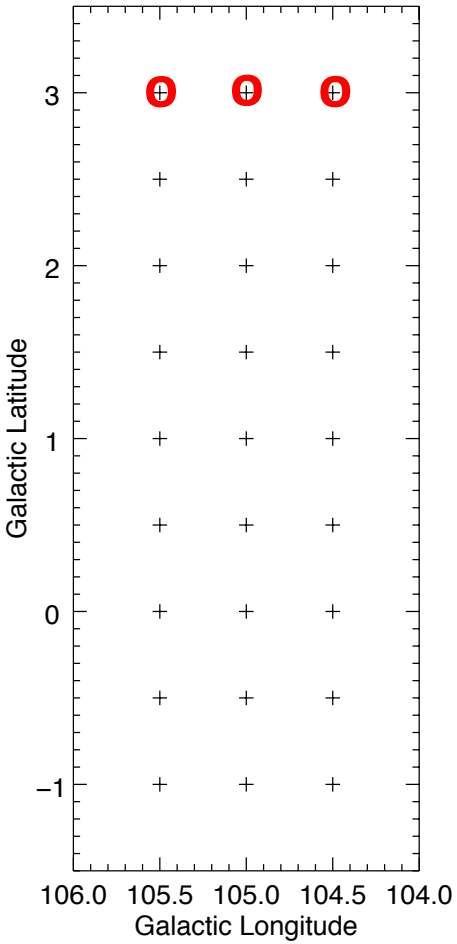
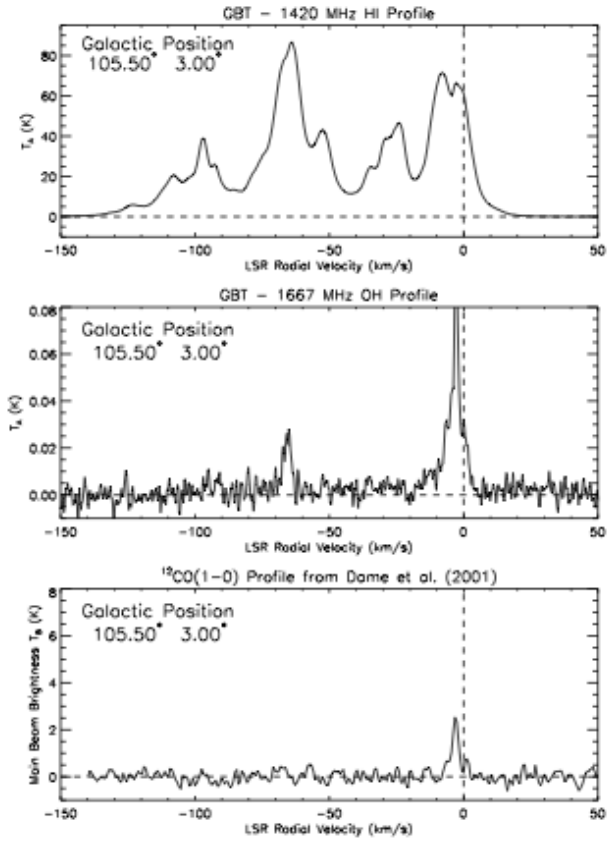
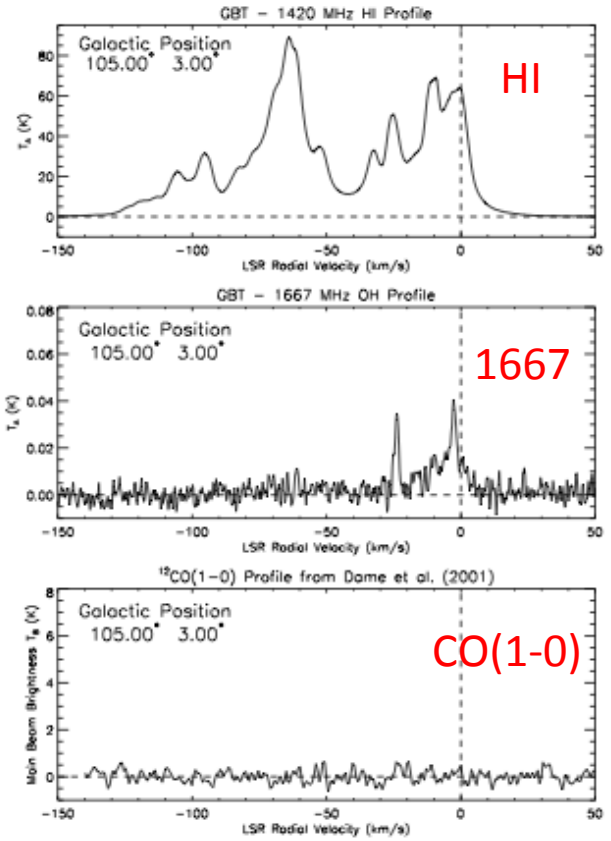


HI, OH 1667, and CO Profiles at B = 3.00

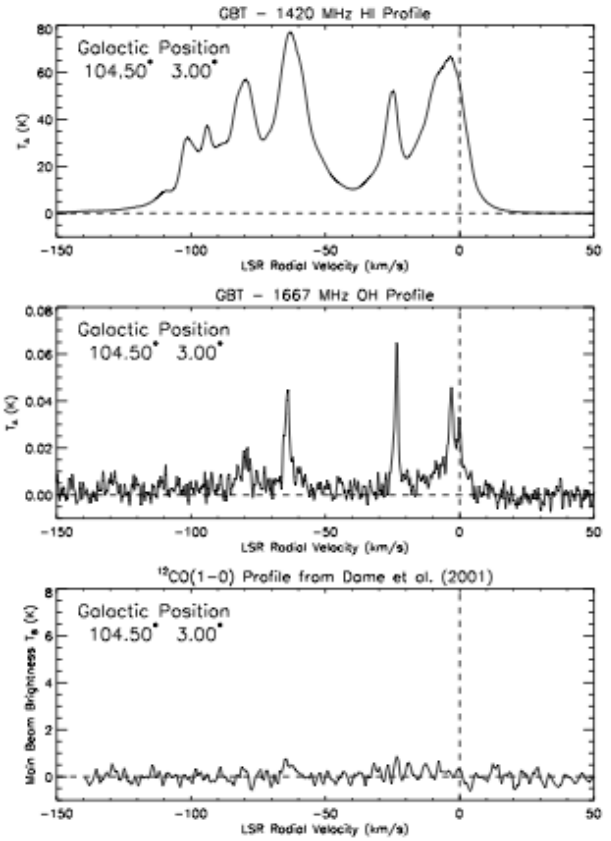
L = 105.5



L = 105.0



L = 104.5



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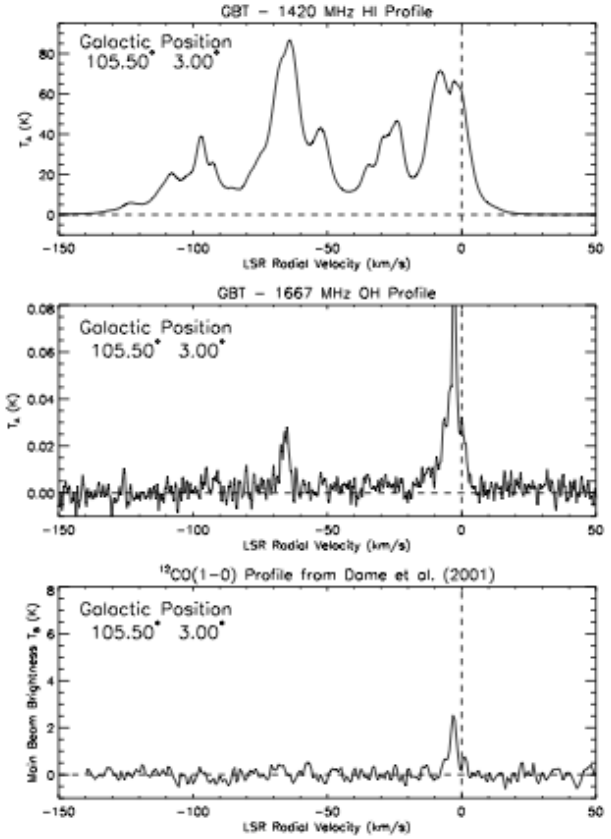

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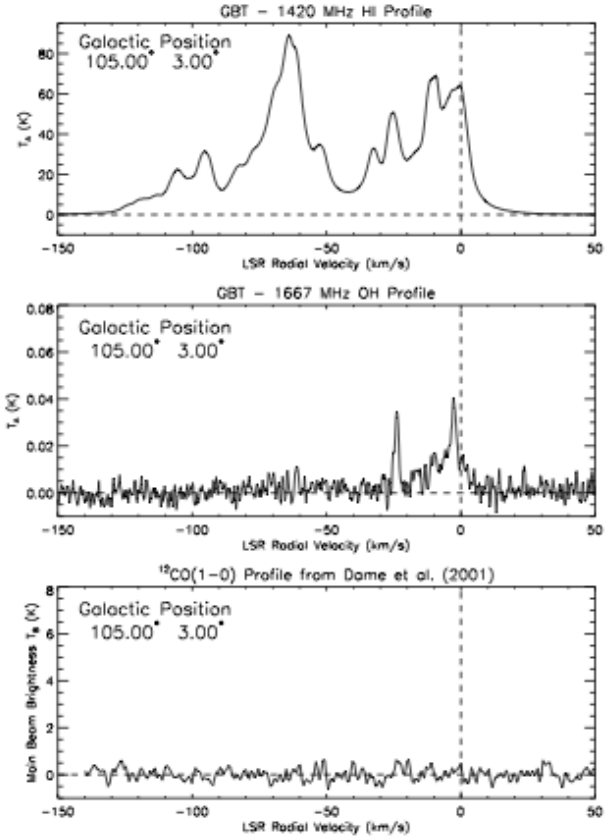

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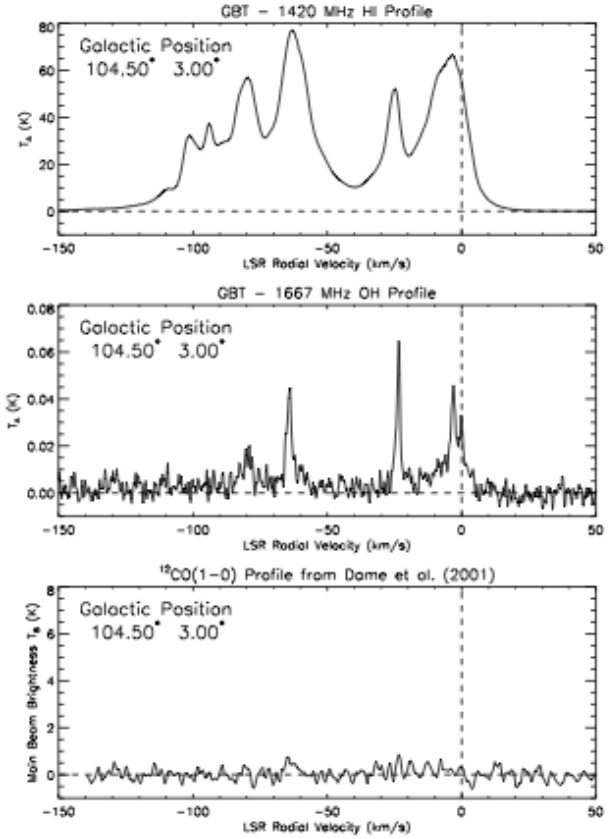

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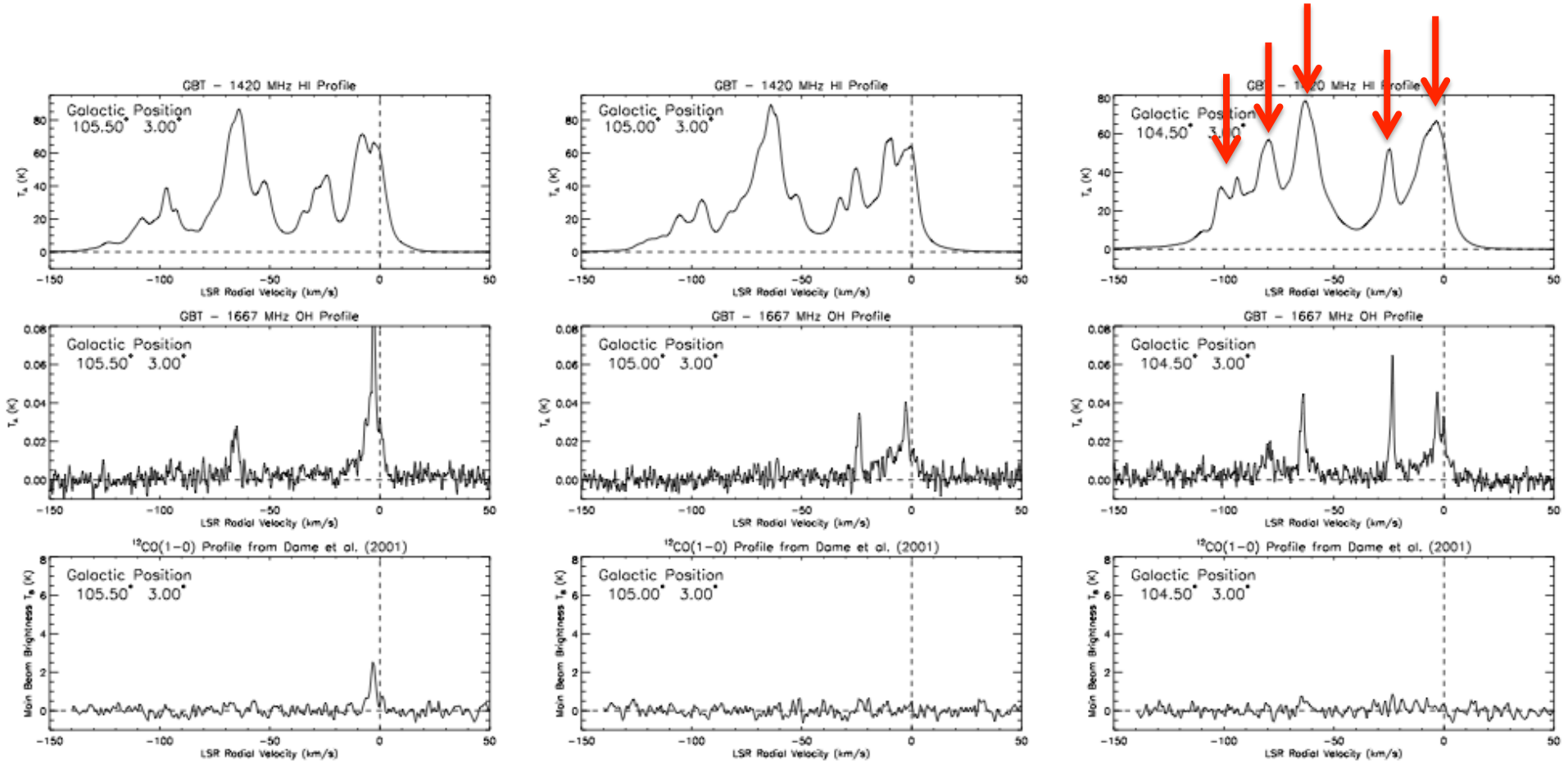

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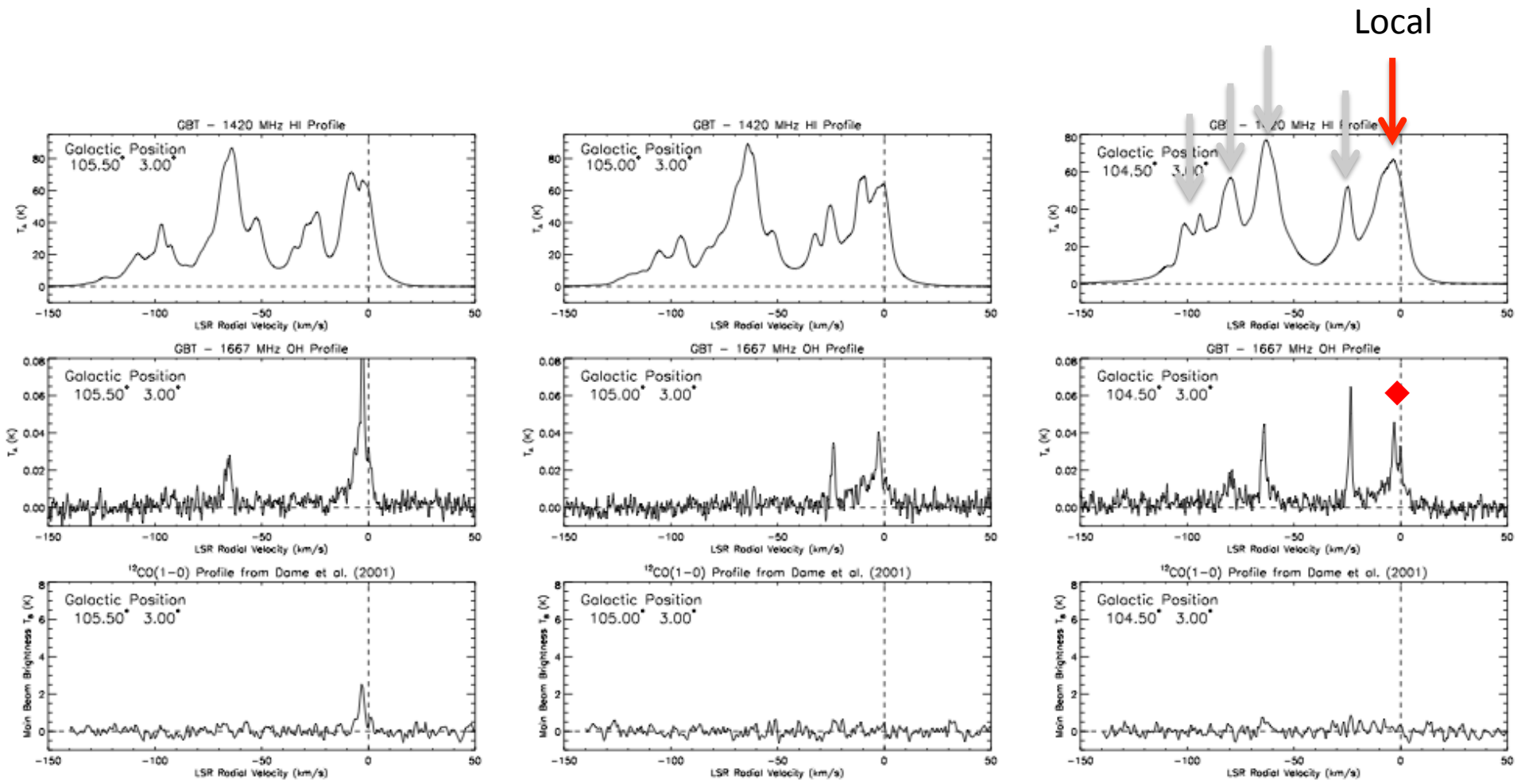

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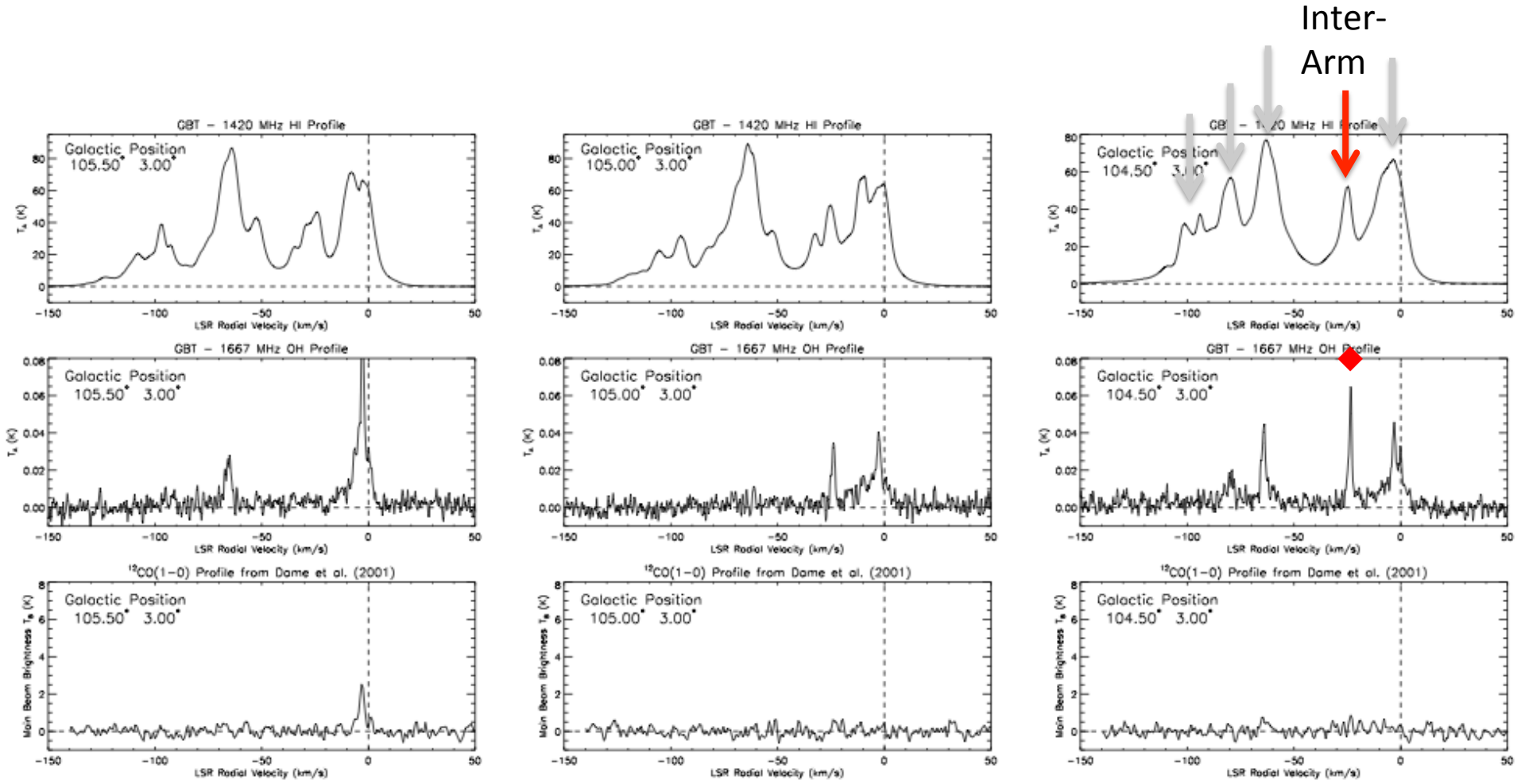

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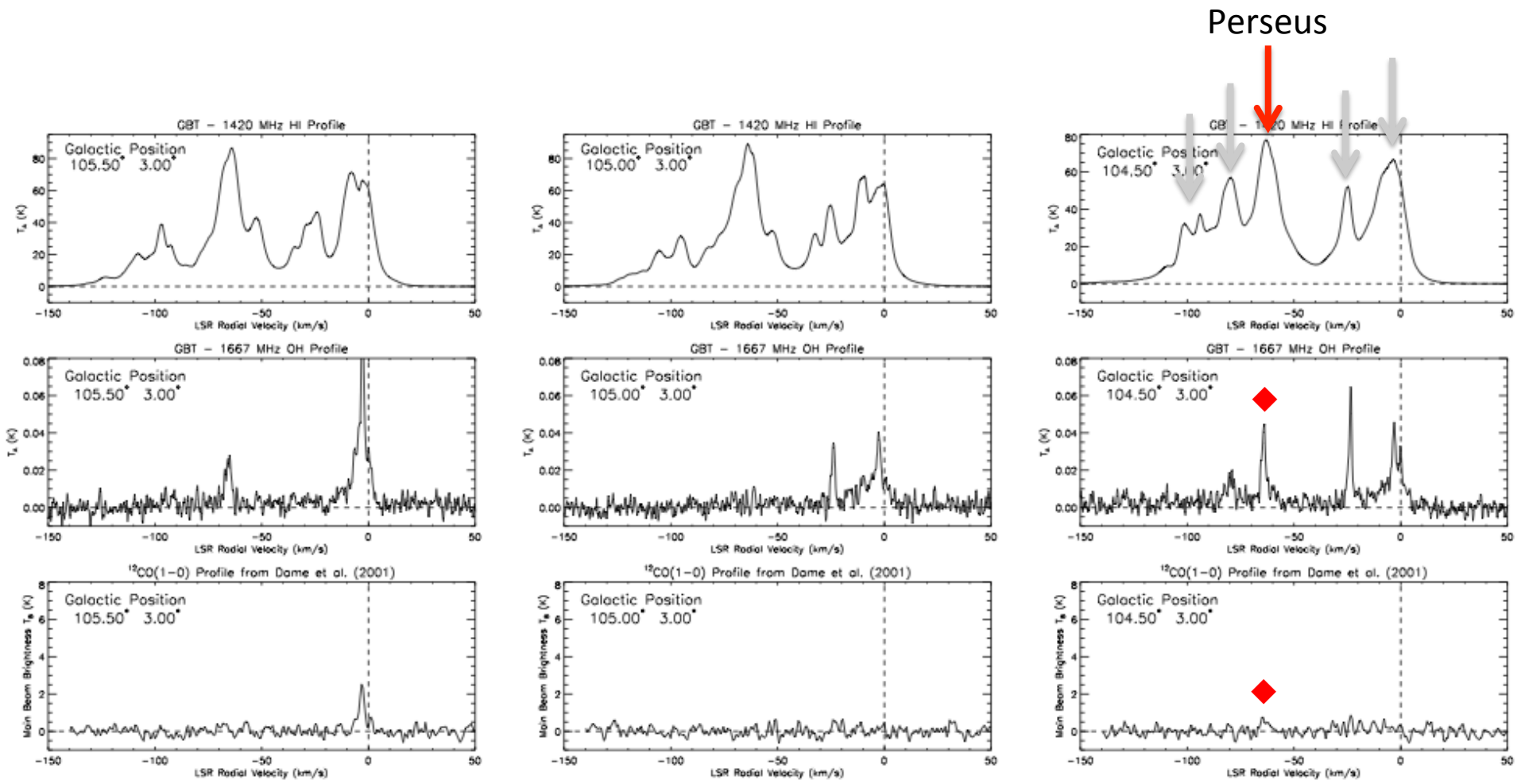

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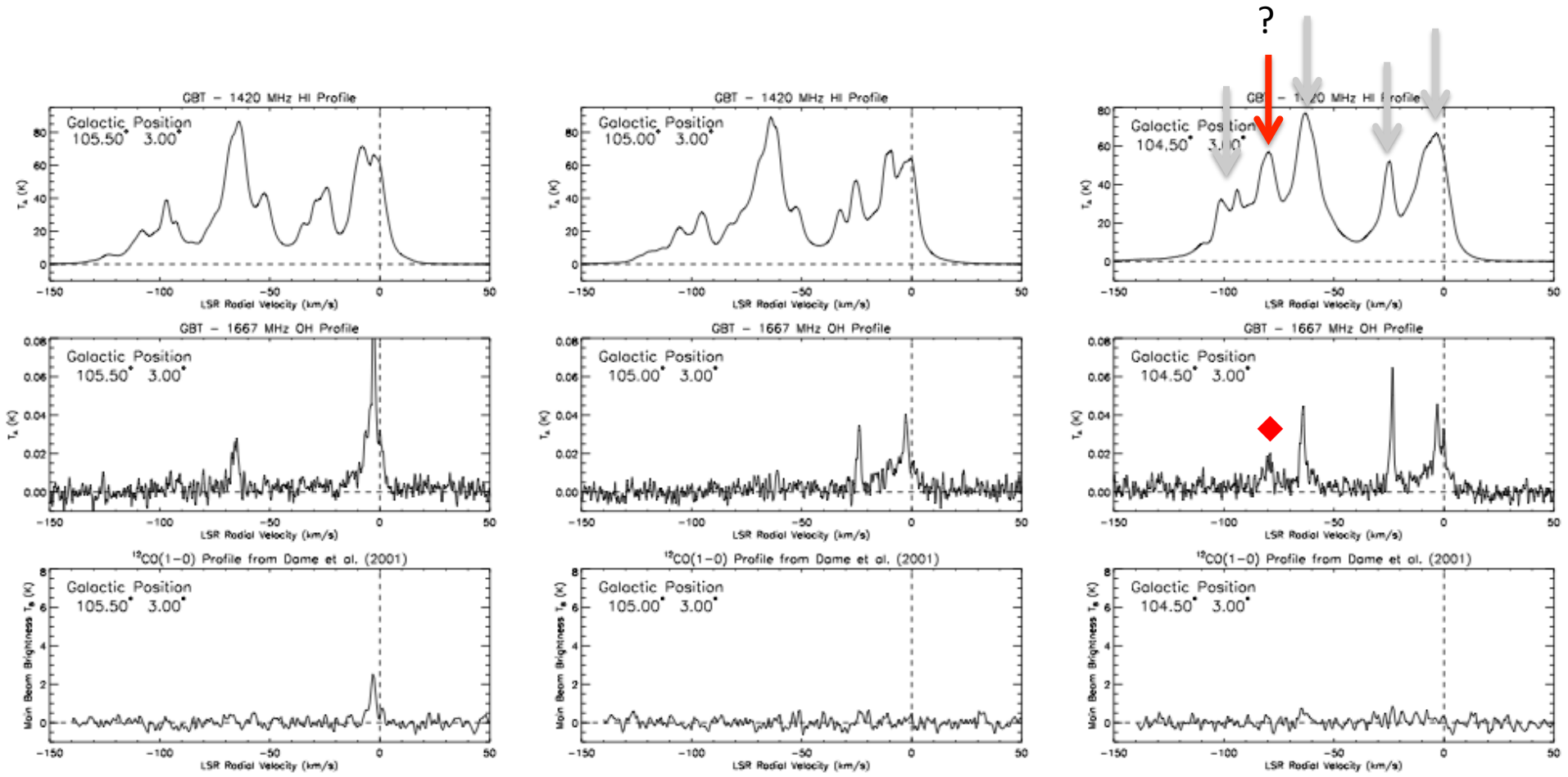

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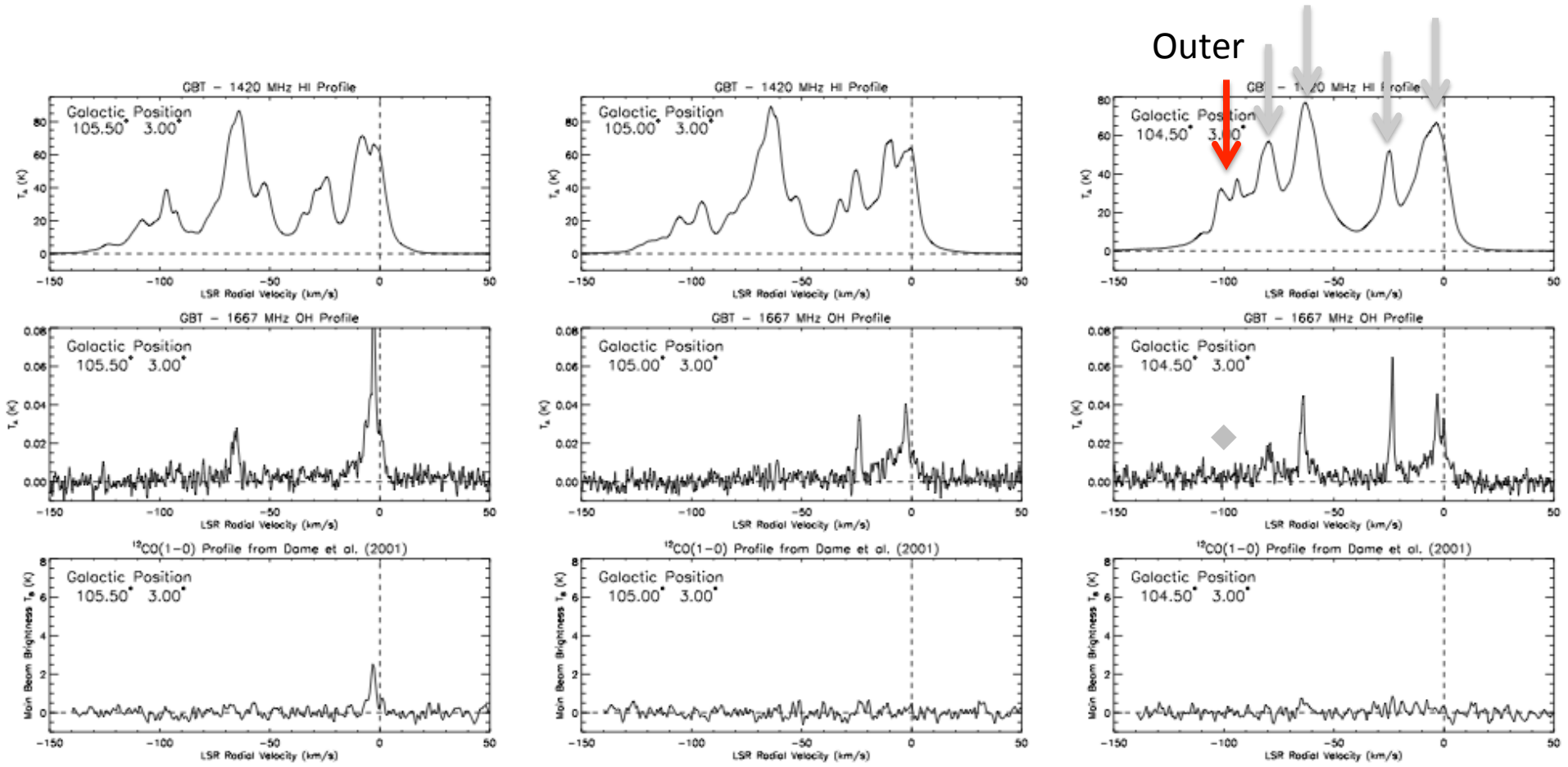
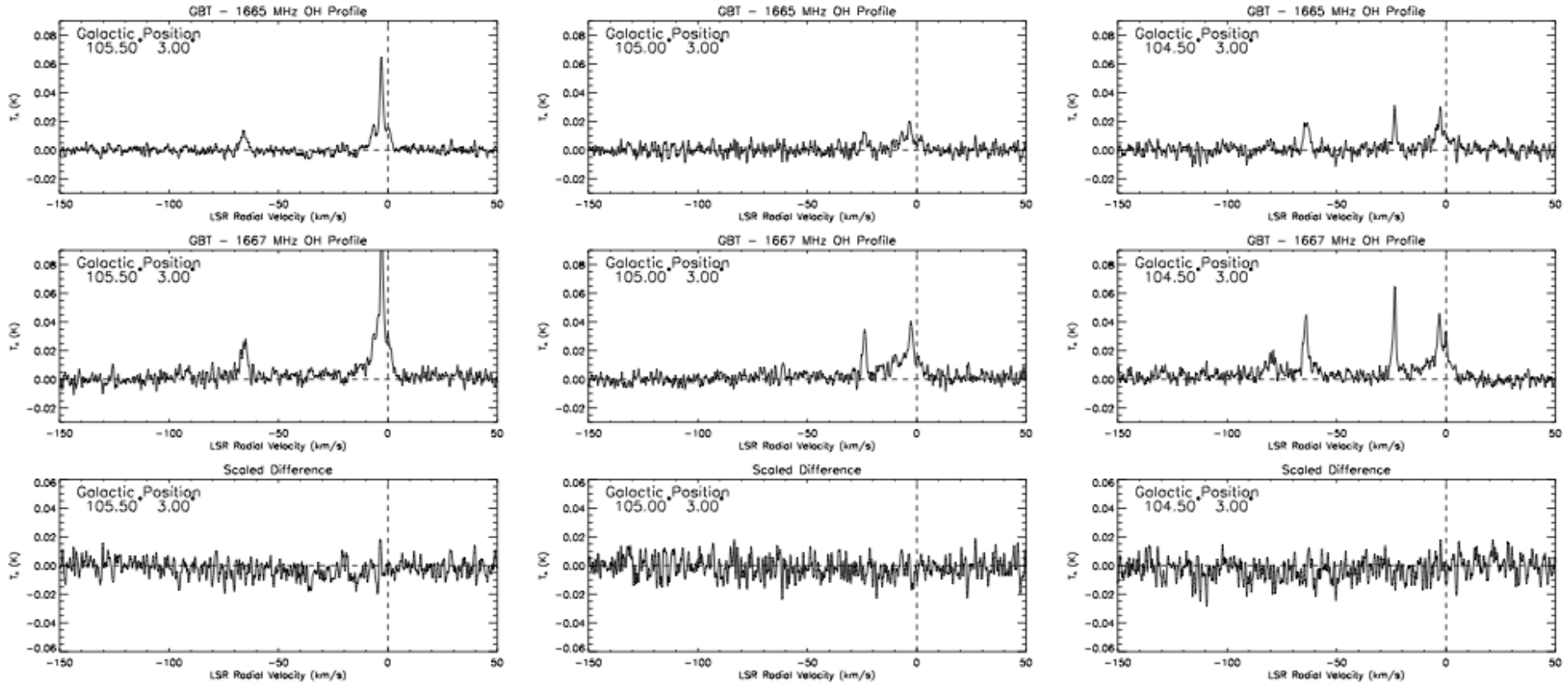


Main line ratios are 5/9 (LTE)



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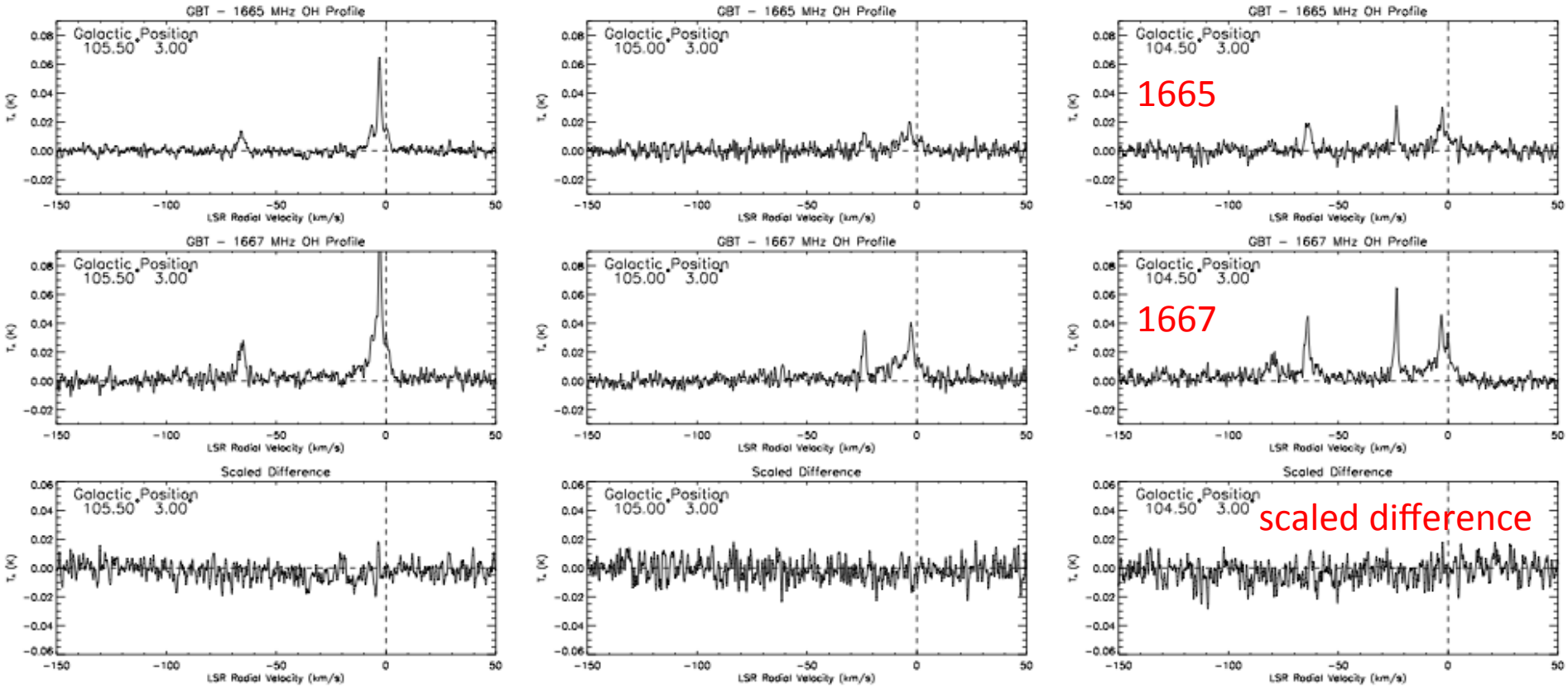
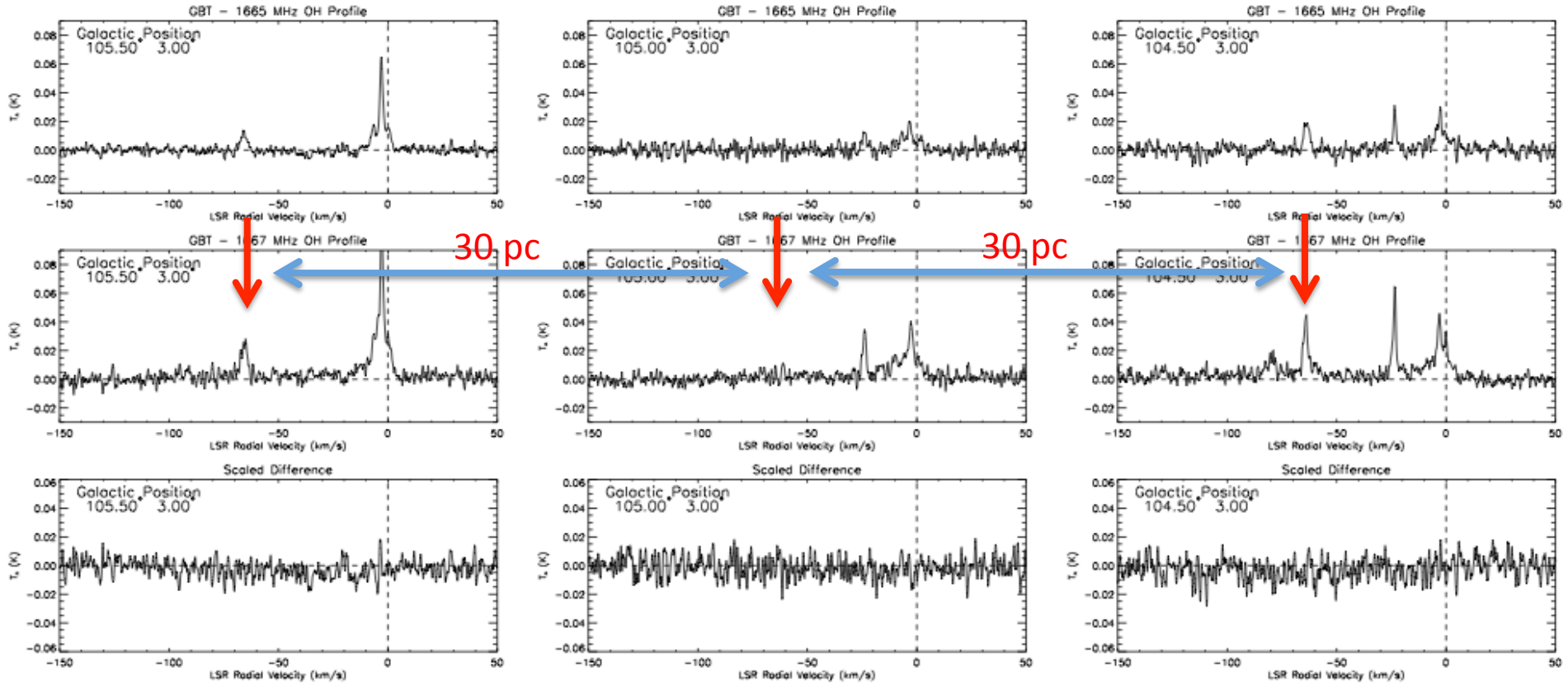
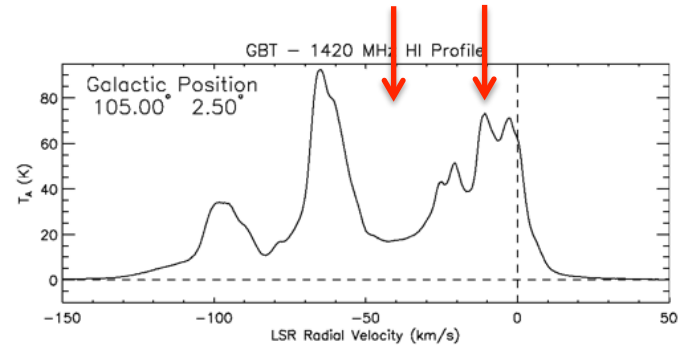
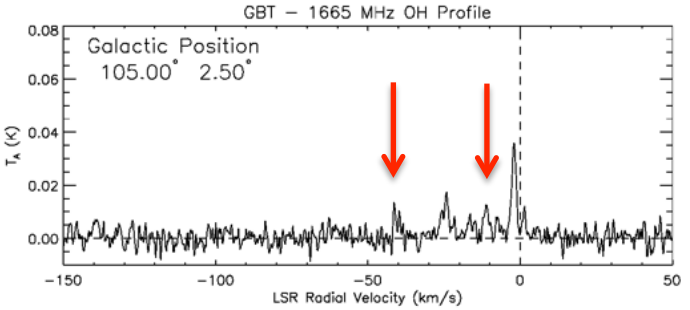


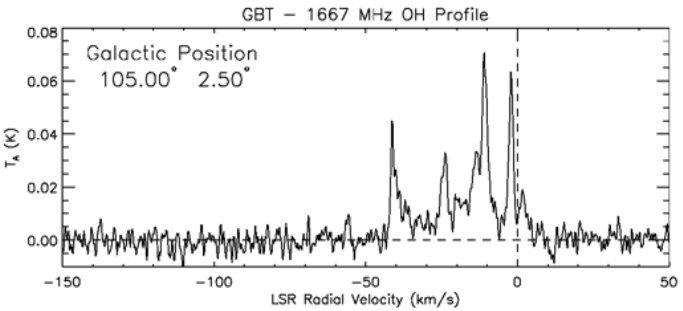
Spatial structure varies rapidly ...

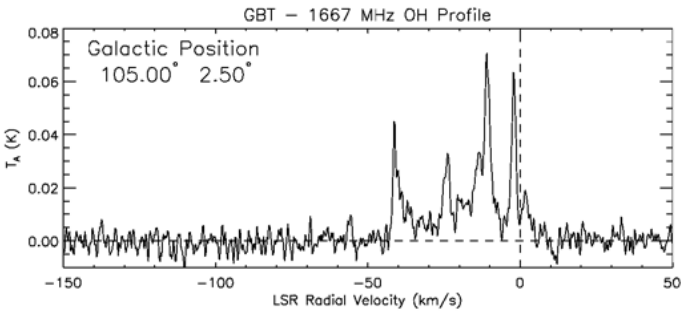


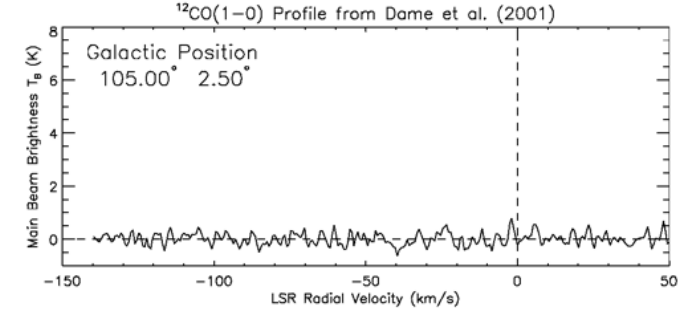
A few profiles show anomalies ...

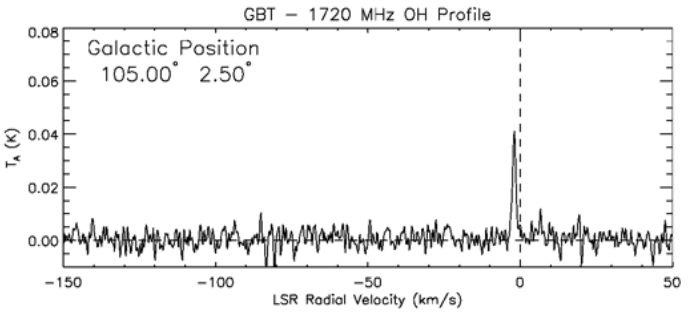




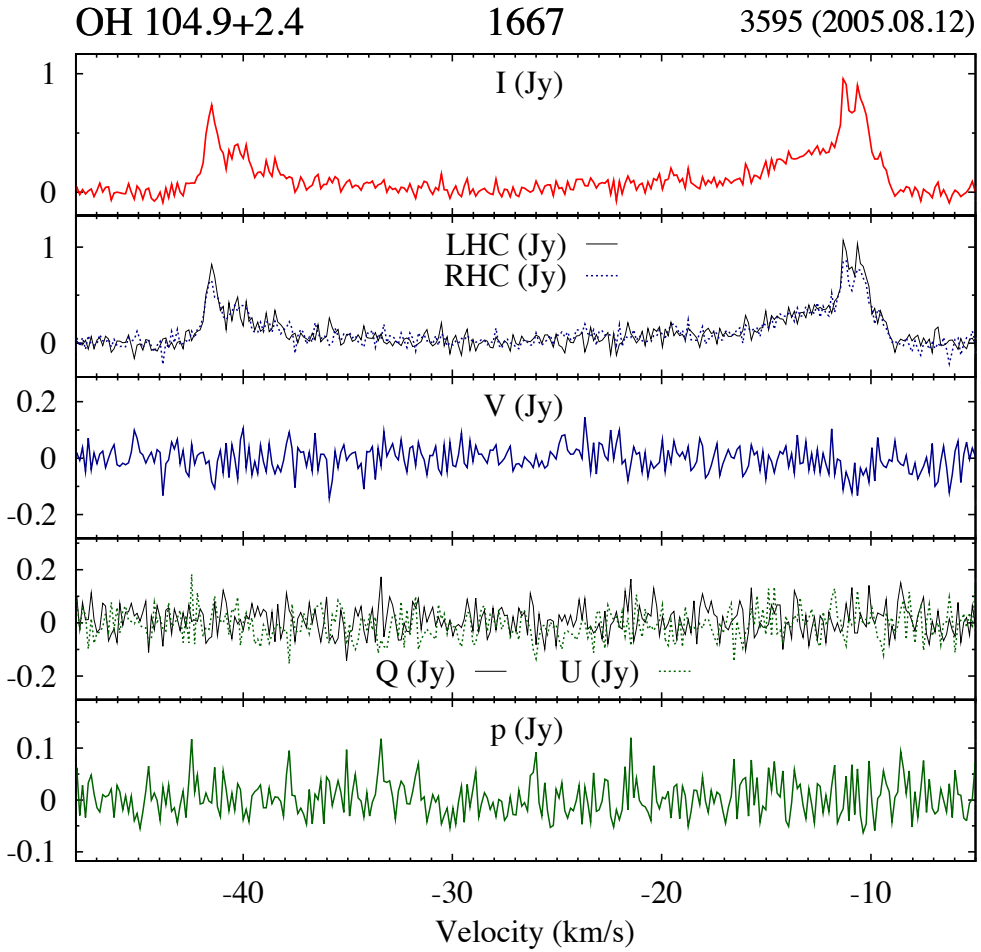








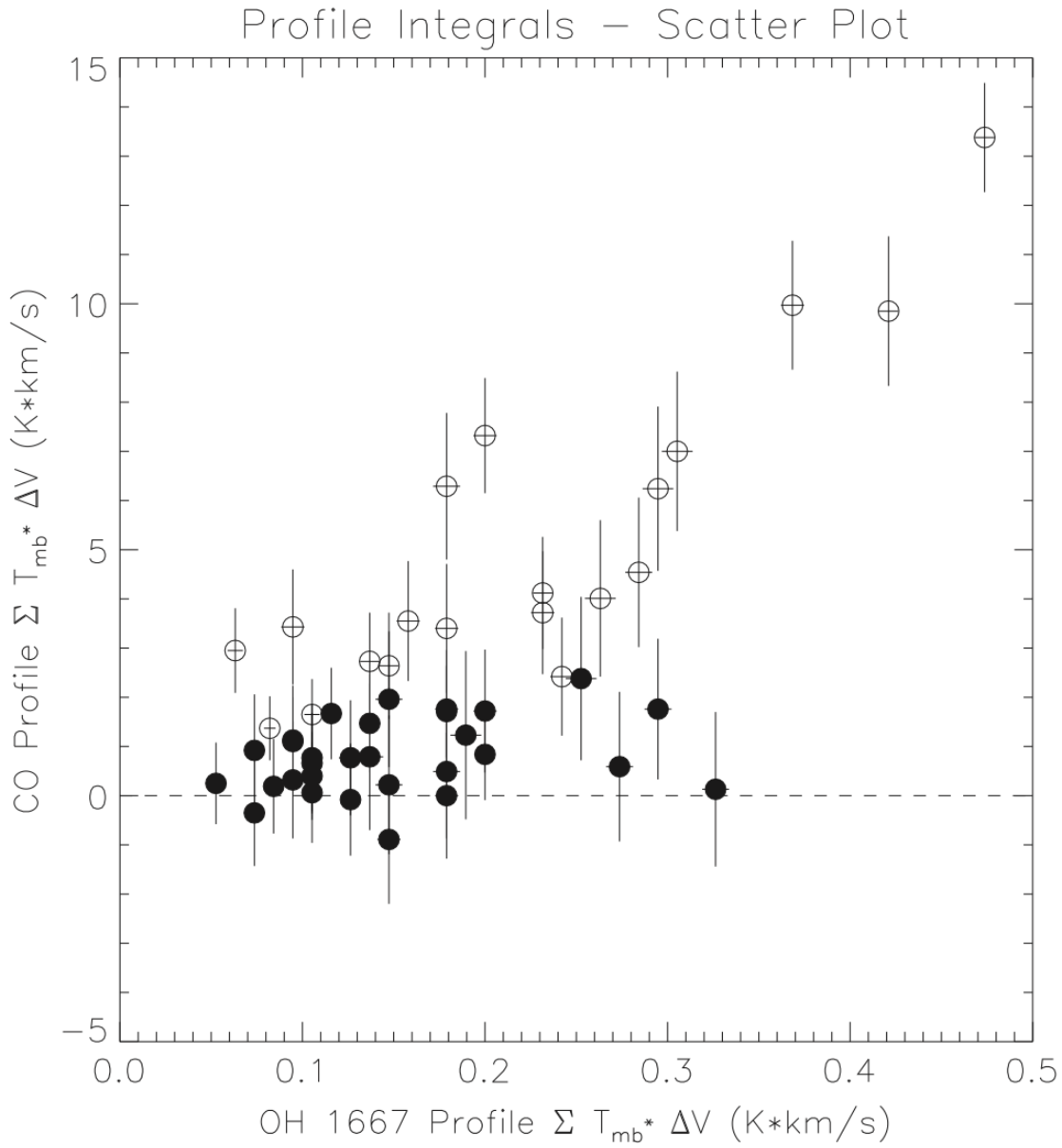
… which turn out to be known things.



Wolak et al (2012)

What did we find? - I

- We have confirmed the ubiquity of faint OH emission in the Galaxy. The GBT data is more sensitive and has a wider velocity coverage than our earlier survey with the Onsala telescope:
  - OH identified in more than 23 of the total of 27 pointings.
  - 55 separate OH features found, corresponding with familiar features of Galactic structure: the Local Arm, the Interarm, and the Perseus Arm.
- (almost) All 1667 MHz OH features correspond with peaks in the HI profiles at the same positions:
  - but not every peak on an HI profile shows up in OH (sensitivity?)
- CO is generally faint or absent. This is in part a result of the location chosen for this blind survey, but the contrast is striking:
  - less than 1/3 of the 55 OH features show detectable CO in the CfA data.
  - there are no CO features without OH emission.



Allen, Hogg, & Engelke (2015)

What did we find? - II

- We have confirmed that the main OH lines in the quiescent Galactic ISM are generally in LTE:
  - the difference profiles (1665 – 1667/1.8) generally show just noise.
  - counterexamples arise from known anomalous features:
    - One of the 27 survey positions is near a known OH-IR star.
    - a narrow feature that appears in the main OH lines at nearly the LTE ratio but is enhanced at 1720 MHz may be a large-scale shock.
- The spectra show significant changes in structure from one survey pointing to the next:
  - we have clearly not resolved the structure of molecular clouds in the Perseus Arm at linear scales of ≈ 30 pc (0.5° at 3.2 kpc).

What did we NOT find?

- No absorption features were found in the area of our "blind" GBT 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.
    - primarily a result of the low excitation temperature of OH and the brighter Galactic continuum emission in the southern sky.
  - they do not find OH without CO.
    - primarily a result of their lower sensitivity, a consequence of shorter integration times, but also
    - the proximity of OH excitation temperatures to the ambient continuum emission reduces their ability to detect faint OH emission.

The current bottom line ...

- The 18-cm OH lines are an effective alternative as a large-scale quantitative tracer for H_2 in the ISM, at least in the Outer Galaxy.
  - OH is more sensitive to low-density regions than is CO.
  - OH reveals H_2 even in CO-poor regions.
  - OH excitation is well understood and LTE is easily verified.
- OH is a promising tracer for studying the distribution and motions of the "Dark Molecular Gas" in the Outer Galaxy.
  - It is a molecular tracer with a wide spatial distribution.
  - It can provide kinematic distance estimates using Galactic rotation.
  - Observations of OH are expected to indicate a significant increase in the estimates of H_2 mass in the Galaxy. We are working to quantify this.
- Reference to a recent publication on the GBT survey results:
  - Allen, R.J., Hogg, D.E., & Engelke, P.D. 2015, Astron. J., 149, 123.

The "To Do" List ...

- New OH observing initiatives with the GBT:
  - The "One-Square-Degree" Blind Survey *(data acquired)*:
    - Resolve the structure of the molecular clouds in the Perseus Arm; measure sizes in parsec?
  - Establish the molecular content of a major HI feature in Galactic spiral arms *(in progress)*:
    - detect the "Rolling Motion" of spiral arms in H_2 .
  - Address the question: To what extent do star-forming regions *really* have more H_2? *(Proposal submitted)*
    - How much of this is real, and how much is an effect of elevated excitation acting on our favorite gas mass tracers?