Single Dish Radio Observation

The line spectra originating from the Orion KL outflows

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Orion BN/KL

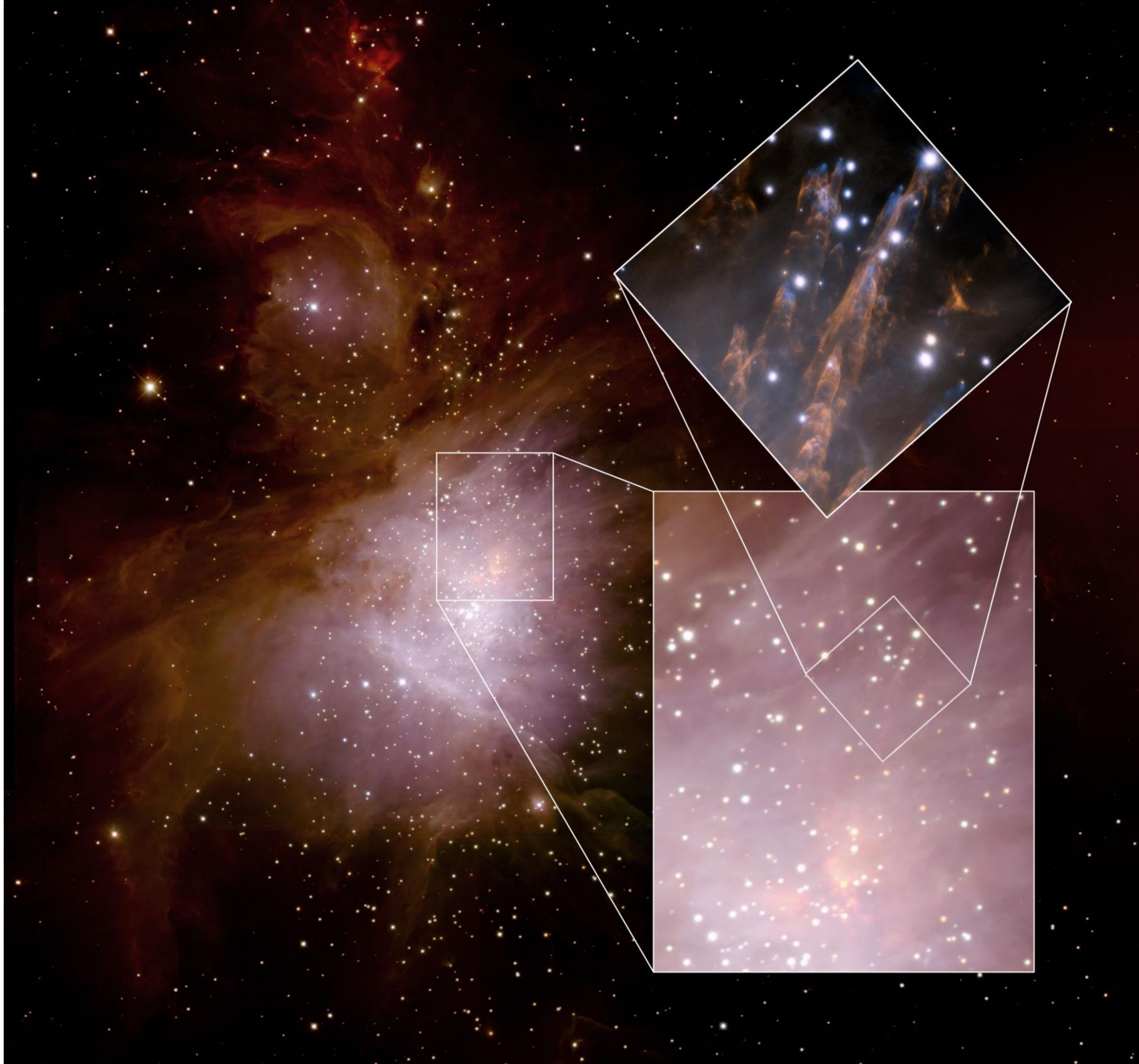
- An object visible only in the infrared (Becklin & Neugebauer 1967) in the Orion KL nebula (Kleinmann & Low 1967).
- The most luminous source within OMC-1 with an infrared luminosity of $\sim 10^5\ L_\odot$.
- Thought to be an intermediate-mass protostar
- Shock and outflow phenomena are widely present.

Orion BN/KL

- Wide-field image of Orion nebular obtained with the ISPI near IR camera on the Blanco 4-m telescope

+

- The Orion H2 bullets observed using the Gemini North with the ALTAIR adaptive optics system.



Zuckerman & Palmer (1975)

- Found a composite spectrum of ^{12}CO J=1-0 in which **a narrow emission 'spike'** is superposed on **a much broader 'plateau'** of emission.

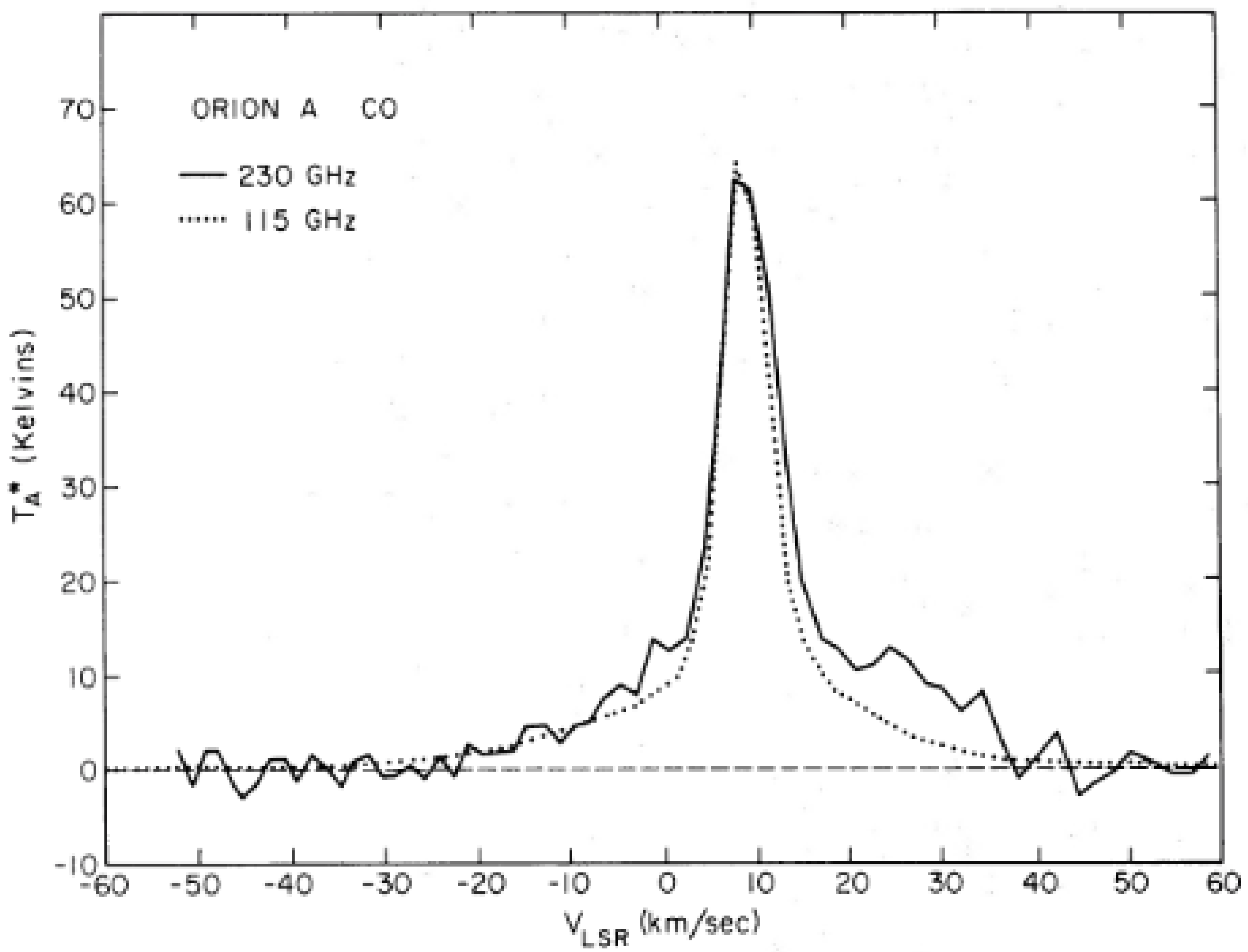
- **The spike is spatially extended** over many minutes of arc and has a radial velocity ~8-9 km s^{-1}.
- **The plateau appears to be localized** to a region ≤ 1′ in diameter approximately centered on KL.

- The large line width in plateau could be due to collapse, expansion, rotation, or turbulence.

Wannier & Phillips (1977)

- Kwan & Scoville (1976) interpreted the plateau using a simple expansion model.
- Wannier & Phillips (1977) observed ^{12}CO J=2-1 toward Orion BN/KL.

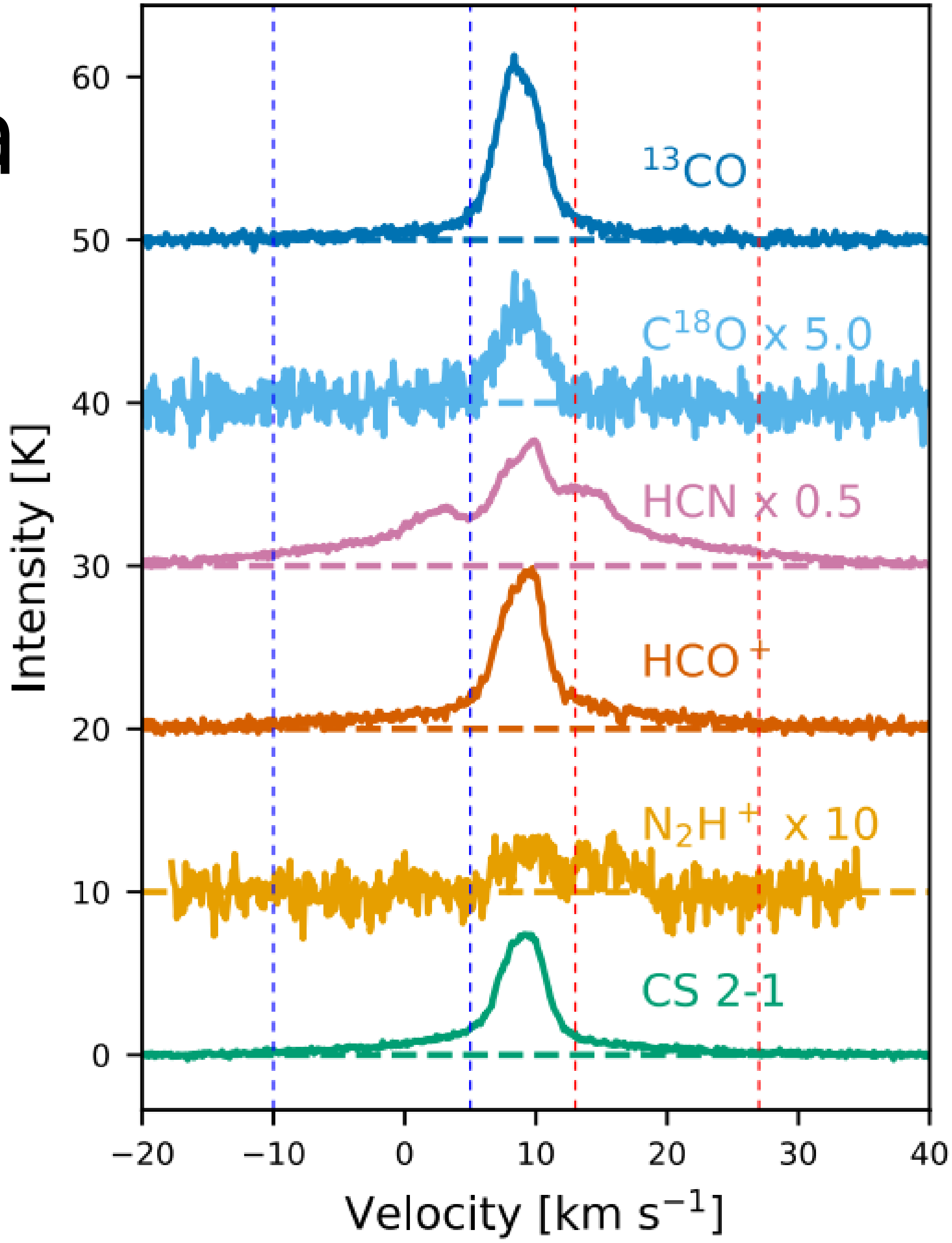
CO EMISSION FROM KL NEBULA



Six molecular line spectra toward Orion KL

- Broad wing structures originating from the Orion KL outflows
  - The ^{13}CO, HCN, HCO^+, and CS lines present the broad wing structures.
  - The $C^{18}O$ and N_2H^+ lines do not present clear wing structures.

❖How can we check whether or not the weak broad structures exist in the $C^{18}O$ and N_2H^+ lines?



From Yun et al. (2021)

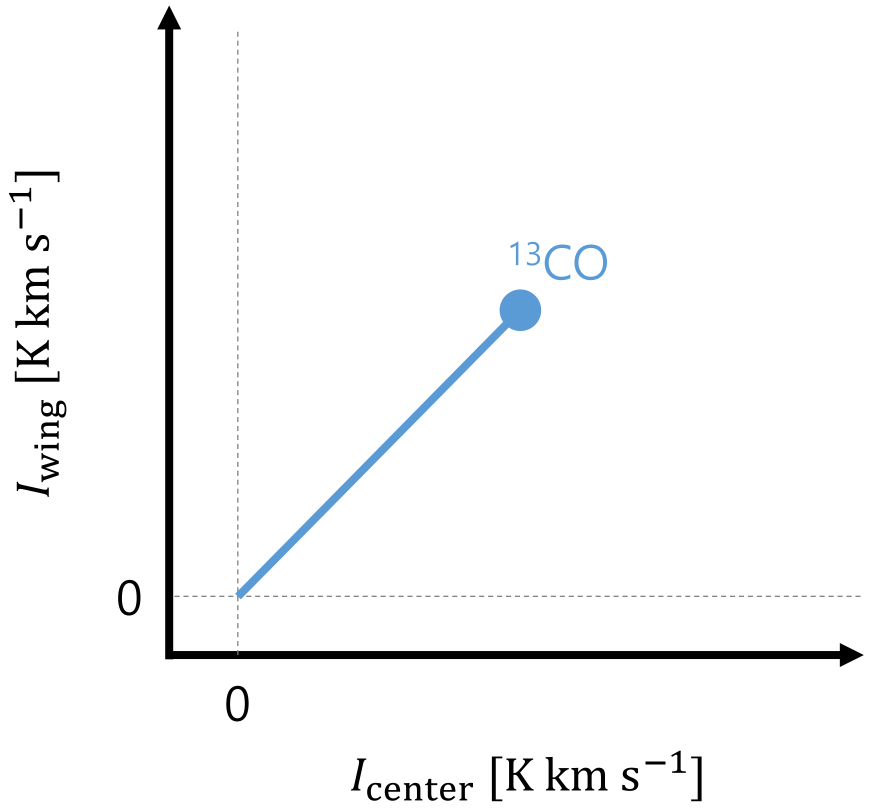
Figure 10. Observed lines toward Orion KL. The red and blue dotted vertical lines indicate the velocity ranges where the red (from −10 to +5 km s^{-1}) and blue (from +13 to +27 km s^{-1}) wing structures are presented.

Comparison between the integrated intensities of the central peak and the broad wing structures

Integrated intensities of each components

- $I_{\text{center}} = \int_{5}^{13} T(v)dv$
- $I_{\text{wing}} = \int_{-11}^{5} T(v)dv + \int_{13}^{29} T(v)dv$

- Produce a plot of $\left(I_{\text{center}}, I_{\text{wing}}\right)$.



I_{center} v.s. I_{wing}

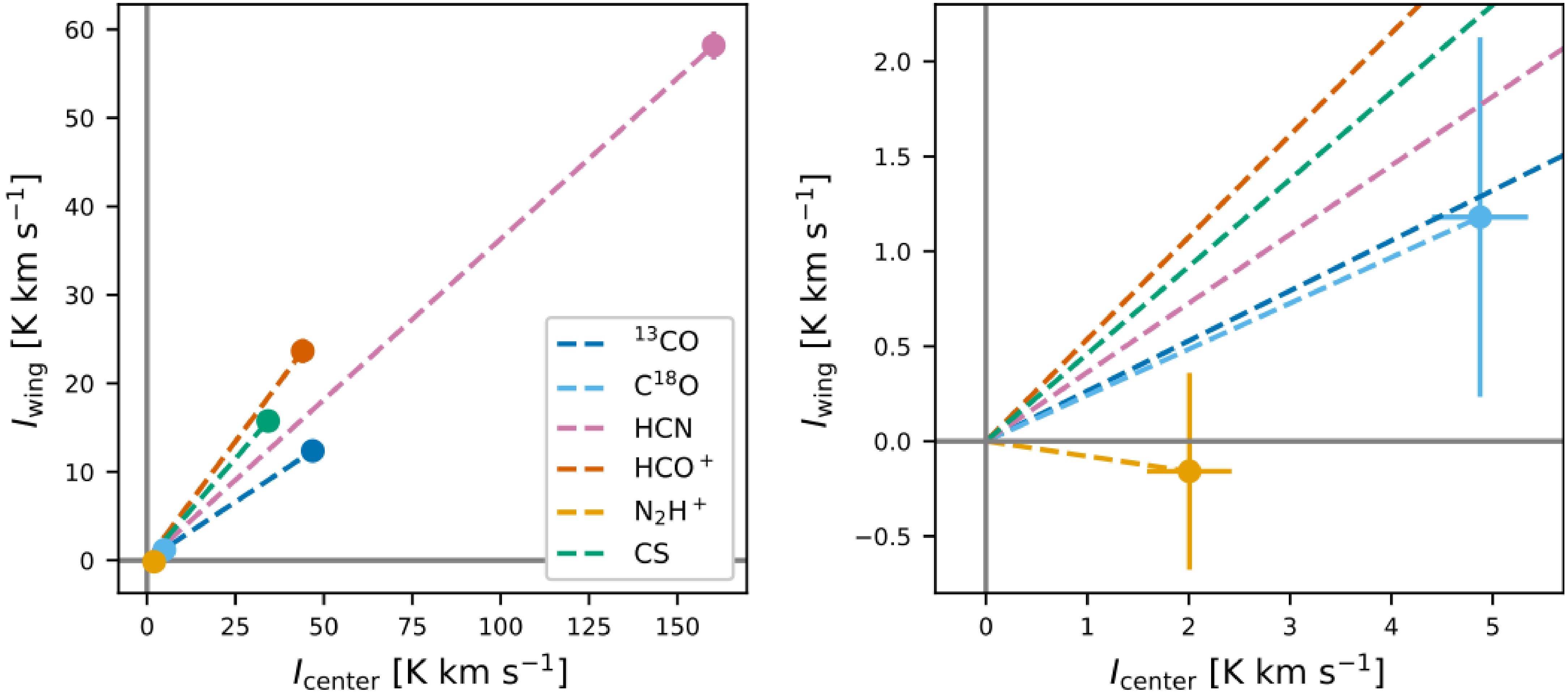
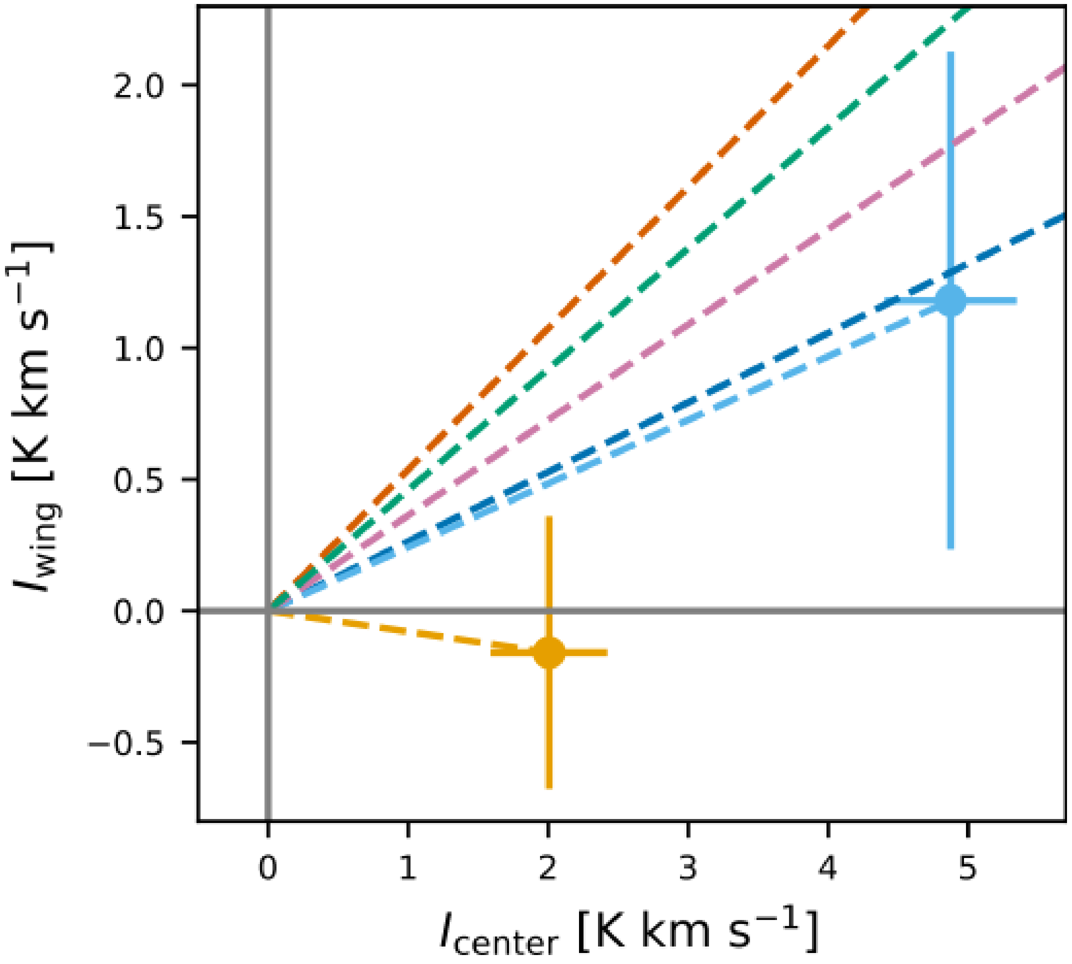


Figure 11. Left: comparison between the integrated intensities for the central peak (I_{center}) and broad wing structures (I_{wing}) of the Orion KL line spectra presented in Figure 10. The 3σ error ranges are presented in the error bars; however, their sizes are similar to or smaller than the symbol size. The gray solid lines indicate the position of the origin, and each dashed line presents the straight line from the origin to each data point. Right: zoom-in on the origin of the diagram.

$I_{\rm center}$ v.s. $I_{\rm wing}$

- $I_{\rm wing}$ of $C^{18}O$ is barely detected (1.1 ± 0.3 K km s^{-1})
- The N_2H^+ line is not detected with a value of -0.16 ± 0.17 K km s^{-1}.

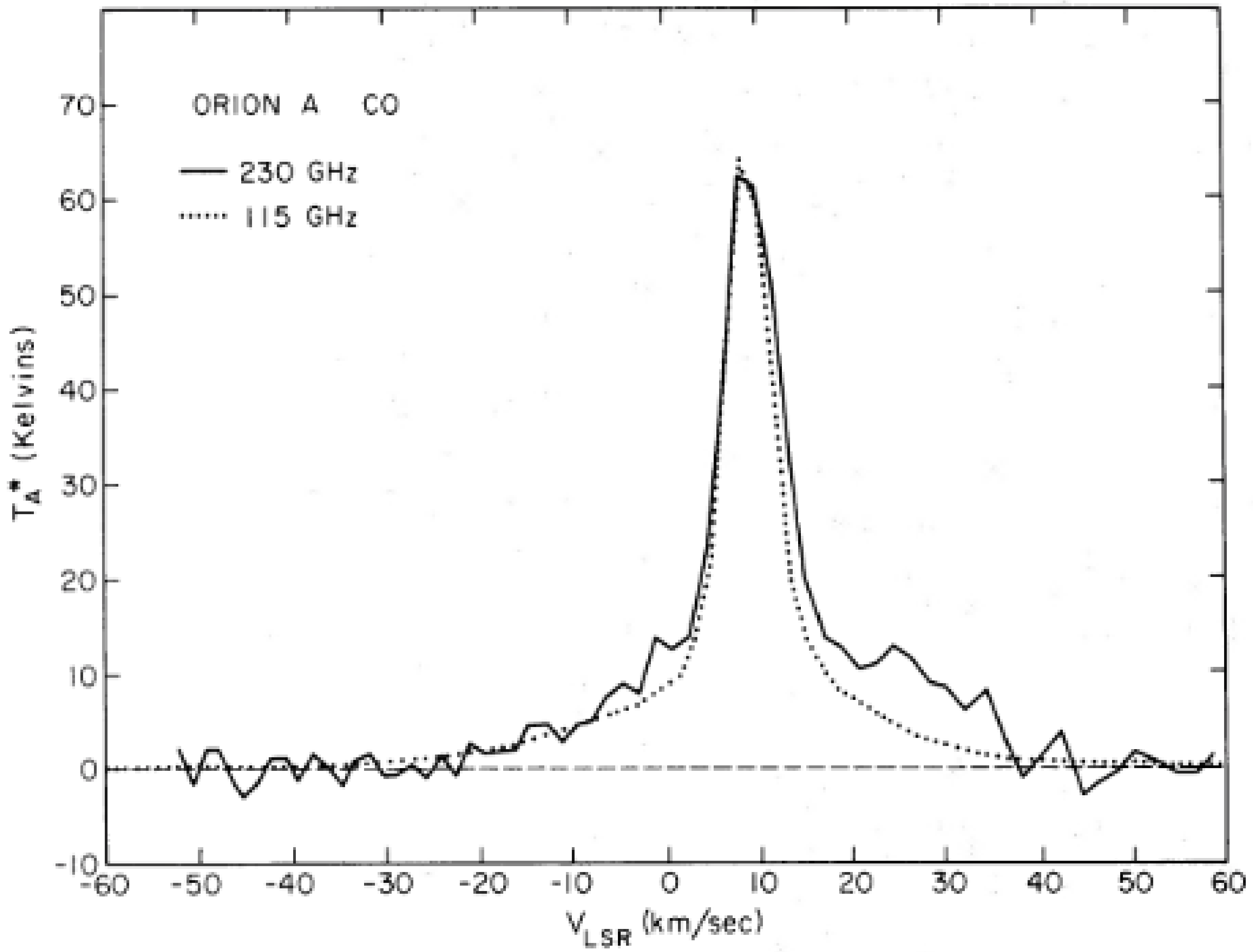


Wannier & Phillips (1977)

- Kwan & Scoville (1976) interpreted the plateau using a simple expansion model.
  -> The plateau is not highly saturated.

- Observed ^{12}CO J=2-1 toward Orion BN/KL.

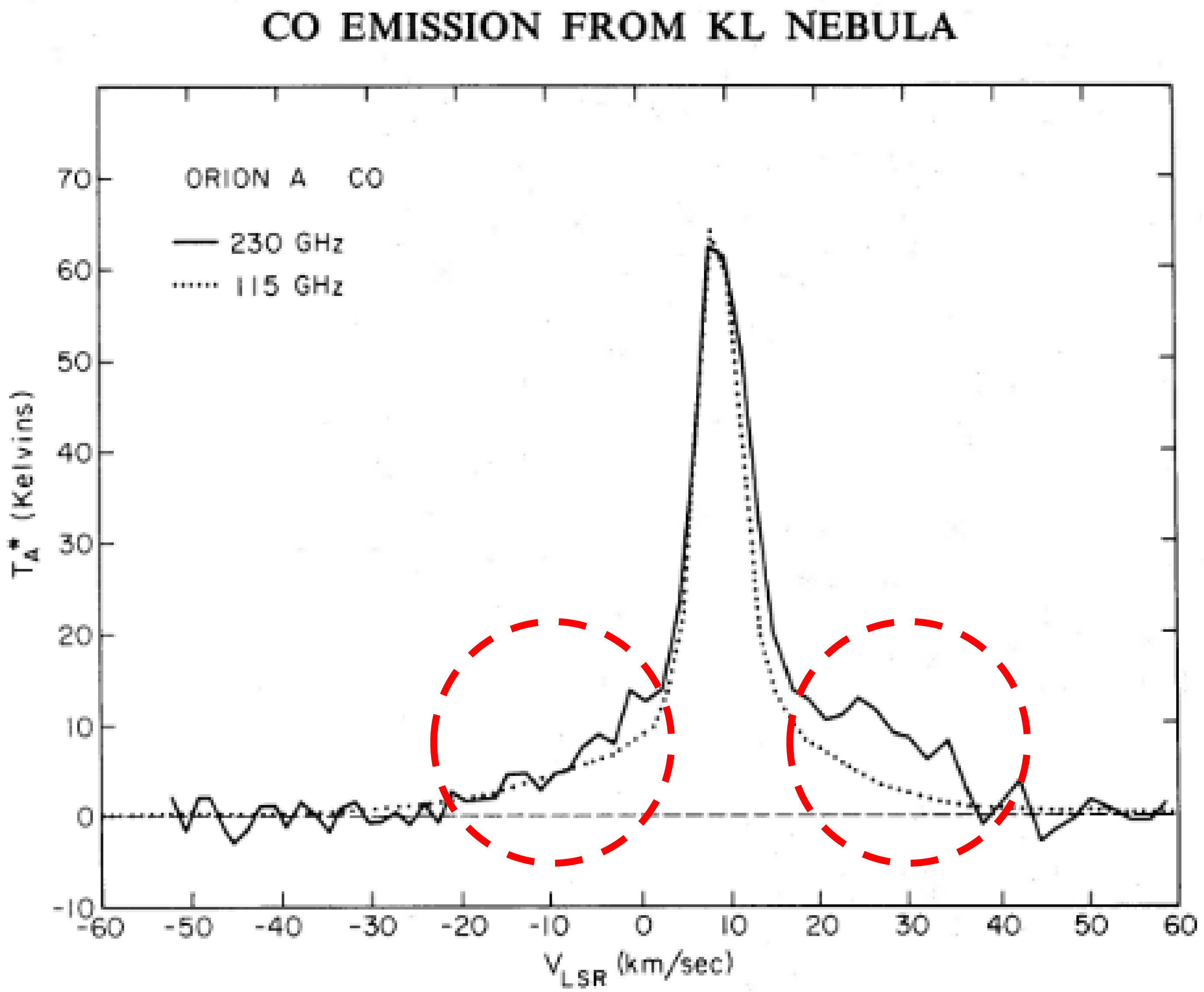
CO EMISSION FROM KL NEBULA



Wannier & Phillips (1977)

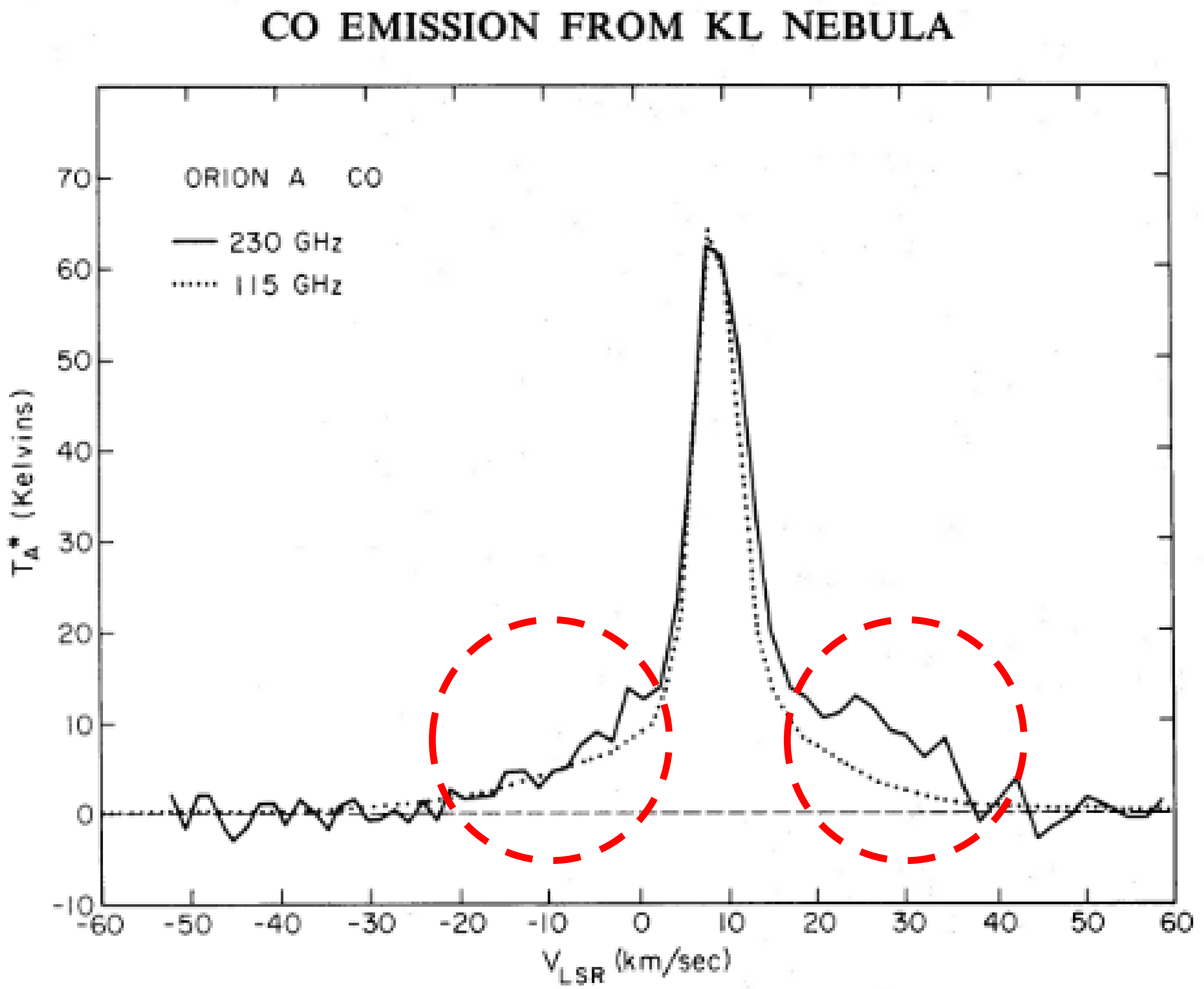
- Observed ^{12}CO J=2-1 toward Orion BN/KL.

- Comparable T_A in the spike
- ^{12}CO J=2-1 has approximately double T_A in the plateau.
  -> **low-optical depth** (Goldreich & Kwan 1974; Scoville & Solomon 1974)



Wannier & Phillips (1977)

- The optically thin CO lines should present interesting possibilities for making isotope abundance measurements.



Isotope abundance ratio between ^{13}CO and C^{18}O

- Assuming that the *J*=1-0 transitions of ^{13}CO and C^{18}O are emitted from the same gas component.
- Assuming an optically thin condition
- Einstein coefficient A
  - ^{13}CO *J*=1-0 : $6.294 \times 10^{-8}\ \mathrm{s}^{-1}$
  - C^{18}O *J*=1-0 : $6.266 \times 10^{-8}\ \mathrm{s}^{-1}$

Similar!!

- Adopt The ratio between the line integrated intensities $\left(\frac{I_{\mathrm{wing},^{13}\mathrm{CO}}}{I_{\mathrm{wing},\mathrm{C}^{18}\mathrm{O}}}\right)$ as the isotope abundance ratio $\left(\frac{X(^{13}\mathrm{CO})}{X(\mathrm{C}^{18}\mathrm{O})}\right)$.

Typical Isotope abundance ratio in ISM

- From Wilson & Rood (1994, ARA&A, 32, 191)

- Let

$$\begin{cases} \dfrac{X(^{12}\mathrm{CO})}{X(^{13}\mathrm{CO})} \sim \dfrac{X(^{12}\mathrm{C})}{X(^{13}\mathrm{C})} \\ \dfrac{X(^{12}\mathrm{CO})}{X(\mathrm{C}^{18}\mathrm{O})} \sim \dfrac{X(^{16}\mathrm{O})}{X(^{18}\mathrm{O})} \end{cases}$$

❖ $\dfrac{X(13_{\mathrm{CO}})}{X(\mathrm{C}^{18}\mathrm{O})} = ?$

Table 4 Ratios for Galactic center, 4 kpc molecular ring, carbon stars, Solar System, local ISM, and galaxies

Isotope	Galactic center	4 kpc molecular ring	Local ISM[b]	Solar System[c]	Carbon stars[d]	Nuclei of galaxies
$(^{12}\mathrm{C}/^{13}\mathrm{C})$	~ 20	53 ± 4[b]	77 ± 7[b]	89	> 30	~ 40[h]
$(^{14}\mathrm{N}/^{15}\mathrm{N})$	> 600	375 ± 38[b]	450 ± 22[b]	270	> 515	...
$(^{16}\mathrm{O}/^{18}\mathrm{O})$	250	327 ± 32[b]	560 ± 25[b]	490	320 to 1260 > 2700	~ 200[i]
$(^{18}\mathrm{O}/^{17}\mathrm{O})$	3.2 ± 0.2[e]	3.2 ± 0.2[e]	3.2 ± 0.2[e]	5.5	0.6 to 0.9 < 1	8[i]
$(^{32}\mathrm{S}/^{34}\mathrm{S})$	~ 22[f]	~ 22[f]	~ 22[f]	22	...	...
$(^{29}\mathrm{Si}/^{30}\mathrm{Si})$	1.5[g]	1.5[g]	1.5[g]	1.5	...	...

[a] Wannier (1980).
[b] Fits to data shown in Figure 2. The error given is that of the mean.
[c] Anders & Grevesse (1989).
[d] Kahane et al (1992), Johansson et al (1984).
[e] Penzias (1981b).
[f] Frerking et al (1980).
[g] Penzias (1981a).
[h] Henkel et al (1993a,b).
[i] Sage et al (1991); Henkel et al (1993a,b).

Isotope abundance ratio between ^{13}CO and C^{18}O

- $\frac{X(13_{\mathrm{CO}})}{X(\mathrm{C}^{18}\mathrm{O})} = 10.5 \pm 2.8$
- Close to the abundance ratio determined by Shimajiri et al. (2014) ($\frac{X(13_{\mathrm{CO}})}{X(\mathrm{C}^{18}\mathrm{O})} = 12.14$).
- Larger than the value of $\begin{cases} 5.5 \text{ in soloar system} \\ 7.2 \text{ in ISM} \end{cases}$
- Selective photodissociation of C^{18}O makes the high $\frac{X(13_{\mathrm{CO}})}{X(\mathrm{C}^{18}\mathrm{O})}$ value in the PDR region (Shimajiri et al. 2014).