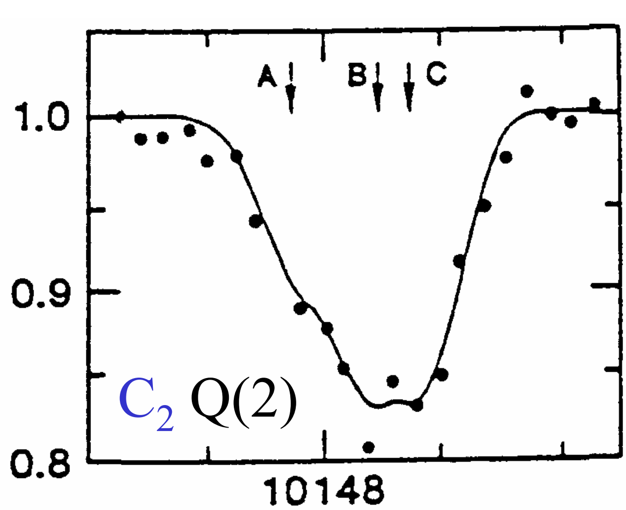
Molecules in Diffuse ISM

Ben McCall

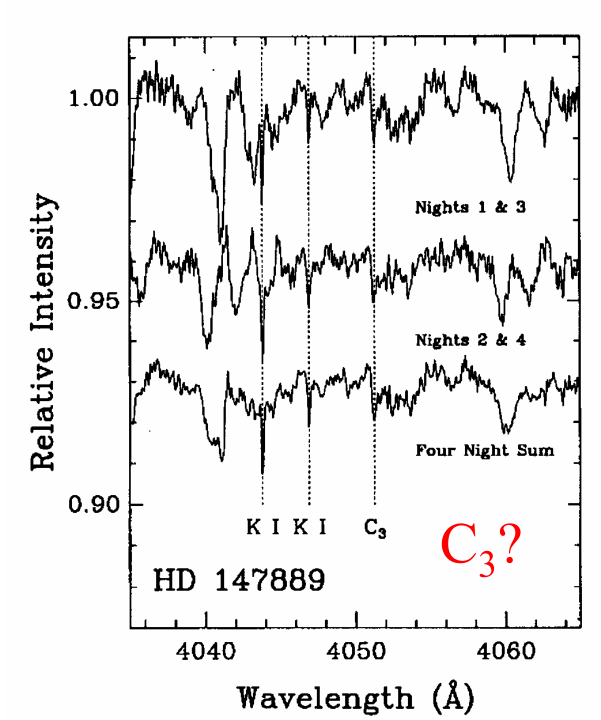
Diffuse clouds are not chemical warehouses like dense clouds. Some diatomic molecules -- H_2, OH, NH, CH, CH^+, CN, CO, and C_2 -- have been observed in many diffuse clouds. The triatomic molecule C_3 was tentatively detected toward the "translucent" cloud HD 147889 (see below).

A much simpler chemistry is expected in diffuse clouds because they are not completely opaque to ultraviolet starlight In dense clouds, nearly 100% of C is in the form of CO -- in diffuse clouds, this fraction is closer to 1%. At most about half of H is in the form of H_2.



Cygnus OB2 Number 12

Gredel & Münch, A&A 285, 640 (1994)



Haffner & Meyer, ApJ 453, 450 (1995)

H_3^+ Chemistry

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Formation Mechanism:

The formation for H_3^+ in diffuse clouds is the same as for dense clouds

Step 1: Cosmic-ray ionization of H_2:

$$H_2 \xrightarrow[\text{Rate} = \zeta \cdot n(H_2)]{\text{cosmic ray}} H_2^+ + e^-$$

Step 2: Ion-Molecule reaction with H_2:

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

[occurs on every collision]

Destruction Mechanism:

Since molecules (e.g. CO) are less abundant than in dense cloud, the dominant destruction path of H_3^+ is electron recombination.

$$H_3^+ + e^- \rightarrow H + H + H \quad (75\%)$$

$$\rightarrow H + H_2 \quad (25\%)$$

$$\text{Rate} = k_e \cdot n(H_3^+) \cdot n(e^-)$$

$$k_e \sim 2 \times 10^{-7} \text{ cm}^3 \text{ s}^{-1}$$

Steady State $n(H_3^+)$

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Assuming steady-state, the H_3^+ number density can be derived by equating the rates of formation and destruction.

Formation Rate (cosmic rays): $\zeta\ n(H_2)$

Destruction Rate (recombination): $k_e\ n(e^-)\ n(H_3^+)$

Let $n(H_2) \equiv (f/2) \cdot n(\Sigma H)$, where f is the fraction of H in molecular form. Assume electrons come from ionization of C, and all C is ionized, so $n(e^-) = n(C^+) \sim n(\Sigma C)$.

$$n(H_3^+) = \frac{f\zeta}{2k_e} \cdot \frac{n(\Sigma H)}{n(\Sigma C)} = \text{constant!}$$

<u>Adopted values:</u>

$\zeta \sim 10^{-17}\ s^{-1}$ (derived from observations)

$f \sim ½$ (inferred from models)

$k_e \sim 2 \times 10^{-7}\ cm^3\ s^{-1}$ (measured in lab)

$n(\Sigma H)/n(\Sigma C) \sim 10^4$ (cosmic abundance)

$n(H_3^+)$ is constant $\sim 10^{-7}\ cm^{-3}$ which is independent of the density of the cloud!

Galactic Center

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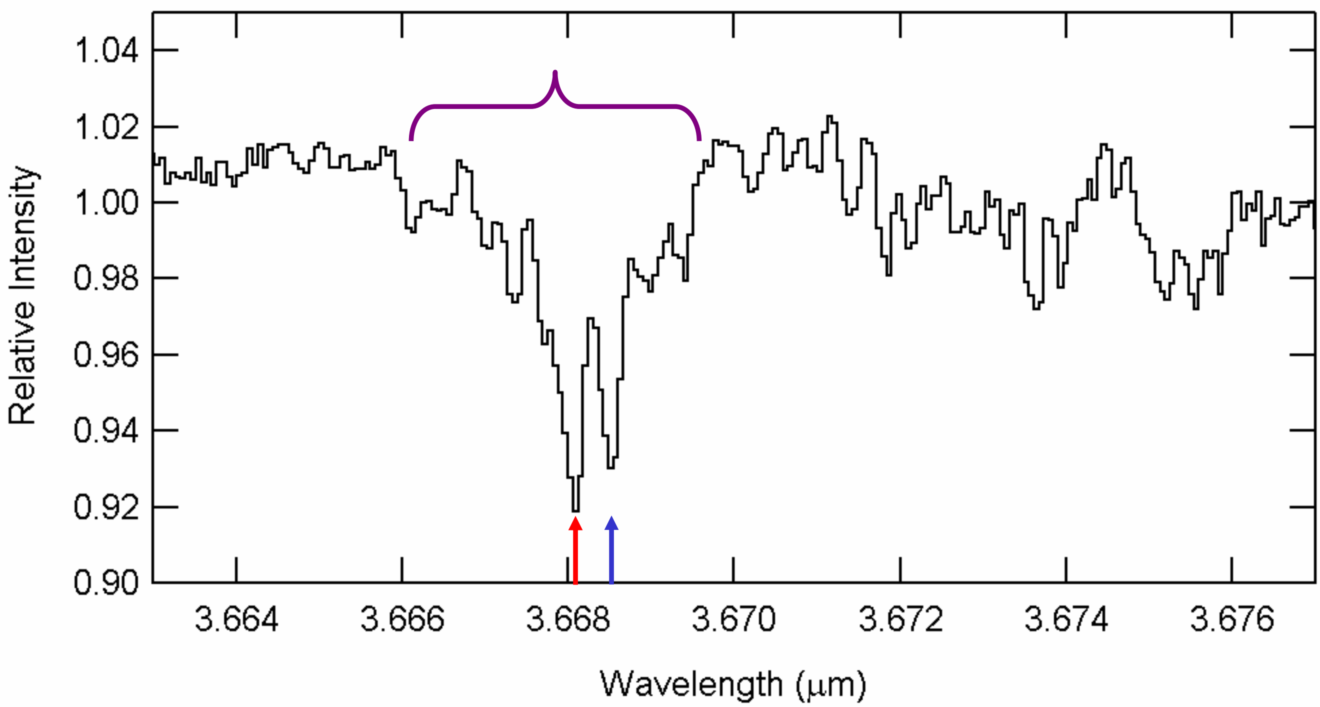

Much to our surprise, the Galactic Center sources IRS 3 (shown above) and GCS 3-2 show deep H_3^+ absorptions. In the case of IRS 3, both a narrow and a broad component was observed. Since the line of sight to the Galactic Center crosses both dense and diffuse clouds, it is difficult to separate the two contributions to the H_3^+ absorption.

$$N_{para} = 5.1(1.7) \times 10^{14}\ cm^{-2}$$
$$N_{ortho} = 2.4(1.1) \times 10^{14}\ cm^{-2}$$
$$N_{broad} = 17.5(3.9) \times 10^{14}\ cm^{-2}$$

Cygnus OB2 Number 12

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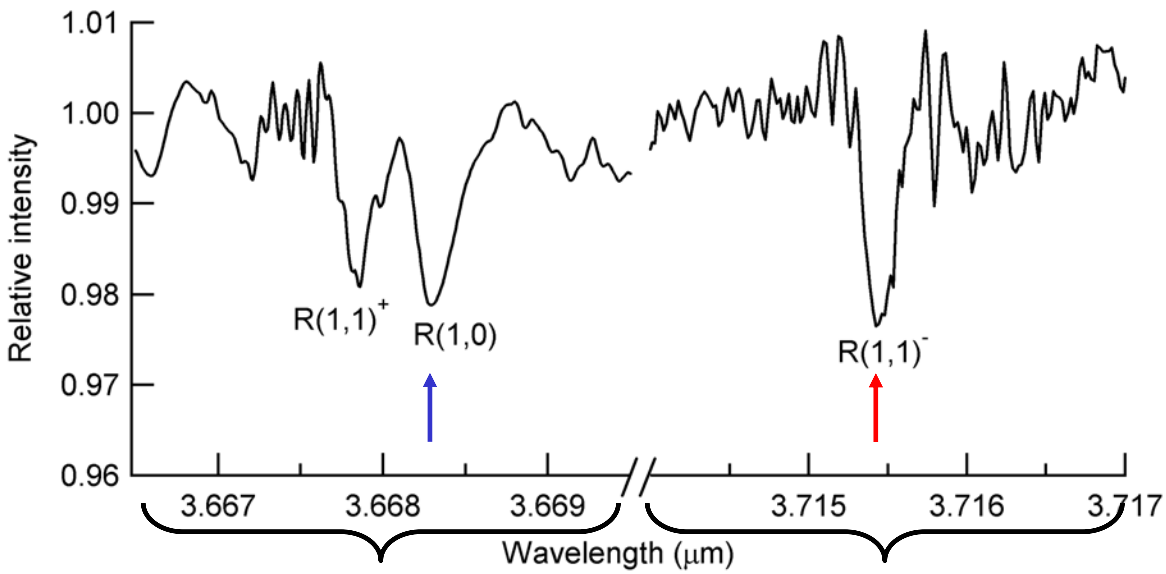
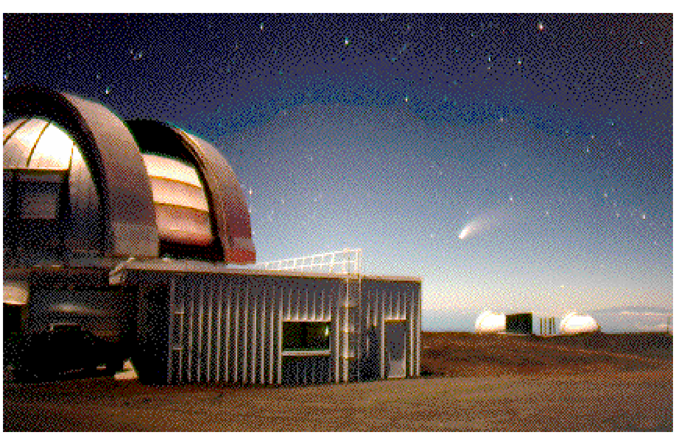
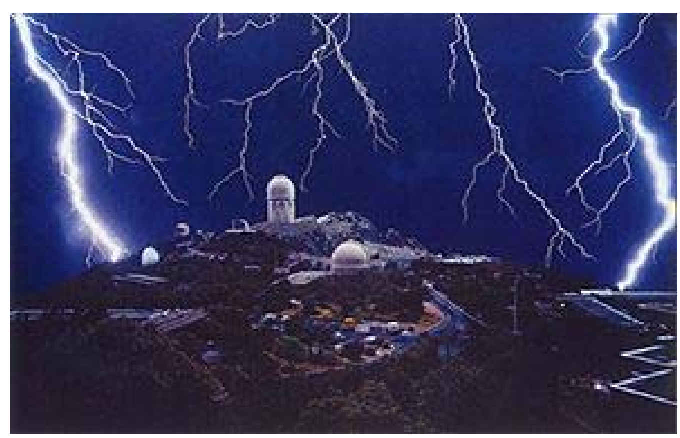


observed at UKIRT



observed at Kitt Peak



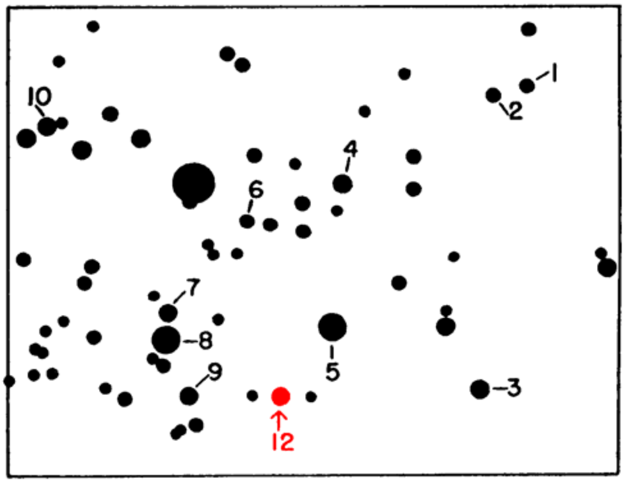
$N_{para} = 2.4(3) \times 10^{14}$ cm^{-2}

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

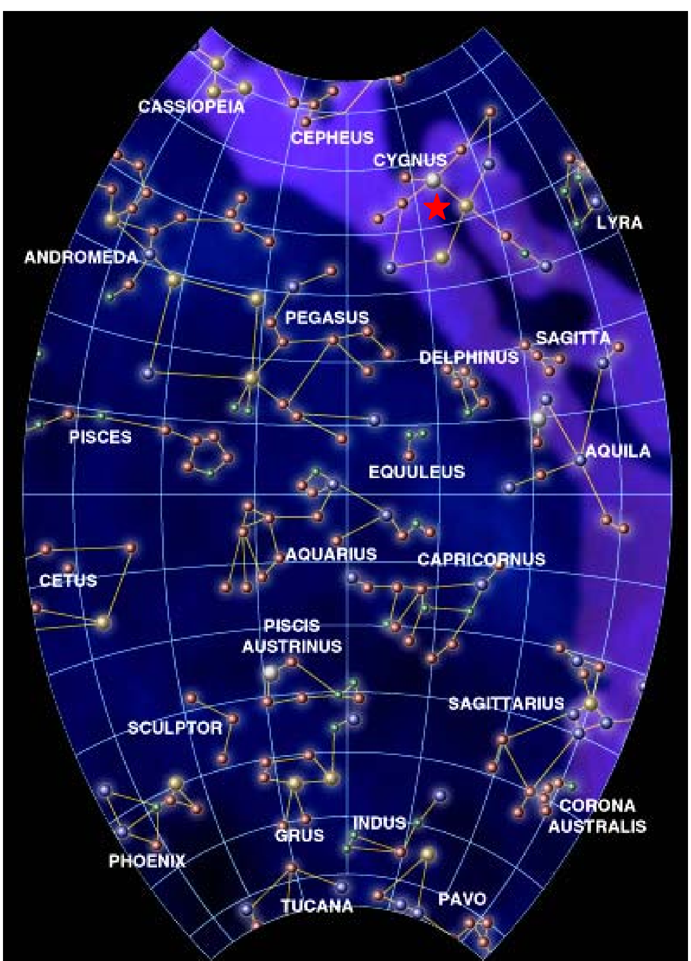
Similar column density to dense clouds!!

About Cygnus OB2 #12

Ben McCall



Morgan, Johnson, & Roman
PASP 66, 85 (1954)



- ★ d ~ 1.7 kpc
- ★ l ~ 80°, b ~ 0°
- ★ A_V ~ 10 mag
- ★ N(H) ~ 2 × 10^{22} cm^{-2}
- ★ M_V ~ -10 mag!
- ★ spectral type B5Ie
- ★ stellar wind ~ 1400 km/s

- ★ no 3.08 μm ice feature
  ⇒ no dense clouds
- ★ strong 3.4 μm C-H band
  ⇒ diffuse clouds
- ★ CH, C_2 observations
  suggest n ~ 300 cm^{-3}

Infrared CO

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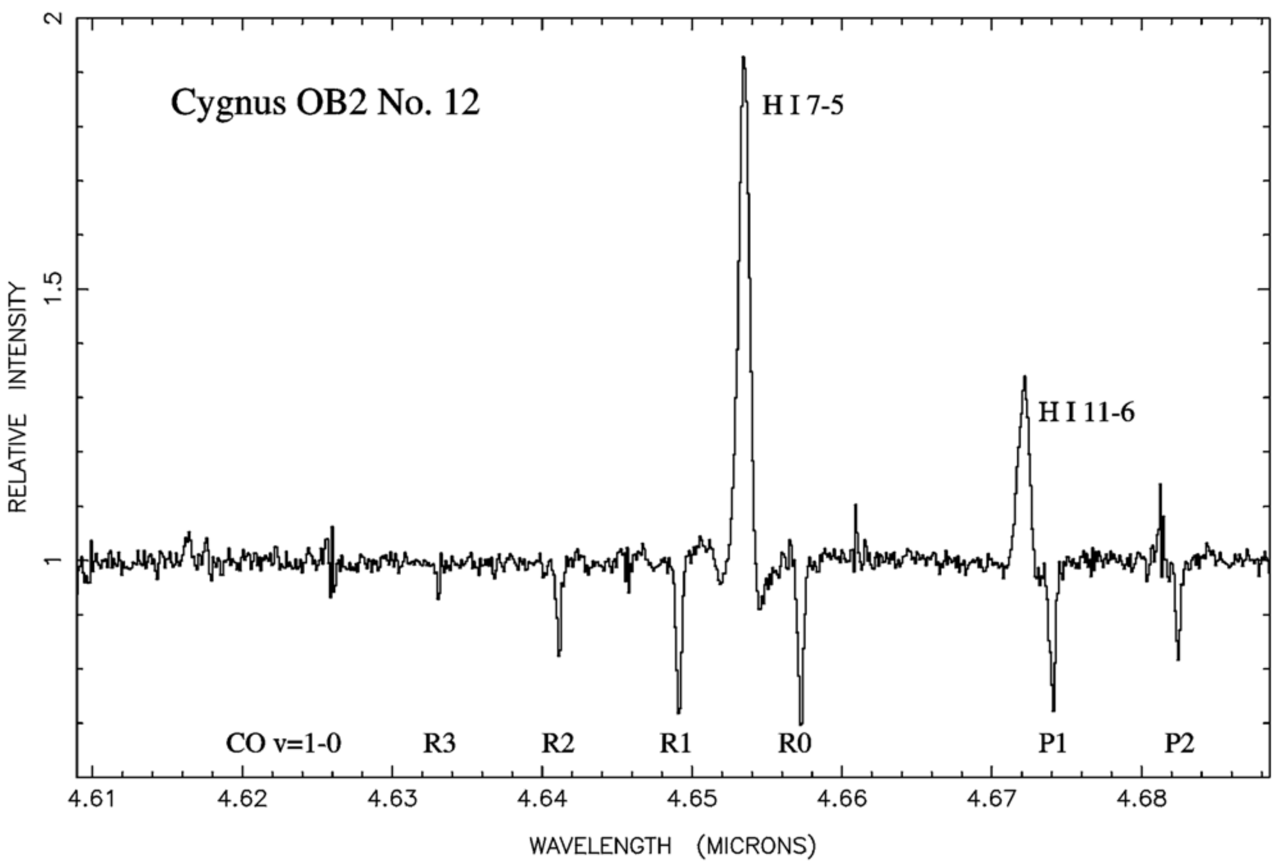

This spectrum of CO in absorption was obtained using CGS4 at UKIRT. The low column density, N(CO) ~ 10^{16} cm^{-3}, compared with N(H) ~ 10^{22} cm^{-3}, suggests that only about 1% of carbon is in the form of CO. This eliminates the possibility that the H_3^+ absorption is due to dense clouds.

mm-wave CO

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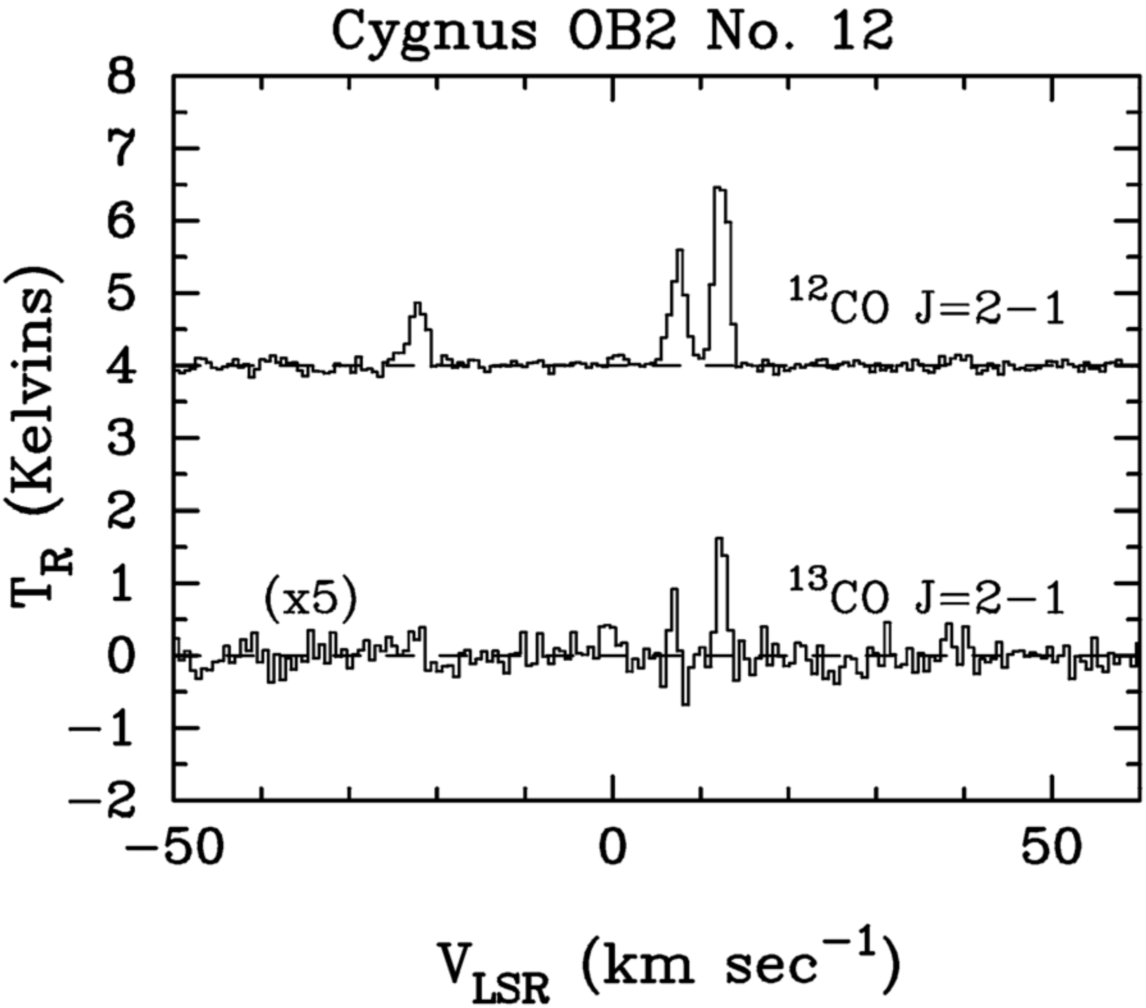

These millimeter-wave spectra of CO, taken with the James Clerk Maxwell Telescope (JCMT) show CO at velocities -21, +7, and +12 km/s. The -21 km/s component is probably behind the source. The +7 and +12 km/s components are in agreement with the infrared CO and H_3^+ absorption spectra.

1 kpc of H_3^+ ?!?!?

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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 $n(H_3^+) \sim 10^{-7}\ cm^{-3}$.

Path Length:

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

$$L \sim \frac{N(H_3^+)}{n(H_3^+)} \sim \frac{3.8 \times 10^{14}\,\mathrm{cm}^{-2}}{10^{-7}\,\mathrm{cm}^{-3}} \sim 3.8 \times 10^{21}\,\mathrm{cm} \sim 1\,\mathrm{kpc!}$$

Density:

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

Problem:
- 1 kpc is over ½ the distance to star!
- ⇒ expect H_3^+ "everywhere"
- ⇒ barely consistent with linewidth

Solutions?:
- ⇒ ζ may be too low?
- ⇒ k_e may be too high?
- ⇒ 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?)