

Gas in the Central Molecular Zone

H_3^+ and CO

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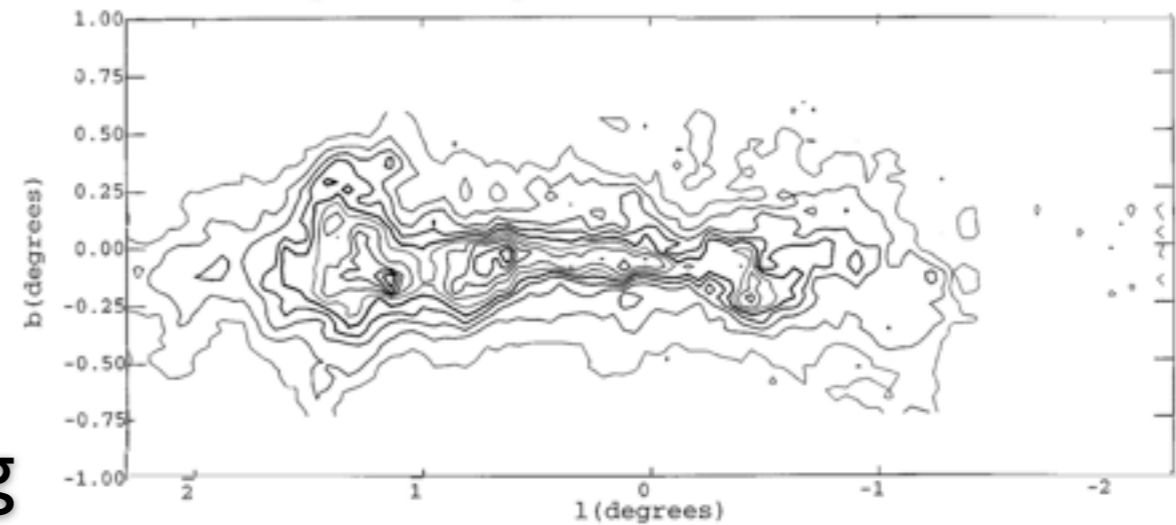
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Takeshi Oka (University of Chicago)

Central Molecular Zone

- $r < 200 \text{ pc}$ ($+2^\circ \rightarrow -1^\circ$) of the Galactic Nucleus*
- Enclosed in Expanding Molecular Ring

Uchida, Morris, CO=1-0



Galactic Center: Region on and around Galactic Nucleus (can be $>100 \text{ pc}$)

Galactic Nucleus: Sgr A* (the central blackhole) and neighbourhood ($<a \text{ few pc}$)

- molecular mass $7 \times 10^8 M_\odot$ (highest estimate)
 $4 \times 10^7 M_\odot$ (lowest estimate)

Expanding Molecular Ring



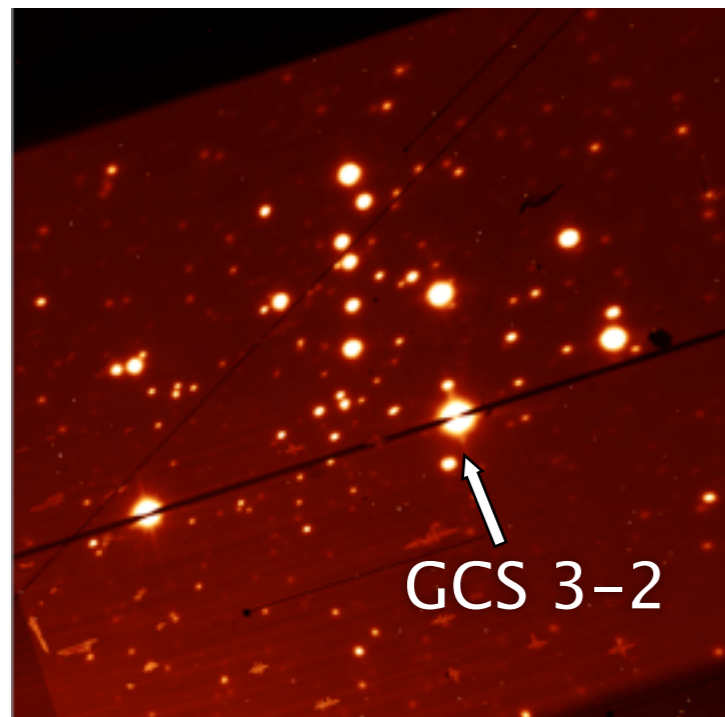
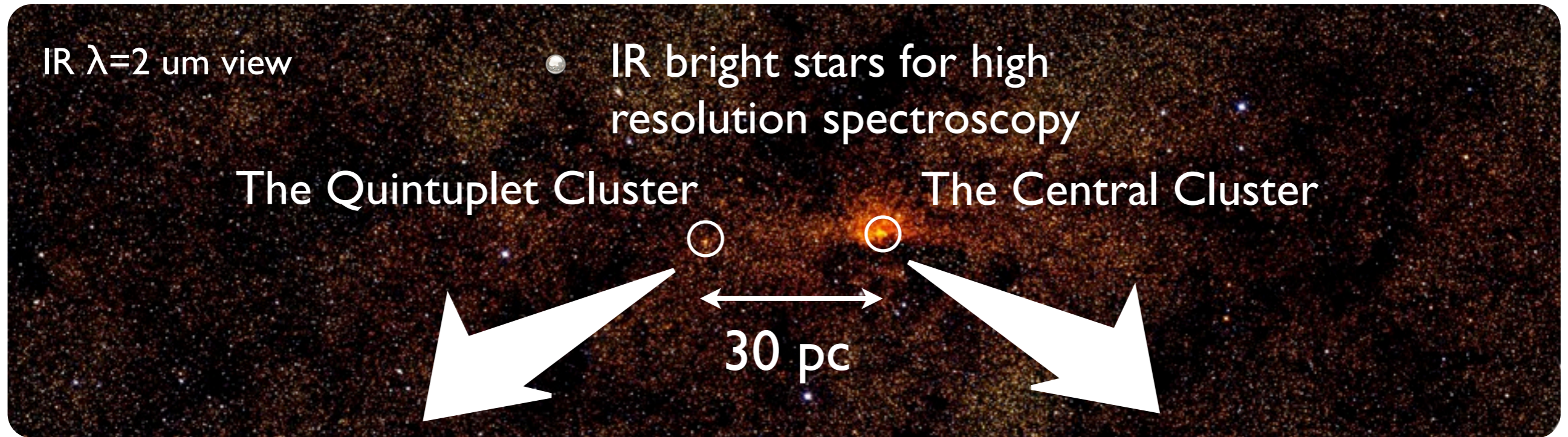
Central Molecular Zone

Sun
8 kpc

10% of whole molecular mass in the Milky Way
in 0.001% of its volume

$f \sim 0.1$ (volumn filling factor)

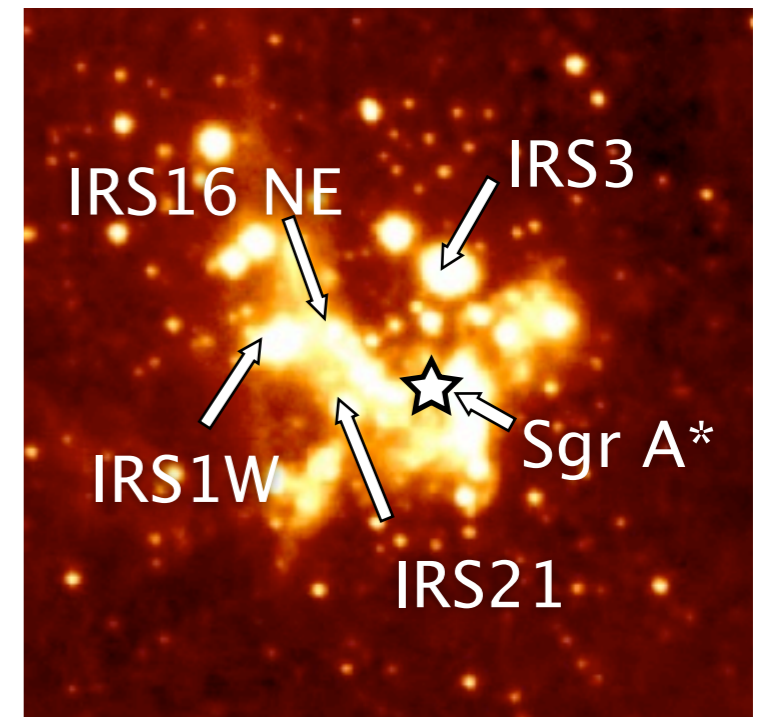
The Central Cluster of the Milky Way (and Quintuplet)



We know they are at the Galactic Nucleus



all observations done by CRIRES/VLT except otherwise mentioned



H₃⁺ Summary:

(I) Warm and Diffuse Cloud

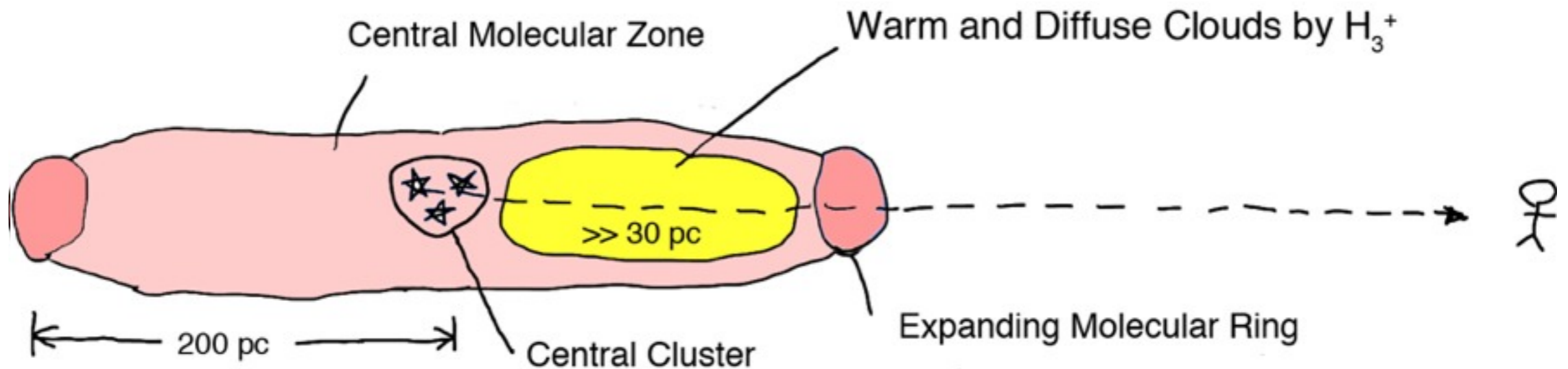
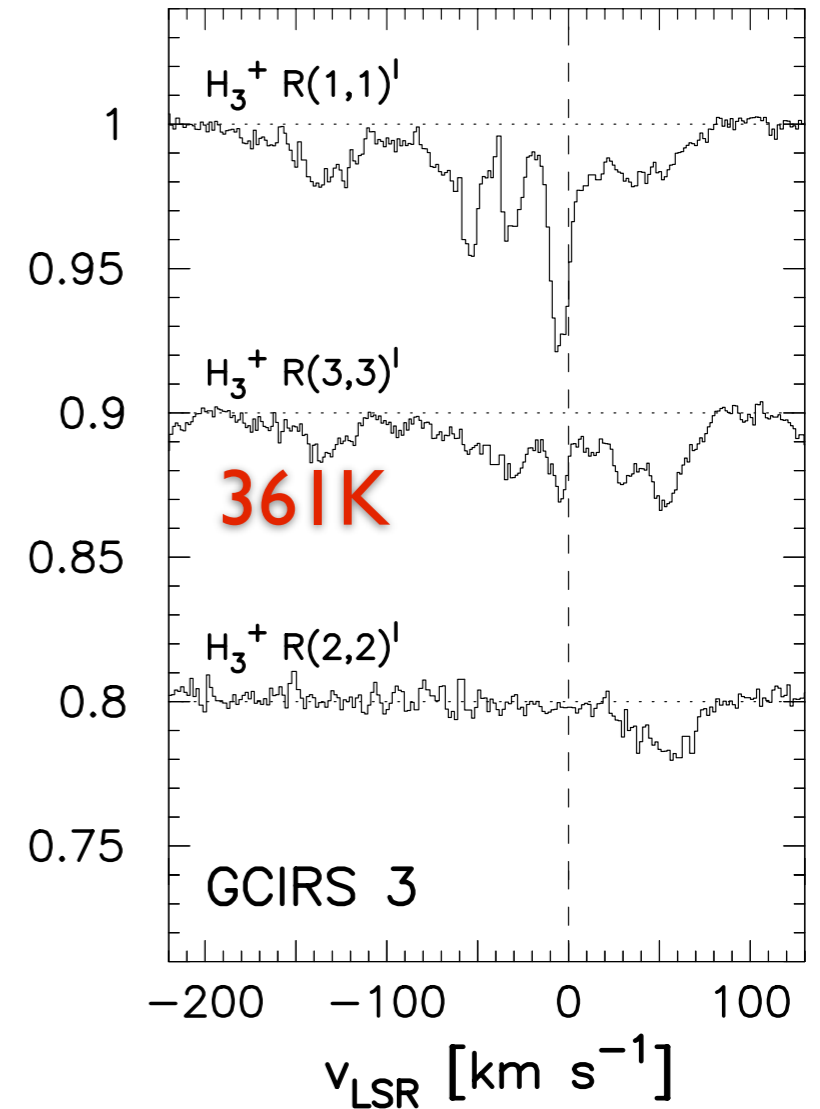
$$n < 100 \text{ cm}^{-3}, T \approx 250 \text{ K}$$

cloud pathlength \times ionization rate

(2) $L\zeta > 2 \times 10^5 \text{ cm s}^{-1}$

Cosmic ray ionization rate is high, $2 \times 10^{-15} \text{ s}^{-1}$

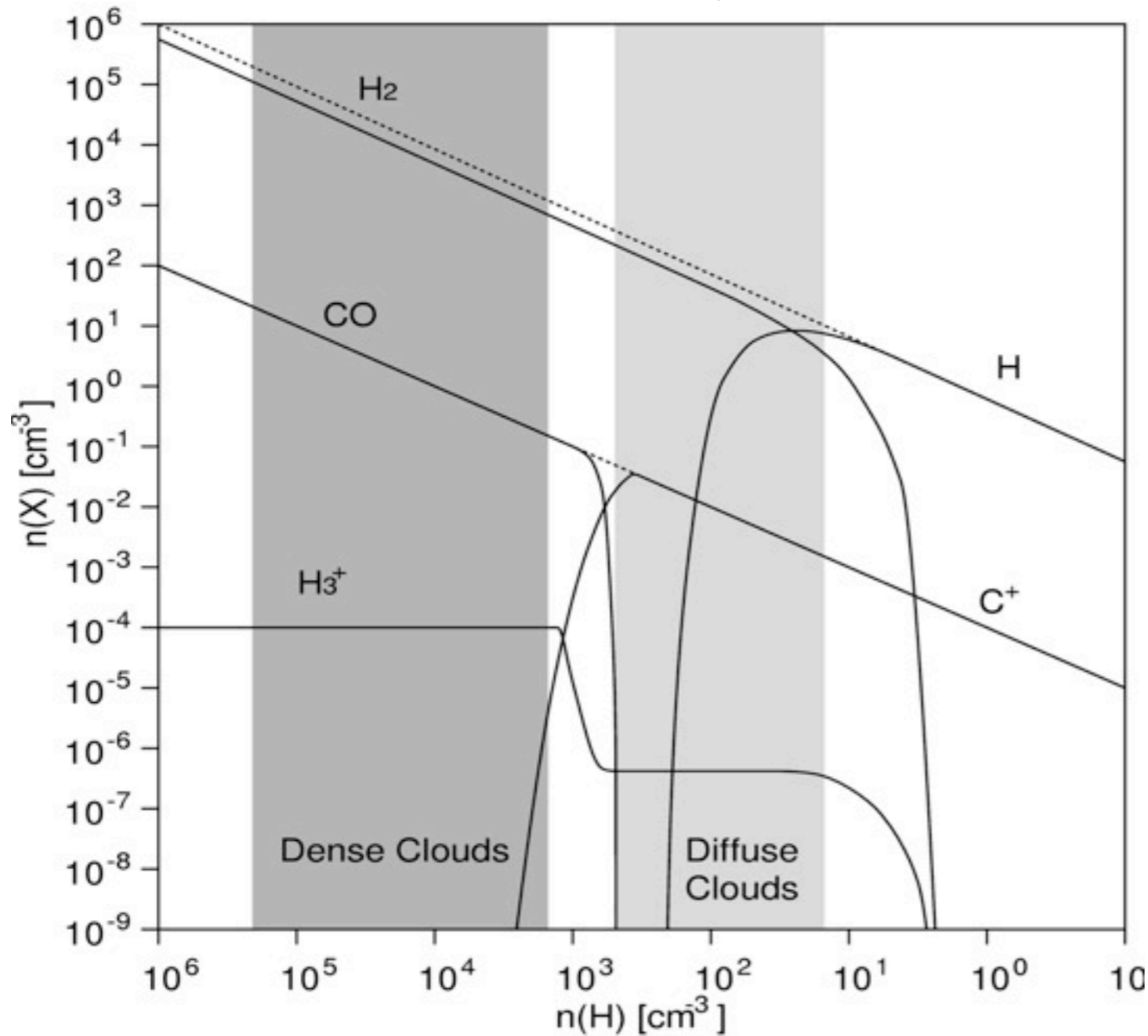
Cloud is large $\gg 30 \text{ pc}$ [$f(\text{H}_2)=1$]



How this Diffuse Cloud Fits in Central MOLECULAR Zone?

C is in C⁺
not in CO

H is in H₂



Warm

$T \approx 250$ K

Diffuse

$n < 100$ cm^{-3}

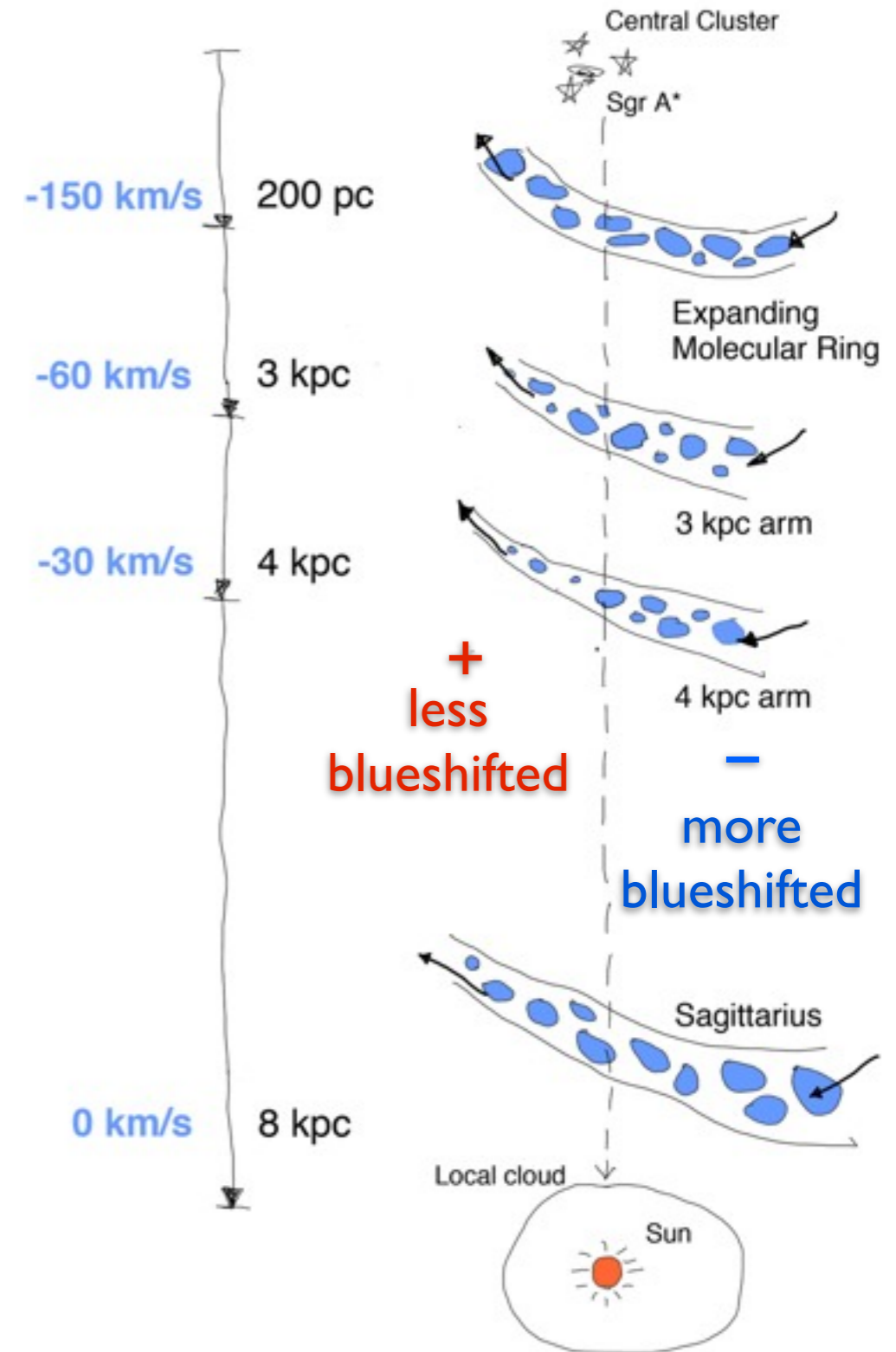
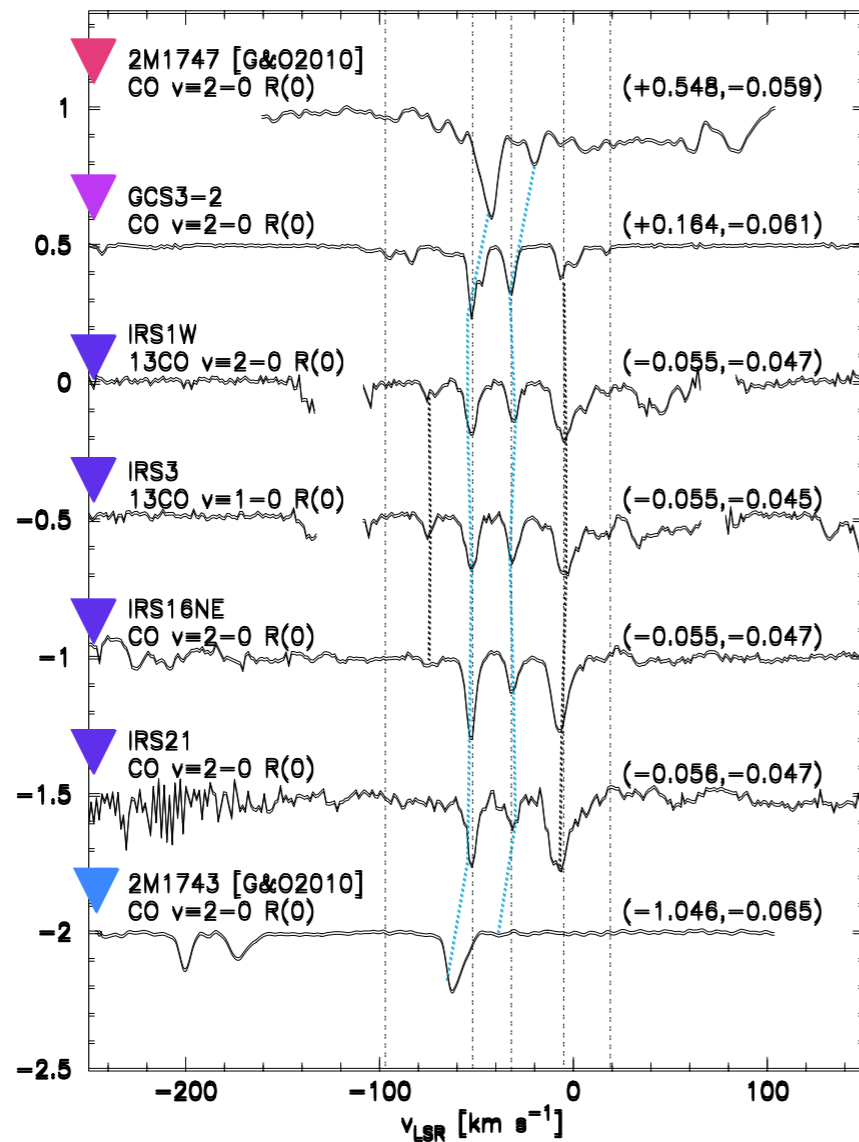
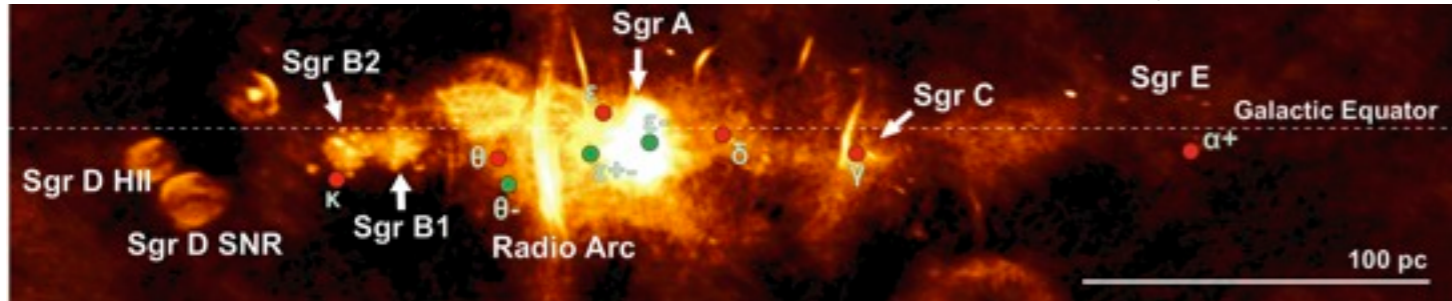
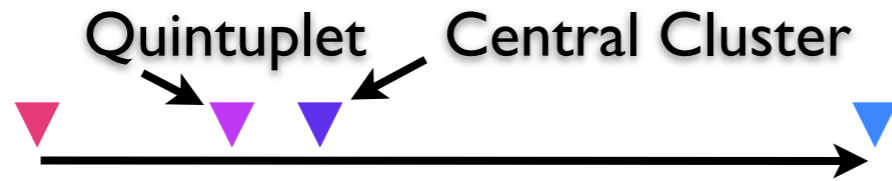
Large

$L \gg 30$ pc

Where is CO?

Where is CO?

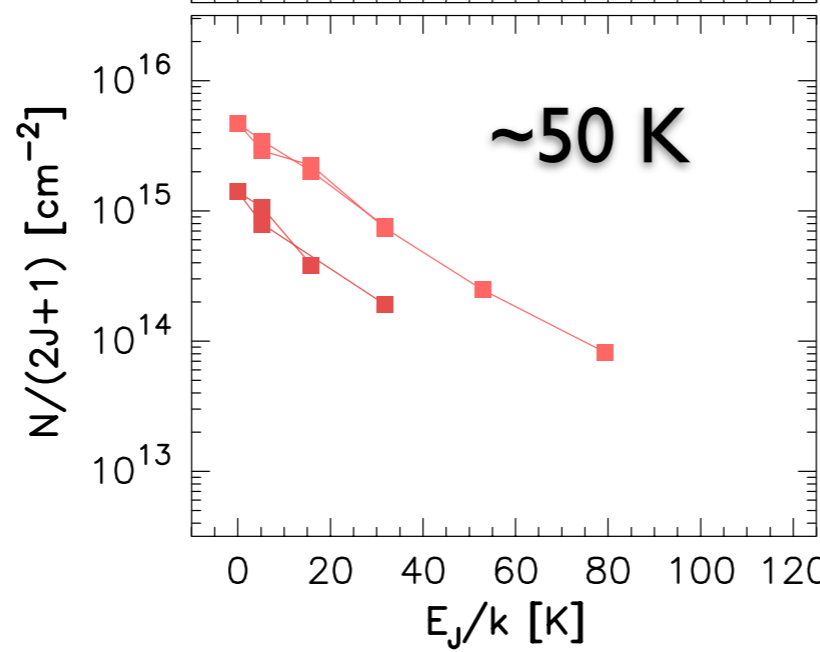
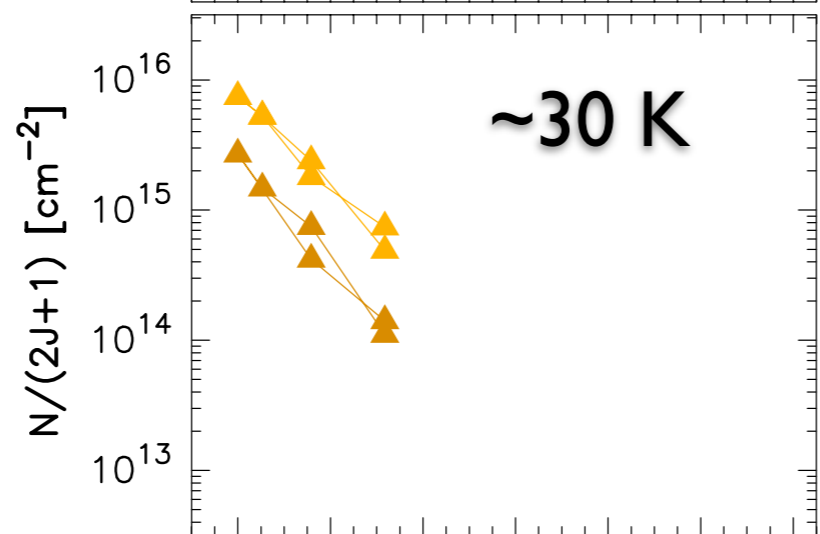
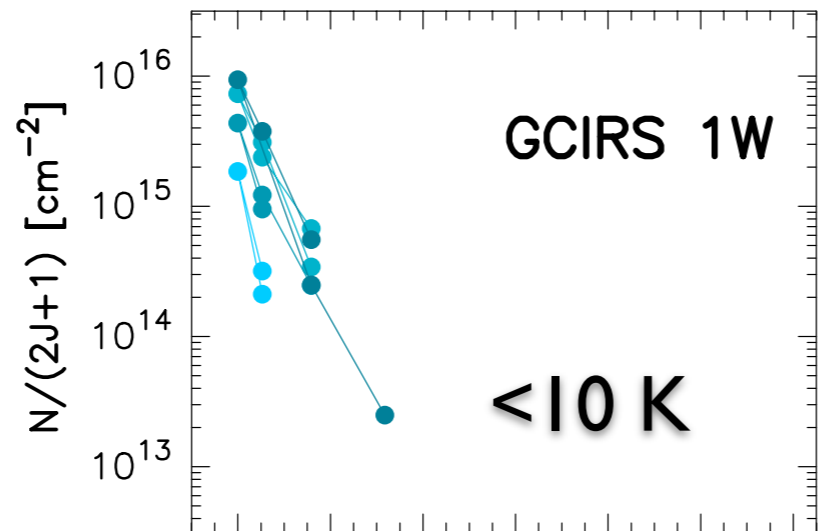
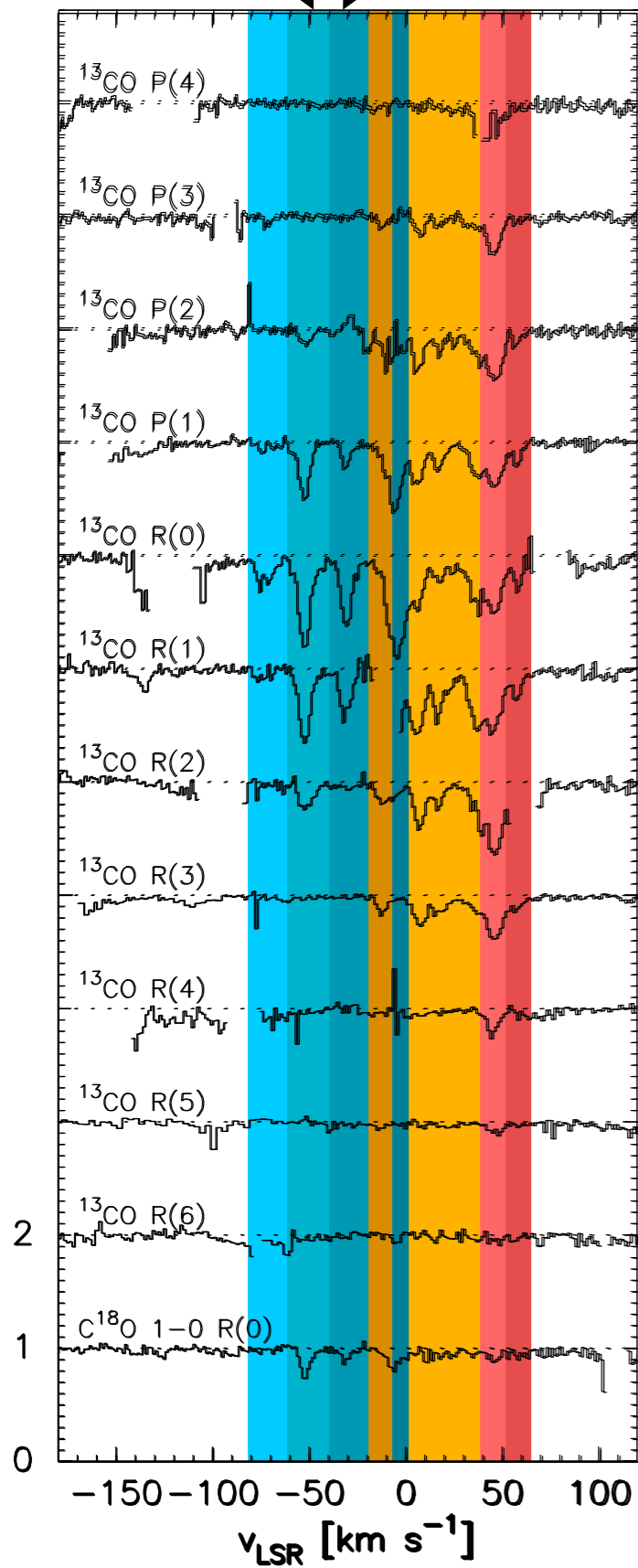
First we have to remove absorptions in the foreground (non-Galactic Center) clouds.



IRS 1W ^{13}CO $v=1-0$ P(4)-R(6)

3 kpc \swarrow \swarrow 4 kpc

Excitation Temperature



● 3 kpc, 4 kpc arms
 → Nice and cold

● -72 km/s
 → foreground

although we do not know what is it exactly

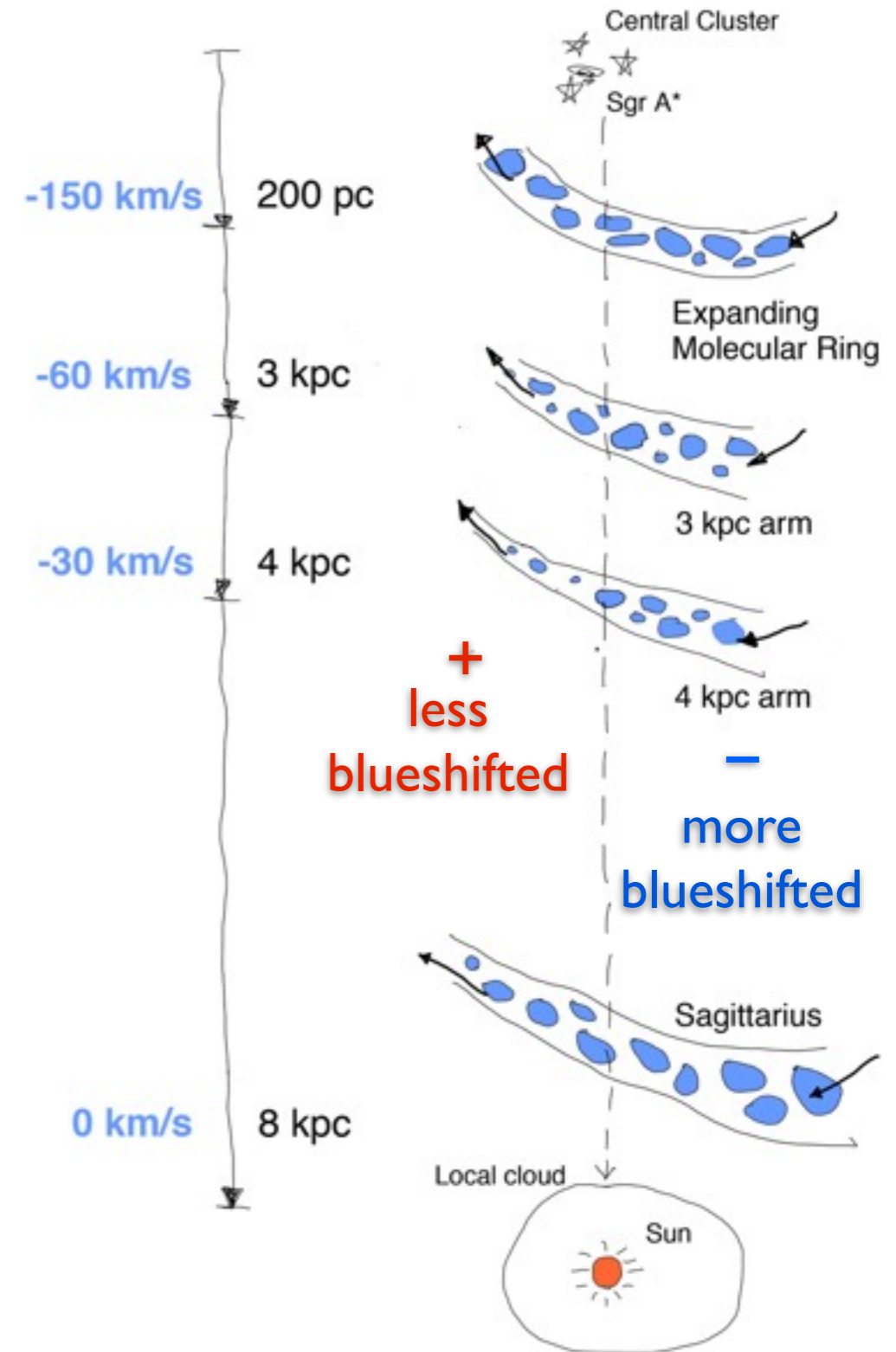
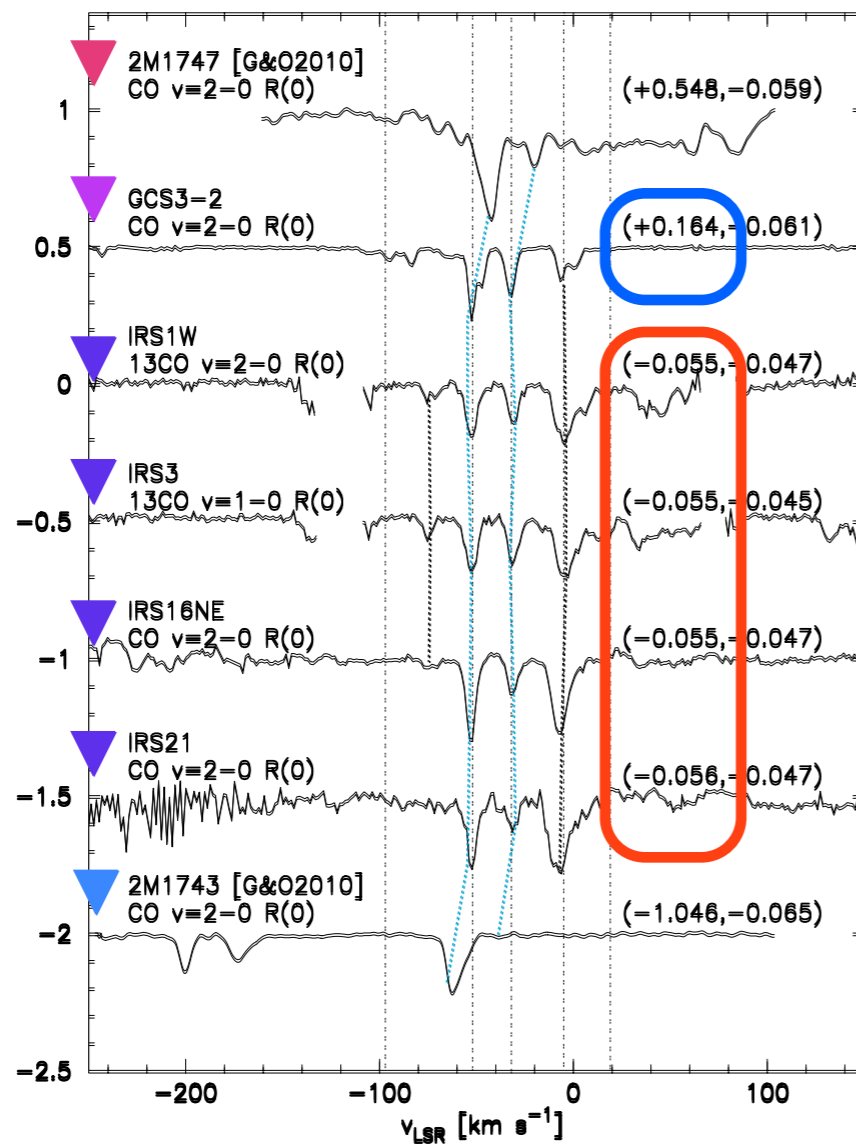
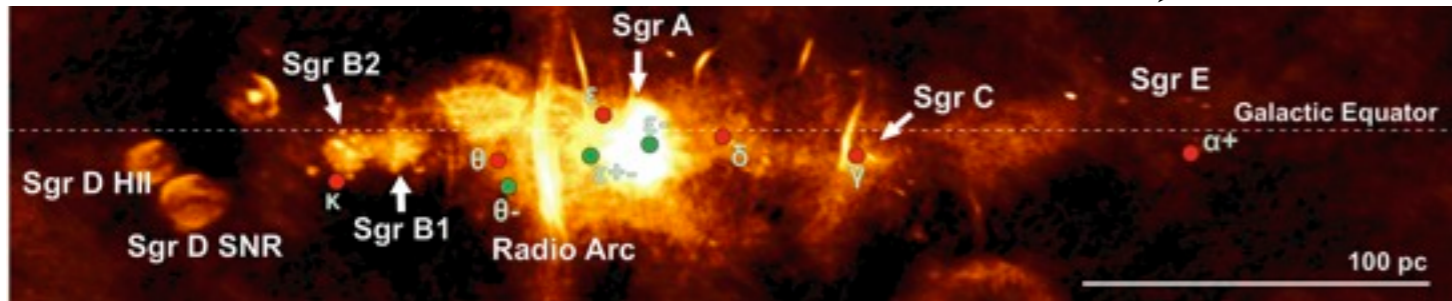
● 0 km/s
 → GC + foreground

● > 0 km/s
 → GC
 likely local to the Central Cluter

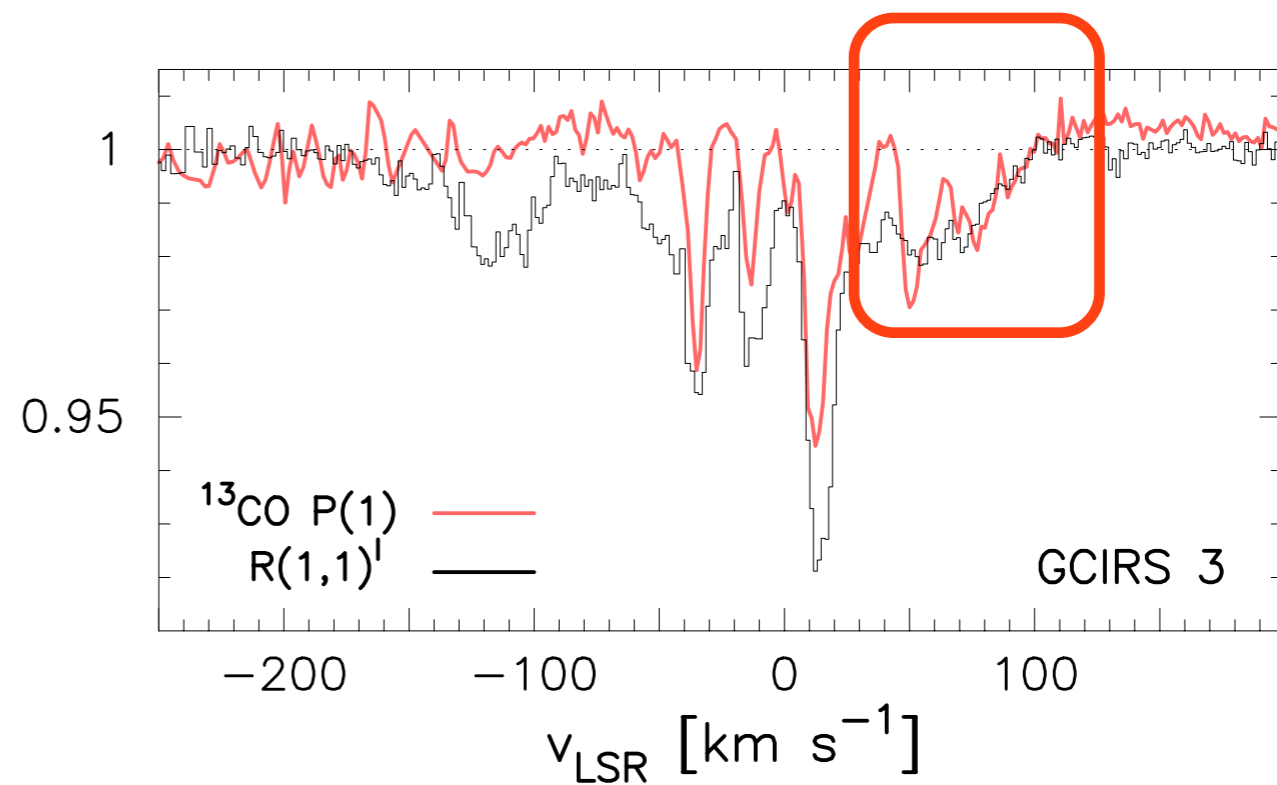
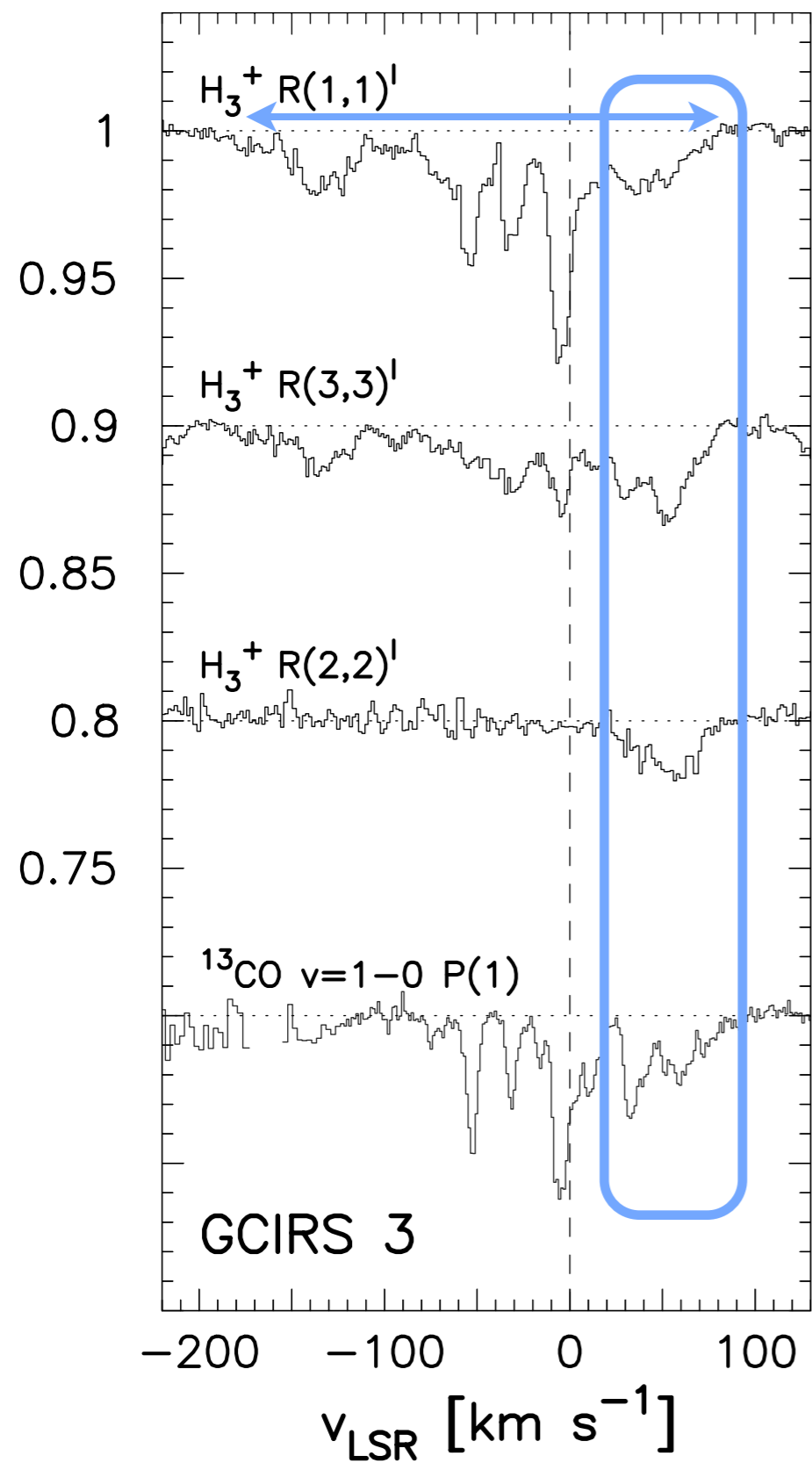
Where is CO?

First we have to remove absorptions in the foreground (non-Galactic Center) clouds.

Quintuplet Central Cluster

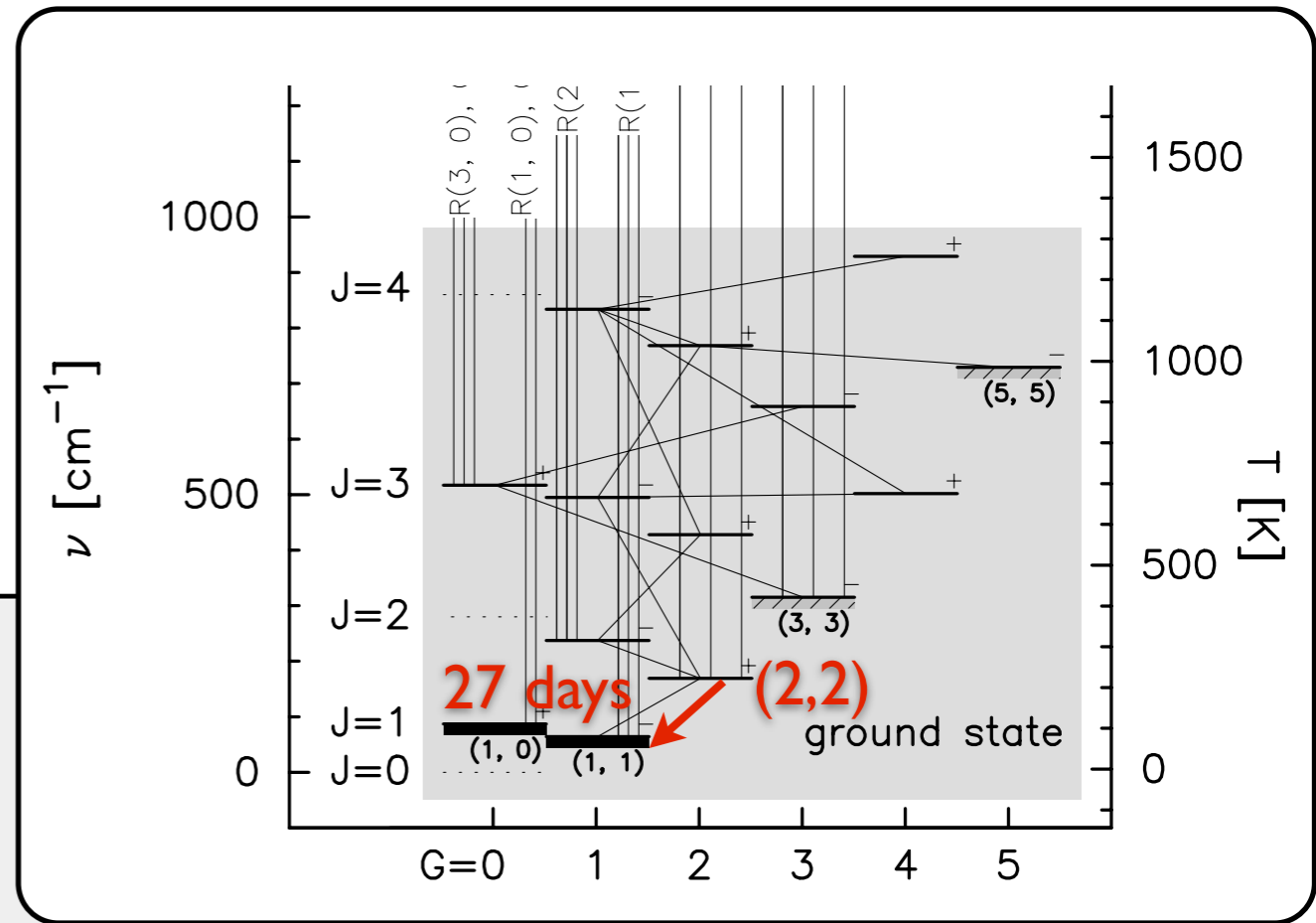
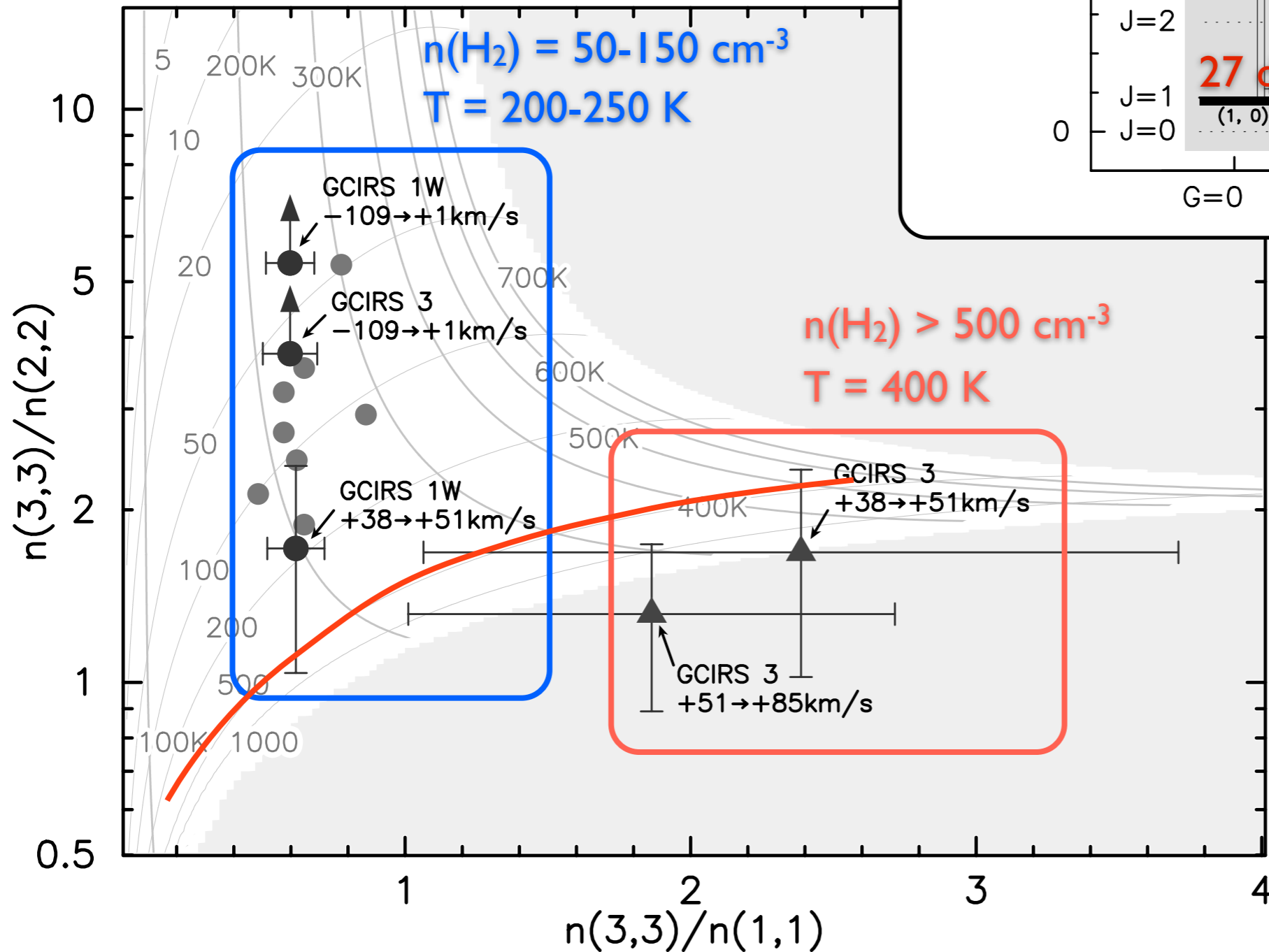


Dense Clouds local to the Central Cluster



R(2,2)^l detection: n(H₂) > 500 cm⁻³

Calculation:
Oka & Epp 2004



$$L\zeta > 1.8 \times 10^3 \text{ cm s}^{-1}$$

(cloud pathlength
x ionization rate)

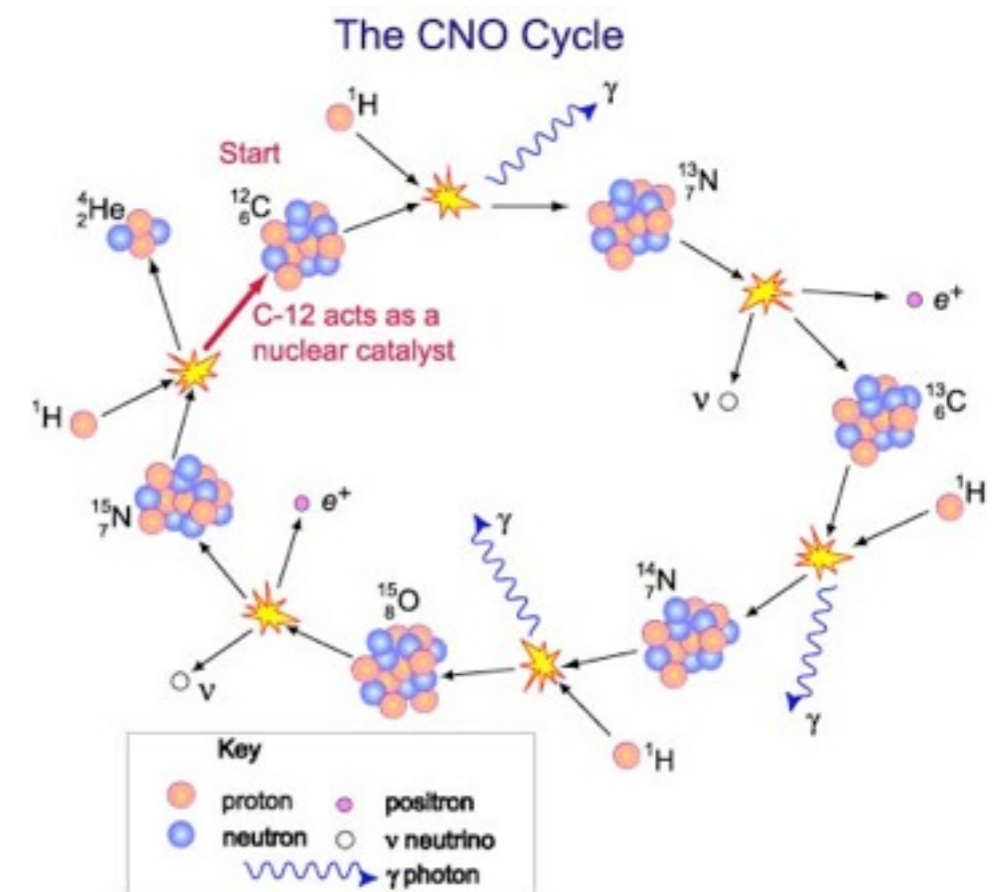
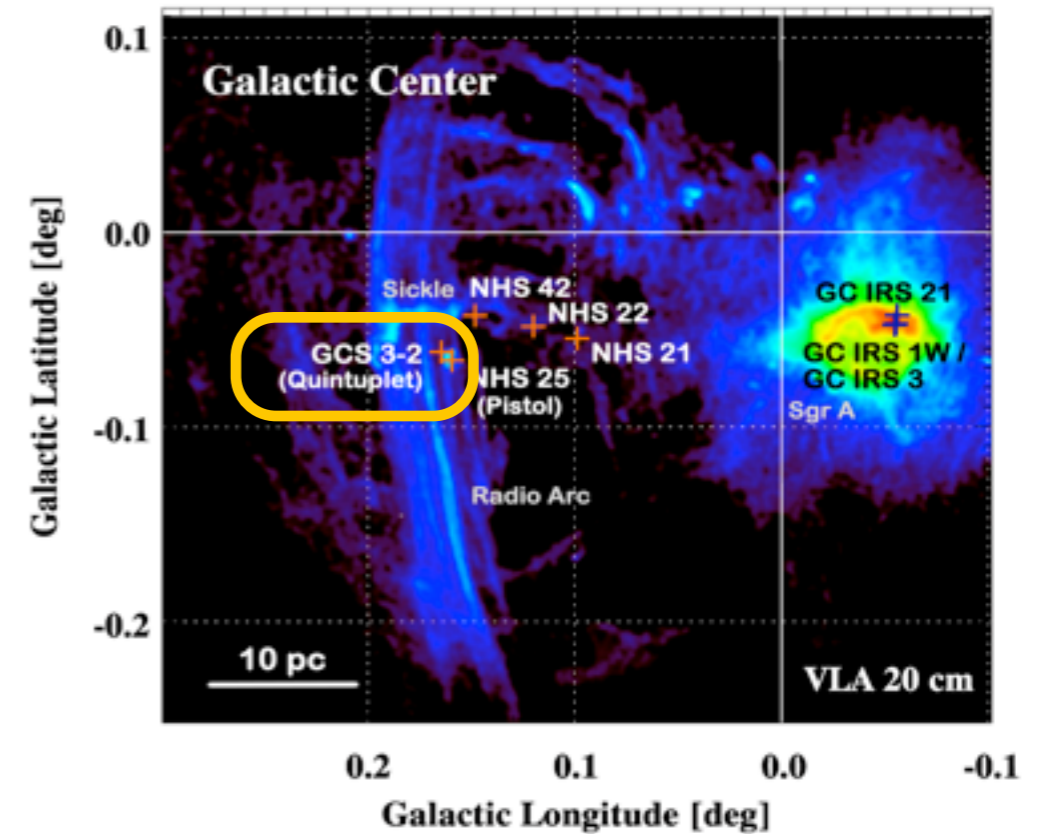
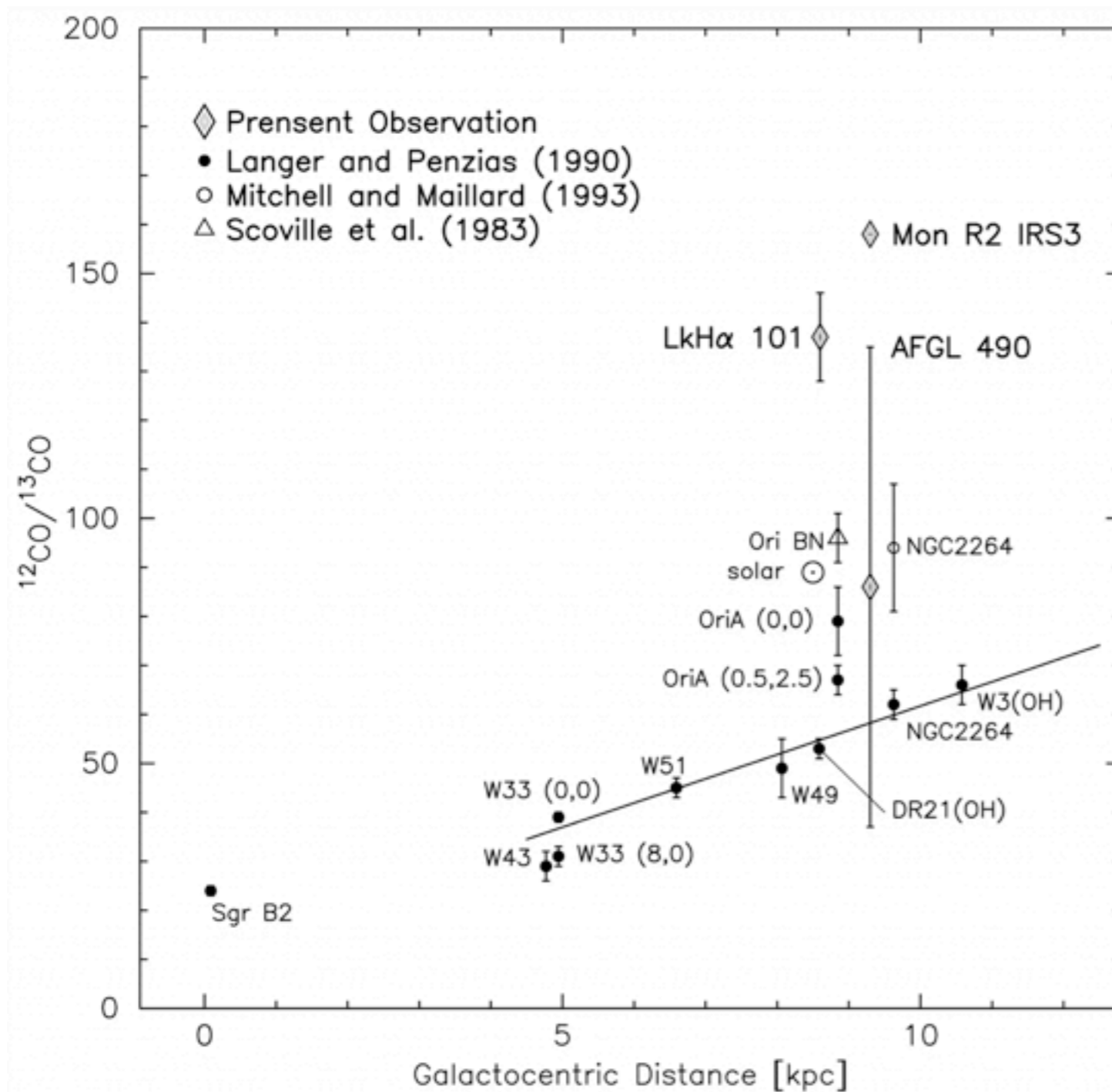
$$\zeta > 1.2 \times 10^{-15} \text{ cm s}^{-1}$$

$k_L = 2 \times 10^{-9} \text{ cm}^3 \text{ s}^{-1}$
(Langevin Rate)

Dense and high ζ gas
x-ray from Sgr A*?
(Yusef-Zadeh et al .2003)

Isotope Ratio

potentially a good index of the distance from the Galactic center

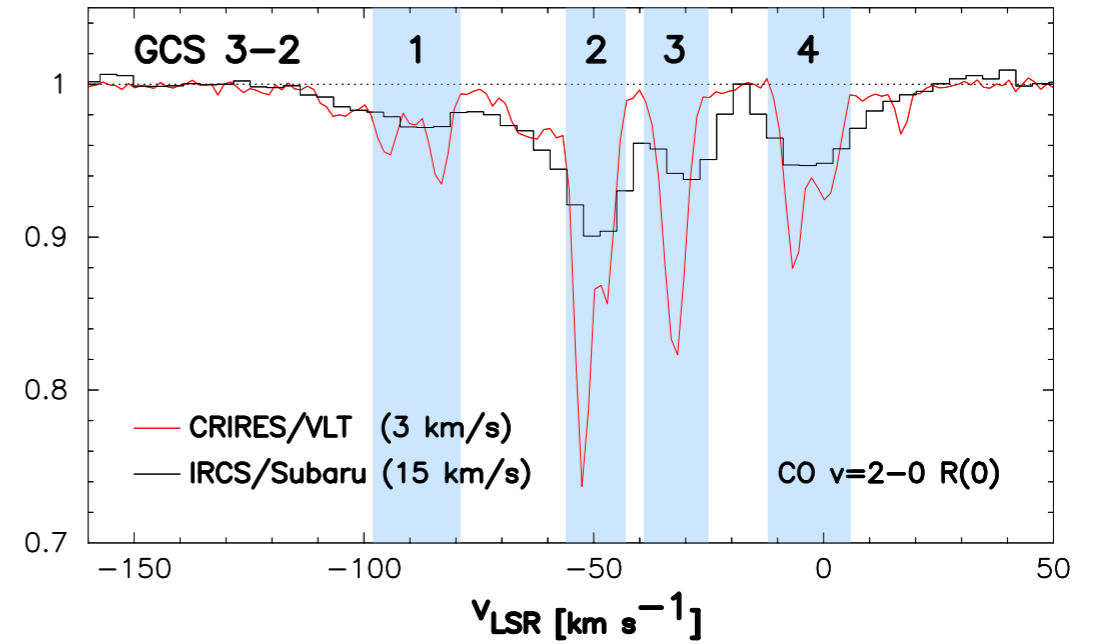
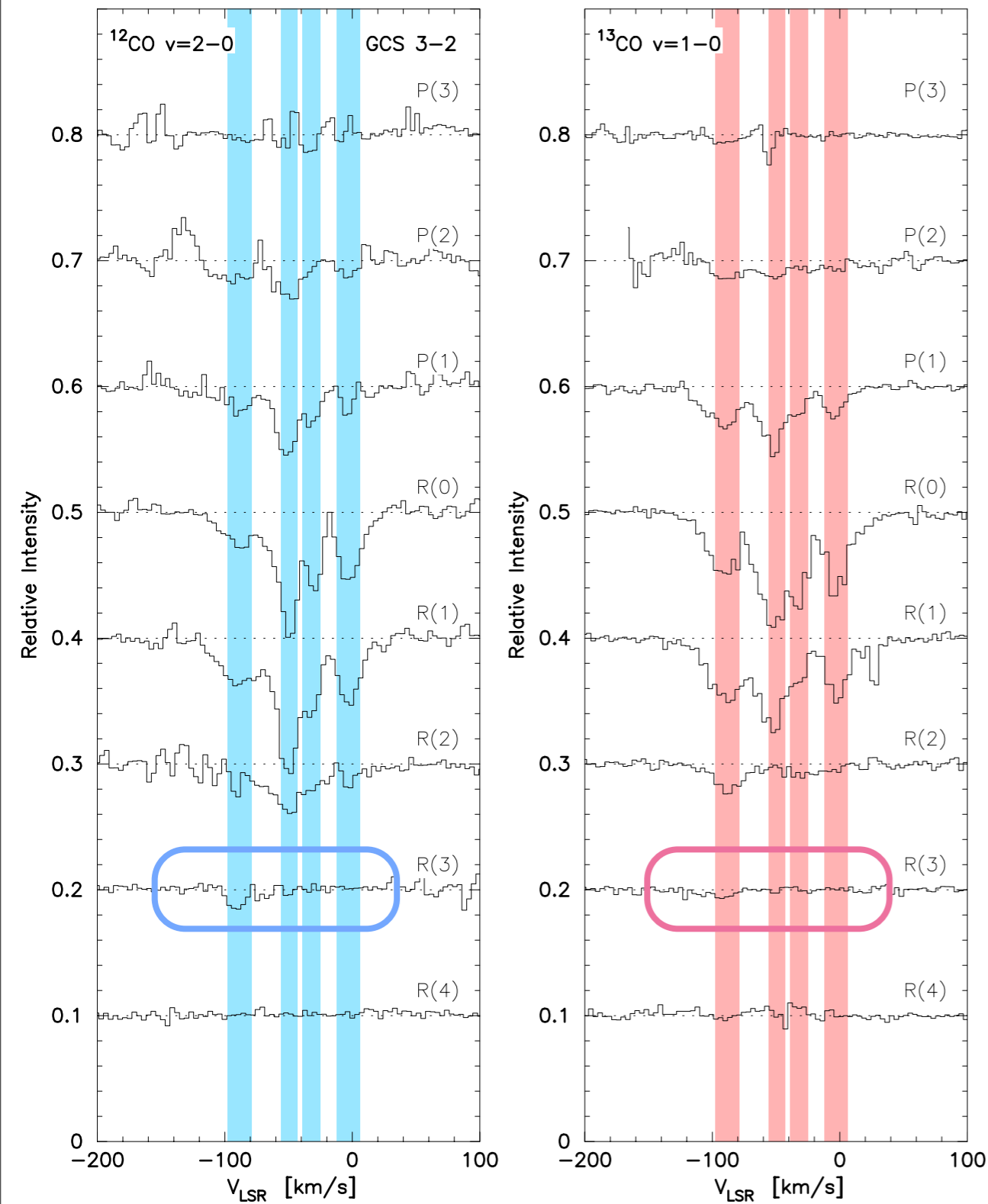


Isotope Ratio + Temperature

$^{12}\text{CO } v=2-0$

$^{13}\text{CO } v=1-0$

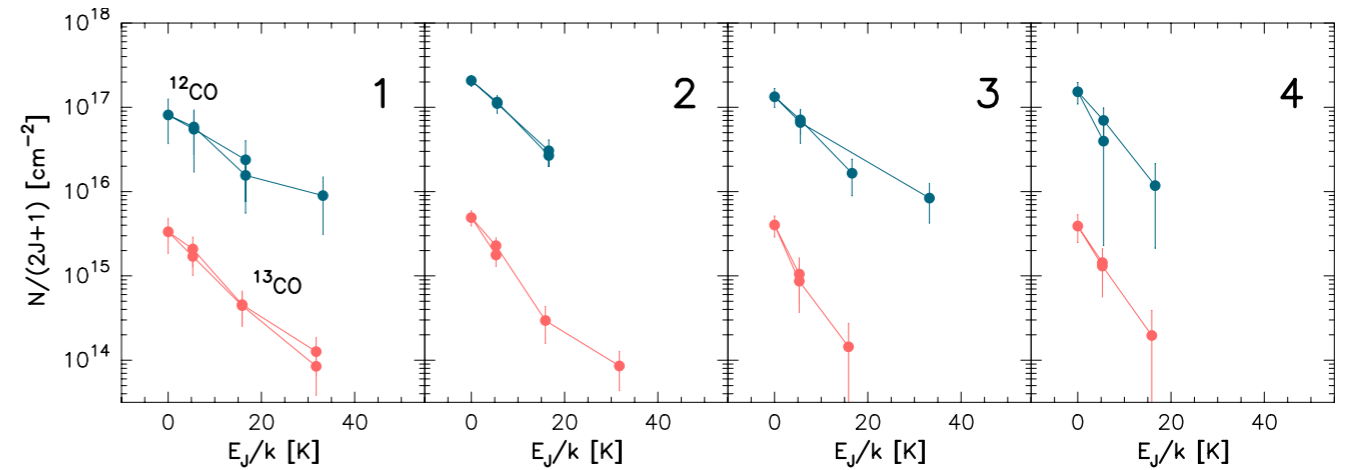
Subaru/IRCS
(x1/5 velocity resolution)



$T_{\text{ex}} = 14 \text{ K} \quad 8.3 \text{ K} \quad 11 \text{ K} \quad 6 \text{ K}$

$^{12}\text{CO}/^{13}\text{CO} =$

25 49 32 39



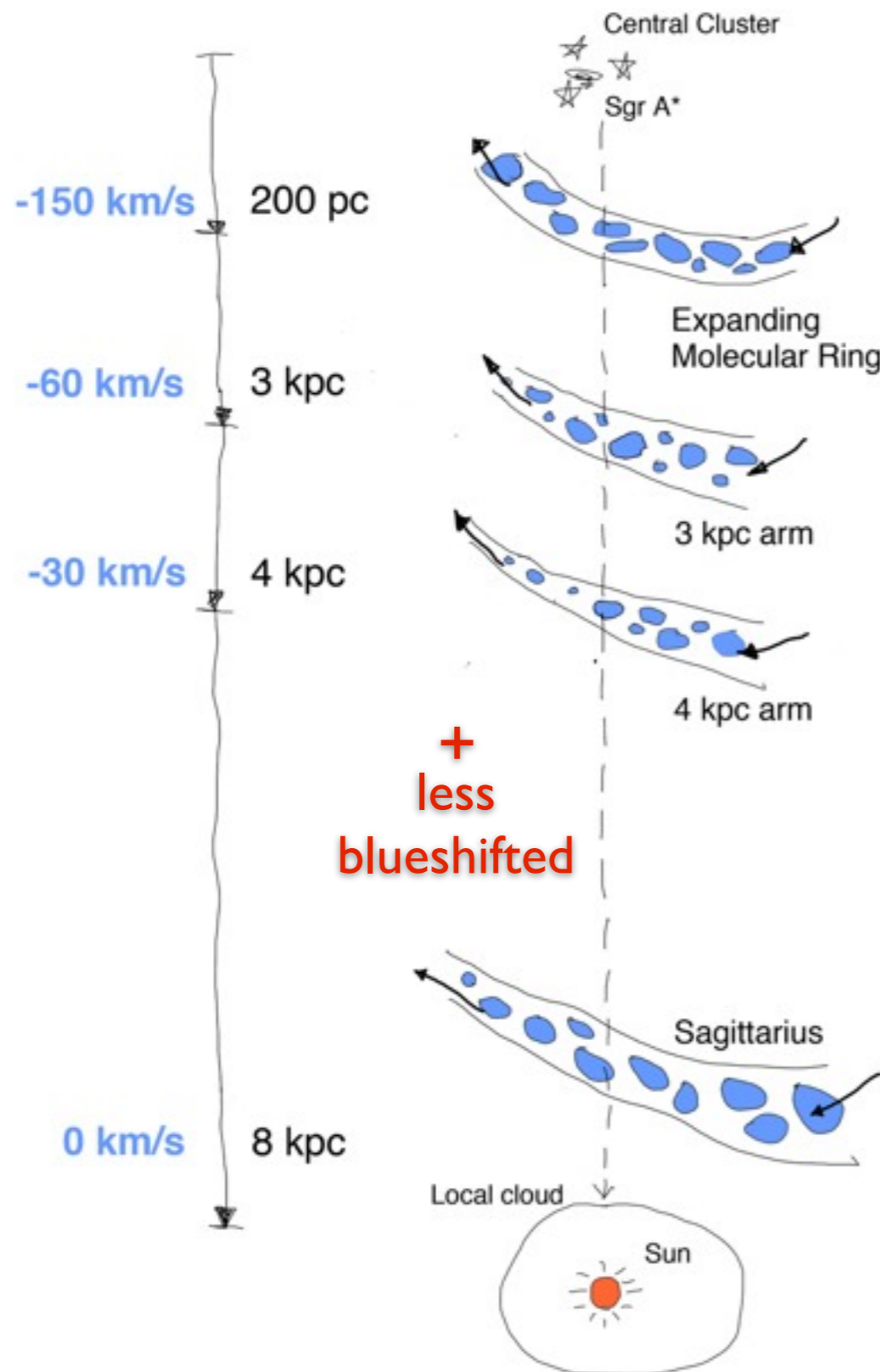
GC

3 kpc

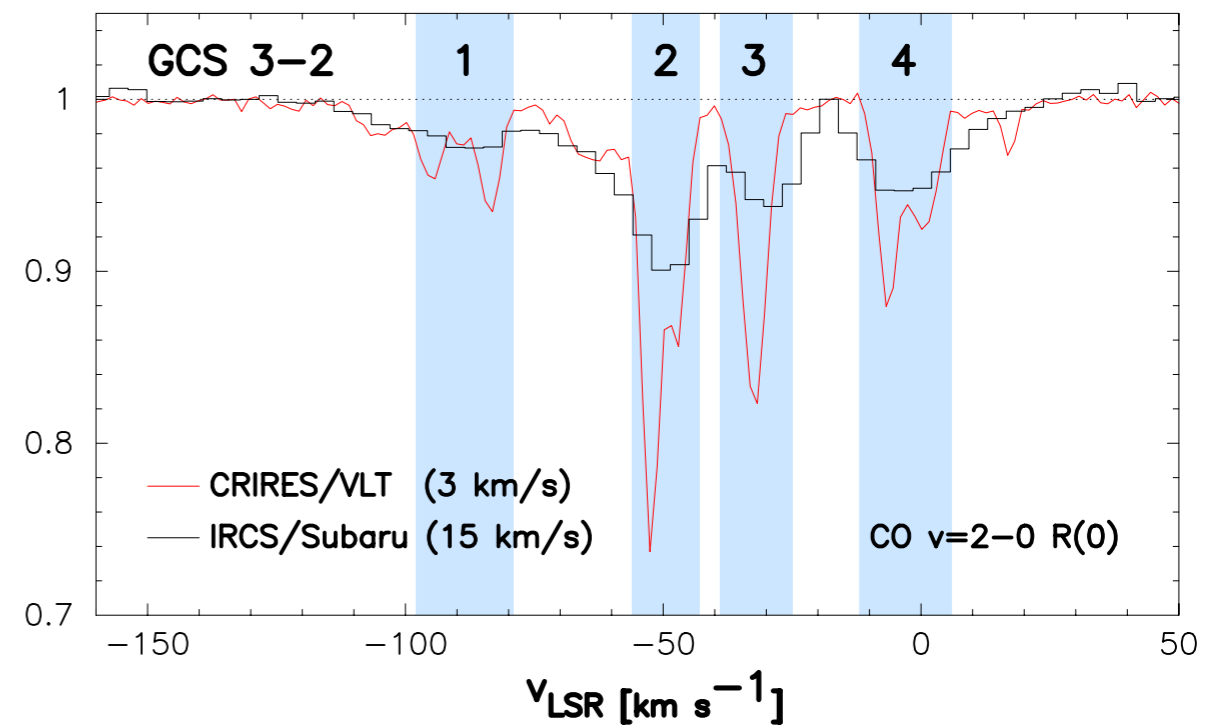
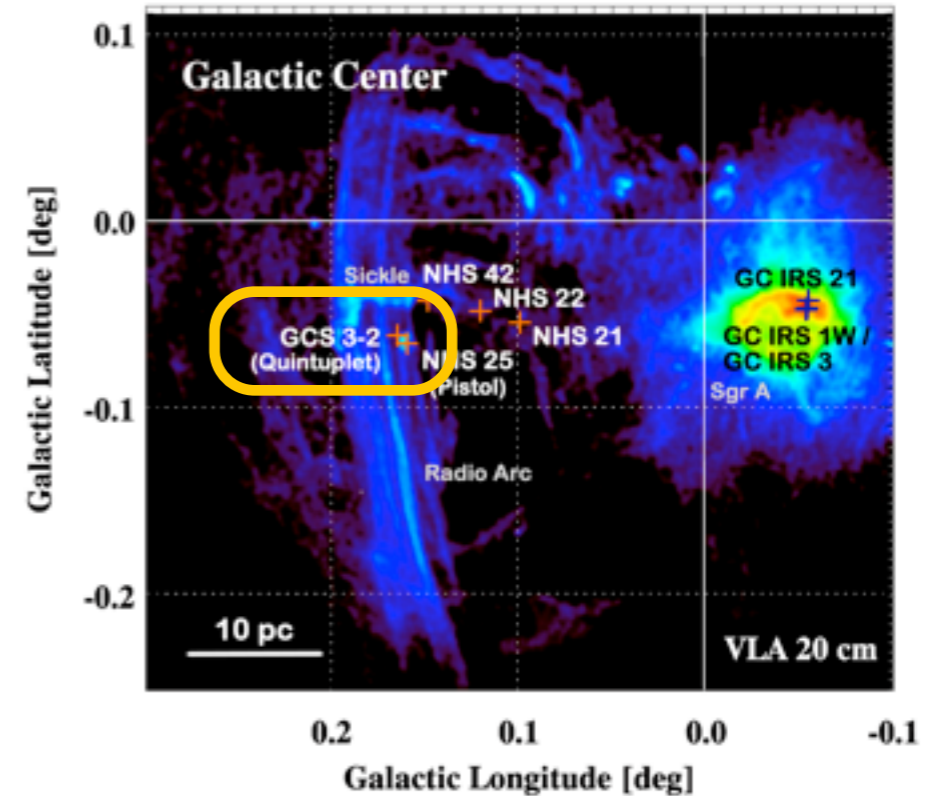
4 kpc

GC +
solar local

Expanding Molecular Ring

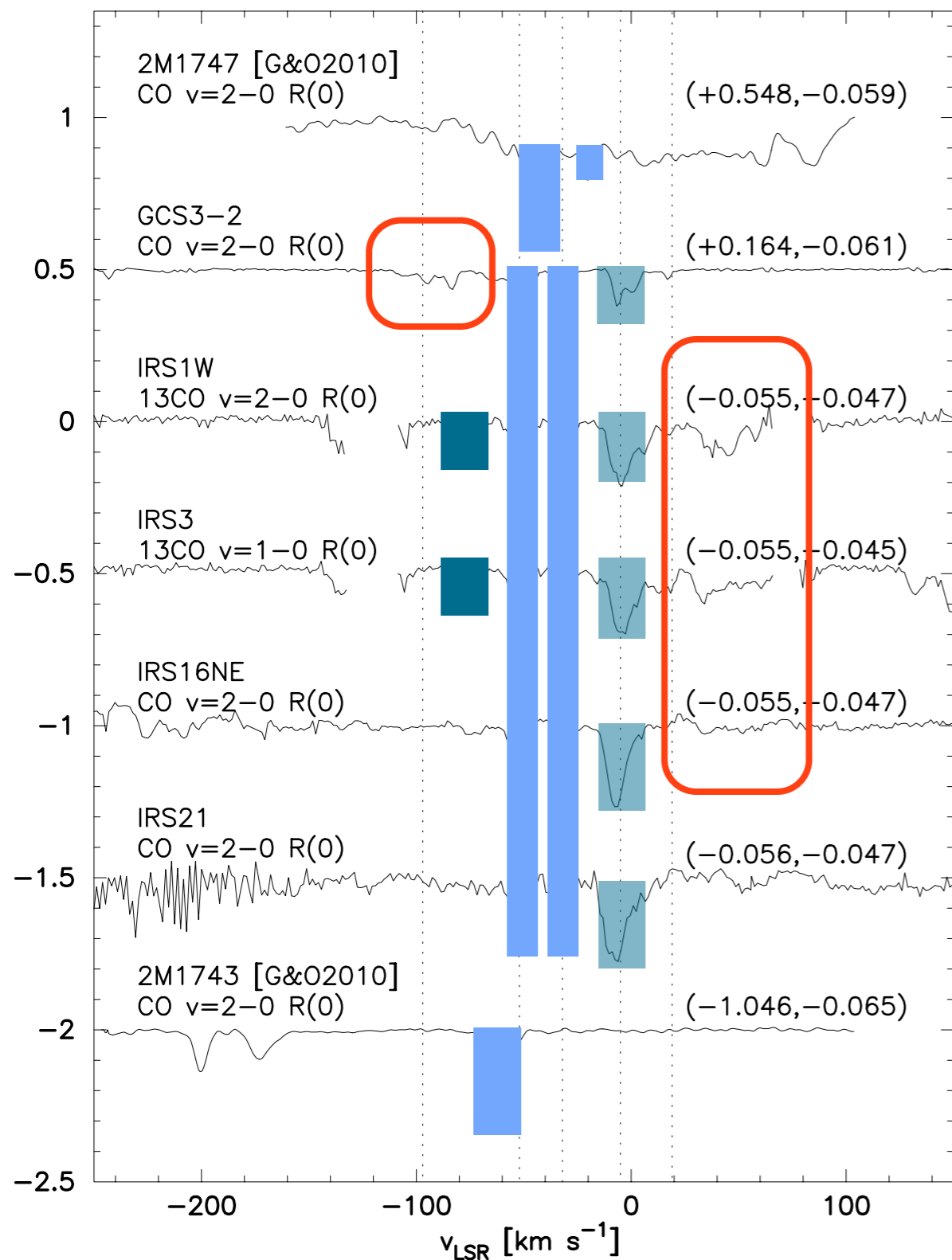


Radial expansion velocity -150 km/s



can be Expanding Molecular Ring

Large part of CO in foreground



$N(^{12}\text{CO}) =$

GCS 3-2 **Expanding Molecular Ring**
 $4.9 \times 10^{17} \text{ cm}^{-2}$
 (-98 → -79 km/s)

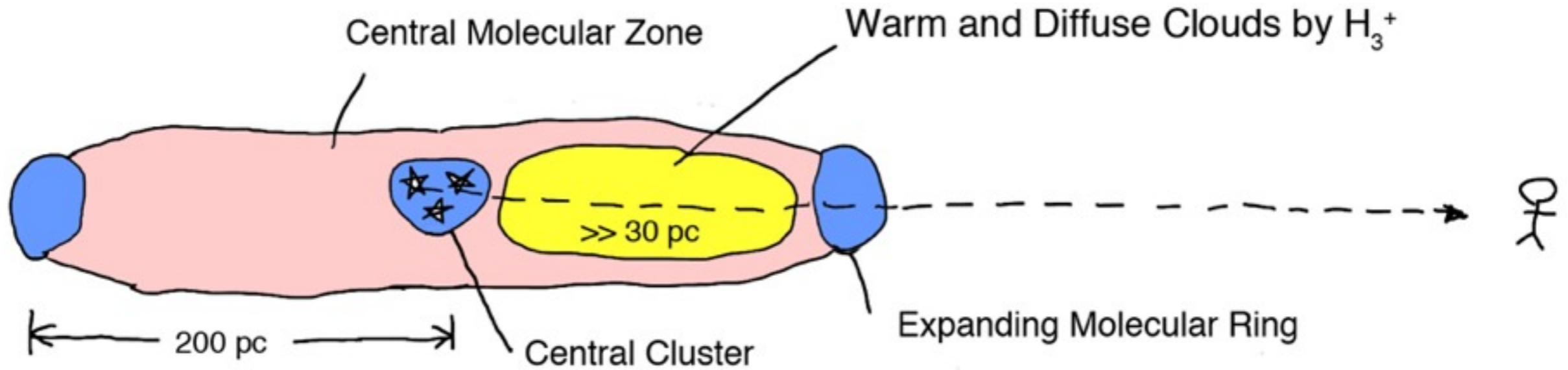
IRS1W **Central Cluster**
 $2.7 \times 10^{18} \text{ cm}^{-2*}$
 (-20 → +64 km/s)

IRS3 **Central Cluster**
 $3.8 \times 10^{18} \text{ cm}^{-2*}$
 (-20 → +85 km/s)

IRS16NE **Central Cluster**
 $3.9 \times 10^{18} \text{ cm}^{-2}$
 (-38 → +85 km/s)

* Converted to $N(^{12}\text{CO})$
 assuming $^{12}\text{CO}/^{13}\text{CO} = 25$

Molecules (CO) are in Core and Skin



$\times 10^4$



$$N(\text{CO}) = 4 \times 10^{18} \text{ cm}^{-2}$$

$$N(\text{H}_2) = 4 \times 10^{22} \text{ cm}^{-2}$$

$$5 \times 10^{17} \text{ cm}^{-2}$$

$$5 \times 10^{21} \text{ cm}^{-2}$$

submm spectroscopy (by Tomoharu Oka)

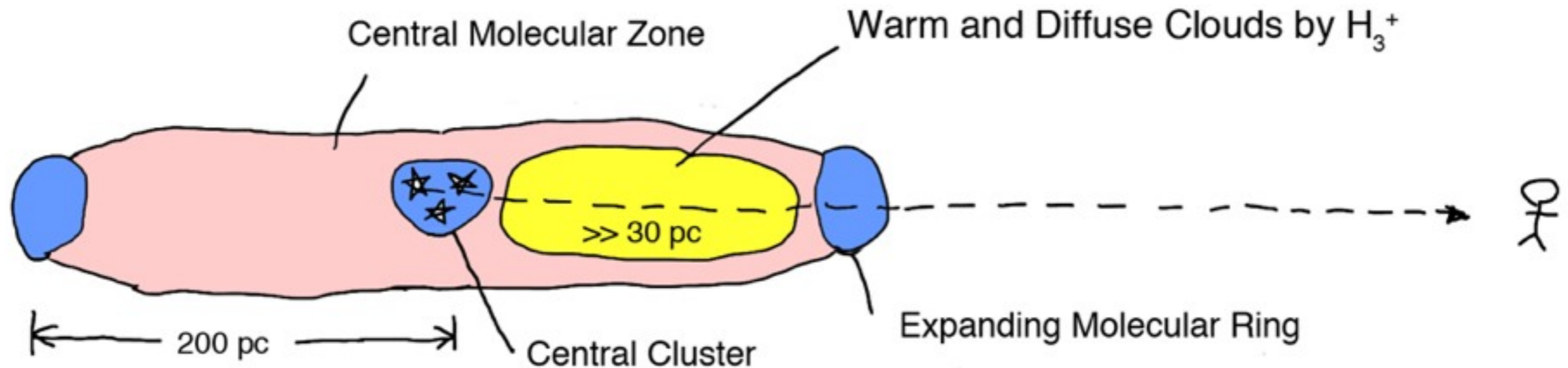
$$n(\text{H}_2) = 300 \text{ cm}^{-3}$$

$$f(\text{H}_2) = 0.1, L = 20 \text{ pc}$$

$$N(\text{H}_2) = 2 \times 10^{22} \text{ cm}^{-3}$$

corresponds to the lowest estimate of $M(\text{H}_2)$ in CMZ : $4 \times 10^7 M_{\odot}$

Conclusion



- Warm and Diffuse cloud found by H₃⁺ is a new population in the GC
- Long pathlength of the cloud does not conflict with CO in the Central Molecular Zone
- Because CO is mostly near the Galactic Nucleus, or the surface of the CMZ, likely in the Expanding Molecular Ring.
- CO and H₃⁺ present one consistent picture in the medium in the GC

Thanks for your attention

The Galactic Center

