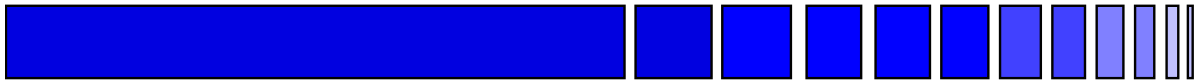


Observations of Interstellar H_3^+

Benjamin McCall
Oka Ion Factory
University of Chicago

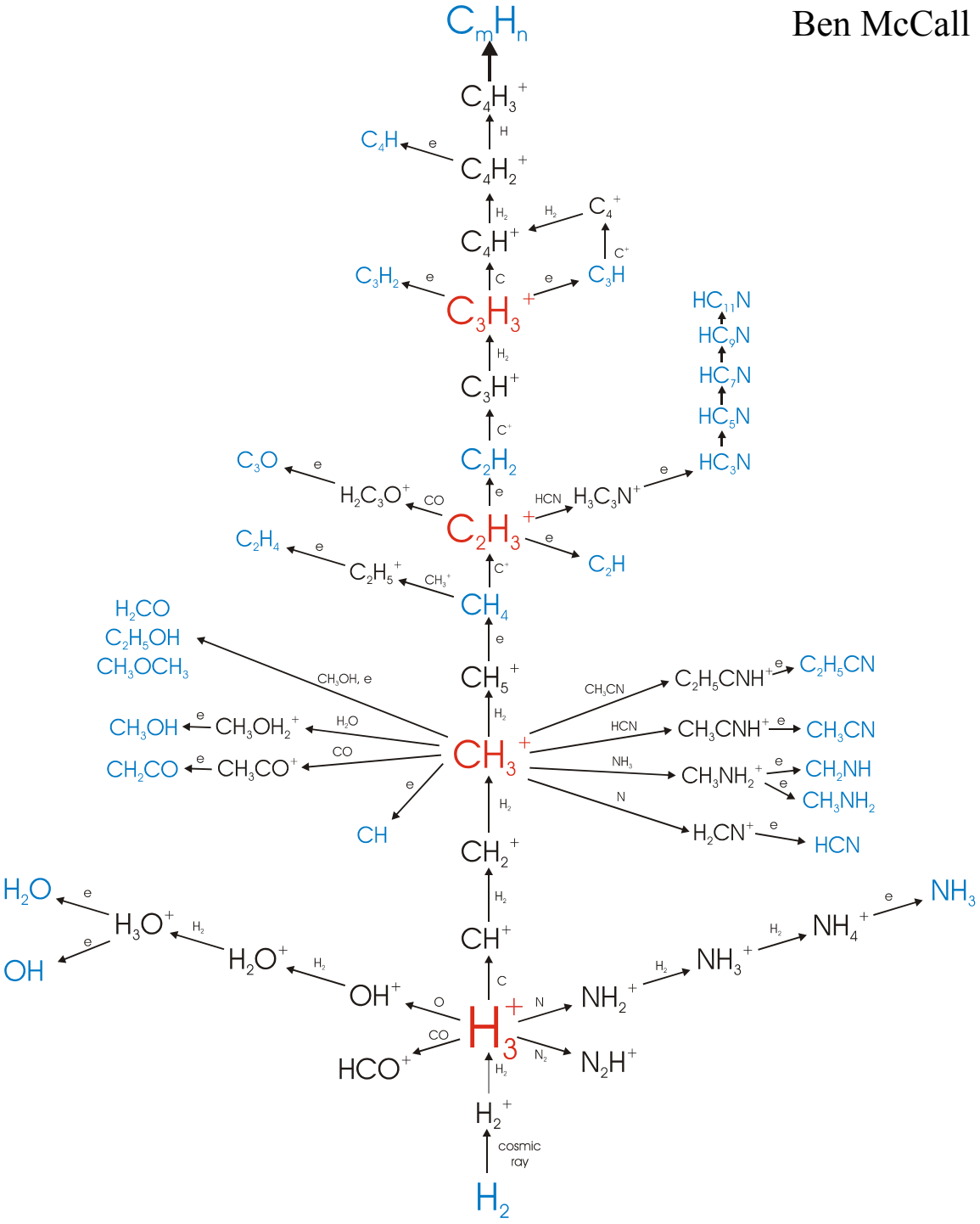
Thomas Geballe
Gemini Observatory (HI)

Kenneth Hinkle
National Optical Astronomy Observatories
Kitt Peak National Observatory (AZ)

Takeshi Oka
Oka Ion Factory
University of Chicago

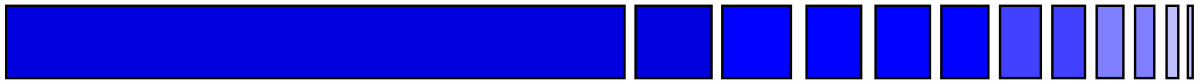
Importance of H_3^+

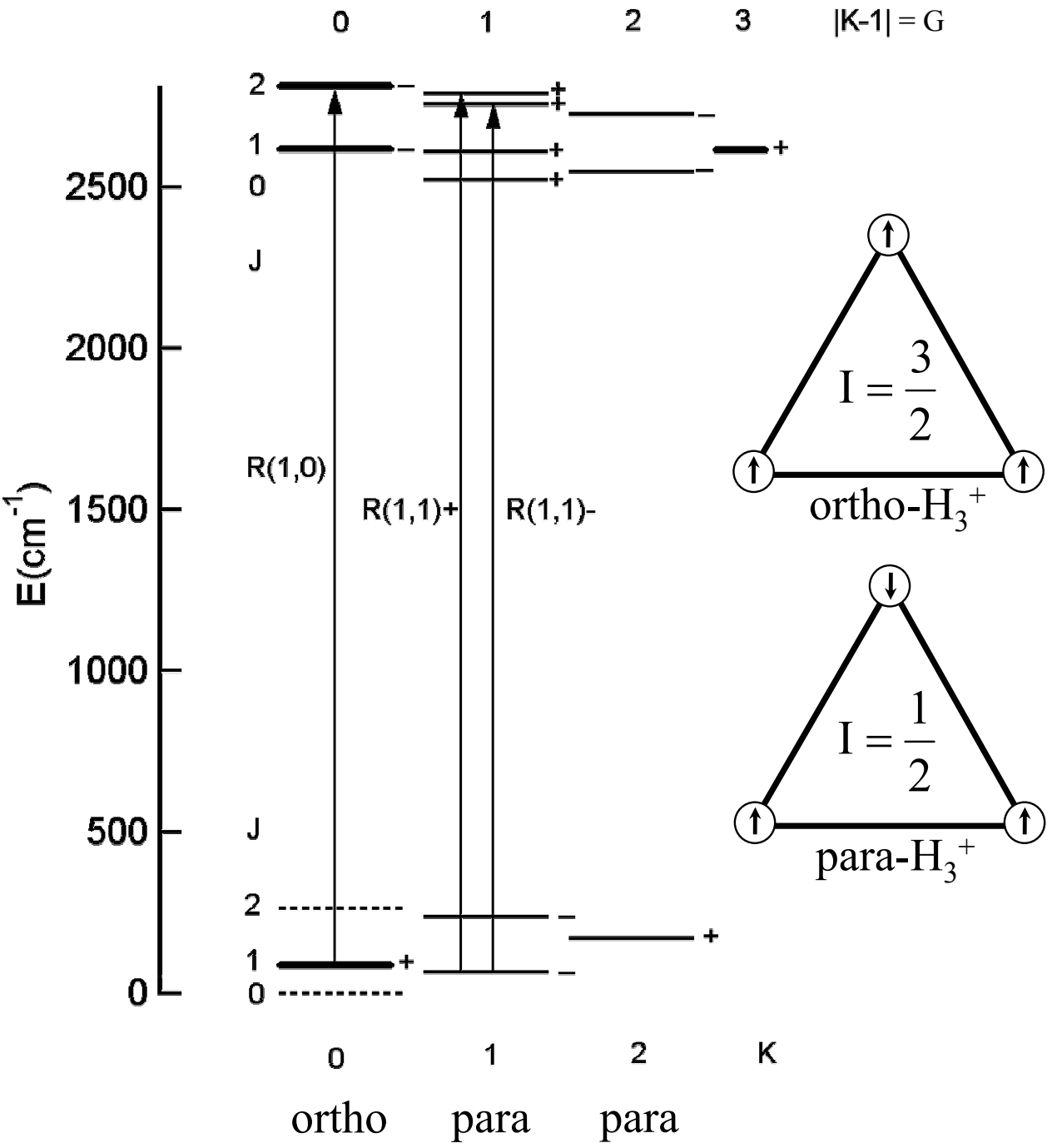
Ben McCall



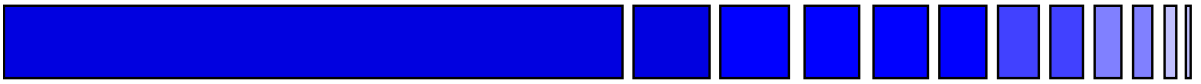
H_3^+ Transitions

Ben McCall





H_3^+ – Interstellar Probe



Ben McCall

Measurements of H_3^+ provide:

→ path length of cloud

→ number density of H_2

→ kinetic temperature

Path Length:

$$L = \frac{N(H_3^+)}{n(H_3^+)}$$

Number Density:

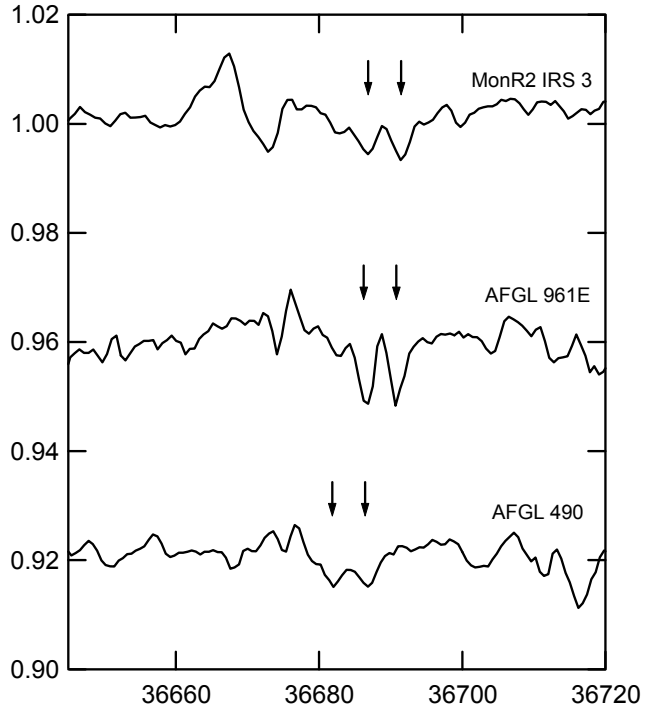
$$n(H_2) = \frac{N(H_2)}{L} = \frac{N(CO)}{L} \times \left(\frac{H_2}{CO} \right)$$

Temperature:

$$\frac{N_{ortho}(H_3^+)}{N_{para}(H_3^+)} = \frac{g_{ortho}}{g_{para}} e^{-\frac{\Delta E}{kT}}$$

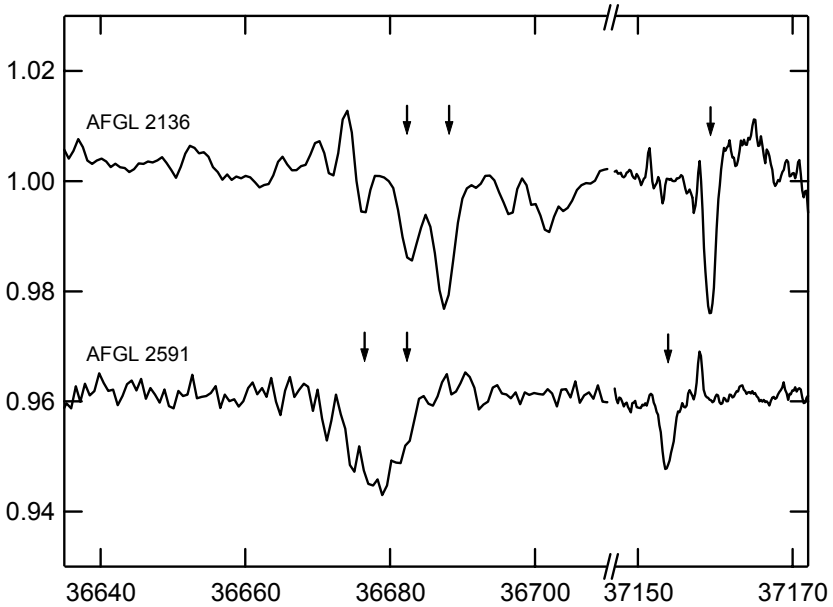
Dense Cloud Detections

Ben McCall



H_3^+ detections toward Mon R2 IRS 3, AFGL 961E, and AFGL 490 from UKIRT's CGS4.

H_3^+ detections toward AFGL 2136 and AFGL 2591 from UKIRT (left doublet) and Phoenix (right singlet).



Dense Cloud Results

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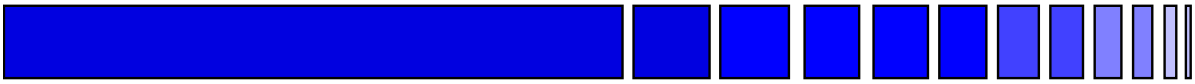


Object	L(pc)	$\langle n(H_2) \rangle$	T(K)
AFGL 2136	1.3	6×10^4	47
W33A	1.7	5×10^4	36
MonR2/3	0.5	5×10^4	31
AFGL 961E	0.6	2×10^4	25
AFGL 490	0.4	6×10^4	26
AFGL 2591	0.7	6×10^4	38

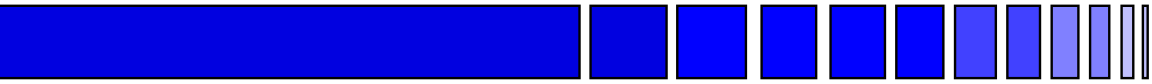
H_3^+ Column Densities:

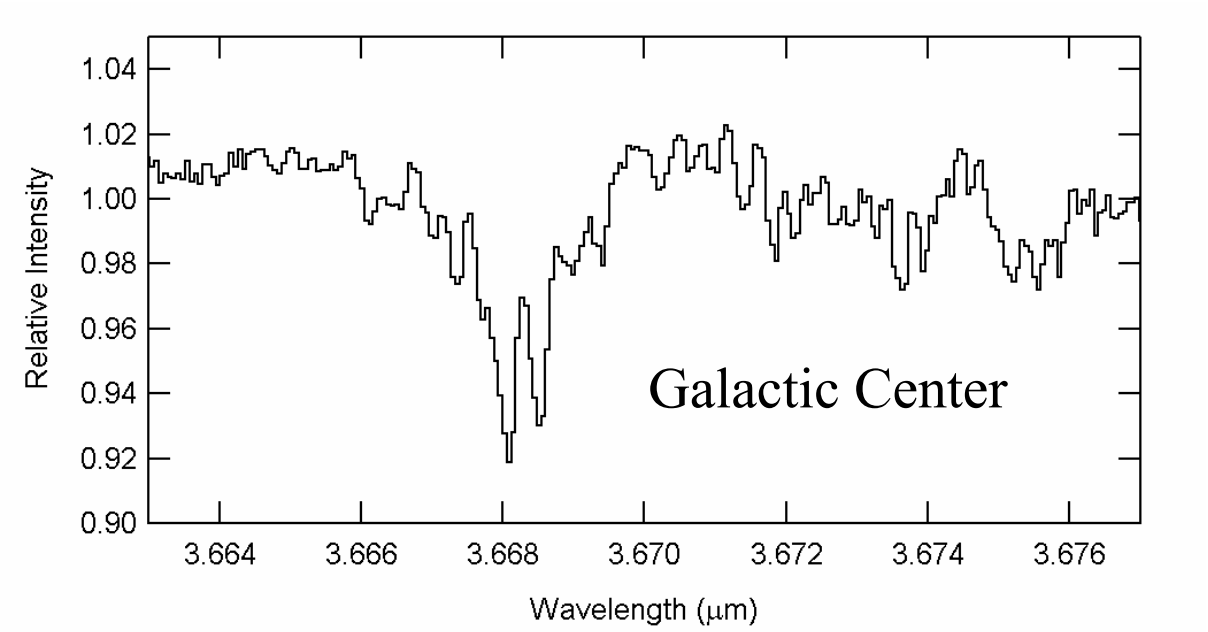
Detections:		Upper Limits:	
AFGL 2136	3.8×10^{14} cm^{-2}	Orion BN	$< 2.5 \times 10^{14}$ cm^{-2}
W33A	5.2×10^{14} cm^{-2}	NGC 2024/2	$< 1.4 \times 10^{14}$ cm^{-2}
MonR2/3	1.4×10^{14} cm^{-2}	MonR2/2	$< 2.0 \times 10^{14}$ cm^{-2}
AFGL 961E	1.7×10^{14} cm^{-2}	AFGL 989	$< 1.2 \times 10^{14}$ cm^{-2}
AFGL 490	1.1×10^{14} cm^{-2}	Elias 29	$< 2.4 \times 10^{14}$ cm^{-2}
AFGL 2591	2.2×10^{14} cm^{-2}	M17/1	$< 11 \times 10^{14}$ cm^{-2}
		W3/5	$< 1.1 \times 10^{14}$ cm^{-2}
		S140/1	$< 0.5 \times 10^{14}$ cm^{-2}
		LkHα 101	$< 1.4 \times 10^{14}$ cm^{-2}

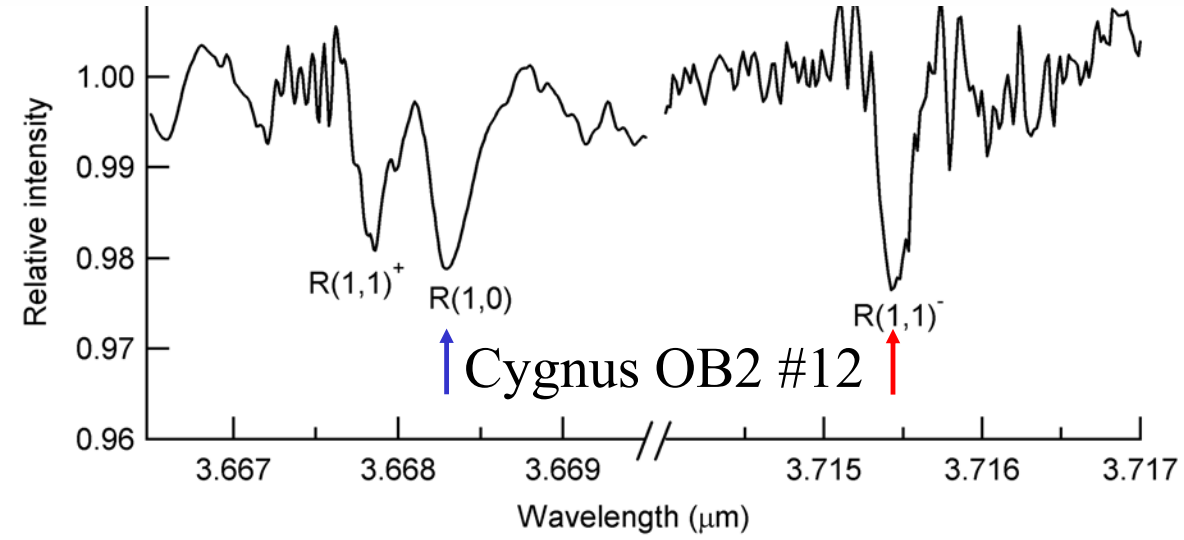
McCall, Geballe, Hinkle, & Oka
ApJ, submitted

H_3^+ in Diffuse Clouds!!

Ben McCall







$N_{para} = 2.4(3) \times 10^{14}$ cm^{-2}

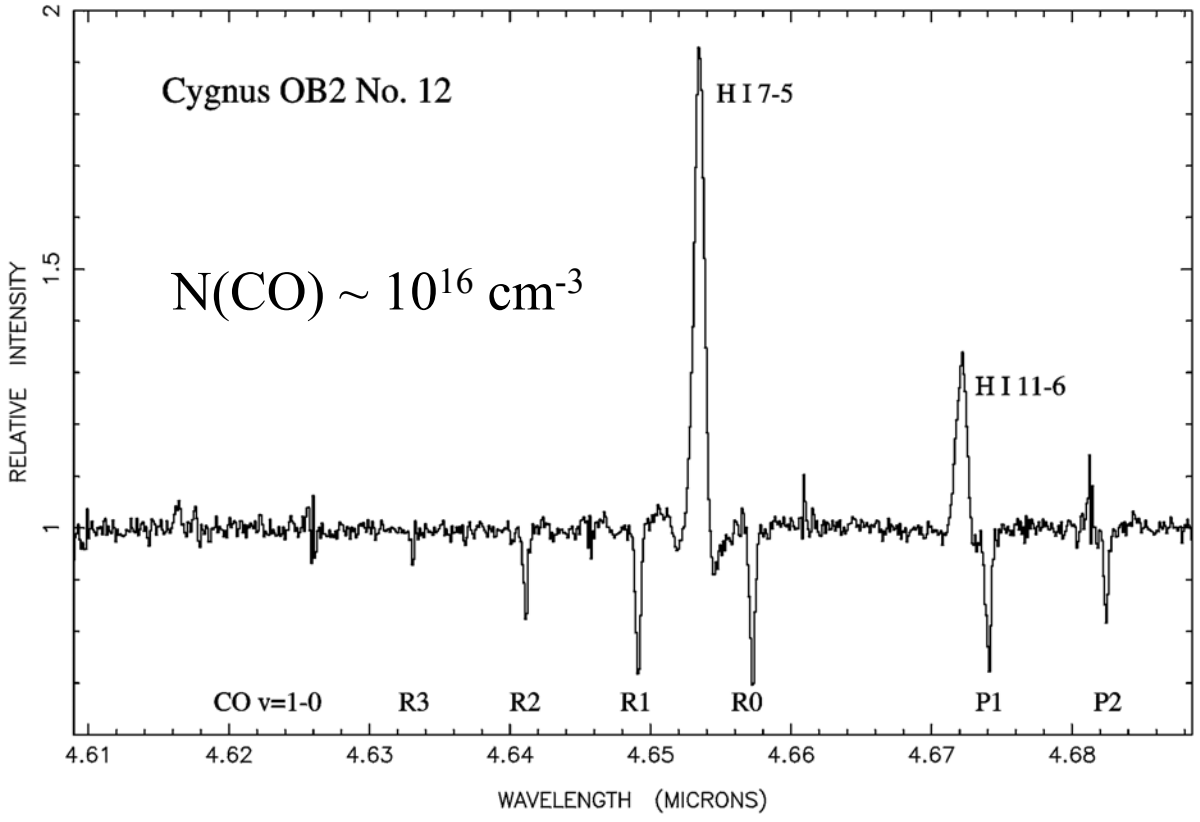
$N_{ortho} = 1.4(2) \times 10^{14}$ cm^{-2}

Similar column density to dense clouds!!

Is Cygnus Diffuse?

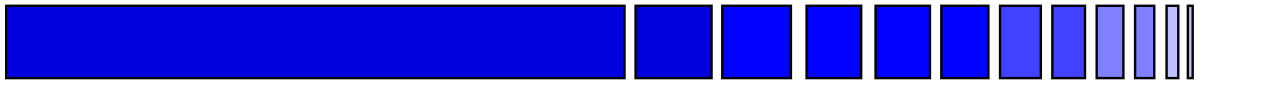
Ben McCall

- ★ Absence of 3.08 μm ice feature
- ★ Presence of 3.4 μm band
- ★ N(CO)/N(C) ~ 0.01



Results for Cygnus OB2#12

Ben McCall



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

$$\mathrm{N}(\mathrm{H}_3^+) = 3.8\times10^{14}\,\mathrm{cm}^{-2}$$

Path Length:

$$L = \frac{N(\mathrm{H}_3^+)}{n(\mathrm{H}_3^+)} = \frac{3.8\times10^{14}\,\mathrm{cm}^{-2}}{5\times10^{-7}\,\mathrm{cm}^{-3}} = 10^{21}\,\mathrm{cm} \approx 300\mathrm{pc}$$

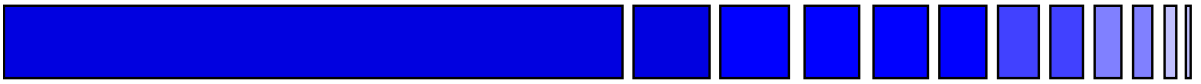
Density:

$$n(\mathrm{H}_2) = \frac{N(\mathrm{H}_2)}{L} = \frac{2\times10^{22}\,\mathrm{cm}^{-2}}{10^{21}\,\mathrm{cm}} = 20\,\mathrm{cm}^{-3}$$

$\therefore$ long path with very low density!

Diffuse Cloud Parameters

Ben McCall



For Cygnus OB2 No. 12, the observed column density is $N(H_3^+) = 3.8 \times 10^{14}$ cm^{-2} and the predicted number density is $n(H_3^+) \sim 4 \times 10^{-7}$ cm^{-3}.

Path Length:

$$L \sim \frac{N(H_3^+)}{n(H_3^+)} \sim \frac{3.8\times10^{14}\,\mathrm{cm}^{-2}}{4\times10^{-7}\,\mathrm{cm}^{-3}} \sim 1\times10^{21}\,\mathrm{cm} \sim 300\,\mathrm{pc}!$$

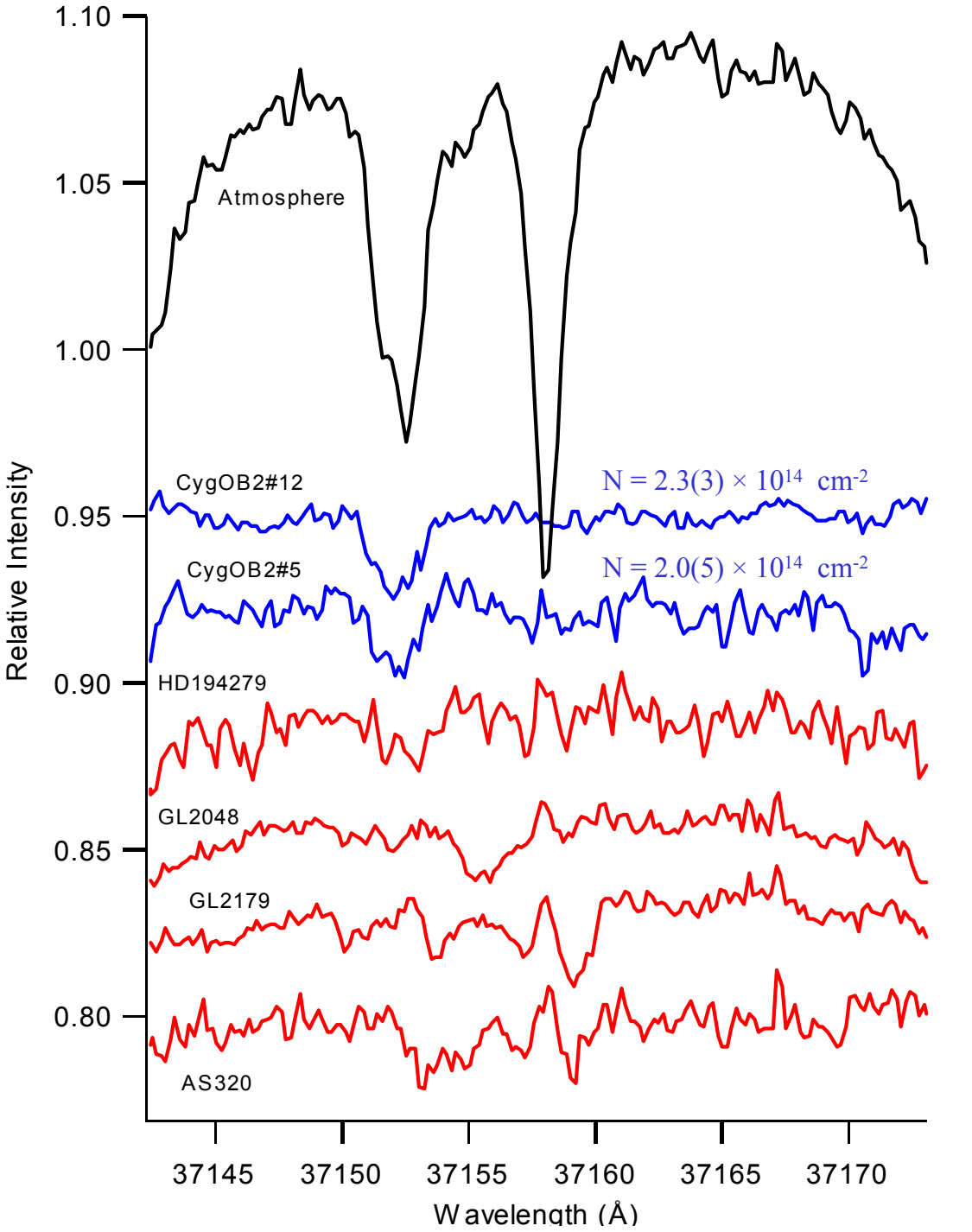
Density:

$$[H_2] \sim \frac{N(H_2)}{L} \sim \frac{2\times10^{22}\,\mathrm{cm}^{-2}}{10^{21}\,\mathrm{cm}} \sim 20\,\mathrm{cm}^{-3}$$

Problem:	Extremely long path length!! ⇒ expect H_3^+ "everywhere" ⇒ barely consistent with linewidth
Solutions?:	⇒ ζ may be much higher? ⇒ k_e may be lower? ⇒ maybe it's true??
Upcoming Observations:	⇒ higher spectral resolution (constrain linewidth) ⇒ nearby objects (spatial extent of H_3^+) ⇒ other diffuse cloud sources (maybe this is a fluke?)

Other Diffuse Clouds

Ben McCall



Summary

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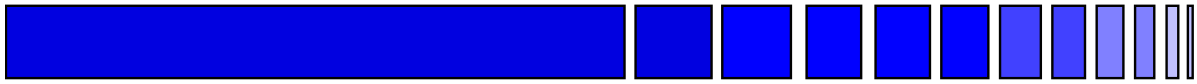

★ H_3^+ prevalent in dense clouds

- ★ detections towards: GL 2136, W33A, GL 961E, MonR2 IRS 3, GL 2591
- ★ yield reasonable estimates of L, n(H_2), T

★ H_3^+ an enigma in diffuse clouds!

- ★ detections towards: Cyg OB2 #12, #5
- ★ yield extremely long path length
- ★ need more observations!!