Hydrides in the Diffuse ISM: an Overview of Observations at Ultraviolet and Visible Wavelengths

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Outline

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CH and H_2

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OH^+ and OH Sample Different Environments

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Observational Details

Wavelength regions

- CH (Visible, NUV, and FUV)
- CH^+ (Visible and NUV)
- OH (NUV, FUV)
- OH^+ (NUV)
- NH (NUV)
- SH (NUV)
- HCl (FUV)
- Species not yet detected
  - H_2O (FUV)
  - H_2O^+ (Visible, NIR)

Chemical Considerations

Historical Development

- Radiative association involving atoms (1940s and 1950s: Bates & Spitzer; ter Haar & Kramers)
- Ion-molecule reactions (1970s: Herbst; Watson)
  - C chemistry (e.g., Black & Dalgarno)
  - O chemistry (Glassgold & Langer)
  - N chemistry (Watson)
- Example – Production of OH
  - Galactic cosmic rays (p and He) ionize H and H_2, producing H^+
  - $H^+ + O \rightarrow O^+ + H + \Delta E$ ($\Delta E/k \approx 232$ K)
  - $O^+ + H_2 \rightarrow OH^+ + H$
  - $OH^+ + H_2 \rightarrow H_2O^+ + H$
  - $H_2O^+ + H_2 \rightarrow H_3O^+ + H$
  - $H_3O^+ + e \rightarrow OH + 2H$ or H_2

Chemical Considerations

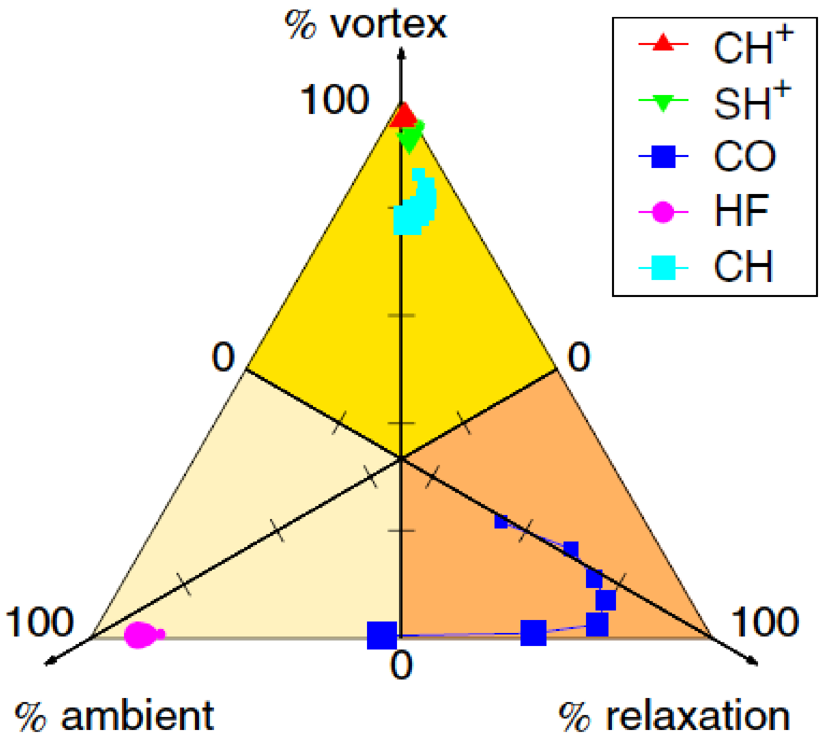
Historical Development (cont.)

- CH^+ production (1980s to the present)
  - Hydrodynamical shocks (Watson)
  - Magnetohydrodynamical shocks (Draine; Flower & Pineau des Fôrets)
  - Shear flows (Duley et al. 1992)
  - Alfven waves (Federman et al. 1996)
  - Vortices (Falgarone, Godard)

Chemical Considerations

Historical Development (cont.)

- CH^+ production (Godard et al. 2014)



- CNO hydrides via grain reactions (Williams)

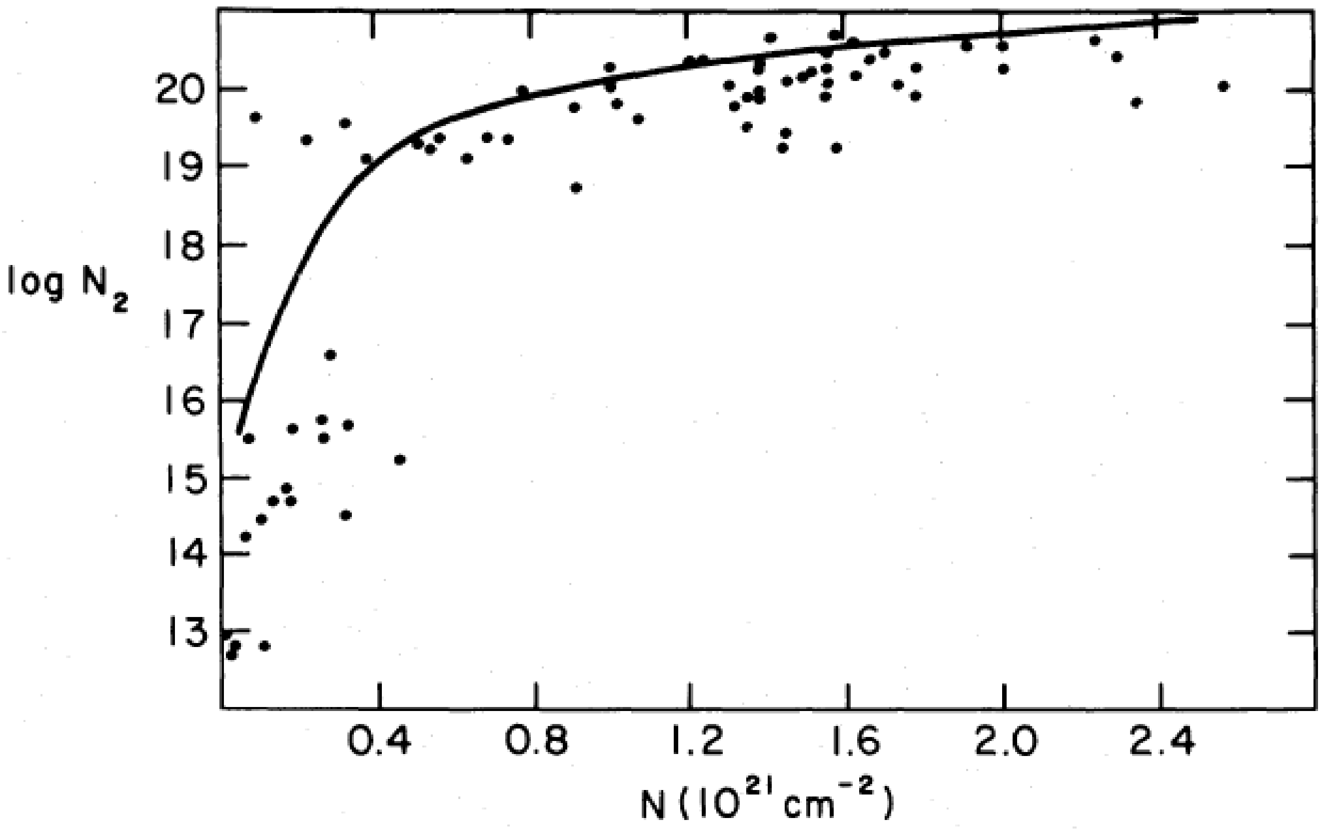
Chemical Considerations

Molecular Production

- CH^+ leads to CH (as well as HCO^+ and then CO in low density gas)
- CH leads to CO (minor channel) and C_2
- CN produced via reactions involving CH, C_2, and NH
- OH (and H_2O) leads to HCO^+ and then CO

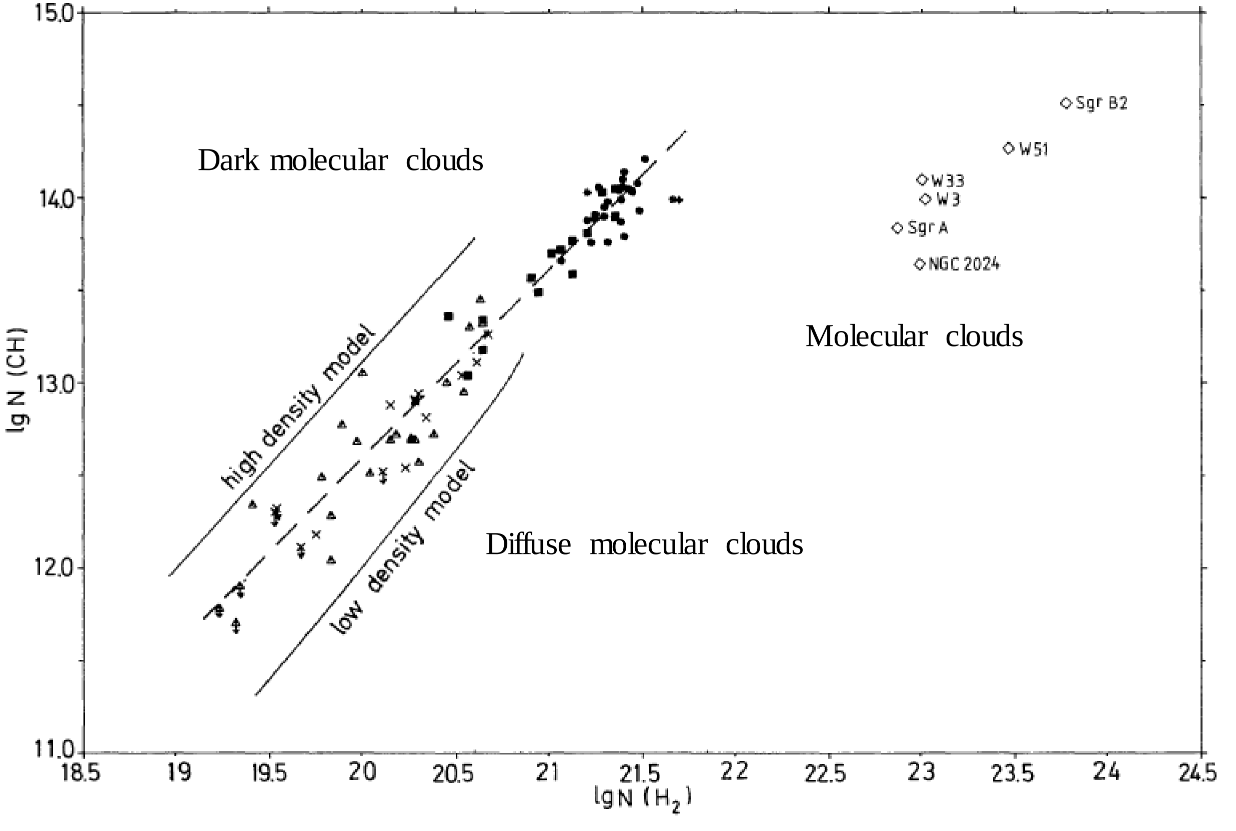
- Through a combination of ion-molecule, neutral-neutral, and dissociative recombination reactions

CH and H_2



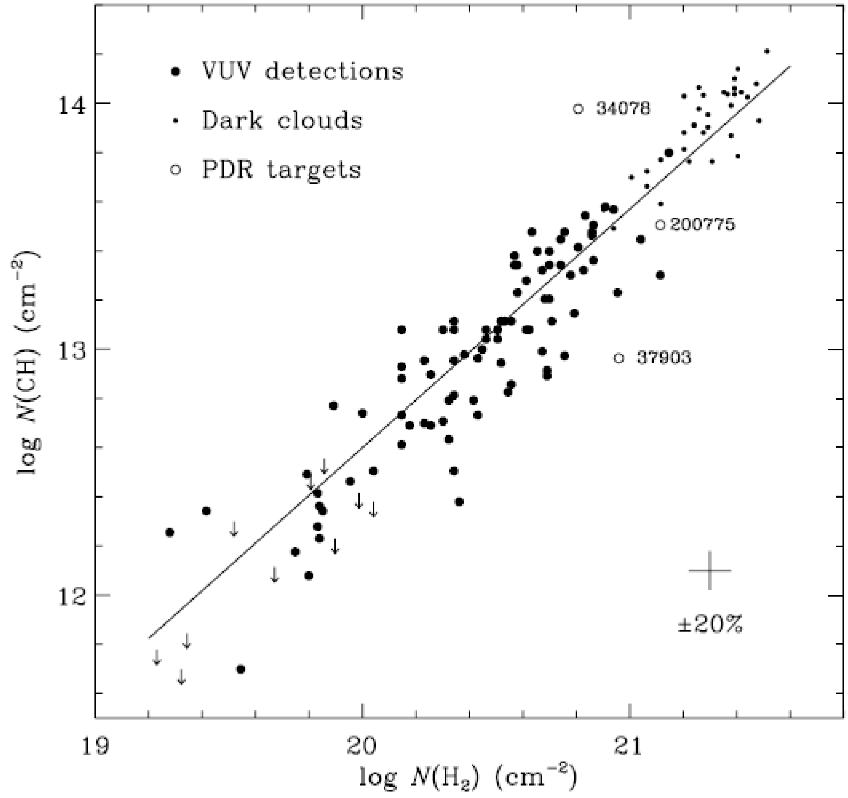
- Federman et al. (1979; data from Savage et al. 1977)

CH and H_2



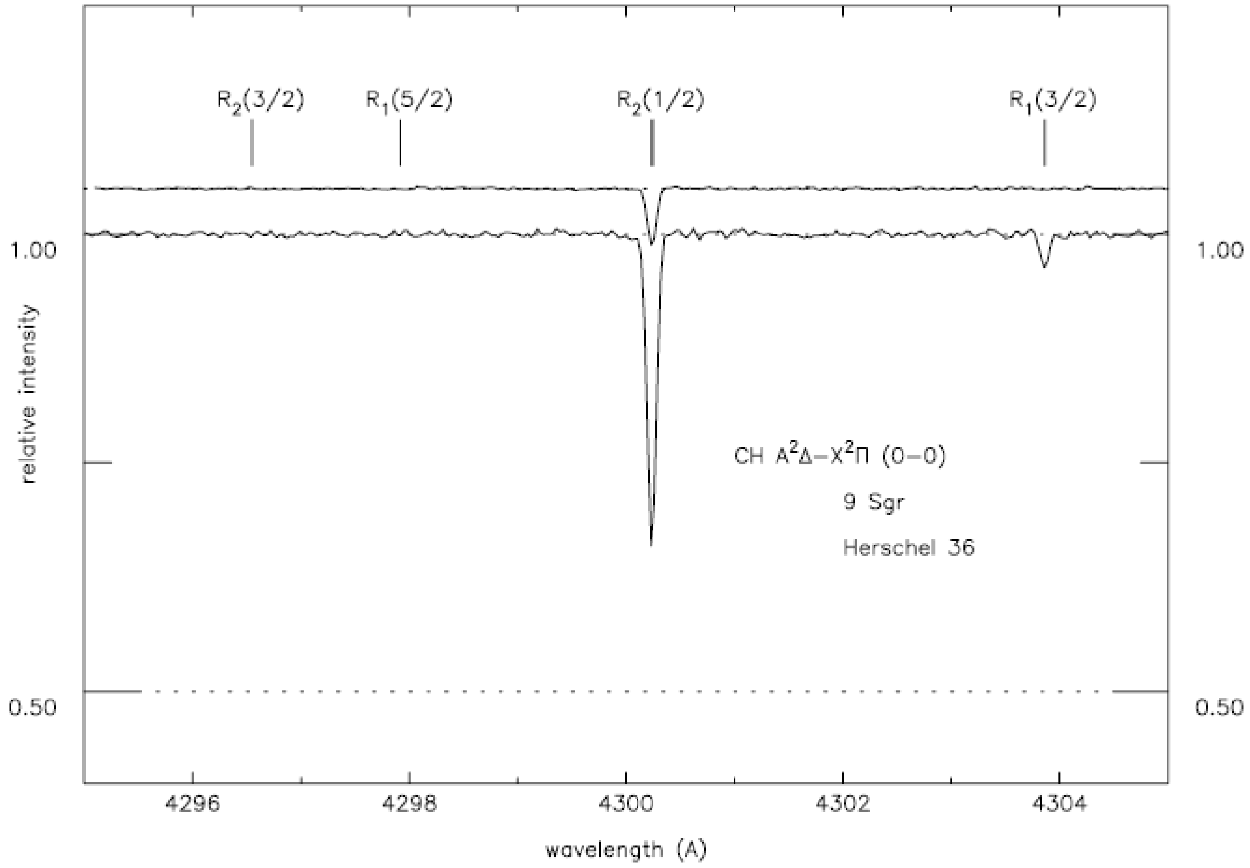
- Mattila (1986)

CH and H_2



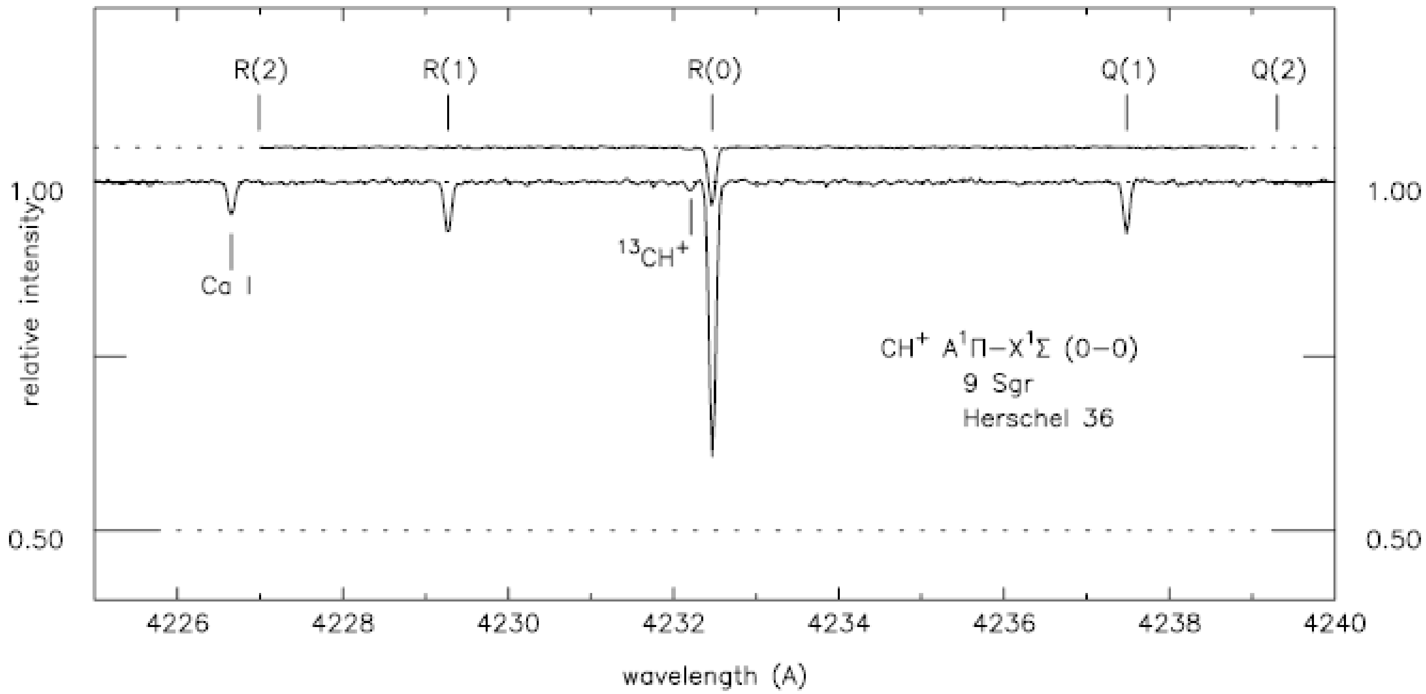
- Sheffer et al. (2008)

CH and H_2



- Oka et al. (2013)

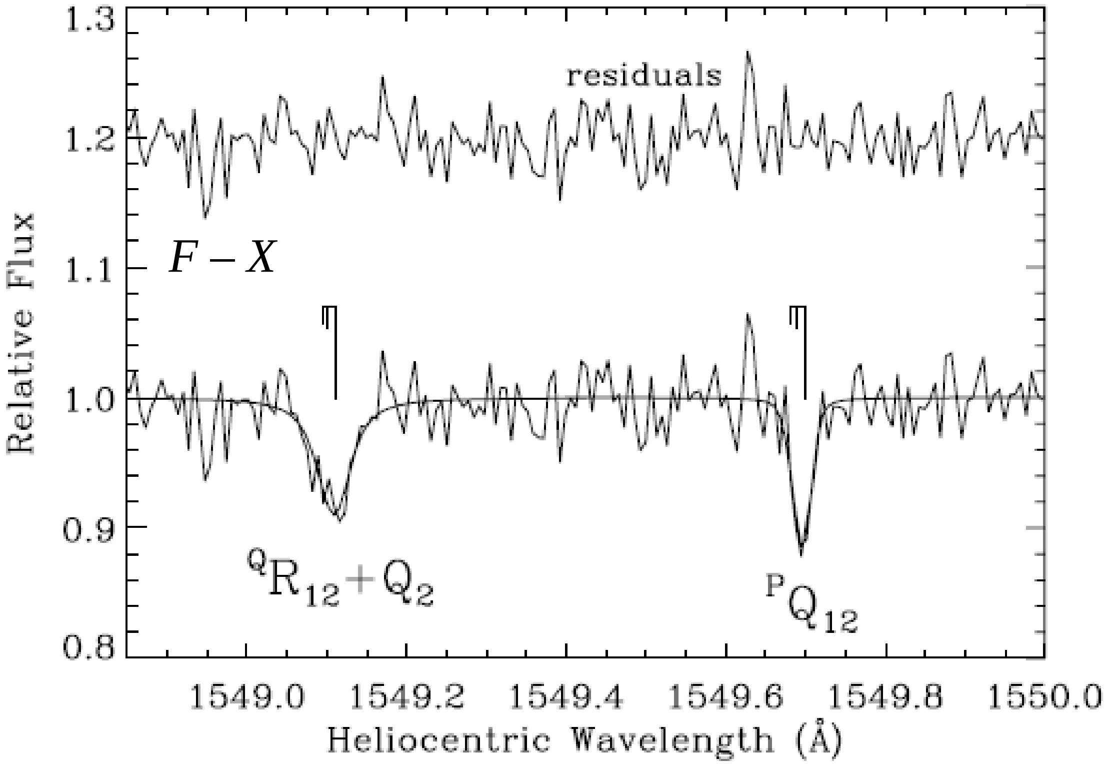
CH and H_2



- Oka et al. (2013)

Molecular Data

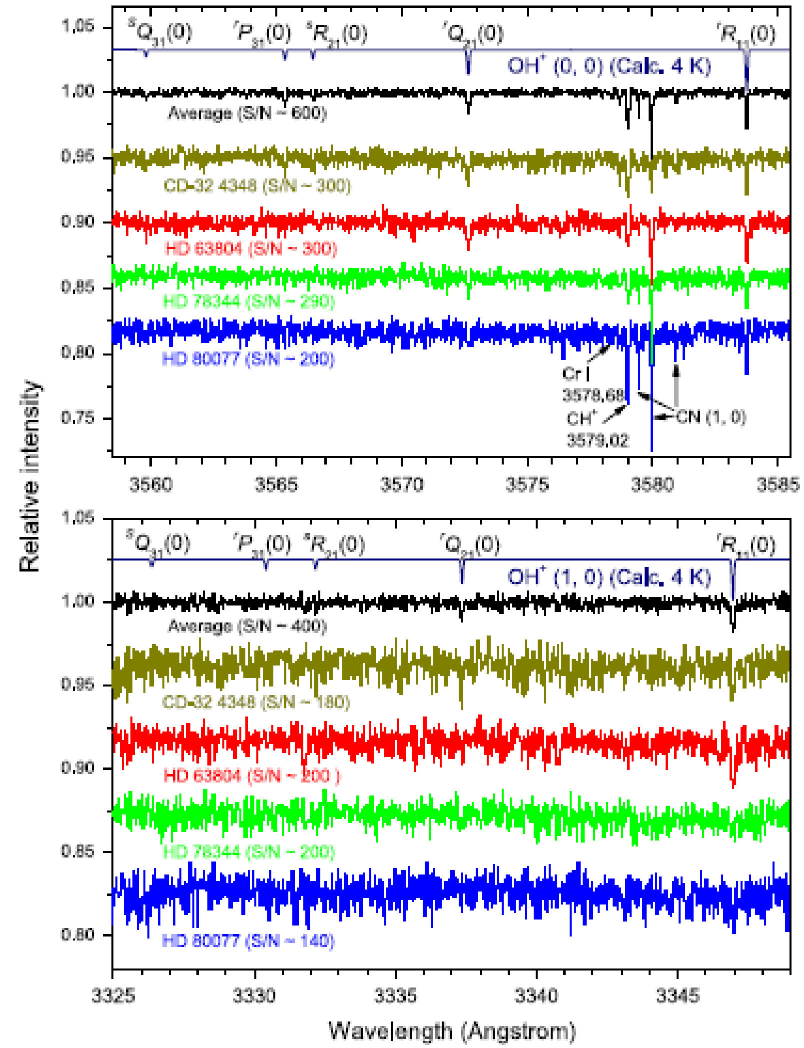
- Profile fitting yields CH predissociation rate (about 2×10^{11} s^{-1})



- Sheffer & Federman (2007)

Molecular Data

- Spectroscopy and *f*-values for OH^+ (Zhao et al. 2015,



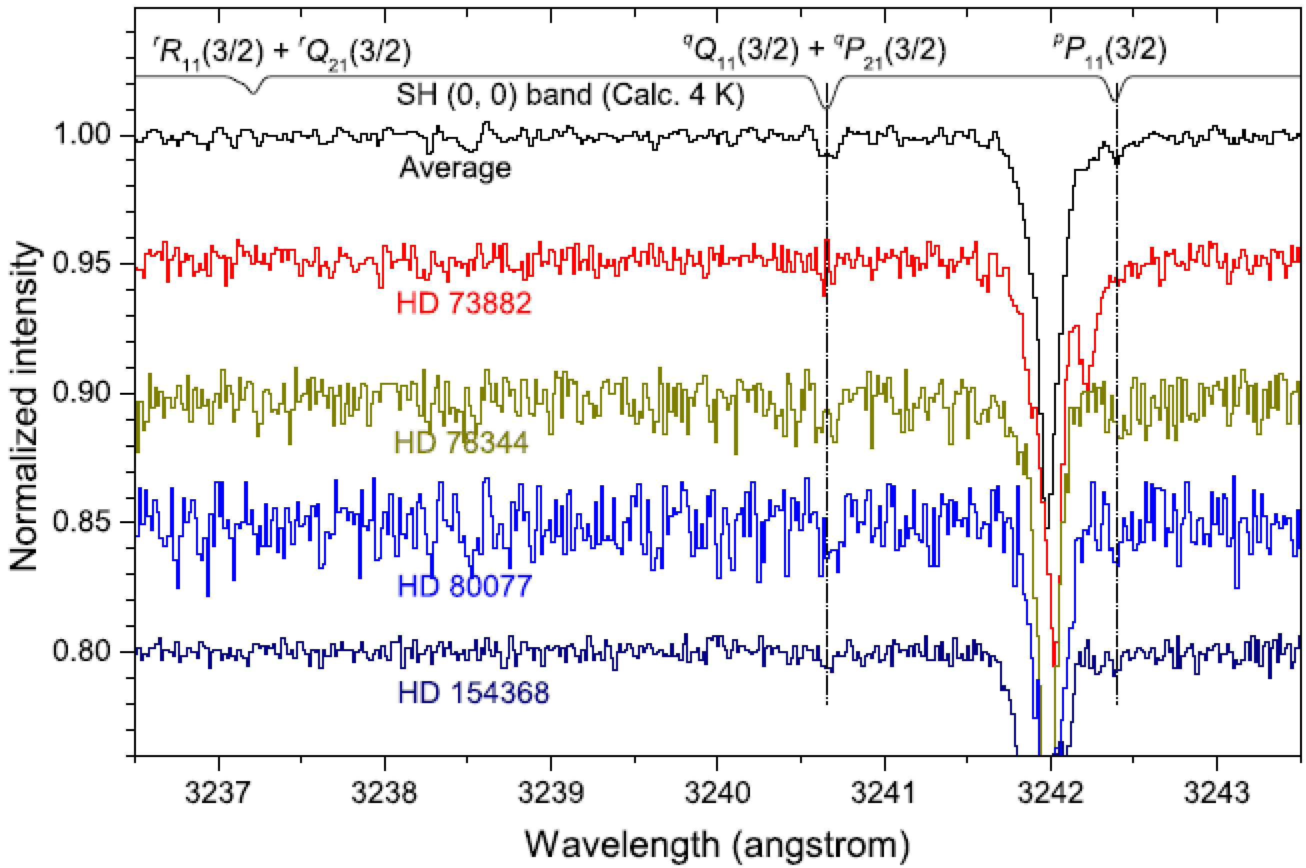
Line Positions and Oscillator Strengths of OH^+ in the Near-UV

	(0, 0)		(1, 0)	
Transition	λ (Å)	f (10^{-4})	λ (Å)	f (10^{-4})
${}^{r}R_{11}(0)$	3583.757	10.20	3346.961	7.11
${}^{r}Q_{21}(0)$	3572.649	6.03	3337.358	4.16
${}^{s}R_{21}(0)$	3566.445	2.29	3332.177	1.66
${}^{r}P_{31}(0)$	3565.341	2.46	3330.409	1.72
${}^{s}Q_{31}(0)$	3559.807	1.67	3326.368	1.29
${}^{t}R_{31}(0)$	3553.329	0.09	3319.971	0.06

Note. Positions of the two ${}^{t}R_{31}(0)$ lines are calculated using molecular constants from Merer et al. (1975).

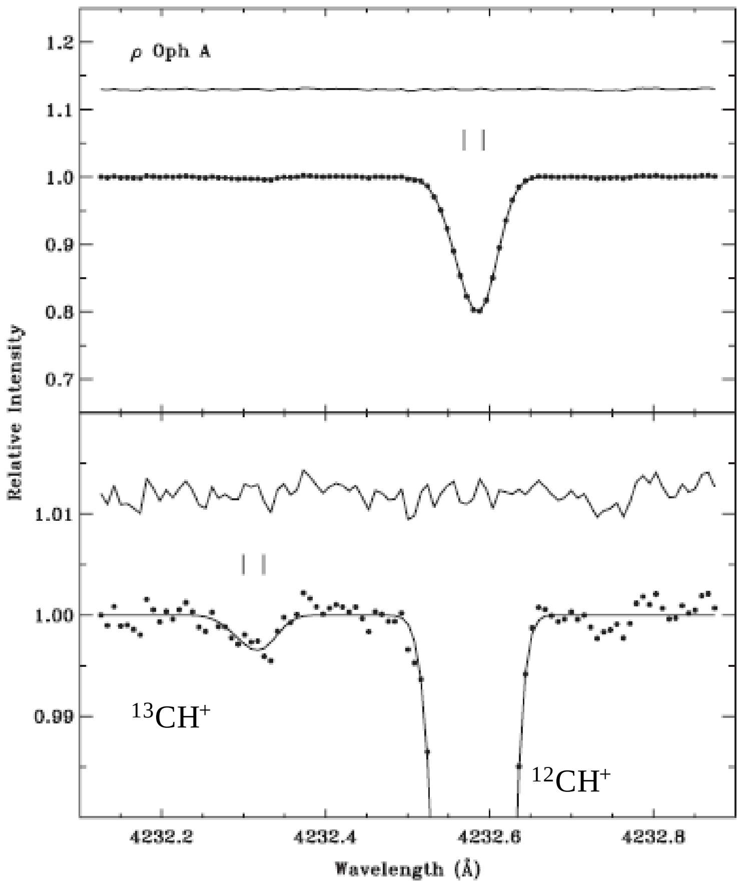
Molecular Data

- Detection of SH (Zhao et al. 2015, A&AL)



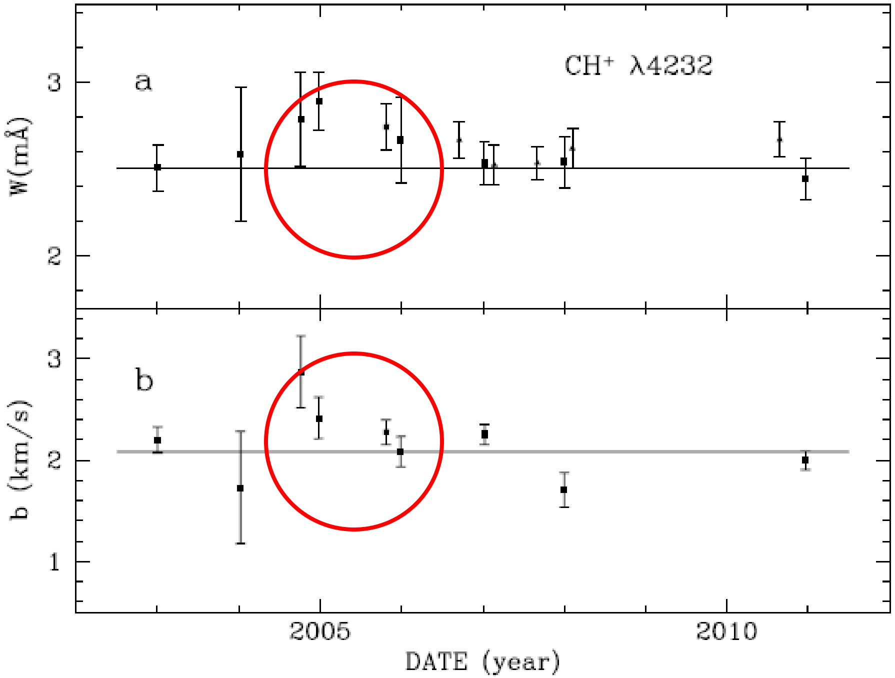
CH^+ and Small Scale Structure

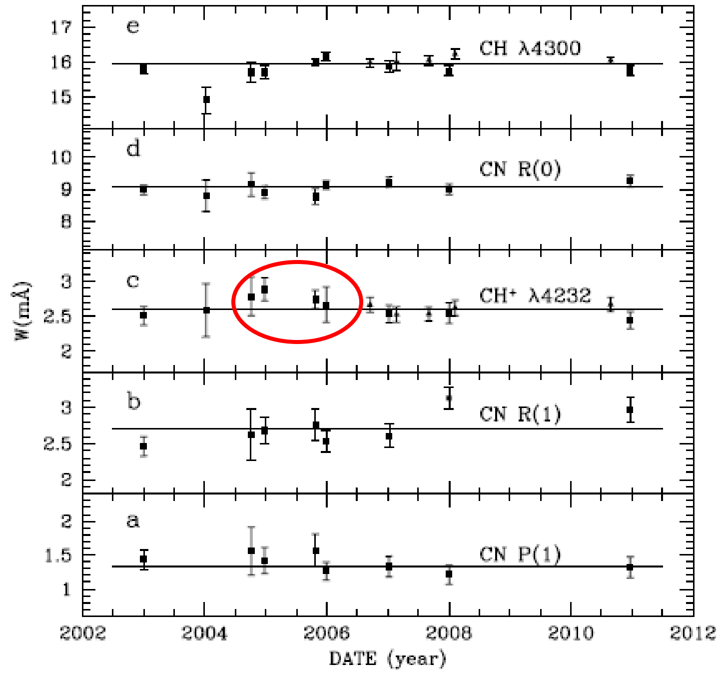
- $^{12}CH^+/^{13}CH^+$ (Ritchey et al. 2011)
  - $^{12}CH^+/^{13}CH^+$ yields ambient $^{12}C/^{13}C$ ratio of 74.4 ± 7.6



CH^+ and Small Scale Structure

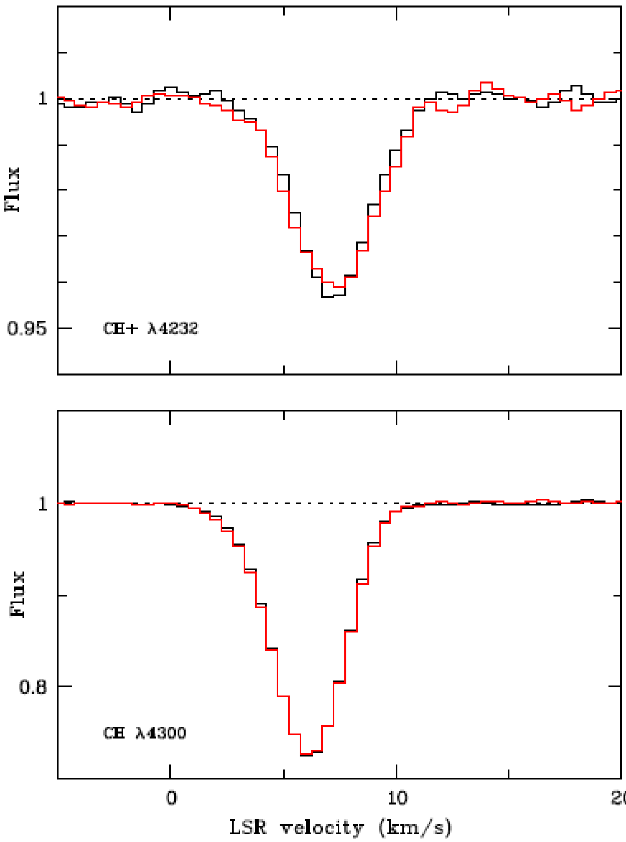
- Small scale variations in W_λ and *b*-value for CH^+ toward ζ Per (Boissé et al. 2013)
  - $N/\delta N \sim 9\%$ over 3 yrs.; not seen in CH, nor CN ($N/\delta N \leq 6\%$)





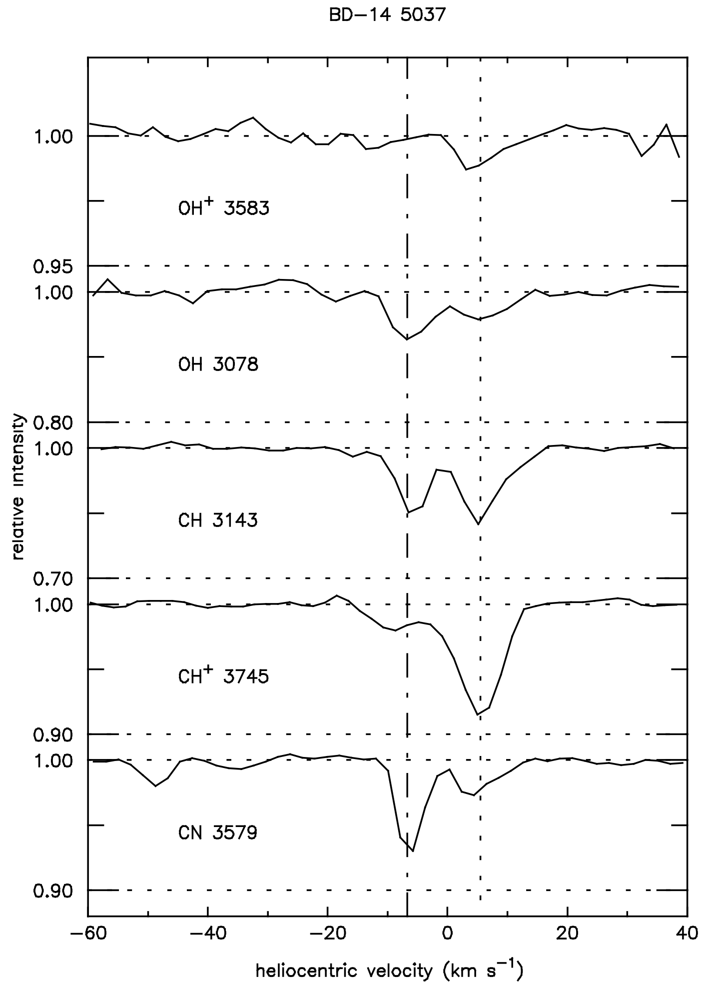
CH^+ and Small Scale Structure

- Small scale variations in W_λ and *b*-value for CH^+ toward ζ Per (cont.)
  - Seems to role out shocks
  - $\delta N(CH^+)$, $\delta N(CH)$ are few 10^{11} cm^{-2}
  - Have ~10 vortices passed line of sight?



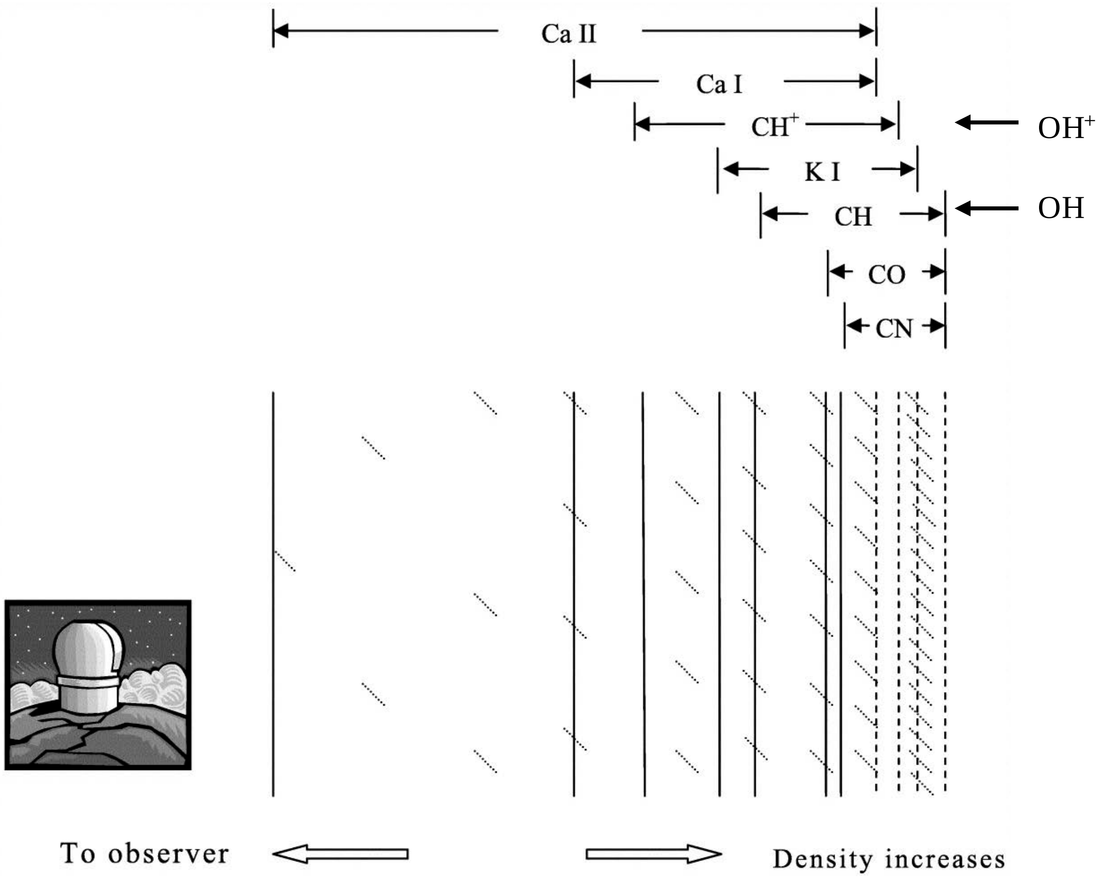
OH^+ and OH Chemistry

- Sample gas with different physical conditions (Porras et al. 2014)
  - OH^+ strongest in CH^+ components, especially those with large CH^+/CH ratios
  - Formed in material with low densities and small H_2 fractions
  - OH strongest in CN components *(higher density and larger H_2 fraction)*



OH^+ and OH Chemistry

- Updating Pan et al. (2005)



Final Remarks

- Chemical models need to extend region where H-to-H_2 transition occurs and to produce abundances of neutral carbon consistent with observations
- CH^+ and OH chemistries distinct
- Ability to allow physical conditions (density and temperature to vary with distance into cloud)
- Focus on individual velocity components, not lines of sight
- Incorporate molecular (and atomic) excitation
- Discern the connection between diffuse gas seen in UV/visible and in radio/sub-millimeter