18-cm OH radio emission: A Possible Tracer for Dark Molecular Gas in the Galaxy

Results of a Pilot Survey for 18-cm OH Emission near $L \approx 105^\circ, B \approx +1^\circ$

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Introduction

• What did we do?
  – A Pilot Survey for 18-cm OH radio emission using the Green Bank Telescope

• Why might this be interesting?
  – Earlier work suggested a similarity of the OH distribution with the “Dark Gas”

• Where did we look?
  – The Outer Galaxy is a key direction in order to avoid confusion

• What tracer do we use?
  – Main-line OH emission at 1665/1667 MHz (plus OH 1720 and HI 1420)

• What did we find?
  – Significant amounts of molecular gas without accompanying CO(1-0)

• What are we doing next?
  – Studying the Z-structure of the Perseus Arm in OH emission (see poster here)
  – Mapping OH over a 1° X 1° area for detailed comparison with FERMI LAT data
  – Searching for OH emission in the Outer Arm (ask about the latest results)
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

In the Outer Galaxy, 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 to Perseus are known in parsec by triangulation:

NRAO
Green Bank Telescope

Area of our Blind OH Survey on the CO(1-0) All-Sky Map ...
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 ≤ 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
    • GBT resolution at OH is the same as CfA at CO

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

L = 105.5

L = 105.0

L = 104.5
HI, OH 1667, and CO Profiles at B = 3.00

L = 105.5  
L = 105.0  
L = 104.5
HI, OH 1667, and CO Profiles
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HI, OH 1667, and CO Profiles

Inter-Arm

Ron Allen - STScI/JHU 6th FERMI Symposium - Nov. 2015
HI, OH 1667, and CO Profiles

Perseus
HI, OH 1667, and CO Profiles
HI, OH 1667, and CO Profiles
Main line ratios are 5/9 (LTE)
Main line ratios are 5/9 (LTE)
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 radio telescope in Sweden:
  – OH was identified in the GBT survey 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 Inter-arm, 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 1/2 of the ≥ 55 OH features show detectable CO in the CfA data.
  – there are no CO features without OH emission.
Profile Integrals – Scatter Plot

CO Profile $\sum T_{mb}^* \Delta V$ (K*km/s)

OH 1667 Profile $\sum T_{mb}^* \Delta V$ (K*km/s)

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.
  - counter-examples 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 towards the inner Galaxy
  – 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 the OH excitation temperature (≤ 10K) 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 from the line ratios.
- 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:
The “To Do” List …

• New OH observing initiatives with the GBT:
  – Establish the credentials of OH emission as a tool for studying Galactic Structure (*in progress – see poster on Perseus Arm at this meeting)*:
    • Measure the Z-extent of OH emission and compare to HI 1420
    • Look for the “Rolling Motion” of spiral arms in molecular gas
    • Search for the “Outer Arm” of the Galaxy in OH
  – Resolve the molecular clouds in the Perseus Arm (*data acquired)*:
    • The “One-Square-Degree” Blind Survey in the Outer Galaxy
    • Results will measure OH molecular cloud sizes in parsec
  – Measure the molecular content of a star-forming region using OH and compare to the results inferred from CO data (*proposal submitted*):
    • Obtain a “second opinion” on the H₂ content of a star-forming region.
    • How can any differences be explained?
BACKUP SLIDES - I