Thermal OH as a Tracer for the Molecular ISM in the Galaxy

Ron Allen
Space Telescope Science Institute
OH - a “well-plowed” field ...

• A lot of work has been done on OH in the nearly 50 years since the discovery of the 18-cm line emission:
  – Discovery: Weinreb, Barrett, Meeks & Henry (1963)
  – Dust clouds in the Galaxy (...Heiles, Turner, Crutcher, ...)
  – Absorption surveys (... Goss, Dickey, ...)
  – Magnetic fields from Zeeman effect (... Goodman, ...)
  – Excitation determinations (... Rieu, Liszt, ...)
  – Maser sources in the Galaxy, and nearby galaxies (...)
  – Megamasers emission from AGN (...)

TF35 - Green Bank

Ron Allen - 3 April 2012
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Thermal OH in the Galaxy ...

• The 18-cm lines of OH have been widely observed along specific lines of sight in the Galaxy.
  – Emission/absorption measurements along many lines of sight toward known dust clouds and bright continuum sources have established that low-excitation OH is widespread in the ISM.
  – In the general ISM away from intense IR emission sources the OH emission is faint and the line ratios are in LTE.

• The general Galactic distribution of OH emission is still unknown.
  – A recent mini-survey has highlighted the similarities in the large-scale spatial distributions of 18-cm OH emission and 21-cm HI emission in the Galaxy.
A search for OH in the Outer Galaxy ...

\[ l \approx 107^\circ, \ b \approx +5^\circ \]

CO(1-0) GMCs:

Figures from: Dame 1993
... in the region surrounding Lynds 1204 ...
... reveals ubiquitous OH 1667 emission ...

Faint OH(1667) at Onsala
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... with wide velocity extent like the HI ...
... and little resemblance to the CO(1-0).
OH/HI Profile correlation

- points represent individual velocity channels

$T_A$ (K) (OH)

$T_B$ (K) (HI)
OH/HI Profile correlation

- points represent individual velocity channels

- HI profile saturation
OH/HI Profile correlation

- points represent individual velocity channels

- OH still growing

- HI profile saturation
Let’s take a closer look ...

Faint OH(1667) at Onsala

... at the profile details:

Faint OH(1667) at Onsala

... at the profile details:

Faint OH(1667) at Onsala

OH Mini-survey conclusions ...

- OH emission is ubiquitous in the Galaxy:
  - The OH extent resembles HI both in space and velocity.
  - Profiles are faint, $T_B \approx 20-40$ mK, with several peaks:
    - Typical features FWHM $\approx 2-3$ km/s, separations $\approx 7-9$ km/s.
  - CO(1-0) appears infrequently in the survey area pixels.
    - If it does, it coincides with one specific OH feature, but <10% of the OH features have corresponding CO emission.
  - OH and HI spectra are approximately linearly related.
    - $T_A(OH \, 1667) \approx 1.5 \times 10^{-4} T_B(HI \, 21-cm)$
  - Local HI profiles ($r \leq 1$ kpc) appear saturated.
    - But OH continues to increase (suggests HI is optically thick).

*Allen et al 2012, AJ, 143, 97*
OH as a tracer for the molecular ISM ...

- 18-cm thermal OH has several advantages as a tracer for the molecular ISM:
  - Low optical depth (few radiative transfer issues)
  - Emission is widespread, similar to 21-cm HI
  - OH traces the low-density ISM (n_{critical} ≈ 1 \text{ cm}^{-3})

- There is one important disadvantage ...
  - The emission is very faint, 10^{-3} of CO(1-0)

- ... and a minor caution:
  - The 18-cm lines are sensitive to anomalous excitation by intense fluxes of thermal IR photons near HII regions.
Can we connect OH to H$_2$?

• UV absorption lines are a possibility:
  – H$_2$ absorption measured towards many hot stars within $\approx 2$ kpc of the sun, primarily with FUSE:
    • Lyman ($B-X$) and Werner ($C-X$) electronic absorption bands lie in the spectral region 844 - 1126 Å
  – OH absorption measurements are starting to appear in the literature (UVES/ESO):
    • A-X electronic absorption line system 3078 - 3082 Å.
OH - UV absorption

The relation between interstellar OH and other simple molecules such as CH, CH$_2$, and CN, identified in ultraviolet absorption bands adding ground-based observations, done using the high-resolution UVES spectrograph toward 10 new targets.

We discuss the close relation between the column densities of interstellar OH and CH molecules. Our results are obtained on the basis of the considered molecular species and of the observed targets, which makes this task very difficult. An extension of both samples, presented in Weselak et al. 2009, A&A, 499, 783, suggests that column densities of the OH molecule and those of simple diatomic molecules such as CH, CH$_2$, and CN, identified in ultraviolet absorption bands adding ground-based observations, done using the high-resolution UVES spectrograph toward 10 new targets.

Increasing E(B-V)
OH – H$_2$ relation from UV lines

![Graph showing the correlation between N(H$_2$) and N(OH)](image)

OH – $H_2$ relation from UV lines

\[ \text{N}(H_2) \times 10^{20} \text{ cm}^{-2} \]
\[ \text{N}(\text{OH}) \times 10^{12} \text{ cm}^{-2} \]

HD 34078

Current state of the data ...

Table 1. UV absorption measurements of molecular column densities.

<table>
<thead>
<tr>
<th>Target Star HD #</th>
<th>Galactic longitude</th>
<th>Galactic latitude</th>
<th>CaII Dist. parsec</th>
<th>Z Dist. parsec</th>
<th>Ref.</th>
<th>$N(OH)$ $\times 10^{-13}$</th>
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<tbody>
<tr>
<td>HD 23180 (ο Per)</td>
<td>160.36</td>
<td>-17.74</td>
<td>371 ± 44</td>
<td>-117</td>
<td>Mea09</td>
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<td>R96, see text</td>
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The data trickle in ...

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... presently the average \( N(H_2)/N(OH) \approx 9 \times 10^6 \)
OH in the Galaxy, ca. 2012

1. The ratios of the main lines (1665 & 1667 MHz) show no significant departures from LTE.

2. Emission and absorption spectra (many LOS) show that:
   - The OH absorbing gas has low $T_{\text{ex}} \approx T_{\text{BG}} + 0.5 \text{ K} \approx 4 \text{ K}$. Emission from this component is weak and narrow in velocity; it adds little to the total emission on any sight line. (Note that $T_{\text{BG}} = T_{\text{GAL}} + T_{\text{CMB}} \approx 0.8 + 2.7 = 3.5 \text{ K}$).
   - OH emitting gas has higher $T_{\text{ex}} \approx T_{\text{BG}} + (4 - 10) \text{ K} \approx 10.5 \pm 3 \text{ K}$.

3. $N(\text{OH})/N(\text{HI}) \approx (2.5 - 5) \times 10^{-8}$ in diffuse Galactic clouds.
   - Our ONSALA data gives $4.7 \times 10^{-8}$ over our mini-survey area.

4. $N(\text{H}_2)/N(\text{OH}) \approx 9 \times 10^6$ from the UV absorption data.
   - New data continue to trickle into the literature.
Summary

• The main OH lines at 18-cm may provide a new way to observe the molecular ISM.

• What is required to convert a measurement of the OH profile integral $T_B(\text{OH})\Delta V$ to $N(\text{H}_2)$ includes:
  – The OH excitation temperature $T_{\text{EX}}(\text{OH})$
    • Measurable, but we need to understand why the value is so low.
    • Need to model the dependence on the local IR radiation field.
  – The column density ratio $N(\text{H}_2)/N(\text{OH})$
    • Measurements in the solar neighborhood are improving.
    • Need to establish how this ratio would change with metallicity.
Imagine a map of OH emission ...

– A map of the 18-cm OH emission of the Galaxy or a nearby galaxy would resemble ...

A. The CO(1-0) emission
B. The 21-cm HI emission
C. The radio continuum emission
D. The Far-IR dust emission
E. None of the above
F. ??
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  A. The CO(1-0) emission  
  B. The 21-cm HI emission  
  C. The radio continuum emission  
  D. The Far-IR dust emission  
  E. None of the above  
  F. Don’t know
The end ...