H_3^+ in the Diffuse Interstellar Medium toward HD 183143

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Importance of Interstellar H_3^+

Hydrogenic species of fundamental interest

H

He

C N O Ne

Mg Si S Ar

Fe

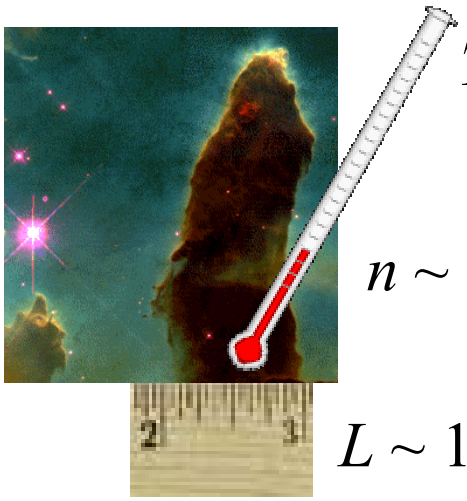
As "universal protonator," H_3^+ initiates ion-neutral reactions

$$H_3^+ + O \rightarrow H_2 + OH^+$$

$$OH^+ + H_2 \rightarrow H + H_2O^+$$

$$H_2O^+ + H_2 \rightarrow H + H_3O^+ \rightarrow H_2O$$

Simple chemistry → probe of cloud L, n, T

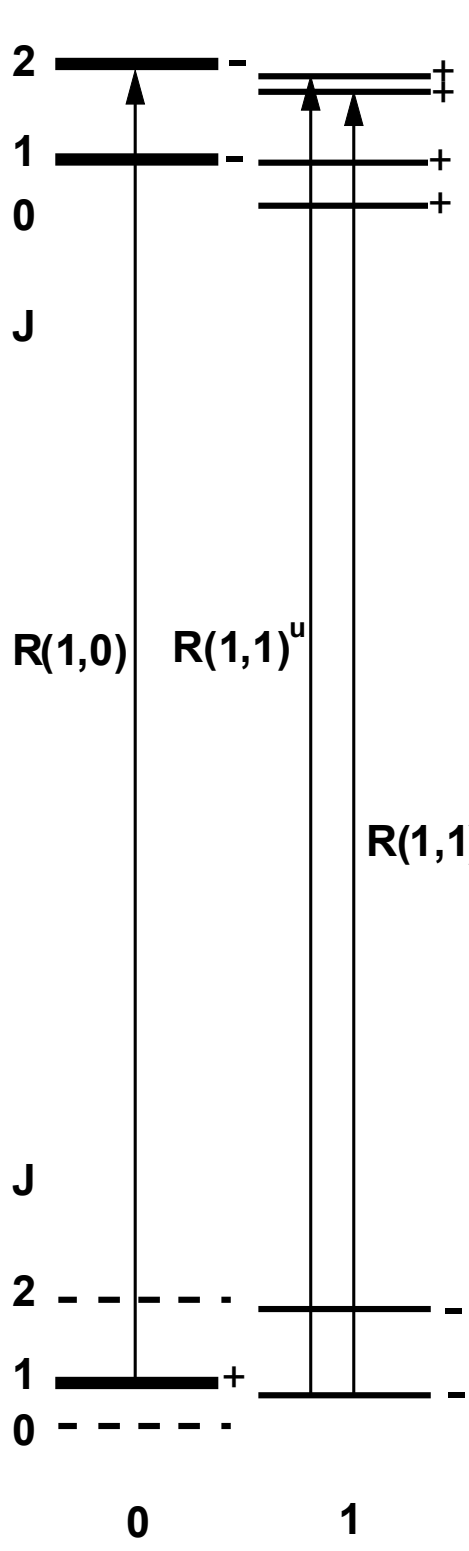


$T \sim 30$ K

$n \sim 10^5$ cm^{-3}

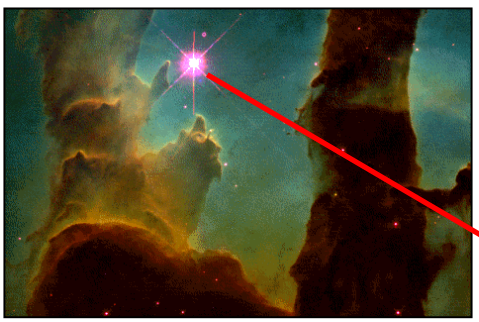
$L \sim 1$ pc

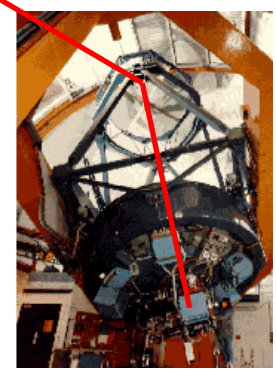
Spectroscopy of H_3^+



United Kingdom Infrared Telescope
Mauna Kea, Hawaii

Nicholas U. Mayall Telescope
Kitt Peak, AZ





Integrated area of absorption lines

↓

H_3^+ column density $N = [H_3^+] \times L$

H_3^+ in Dense Clouds

Barnard 68 (courtesy João Alves, ESO)

$H \rightarrow H_2$

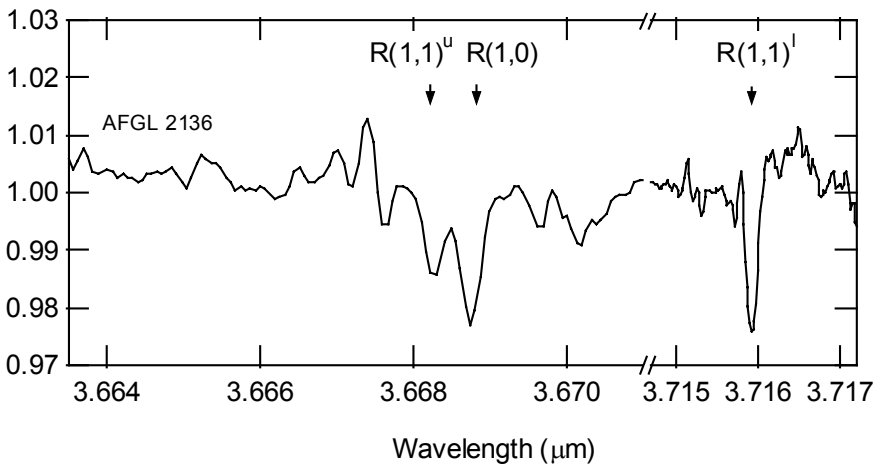
$C \rightarrow CO$

$[H_2] \sim 10^5$ cm^{-3}

$L \sim 1$ pc (3×10^{18} cm)

$T \sim 30$ K

dust extinction → no visible/UV light



Observed spectrum:
$N(H_3^+) \sim 3\times10^{14}$ cm^{-2}

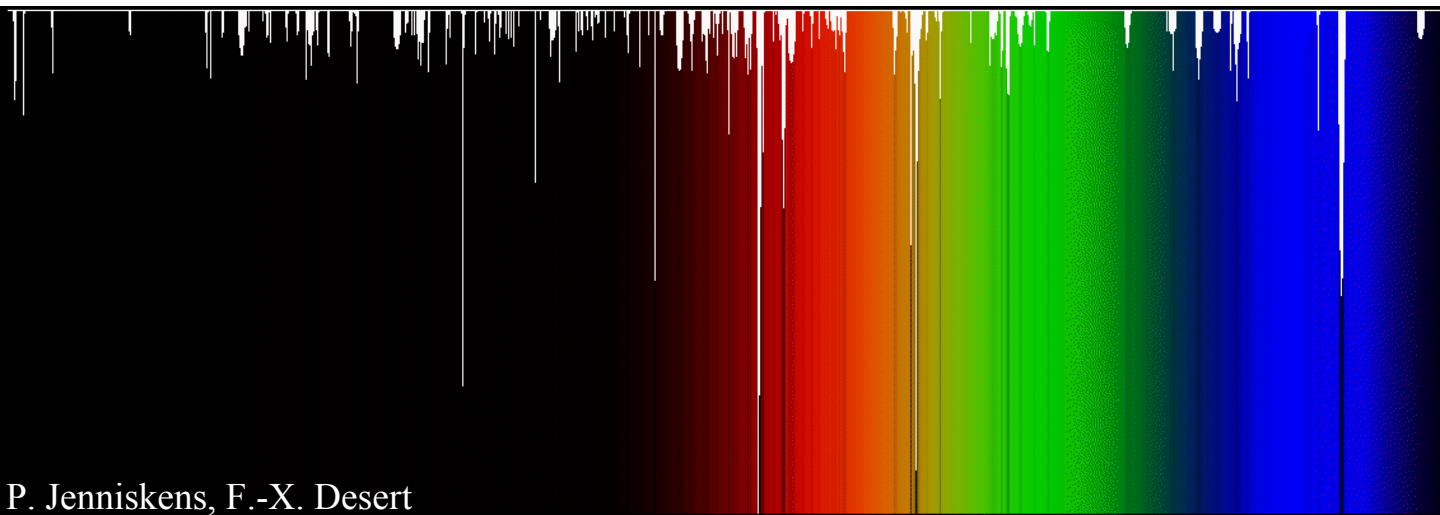
Chemical model:
$[H_3^+] \sim 10^{-4}$ cm^{-3}

$L = N(H_3^+) / [H_3^+]$ ~ 1 pc
$[H_2] = N(H_2) / L$ ~ 10^5 cm^{-3}
T (ortho:para) ~ 30 K

Diffuse Clouds

Dense Clouds:	Diffuse Clouds:
$H \rightarrow H_2$	$[H] \sim [H_2]$
$C \rightarrow CO$	$C \rightarrow C^+ + e^-$
$[H_2] \sim 10^5$ cm^{-3}	$[H]+2[H_2] \sim 100$ cm^{-3}
$L \sim 1$ pc	$L \sim 10$ pc
$T \sim 30$ K	$T \sim 30$ K
no visible/UV light	large visible/UV flux

- Diatomics observed (CH, CH^+, CN, C_2, CO, OH, NH)
  - CH^+ (over)abundance a mystery
- Until recently, no polyatomics
- Diffuse Interstellar Bands:



P. Jenniskens, F.-X. Desert

H_3^+ in Diffuse Clouds

Formation:

$$H_2 \xrightarrow{\text{cosmic ray}} H_2^+ + e^-$$

$$H_2 + H_2^+ \rightarrow H_3^+ + H$$

Rate = $\zeta\,[H_2]$

Destruction:

$$H_3^+ + e^- \rightarrow H + H + H$$

$$\rightarrow H + H_2$$

Rate = $k_e\,[H_3^+]\,[e^-]$

Steady State:

$$[H_3^+] = \frac{\zeta}{k_e} \cdot \frac{[H_2]}{[e^-]} \sim 10^{-7}\ \text{cm}^{-3}$$

(very low due to efficiency of electron recombination)

Over a typical diffuse cloud pathlength of 10 pc,

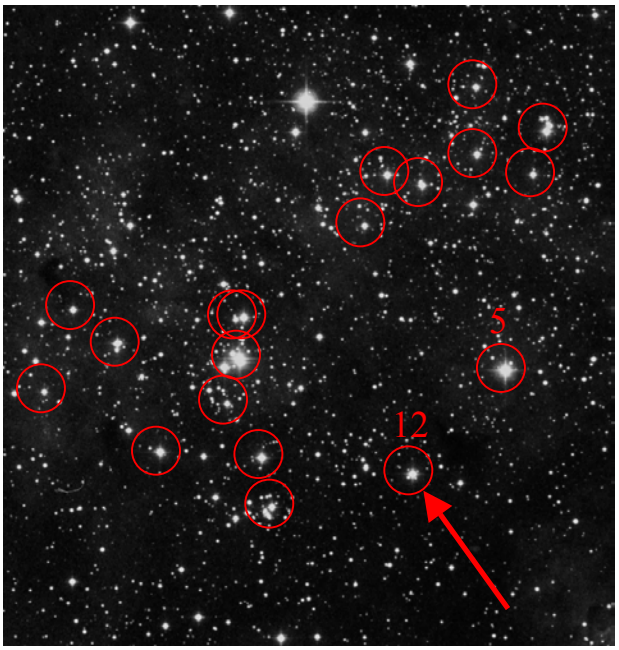
$$N(H_3^+) = [H_3^+] \times L$$

$$= (10^{-7}\ \text{cm}^{-3}) \times (3 \times 10^{19}\ \text{cm})$$

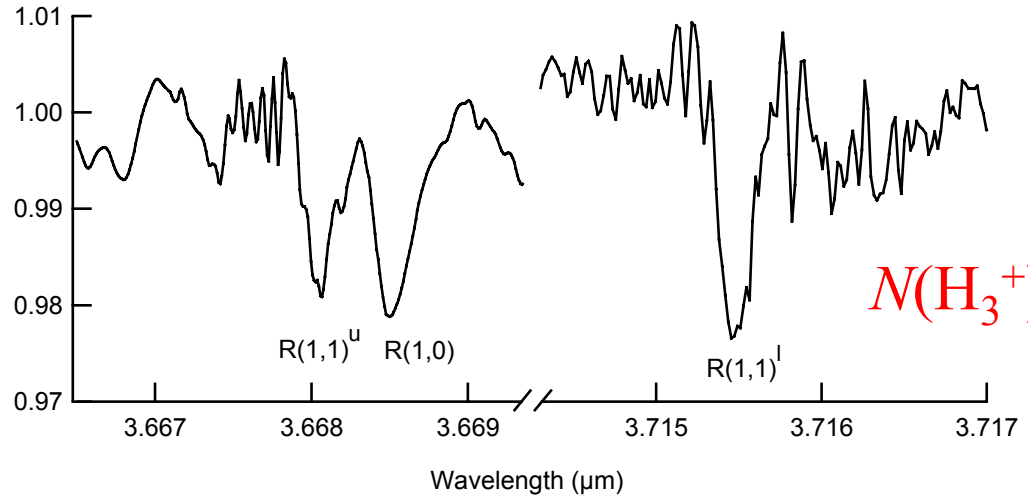
$$\sim 3 \times 10^{12}\ \text{cm}^{-2}$$

NOT DETECTABLE!

Cygnus OB2 12



- Diffuse cloud sightline
- Heavily reddened (A_v~10)
- Member of Cygnus OB2 association



$N(H_3^+) \sim 3\times10^{14}$ cm^{-2}

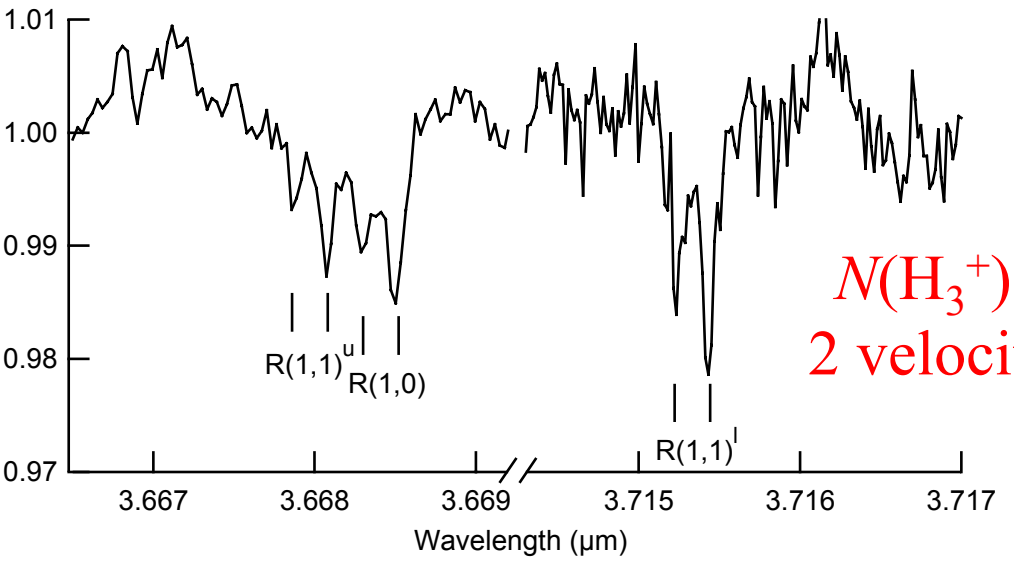
Chemical model $\rightarrow L \sim 900$ pc [too long!]

$\rightarrow [H_2] \sim 5$ cm^{-3} [too low!]

Perhaps H_3^+ production is enhanced by X-ray ionization from the OB association? (J. Black)

HD 183143

- Typical diffuse cloud
- Less reddened (A_v~3)
- Herbig's reference star for Diffuse Interstellar Bands
- Very little C_2, CO

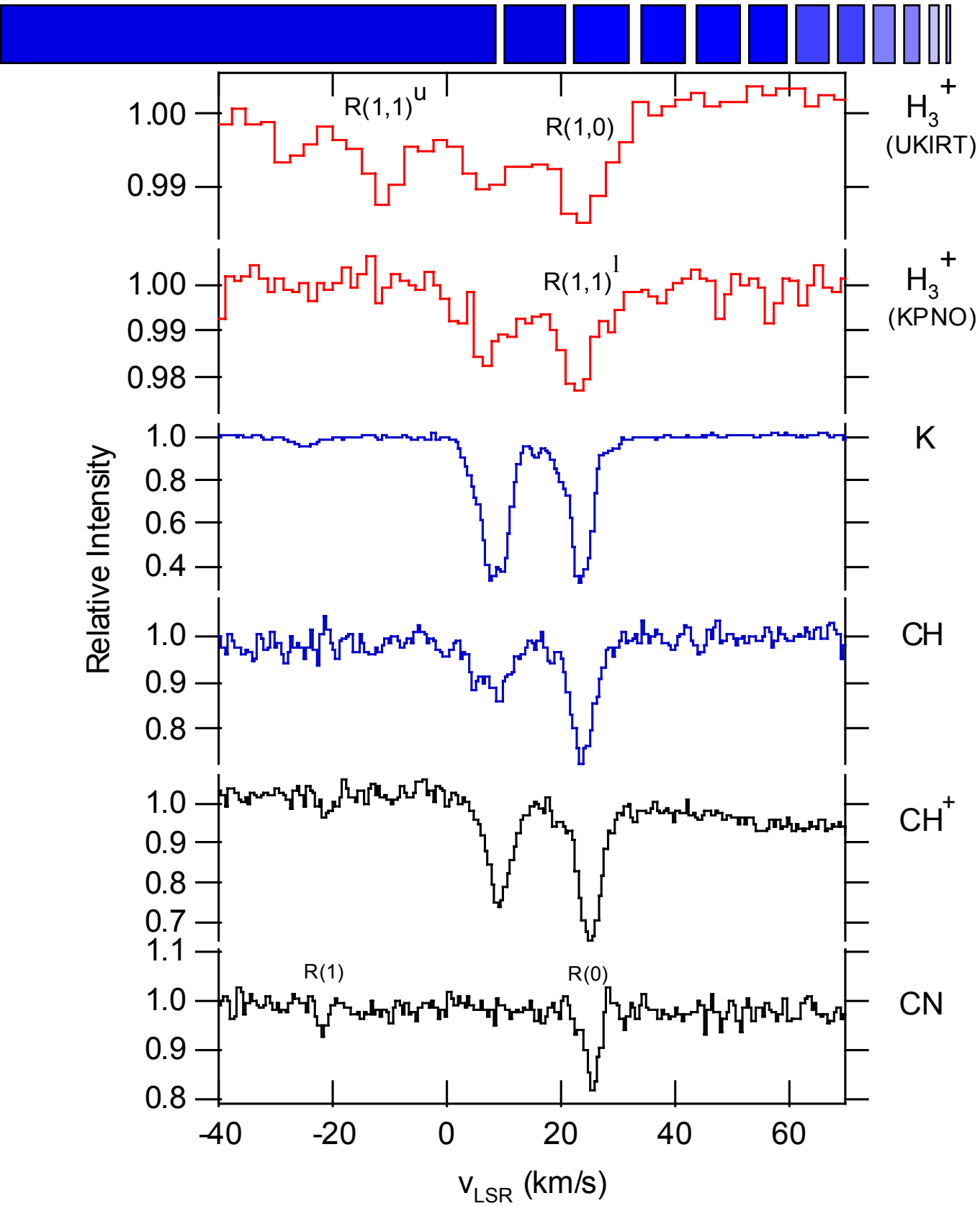


$N(H_3^+) \sim 3\times10^{14}$ cm^{-2}
2 velocity components!

Rules out any "special effect" in Cygnus OB2!

H_3^+ abundance is a general problem! (as DIBs, CH^+)

Visible Spectroscopy



Velocity agreement → H_3^+ coexists with other species

Chemical Model

$$[H_3^+] = \frac{\zeta}{k_e} \cdot \left(\frac{[e^-]}{[H_2]} \right)^{-1}$$

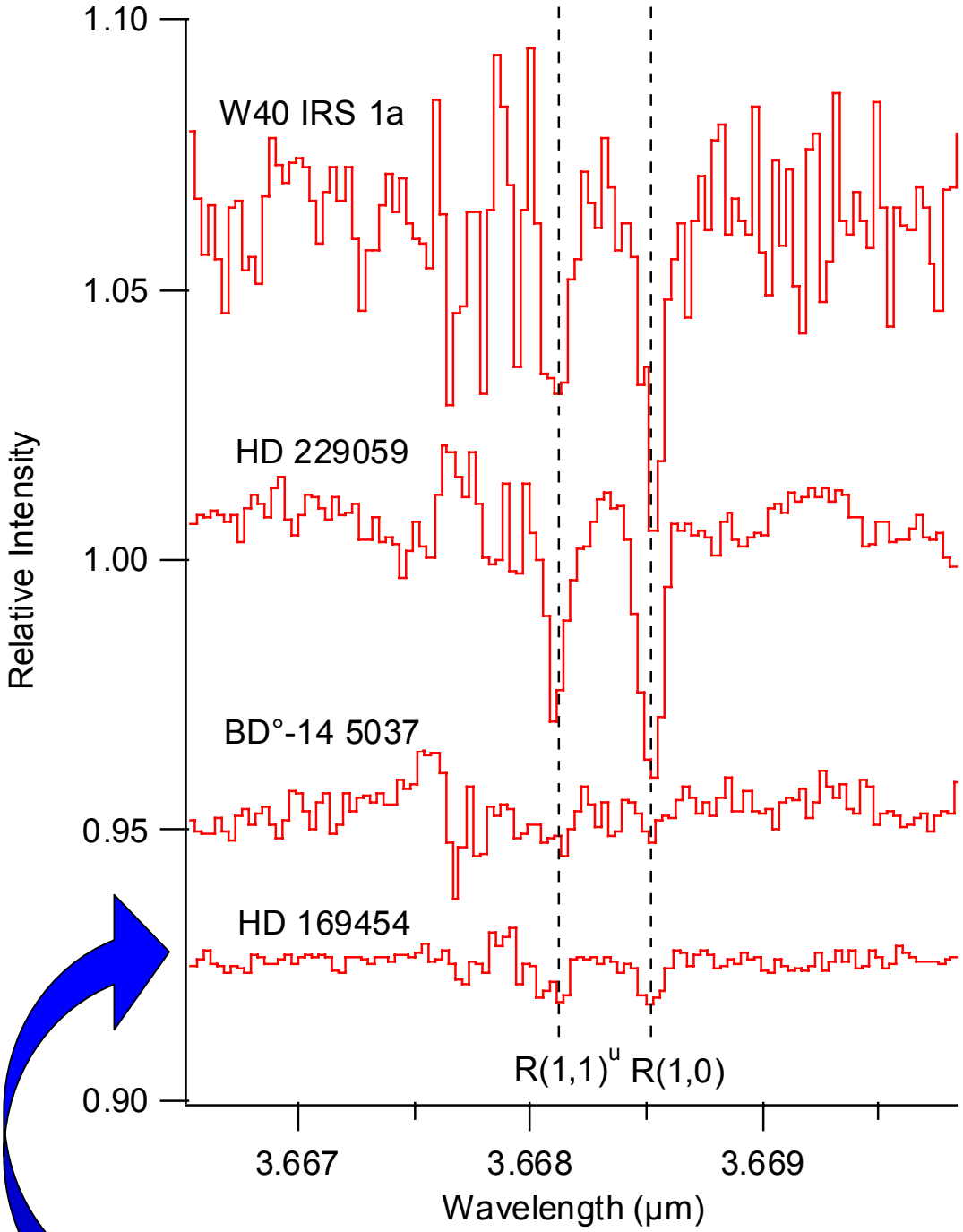
- Uncertain parameters:
  - ζ — cosmic ray ionization rate
    - could be higher in diffuse clouds?
  - k_e — electron recombination rate
    - could be lower than experiments indicate?
    - controversial field — ACS Chicago meeting
  - $[e^-]/[H_2]$ — electron fraction
    - could be lower in "translucent" clouds?

- Observational approach:
  - observe more sources!
  - UV spectroscopy of H & H_2, C & C^+

    with FUSE (Far Ultraviolet Spectroscopic Explorer) and HST (Hubble Space Telescope)

Recent Results

UKIRT: May 24-28, 2001



Possible FUSE target!

Conclusions

- H_3^+ observed in 10 diffuse cloud sources
- Upper limits in several others

- H_3^+ overabundance not peculiar to a particular region
- H_3^+ coexists with other diffuse cloud species

- Major problem with chemical model
  - $[e^-]$, k_e, or ζ is wrong by factor of 100

- Third enigma of diffuse cloud chemistry

For more information, visit http://h3plus.uchicago.edu