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

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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 (…)
  - Megamaser emission from AGN (…)

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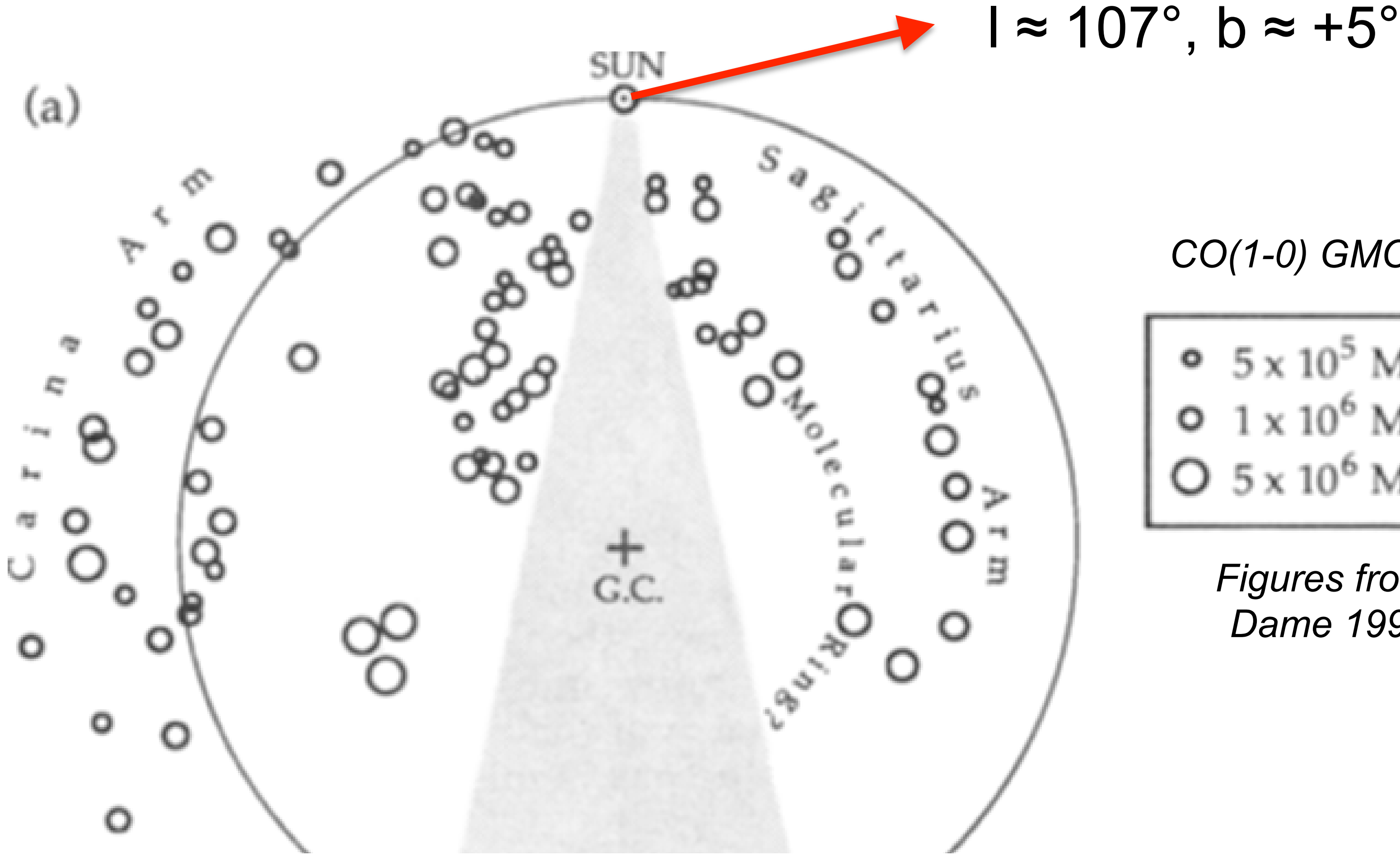
Thermal OH in the Galaxy …

- 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.

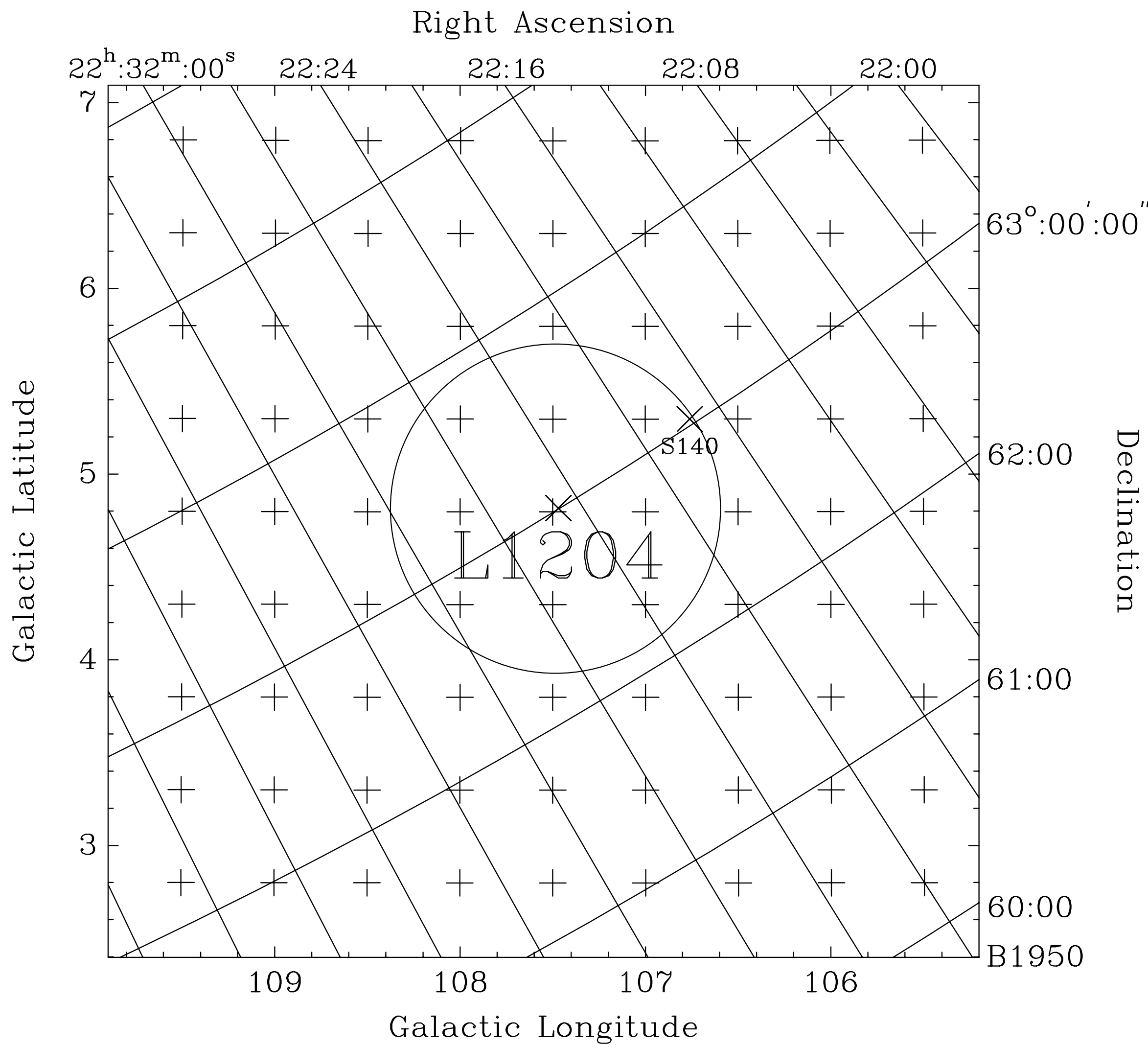
A search for OH in the Outer Galaxy …



CO(1-0) GMCs:

Figures from: Dame 1993

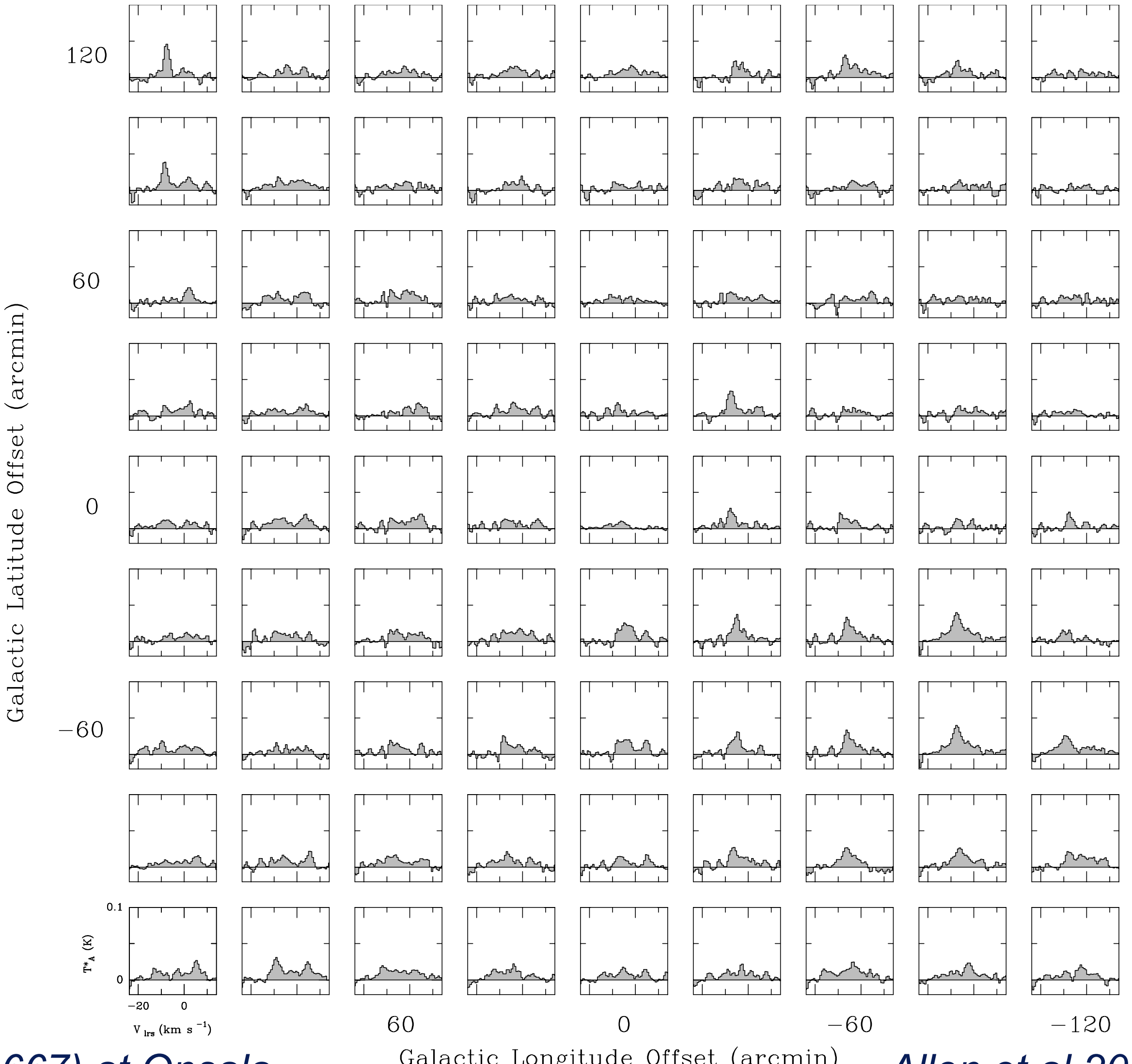
… in the region surrounding Lynds 1204 …



Faint OH(1667) at Onsala

Allen et al 2012, AJ, 143, 97

… reveals ubiquitous OH 1667 emission …



Faint OH(1667) at Onsala

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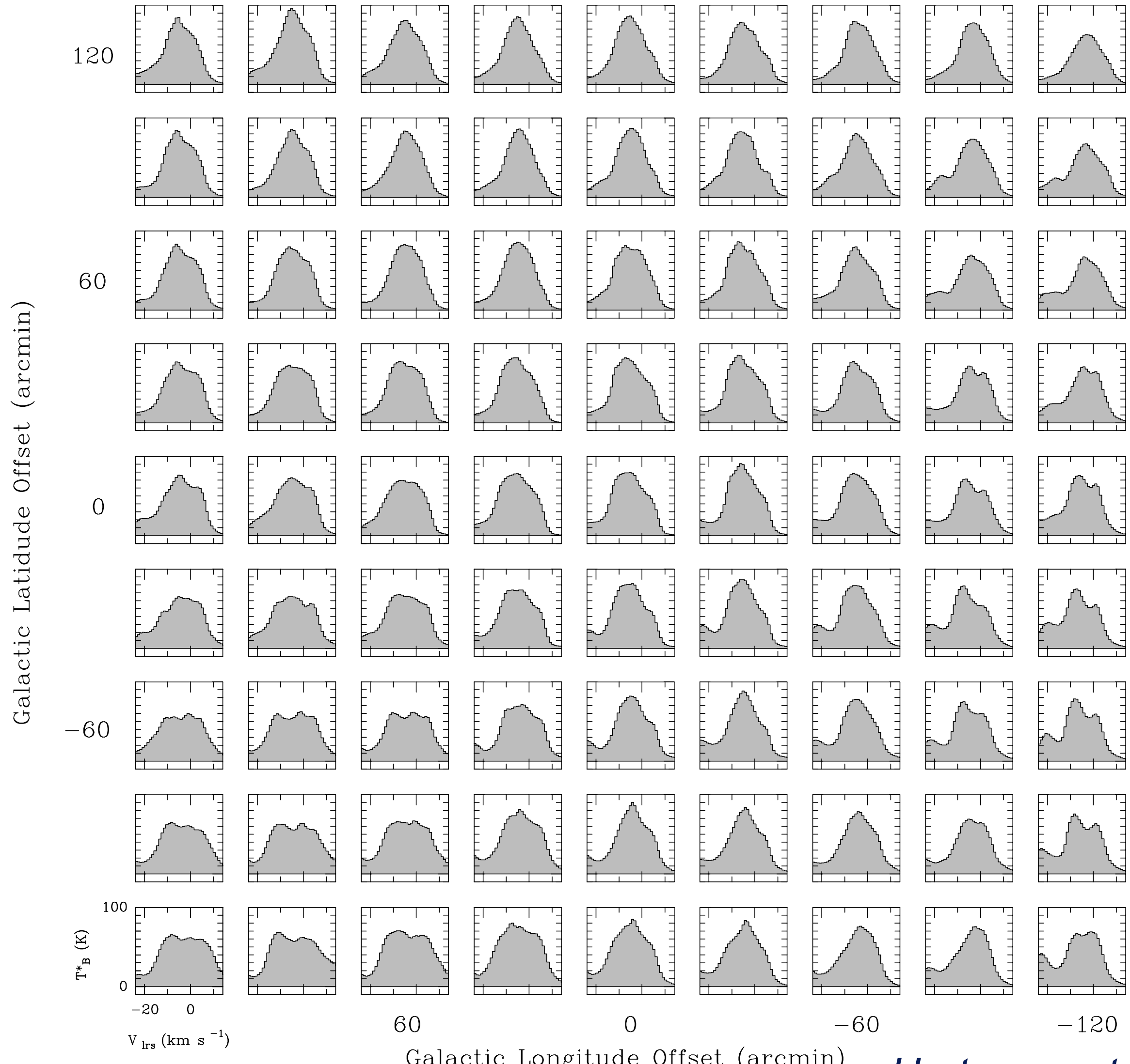
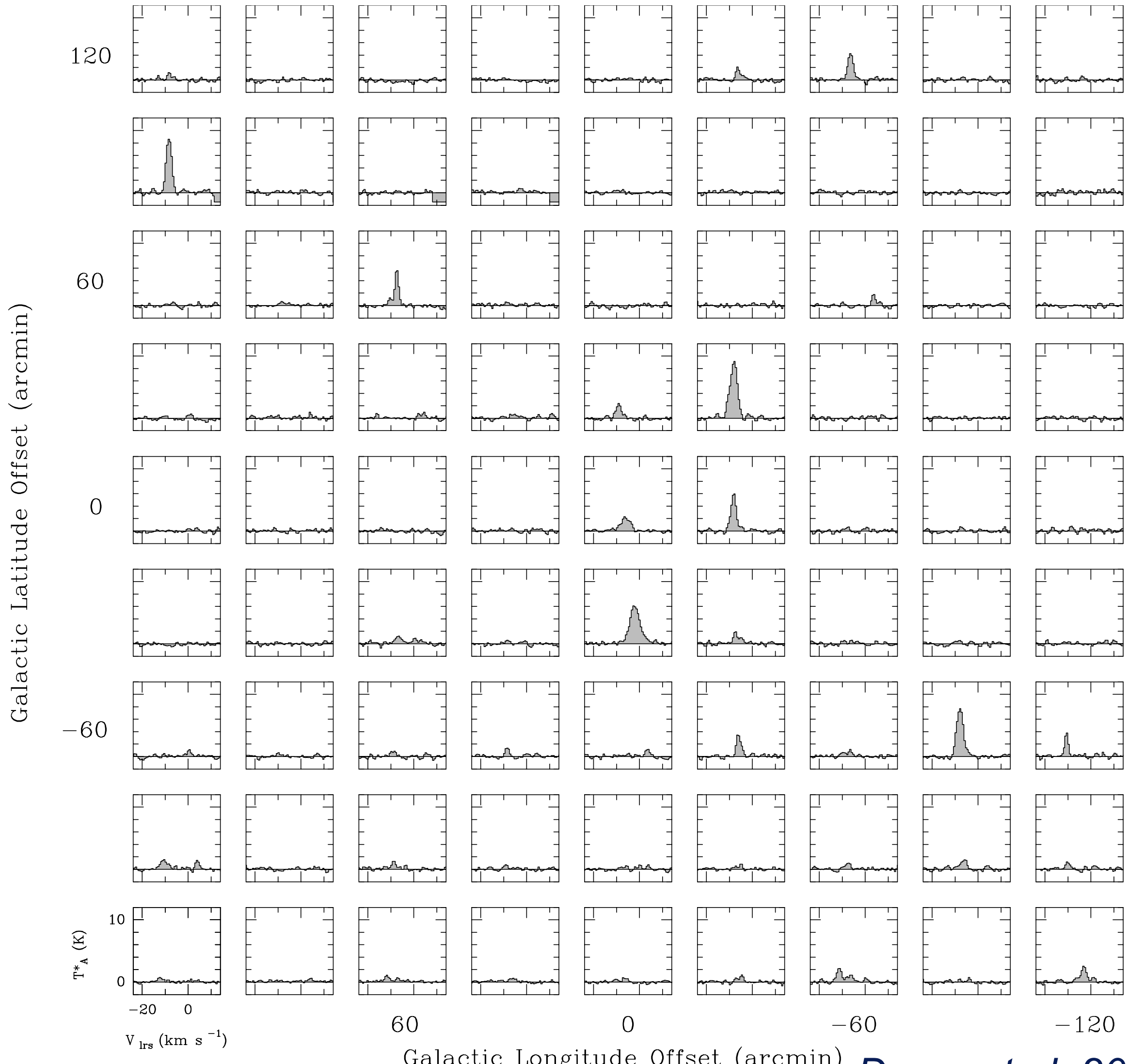
… with wide velocity extent like the HI …



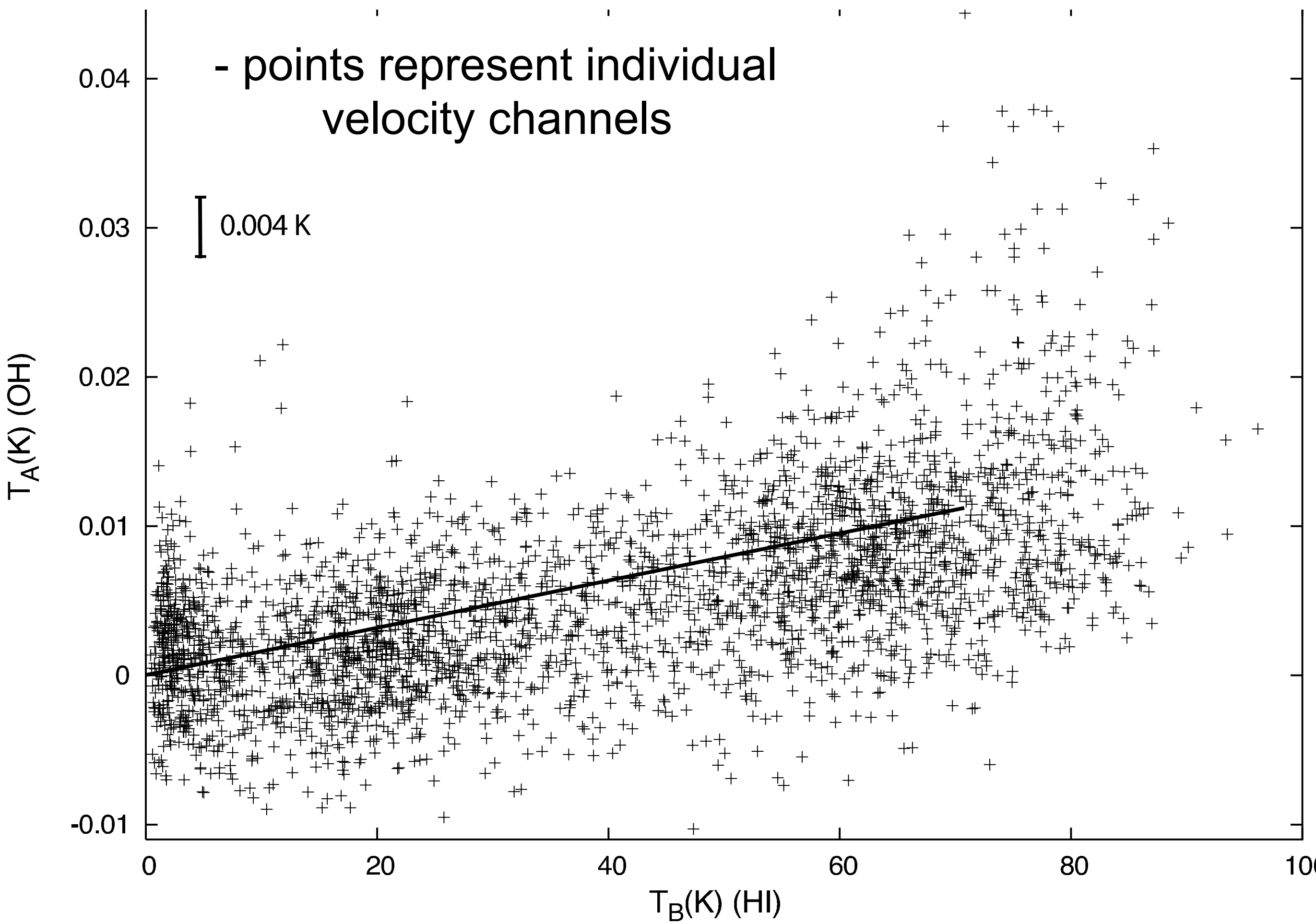
Hartmann et al. 1997

… and little resemblance to the CO(1-0).



Dame et al. 2001

OH/HI Profile correlation



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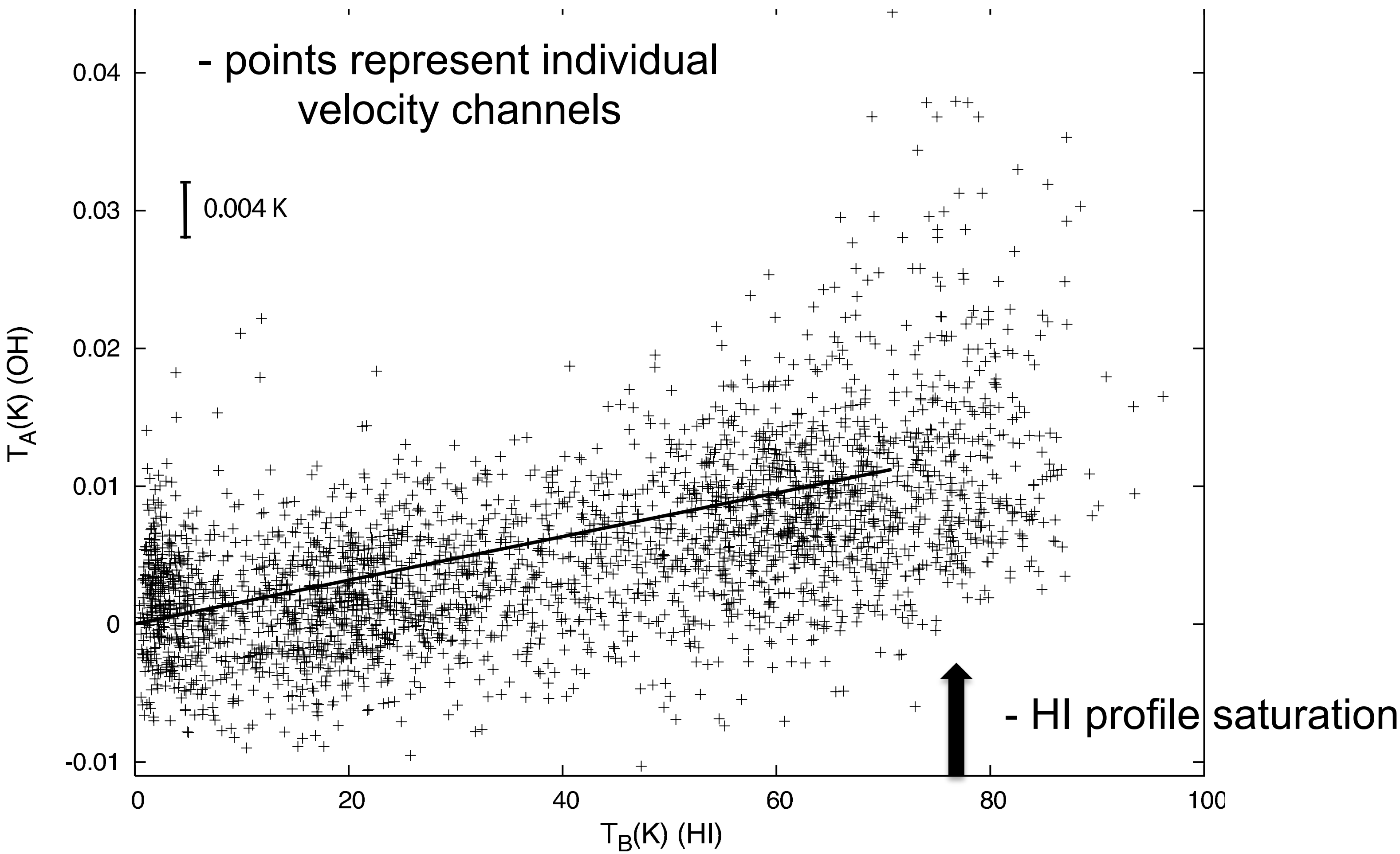

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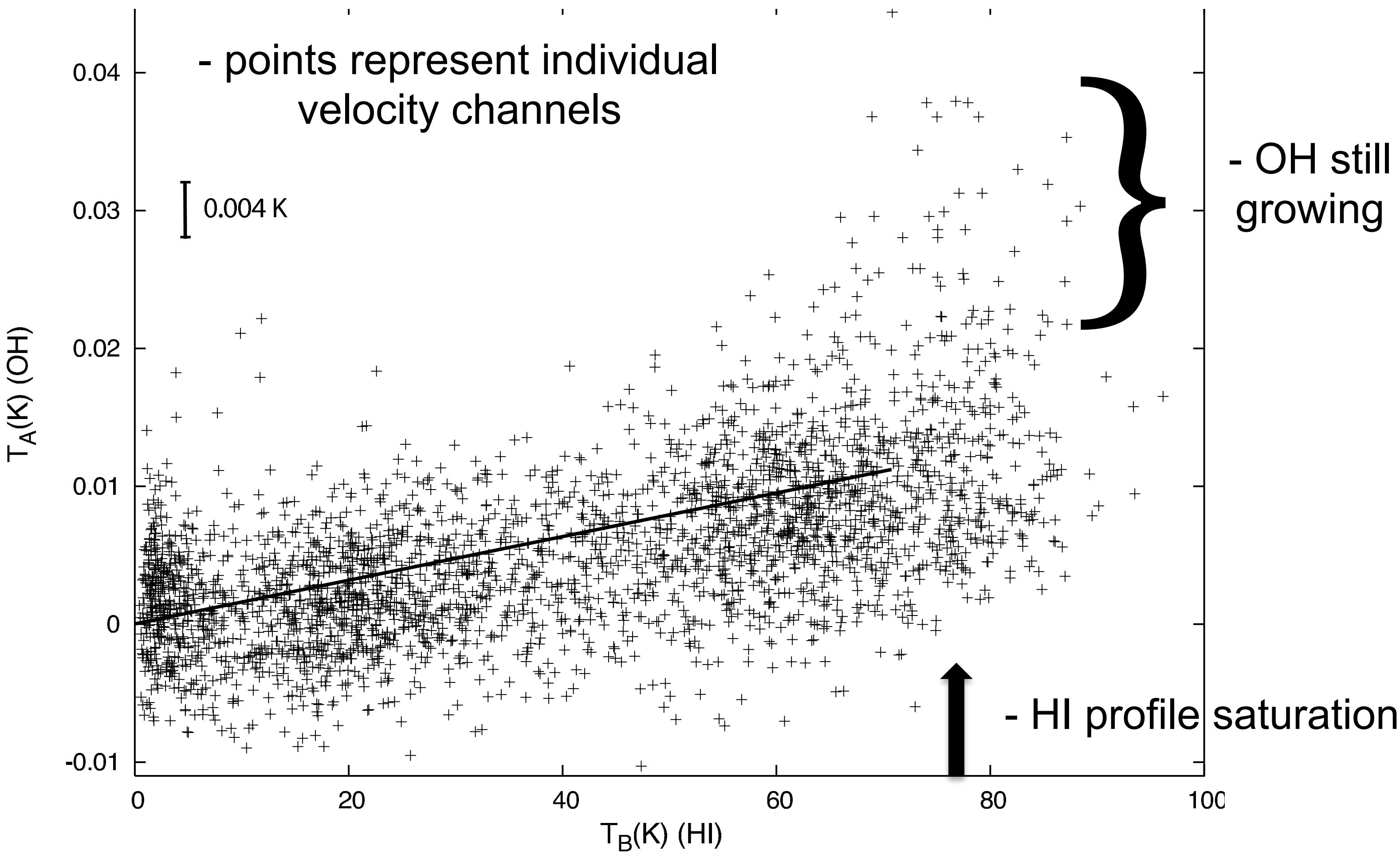
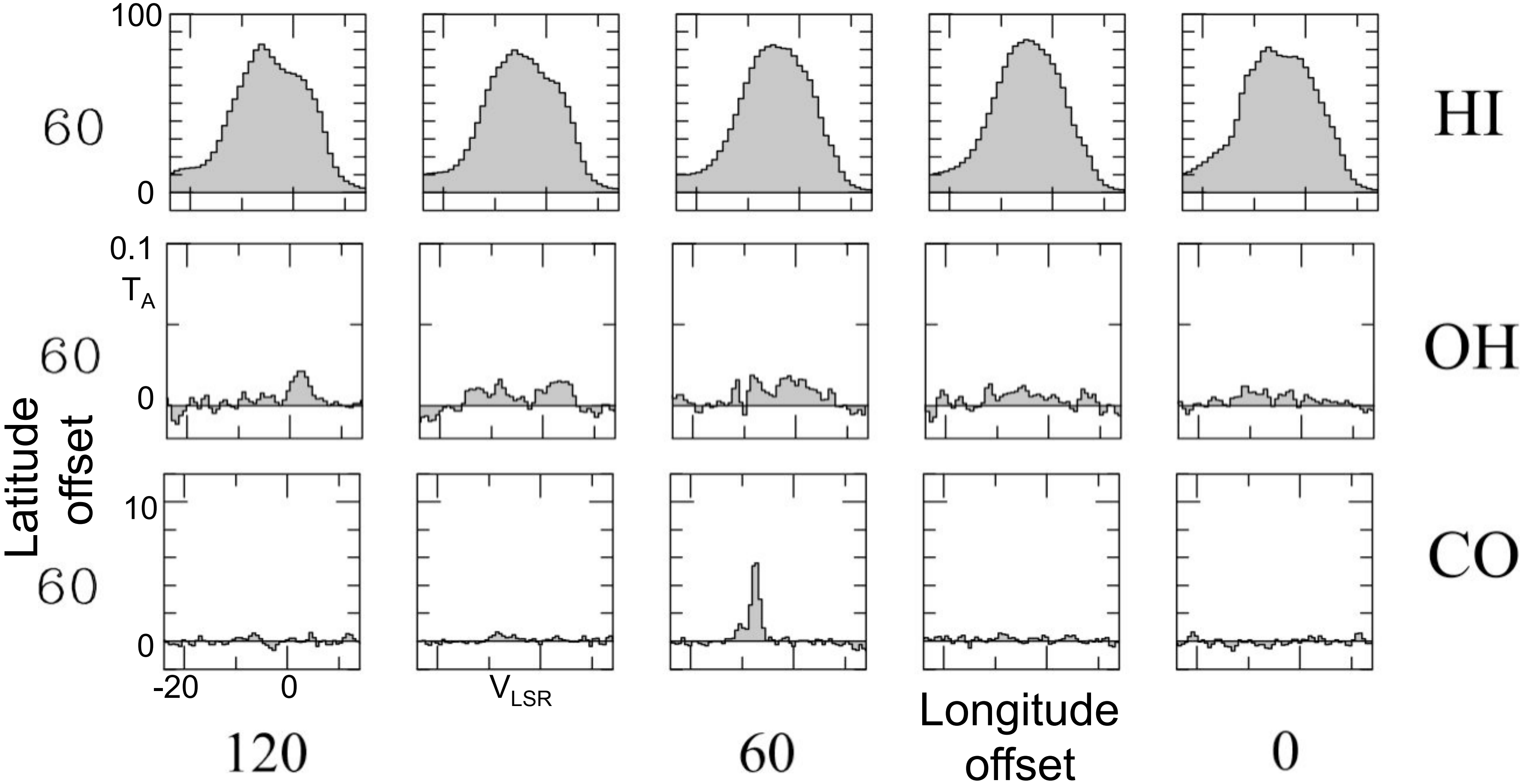


Let’s take a closer look …

Faint OH(1667) at Onsala

Allen et al 2012, AJ, 143, 97

… at the profile details:



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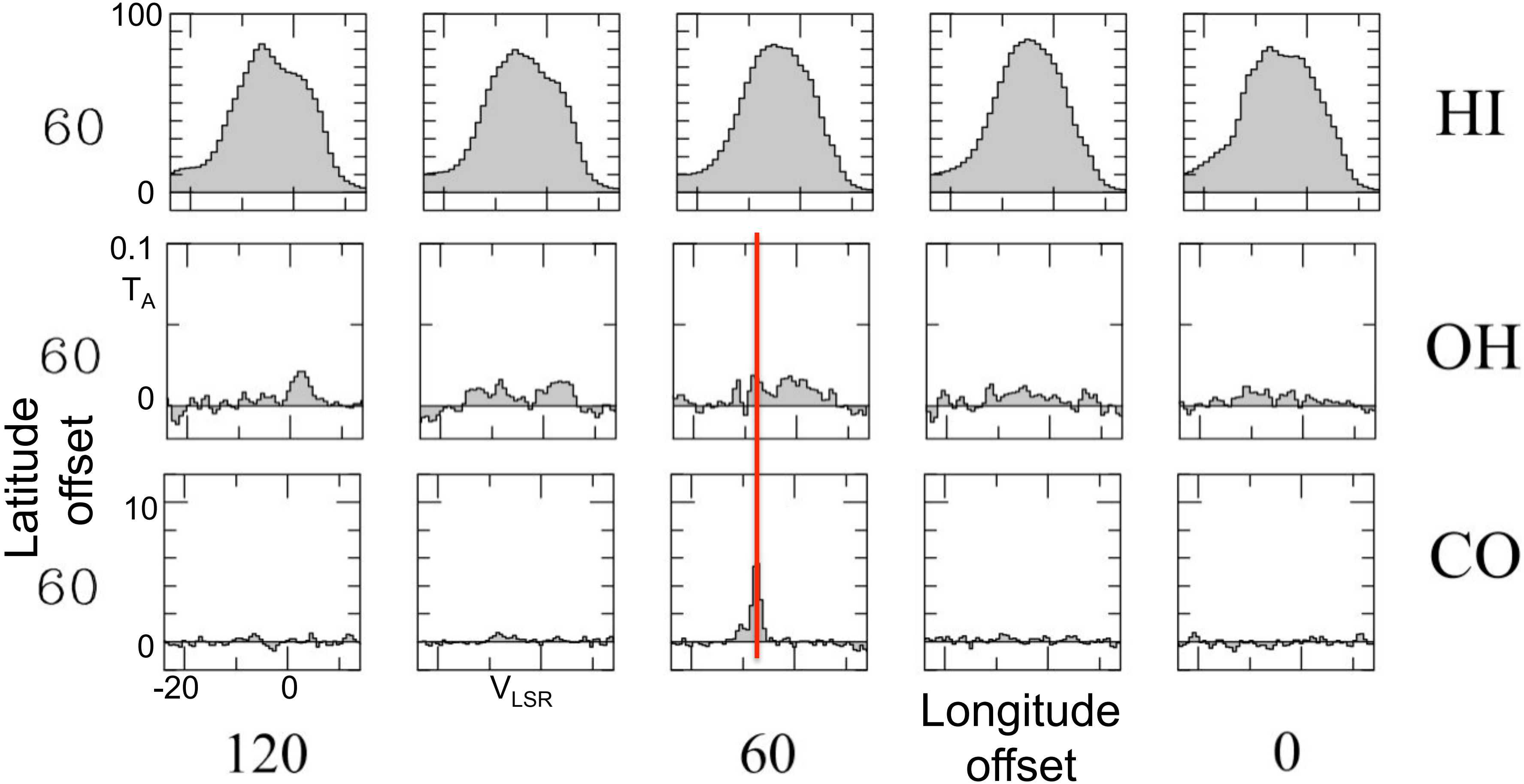

Faint OH(1667) at Onsala

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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 ≈ 2-3 km/s, separations ≈ 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) ≈ 1.5 X 10^{-4} T_B(HI 21-cm)
  - Local HI profiles (r ≤ 1 kpc) appear saturated.
    - But OH continues to increase (suggests HI is optically thick).

Allen et al 2012, AJ, 143, 97

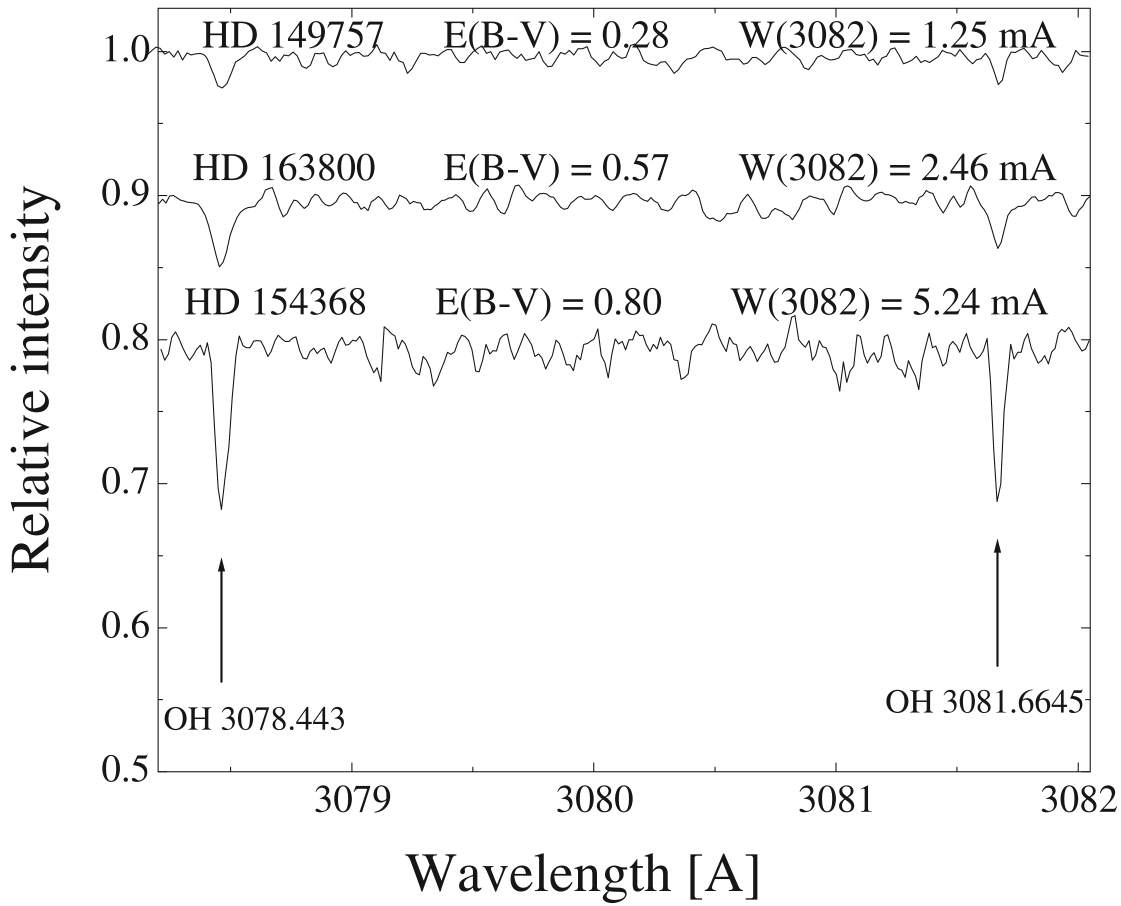
OH as a tracer for the molecular ISM …

- 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 ($n_{critical} \approx 1\ cm^{-3}$)
- 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 ≈ 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



Weselak et.al. 2009, A&A, 499, 783

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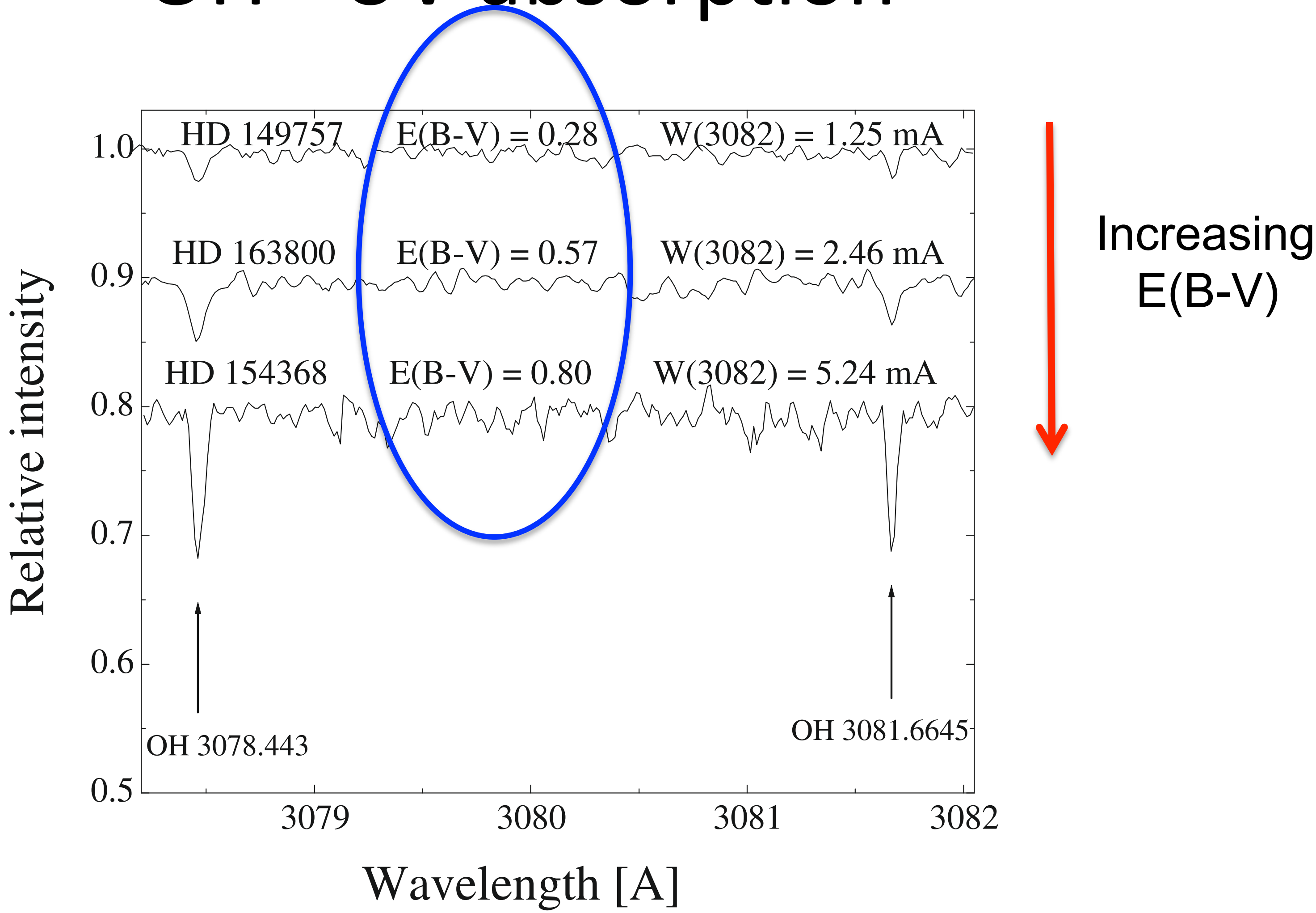

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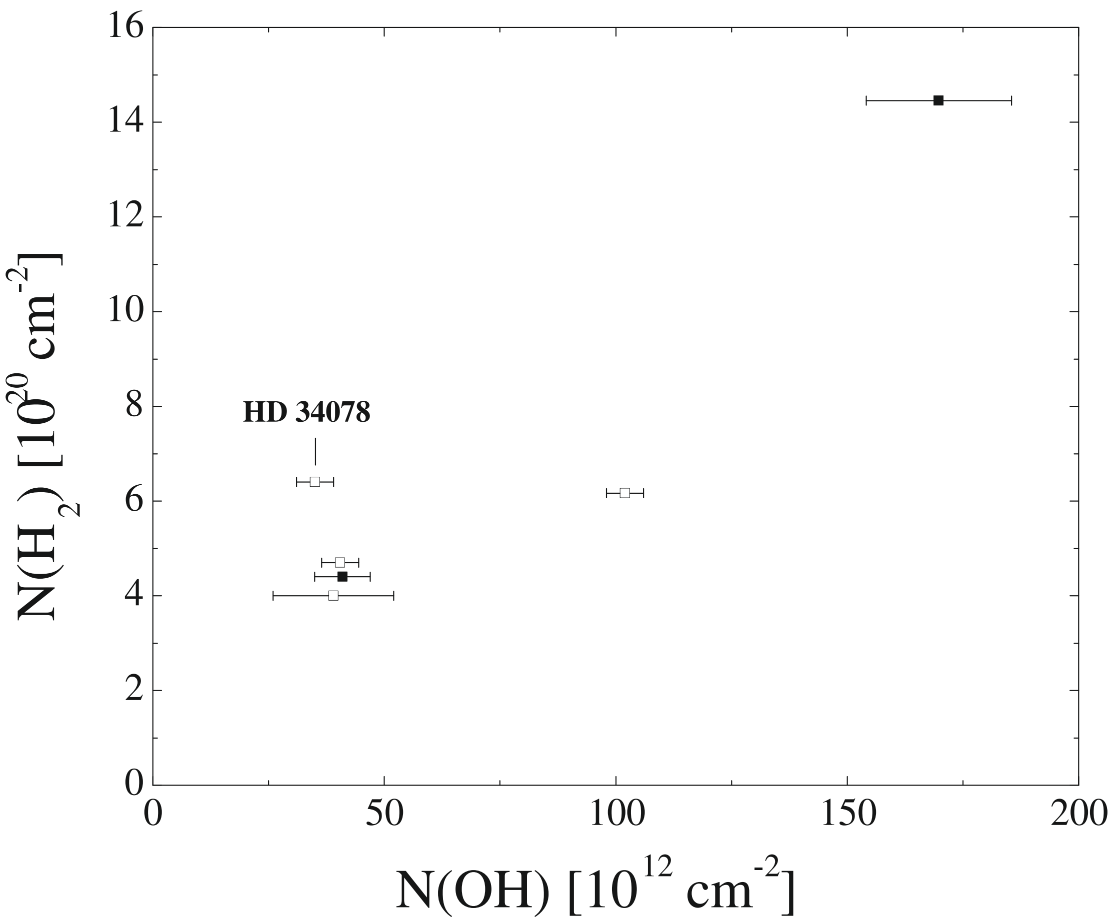
OH – H_2 relation from UV lines



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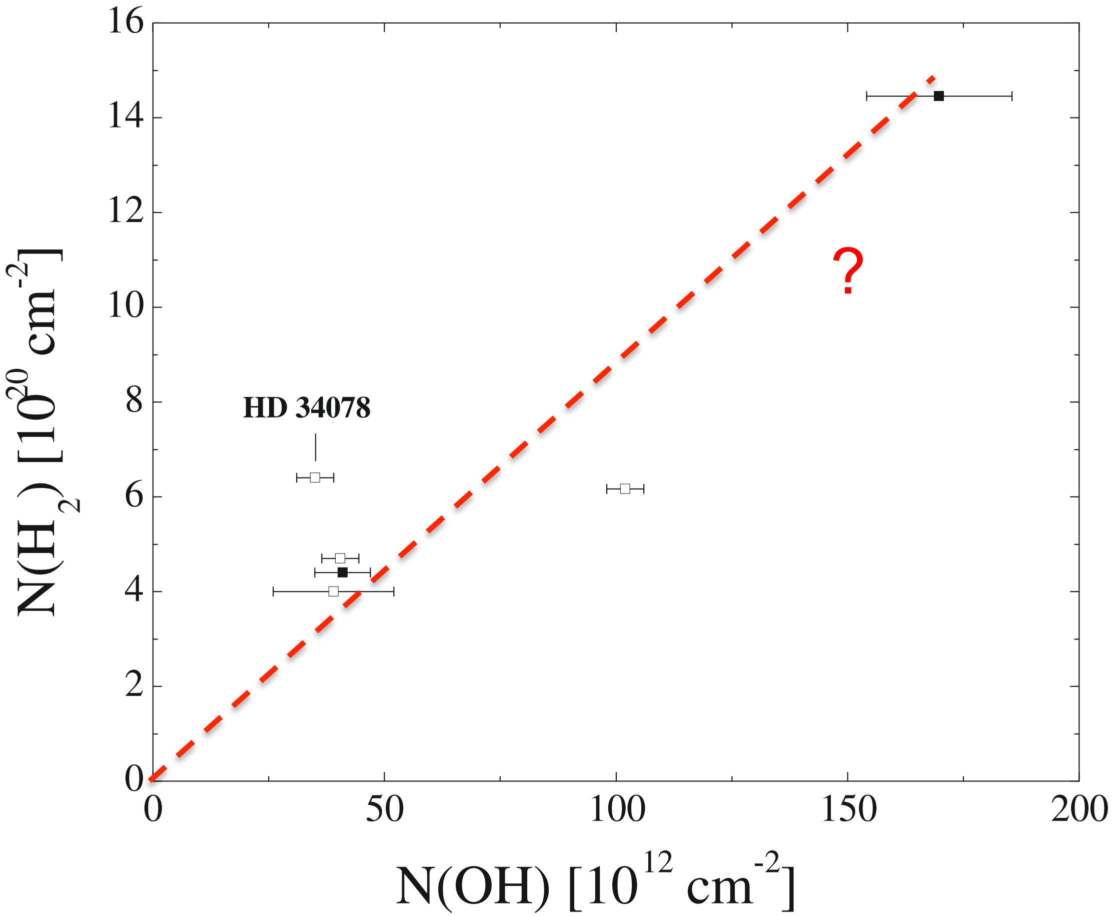

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Current state of the data …

Table 1. UV absorption measurements of molecular column densities.

Target Star HD #	Galactic longitude	Galactic latitude	CaII Dist. parsec	Z Dist. parsec	Ref. -	$N(OH)$ $\times 10^{-13}$	Ref. -	$N(H_2)$ $\times 10^{-20}$	Ref. -
HD 23180 (o Per)	160.36	-17.74	371 ± 44	-117	Mea09	7.8 ± 1.8	R96, see text	4.1 ± 1.5	Sea77
HD 24398 (ζ Per)	162.29	-16.69	400 ± 64	-118	Mea09	4.0 ± 0.4	FR96	4.8 ± 1.7	Sea77
HD 27778	172.76	-17.39	234 ± 59	-72	Mea09	10.2 ± 0.4	FR96	6.2 ± 0.8	Rea02
HD 34078	172.08	-2.26	548 ± 68	-22	Mea09	3.5 ± 0.4	Bea05	6.4 ± 0.5	Bea05
HD 110432	301.96	-0.20	392 ± 55	-1	Mea09	4.0 ± 0.6	Wea10	4.4 ± 0.4	Rea02
HD 149757 (ζ Oph)	6.26	23.59	222 ± 22	94	Mea09	4.1 ± 0.1	Wea09	4.5 ± 0.8	Sea77
HD 152236	343.03	0.87	1581 ± 219	24	Mea09	7.6 ± 0.4	Wea10	5.6 ± 1.5	Rea09
HD 154368	349.97	3.21	1302 ± 200	73	Mea09	17.0 ± 1.6	Wea09	14.5 ± 2.2	Rea02
Partial Totals	-	-	5050 ± 325	-	-	58.2 ± 2.6	-	50.5 ± 3.7	-
HD 170740	21.06	-0.53	-	-	Rea02	4.7 ± 0.9	Wea10	7.3 ± 1.3	Rea02
Grand Total	-	-	-	-	-	62.9 ± 2.8	-	57.8 ± 4.0	-

References. — R96: Roueff (1996); FR96: Felenbok & Roueff (1996); Bea05: Boissé et.al. (2005); Wea09: Weselak et.al. (2009); Wea10: Weselak et.al. (2010); Sea77: Savage et.al. (1977); Rea02: Rachford et.al. (2002); Rea09: Rachford et.al. (2009) (b) Reported in Joseph et.al. (1986) according to Felenbok & Roueff (1996); Mea09: Megier et.al. (2009).

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 $T_{ex} \approx T_{BG} + 0.5$ K ≈ 4 K. Emission from this component is weak and narrow in velocity; it adds little to the total emission on any sight line. (Note that $T_{BG} = T_{GAL}+T_{CMB} \approx 0.8+2.7 = 3.5$ K).
   - OH emitting gas has higher $T_{ex} \approx T_{BG} + (4 - 10)$ K ≈ 10.5 ± 3 K.
3. N(OH)/N(HI) ≈ (2.5 – 5) x 10^{-8} in diffuse Galactic clouds.
   - Our ONSALA data gives 4.7 x 10^{-8} over our mini-survey area.
4. $N(H_2)/N(OH) \approx 9 \times 10^6$ 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 $T_B(OH)\Delta V$ to $N(H_2)$ includes:
  - The OH excitation temperature $T_{EX}(OH)$
    - 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 $N(H_2)/N(OH)$
    - 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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C. The radio continuum emission
D. The Far-IR dust emission
E. None of the above
F. Don't know

The end …