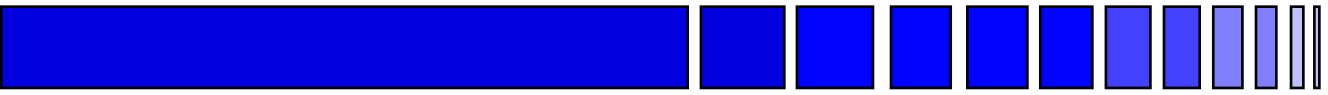


# Observation of $H_3^+$ in the Diffuse Interstellar Medium


Benjamin McCall and Takeshi Oka

University of Chicago

Kenneth H. Hinkle

National Optical Astronomy Observatories

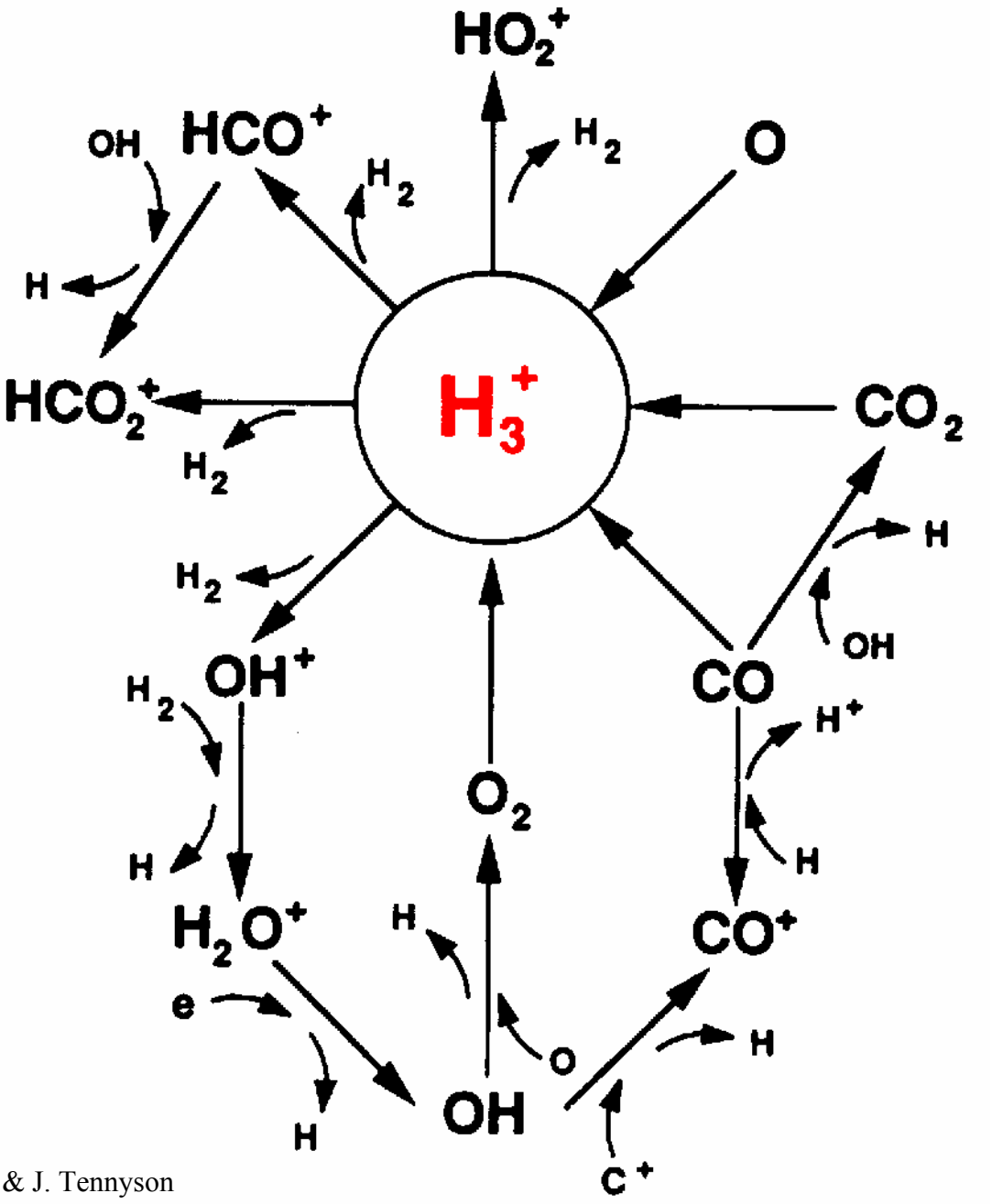
Thomas R. Geballe

Joint Astronomy Centre

# $H_3^+$ in Interstellar Space

Ben McCall

$$H_3^+ + X \rightarrow HX^+ + H_2$$




S. Miller & J. Tennyson
Chem. Soc. Rev. 22, 281 (1992)

# UKIRT & CGS4

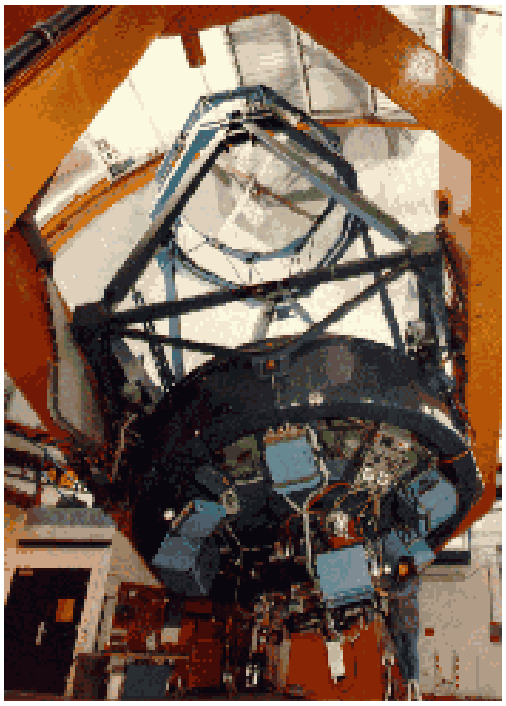
Ben McCall

**U**nited
**K**ingdom
**I**nfra-
**R**ed
**T**elescope

Diameter = 3.8m

**C**ooled
**G**rating
**S**pectrometer
**4**

Resolution ~ 0.1 $cm^{-1}$



# Kitt Peak & Phoenix

Ben McCall

Mayall Telescope at Kitt Peak National Observatory

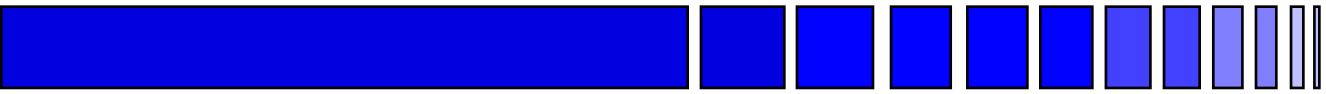
Diameter = 4.0m

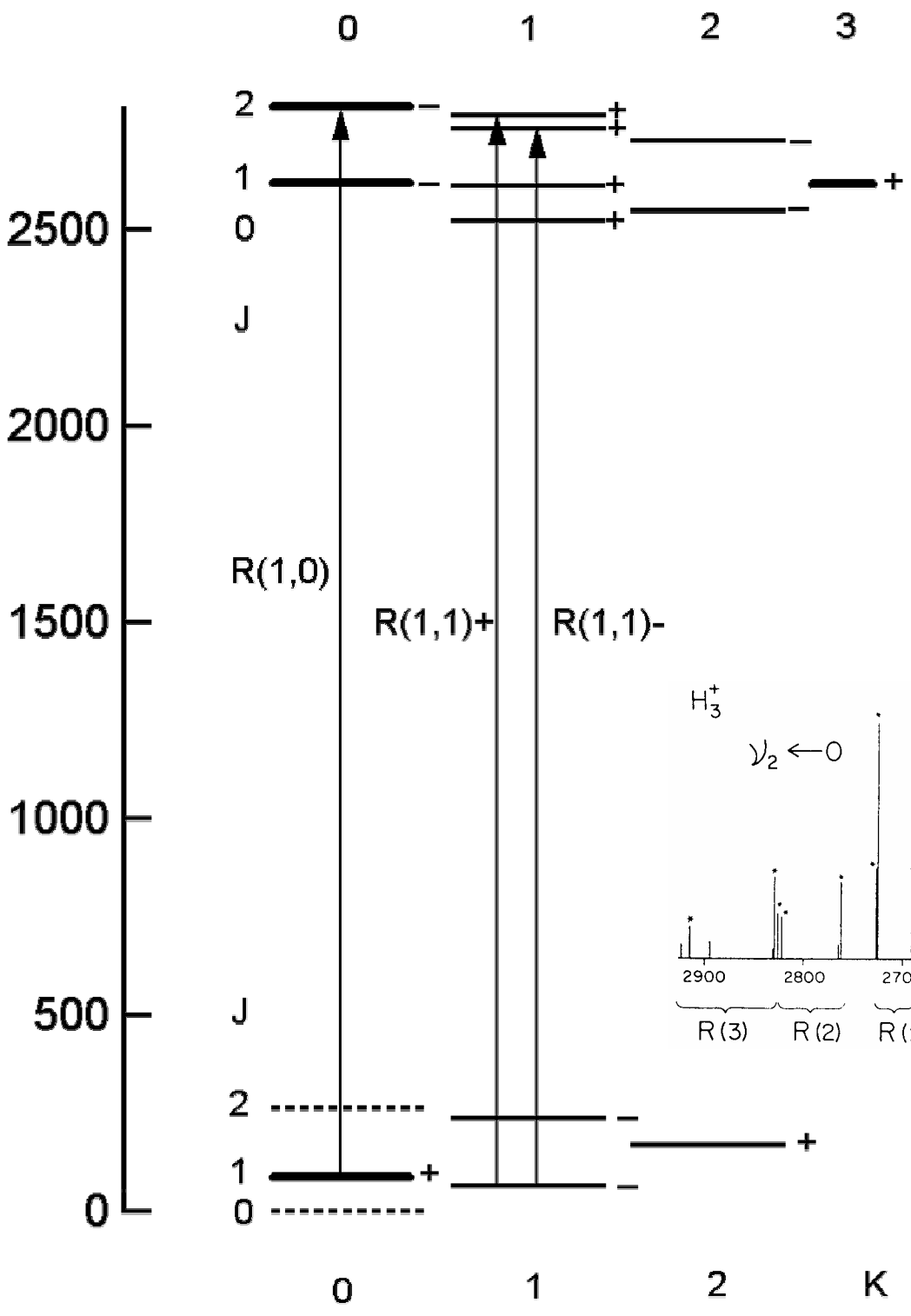
Phoenix Spectrometer

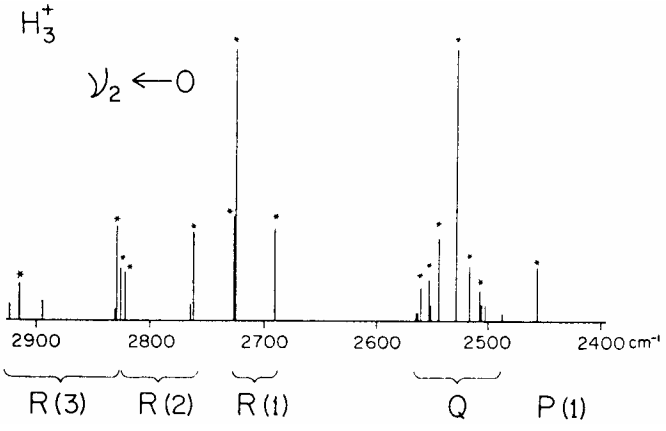
Resolution ~ 0.05 $cm^{-1}$

# $H_3^+$ Transitions Used

Ben McCall



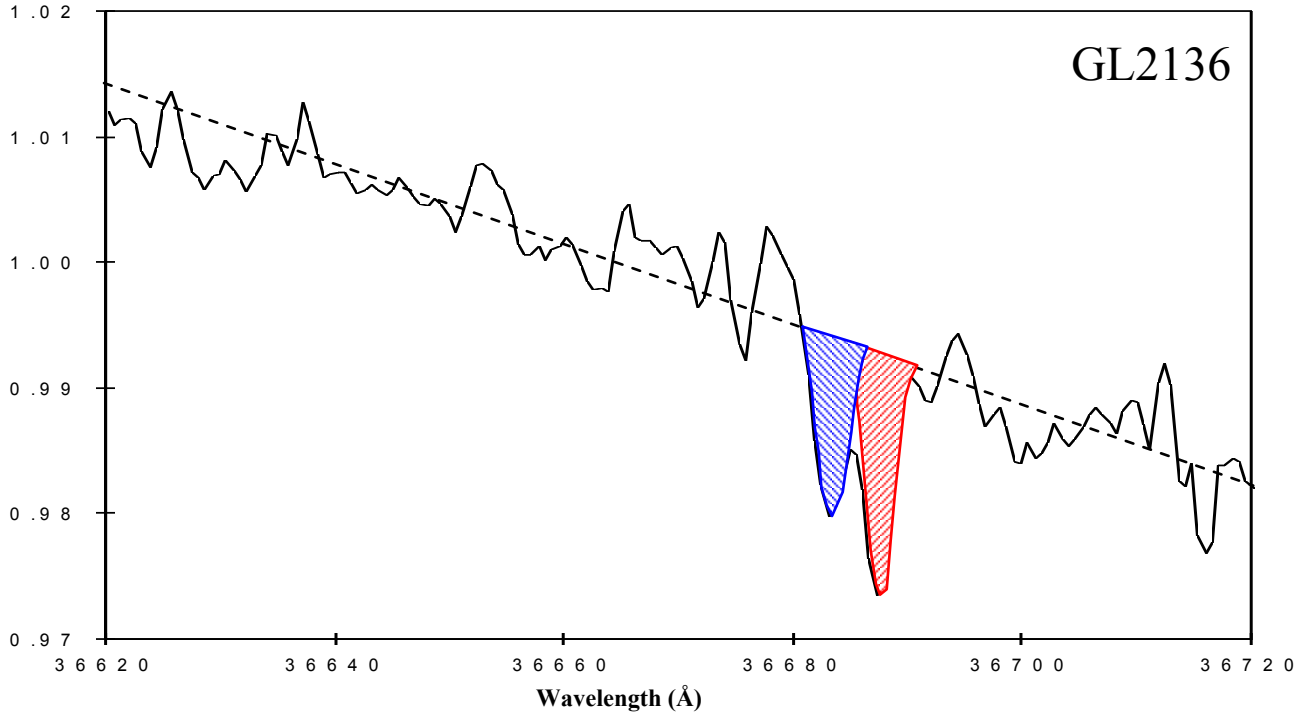



T. Oka,
PRL 45,531 (1980)

# First Detection: Dense Cloud

Ben McCall




T.R. Geballe & T. Oka,
Nature 384,334 (1996)

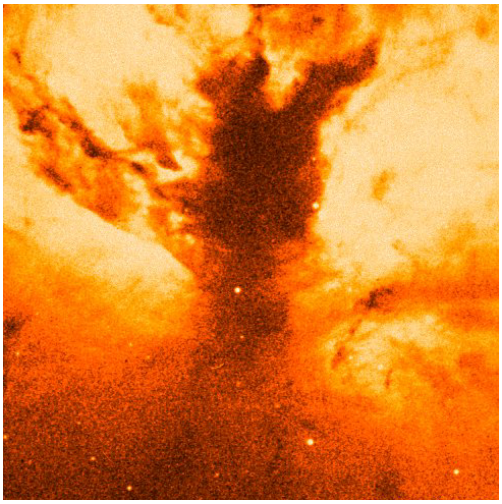
Peak Area $\Rightarrow$ Column Density (N)

$\hookrightarrow$ # molecules in 1 $cm^2$ cross section along line of sight

$\hookrightarrow$ $\int [H_3^+]\, dx$

# Dense Cloud Environment

Ben McCall



* "Dense"

  $\geq 10^3$ cm $^{-3}$

* Molecular

  $H \rightarrow H_2$

  $C \rightarrow CO$

  polyatomics ($H_2O$...$HC_{11}N$)

* Dust grains

  visible light scattered

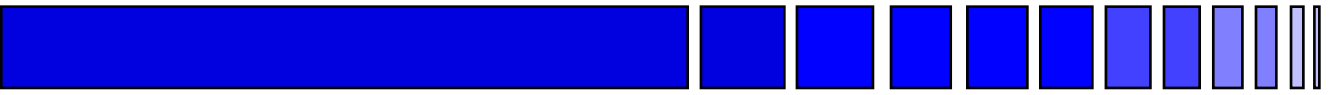
  infrared & radio only probes

* Star formation regions

  embedded protostars w/IR

# $H_3^+$ Chemistry

Ben McCall



Formation Mechanism:

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

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

rate-limiting

Destruction Mechanisms:

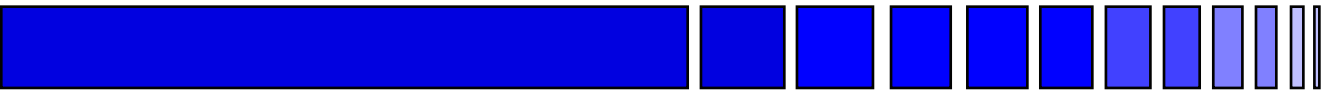
$$H_3^+ + CO \rightarrow HCO^+ + H_2$$

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

if molecules are present

# Dense Cloud Chemistry

Ben McCall



| Formation Rate (Cosmic Ray Ionization) | = | Destruction Rate (Reaction with CO) |
|---|---|---|
| $\zeta\,[H_2]$ | = | $k\,[H_3^+]\,[CO]$ |

$\sim 10^{-17}\ s^{-1}$

$$\frac{\zeta}{k}\,\frac{[H_2]}{[CO]} = [H_3^+] \longrightarrow \textbf{Constant!}\quad \mathbf{[H_3^+] \sim 3 \times 10^{-5}\ cm^{-3}}$$

$\sim 2 \times 10^{-9}\ cm^3\ s^{-1}$

$\sim 6.7 \times 10^3$

Path Length:

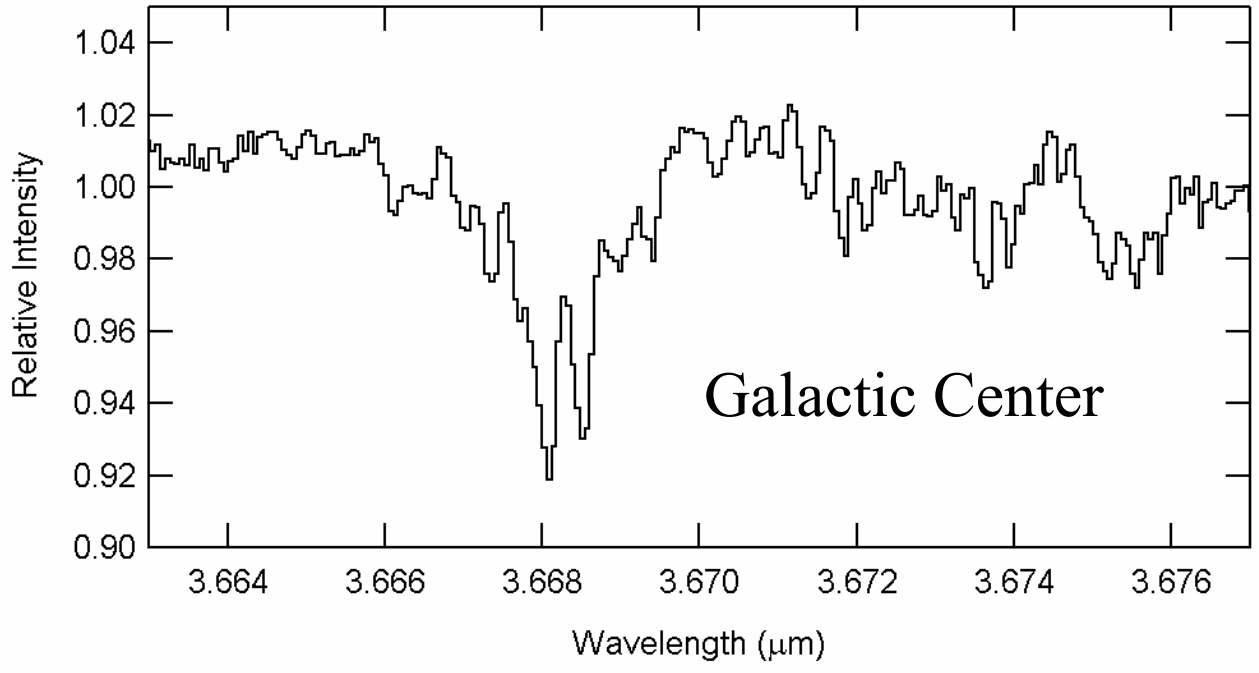
$$L = \frac{N(H_3^+)}{[H_3^+]} = \frac{3\times10^{14}\,cm^{-2}}{3\times10^{-5}\,cm^{-3}} = 10^{19}\,cm \approx 3pc$$

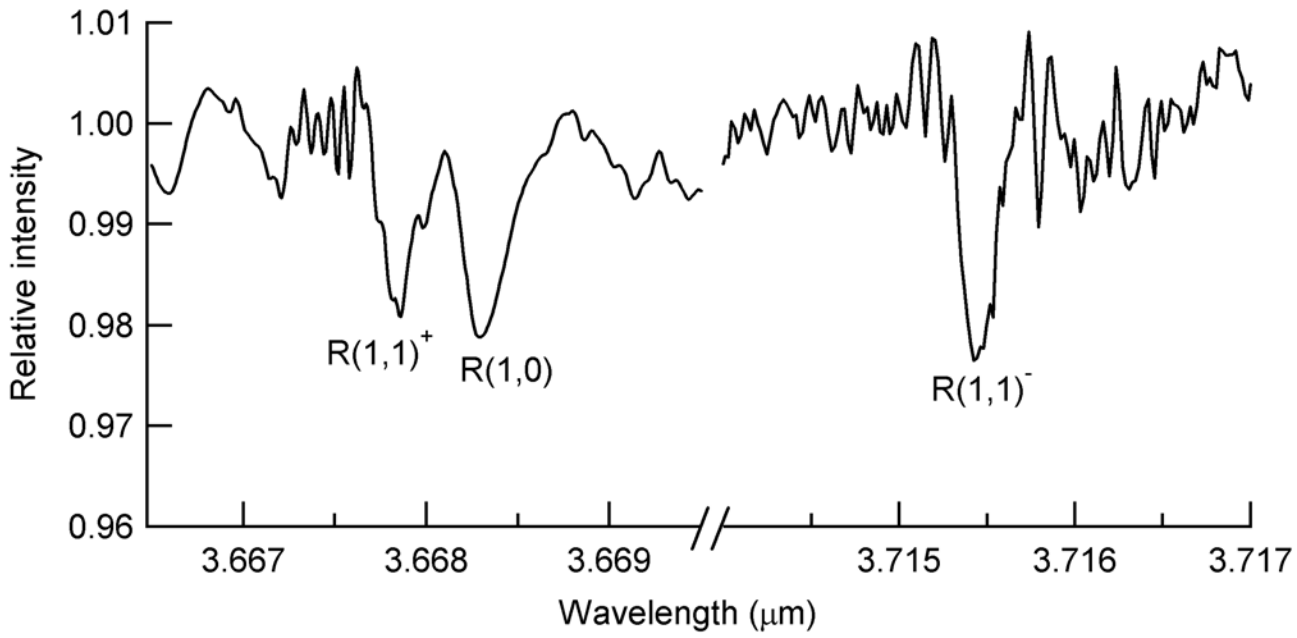
Density:

$$[H_2] = \frac{N(H_2)}{L} = \frac{10^{24}\,cm^{-2}}{10^{19}\,cm} = 10^{5}\,cm^{-3}$$

# $H_3^+$ in Diffuse Clouds!!

Ben McCall

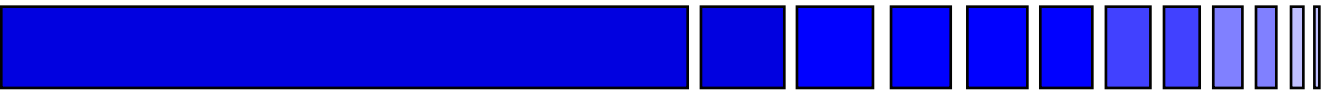



Cygnus OB2 Number 12

# Diffuse Cloud Environment

Ben McCall



* “Diffuse”

  $\leq 10^3$ cm $^{-3}$

* Few Molecules

  $[H] \sim [H_2]$

  $C \rightarrow C^+$

  very little CO

  “no” polyatomics

* Less dust

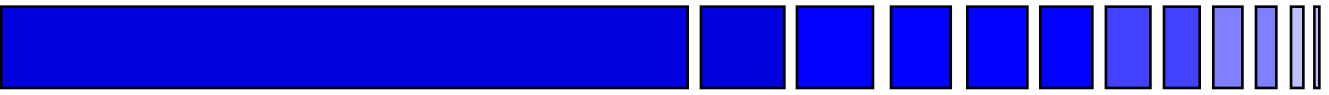
  visible & ultraviolet

  spectroscopy feasible

* Require background star

# Diffuse Cloud Chemistry

Ben McCall



| Formation Rate (Cosmic Ray Ionization) | = | Destruction Rate (Electron Recombination) |
|---|---|---|
| $\zeta\,[H_2]$ | = | $k_e\,[H_3^+]\,[e^-]$ |

$$[H_2] \equiv f\,[\Sigma H]$$

$$[e^-] = [C^+] \sim [\Sigma C]$$

$\sim 10^{-17}\ s^{-1}$ $\sim 0.5$

$$\frac{\zeta f}{k_e}\,\frac{[\Sigma H]}{[\Sigma C]} = [H_3^+]$$

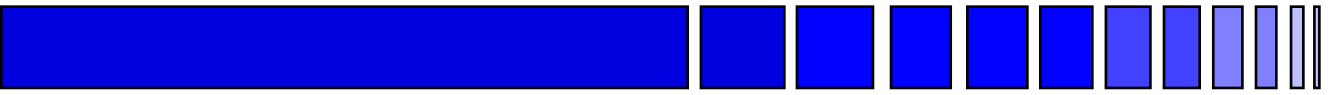
$\sim 10^{-7}\ cm^3\ s^{-1}$ $\sim 10^4$

Constant!

**$[H_3^+] \sim 5 \times 10^{-7}\ cm^{-3}$**

# Results for Cygnus OB2#12

Ben McCall



McCall, Geballe, Hinkle, & Oka
Science 279, 1910 (1998)

$$N(H_3^+) = 3.8 \times 10^{14}\,\mathrm{cm}^{-2}$$

Path Length:

$$L = \frac{N(H_3^+)}{[H_3^+]} = \frac{3.8 \times 10^{14}\,\mathrm{cm}^{-2}}{5 \times 10^{-7}\,\mathrm{cm}^{-3}} = 10^{21}\,\mathrm{cm} \approx 300\mathrm{pc}$$

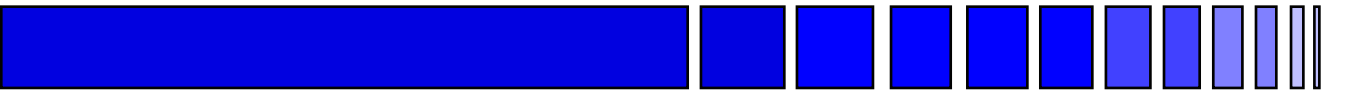
Density:

$$[H_2] = \frac{N(H_2)}{L} = \frac{2 \times 10^{22}\,\mathrm{cm}^{-2}}{10^{21}\,\mathrm{cm}} = 20\,\mathrm{cm}^{-3}$$

$\therefore$ long path with very low density!

# A Long Path Length!

Ben McCall



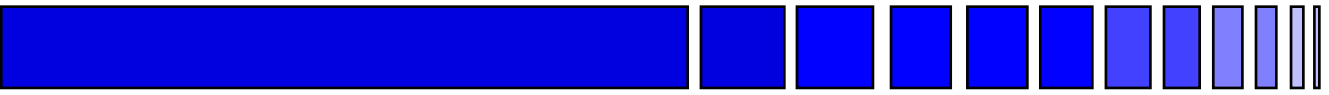
Problem: 300 pc is 1/5 of distance to star!
⇒ expect $H_3^+$ "everywhere"
⇒ barely consistent with linewidth

Solutions?: ⇒ $\zeta$ may be too low?
⇒ $k_e$ may be too high?
⇒ maybe it's true??

Upcoming Observations: ⇒ higher spectral resolution
(constrain linewidth)
⇒ nearby objects
(extent of $H_3^+$)
⇒ other diffuse cloud sources
(maybe this is a fluke?)

# Conclusions

Ben McCall



* $H_3^+$ is a diagnostic probe of dense clouds
  - $\Rightarrow$ path lengths ~ few pc
  - $\Rightarrow$ densities ~ $10^5$ $cm^{-3}$
  - $\Rightarrow$ temperature ~ 30 K

* $H_3^+$ now being extended to diffuse clouds
  - $\Rightarrow$ path length ~ 300 pc!
  - $\Rightarrow$ density ~ 20 $cm^{-3}$!
  - $\Rightarrow$ temperature ~ 30 K

* Path length “discrepancy” to be resolved...

# Detection Scheme

Ben McCall