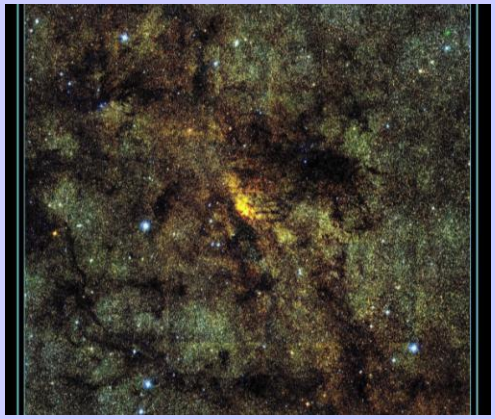
Exploring the Central Molecular Zone of the Galaxy using Infrared Spectroscopy of H_3^+ and CO

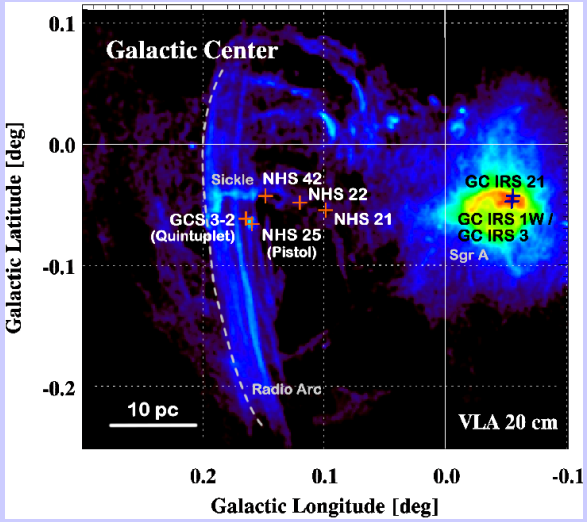
Tom Geballe, Gemini Observatory

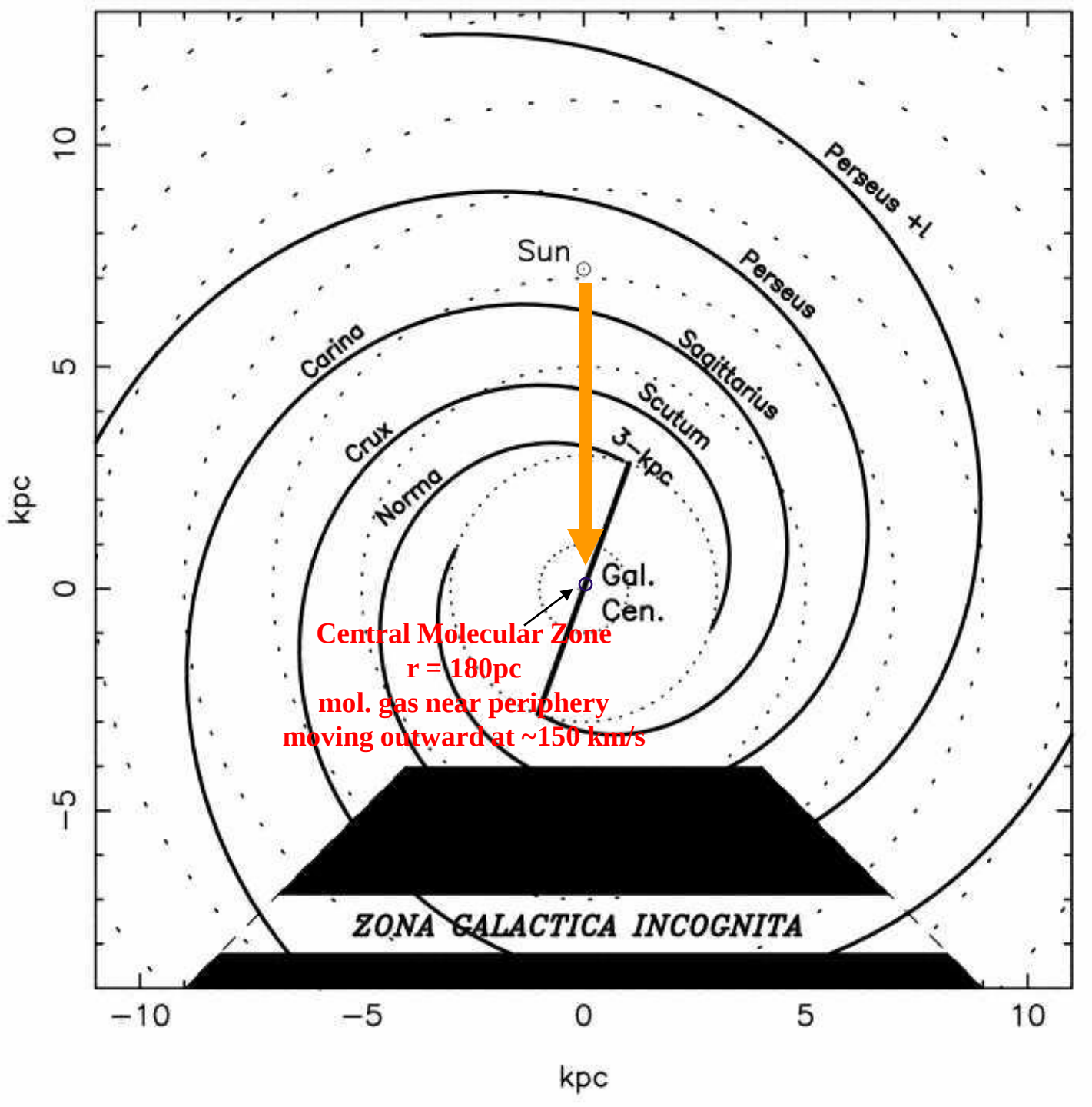
(with thanks to Takeshi Oka, Nick Indriolo, Ben McCall, and Miwa Goto)

The GC contains:

1. Massive (4x 10^6 M_{sun}) black hole
2. Densest cluster of stars in the Galaxy (~10^6 M_{sun} pc^{-3})
3. Several clusters of massive, hot young stars - one cluster surrounds the b.h., two located ~ 30 pc distant.
4. Large amounts of ionized, atomic, and molecular gas (10% of the neutral gas in the entire galaxy) and dust, interacting with gravitational field, stellar winds, SNRs, magnetic fields, and itself.

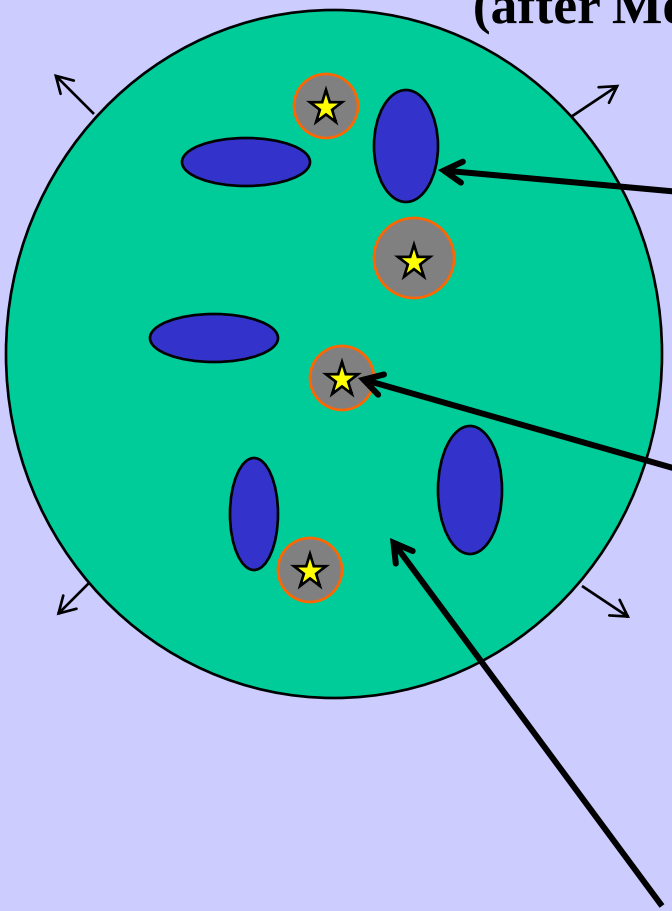




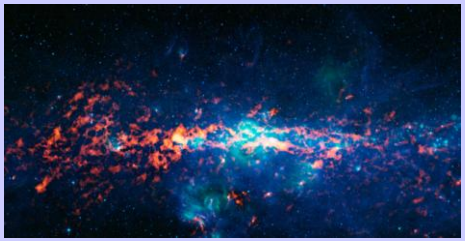

Perseus +l
Perseus
Sagittarius
Scutum
3–kpc
Norma
Crux
Carina
Sun
Gal.
Cen.
Central Molecular Zone
r = 180pc
mol. gas near periphery
moving outward at ~150 km/s
ZONA GALACTICA INCOGNITA
10
5
0
−5
kpc
−10
−5
0
5
10
kpc


WHAT ARE THE
MAJOR GASEOUS
ENVIRONMENTS
IN THE CMZ?
Spitzer + VLA

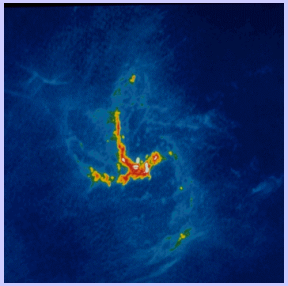
Gaseous environments in the CMZ
(after Morris & Serabyn 1996; Lazio & Cordes 1998)



Dense Mol. Clouds
(e.g., Sgr B)
f ~ 0.1



Ionized gas T~10^4 K
e.g. Sgr A West
f ~ 0.1



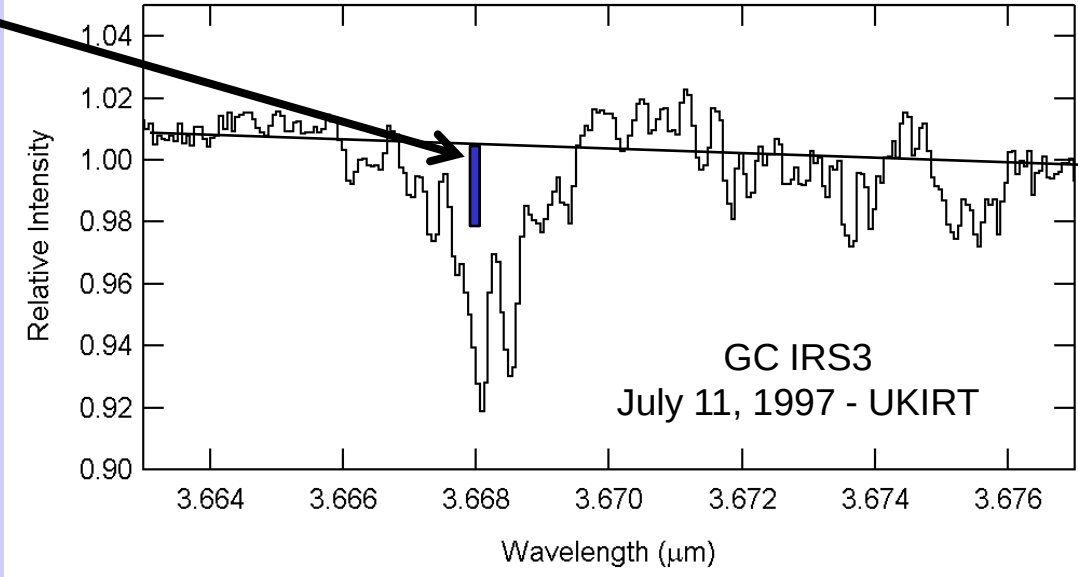
X-ray emitting plasma T~10^{7-8} K
(Diffuse X-ray emission seen by early space telescopes covered a large fraction of the CMZ.
f ~ 0.8

REASONS TO REVISIT THAT VIEW OF THE CMZ

1. Chandra found that much of the extended emission is due to point sources.

2. Amount of H_3^+ in GC is inconsistent with molecular cloud environment.

(typical strength of H_3^+ absorption in a molecular cloud with A_V~30 mag)



IN WHAT PHYSICAL ENVIRONMENT IS ALL OF THIS EXTRA H_3^+ LOCATED ?

To find the answer we have been making more detailed spectra of H_3^+ and comparing them with spectra of CO on the same sightlines.

(UKIRT(CGS4), Gemini (Phoenix&GNIRS), Subaru(IRCS), VLT(CRIRES))

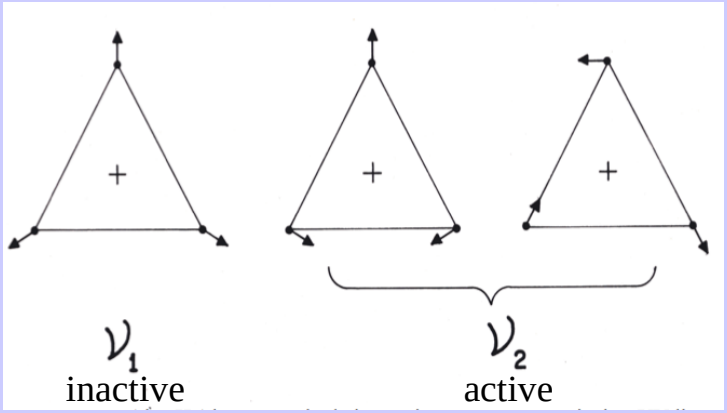
SALIENT FEATURES OF H_3^+

Production by ionization of H_2

H_2 + c.r. → H_2^+ + e ($\zeta \sim 3 \times 10^{-17}$ sec^{-1} in dense clouds)

followed by ion molecule reaction

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



Destruction in dense clouds (mostly) by

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

Destruction in diffuse clouds by diss. recomb.

$H_3^+ + e \rightarrow H_2 + H$ (or H+H+H)

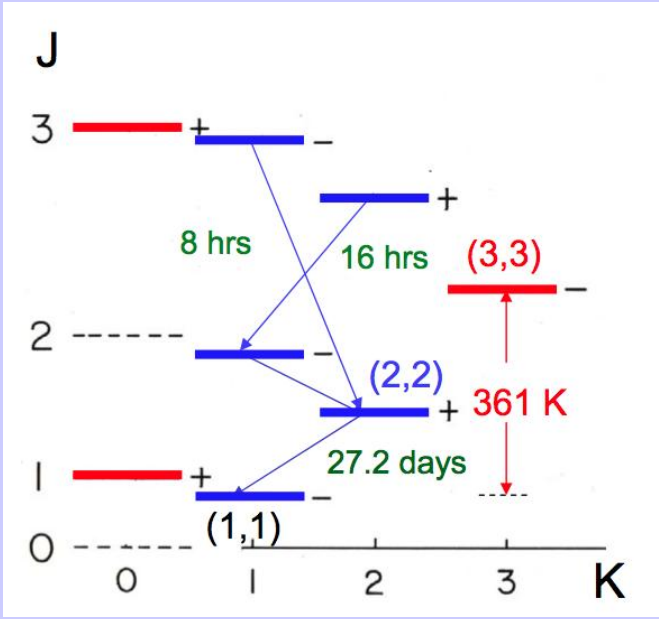
Reaction rates are known. If [CO]/[H_2] or [C/H_2] is known, ***a measurement of N(H_3^+) yields ζL.***

Spectrum:

No rotational spectrum

No electronic spectum

Only IR vib-rot (fundamental band at 3.5-4.0 microns).



Populated states:

Normally only the lowest ortho and para levels are populated.

(2,2) is 250K above (1,1); metastable (3,3) is 361K above (1,1).

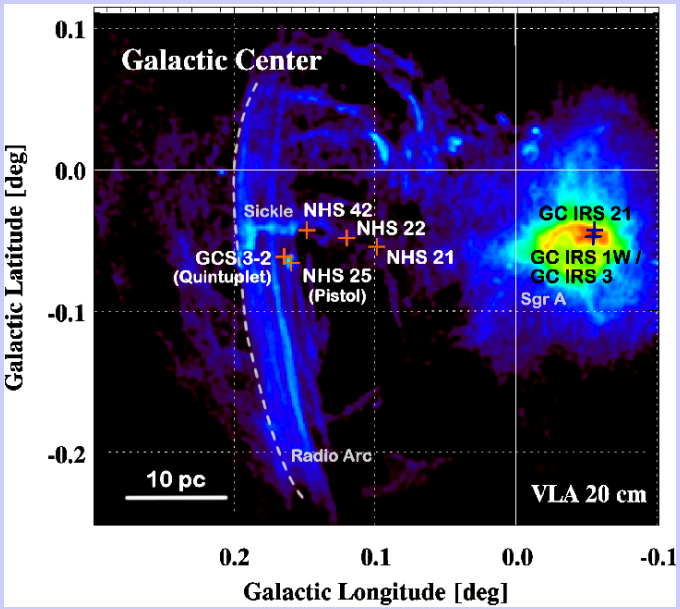
- ***H_3^+ can only be observed in absorption.***
- **H_3^+ lines are weak – thus need bright background sources with smooth spectra.**

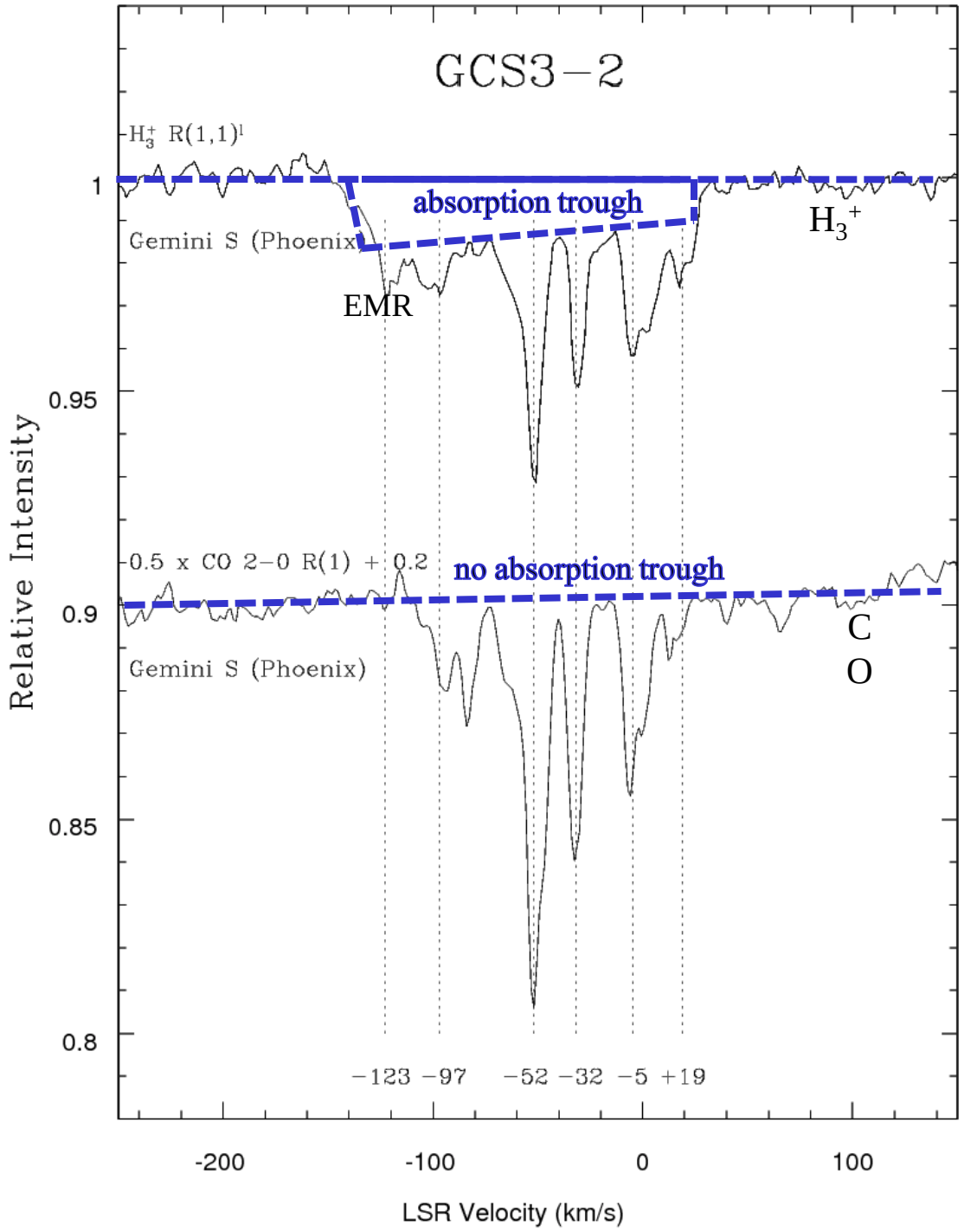
EVIDENCE FOR DIFFUSE GAS

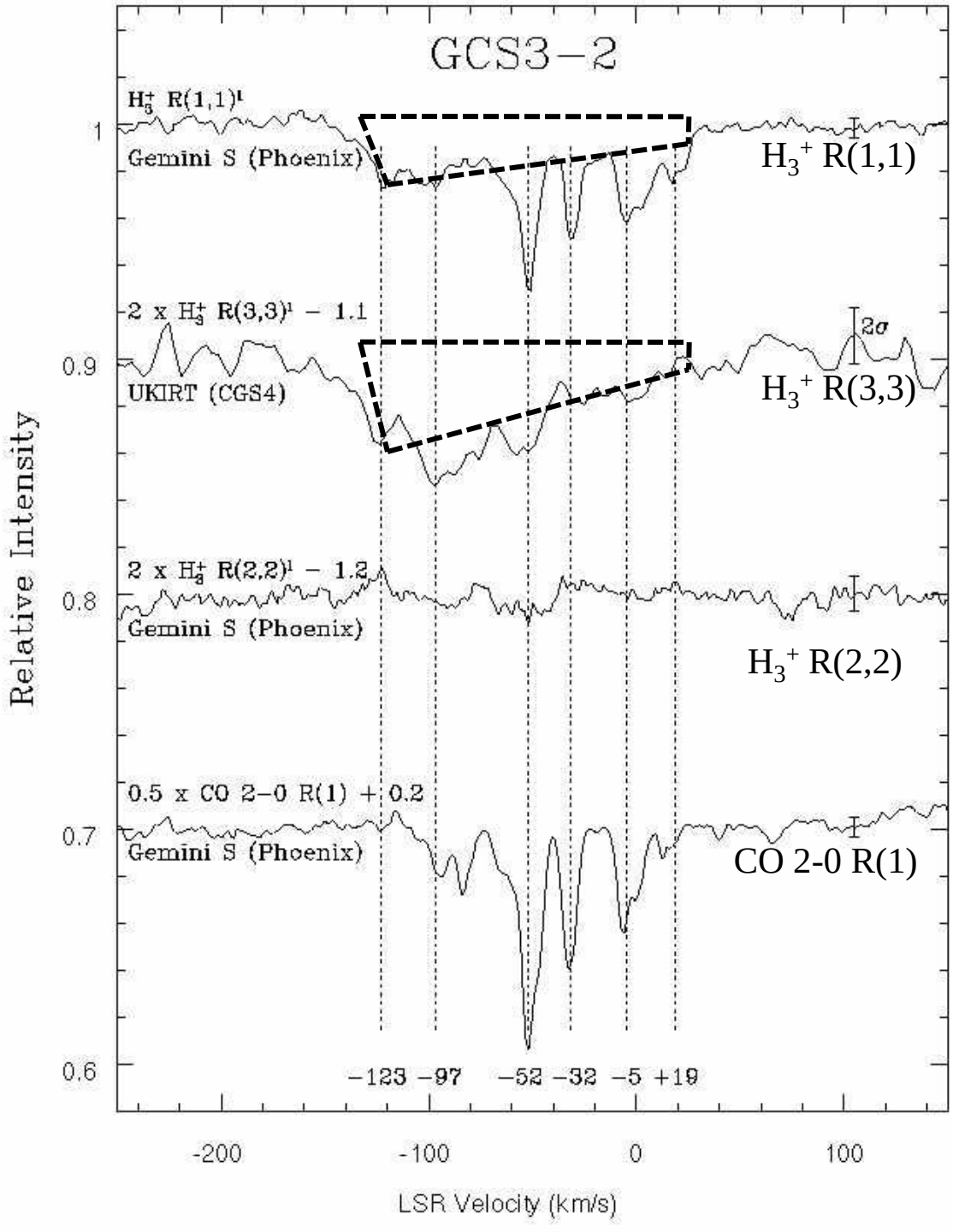
comparison of low lying H_3^+ and CO line profiles toward GCS3-2 (typical of all sightlines toward Central and Quintuplet clusters)

150 km/s wide trough of absorption by H_3^+ in low-lying rotational levels of v=0; has no counterpart in CO

➔Trough cannot arise in dense clouds where both H_3^+ and large amounts of CO are present. Must arise in diffuse gas, but where?







DIFFUSE GAS IS IN THE CMZ

Suggested by wide velocity extent.

But also:

Profile of line from metastable (3,3) (361 K above lowest level): similar to R(1,1) wedge; ratio of wedges ➔ T ~ 250 K

➔Gas must be in the CMZ

No absorption in unstable (2,2) level, 250 K above lowest level; .

➔ $n \leq 100$ cm^{-3}

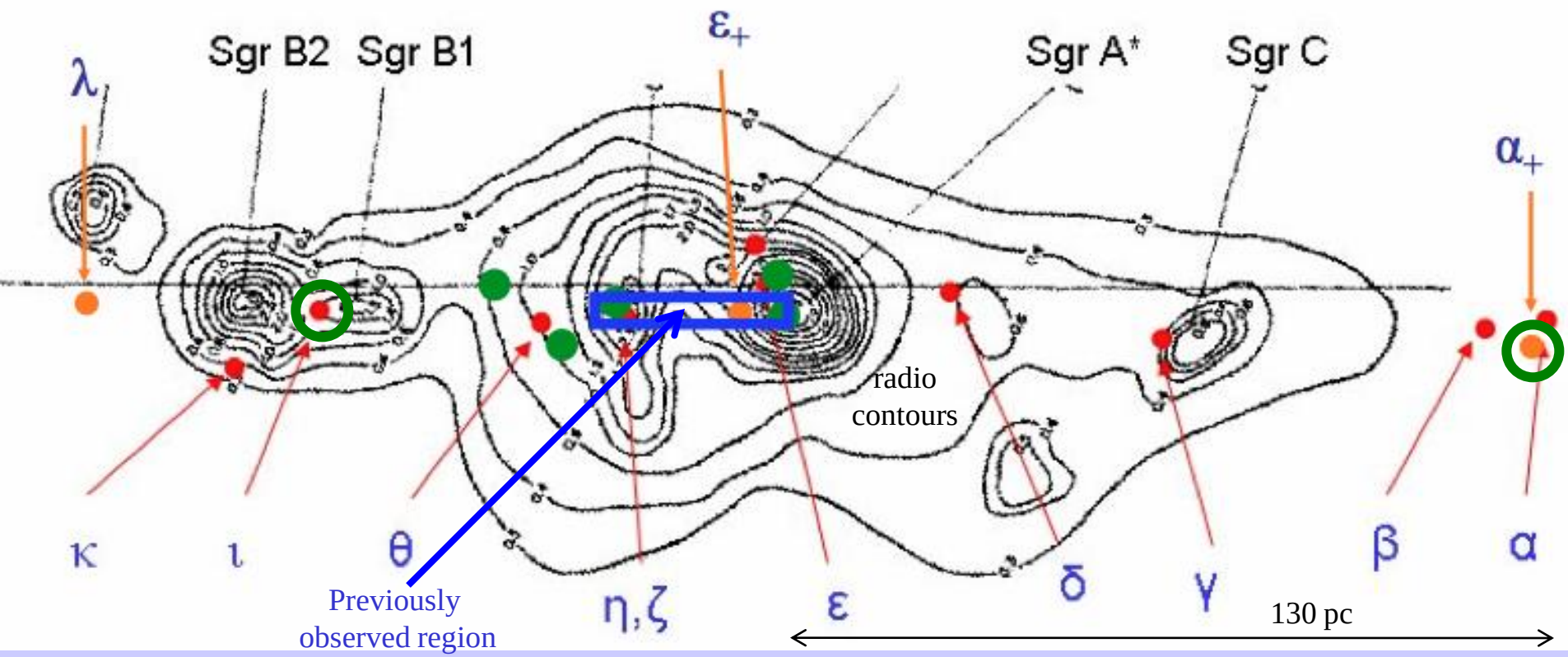
➔Diffuse

N(warm diffuse H_3^+) ~ 3×10^{15} cm^{-2} (v large)
Suggests long path lengths (10s of pc).

These are sightlines near Sgr A* and 30pc E.

How ubiquitous is warm diffuse gas in the CMZ?

HOW WIDESPREAD IS THE WARM DIFFUSE GAS IN THE CMZ ?

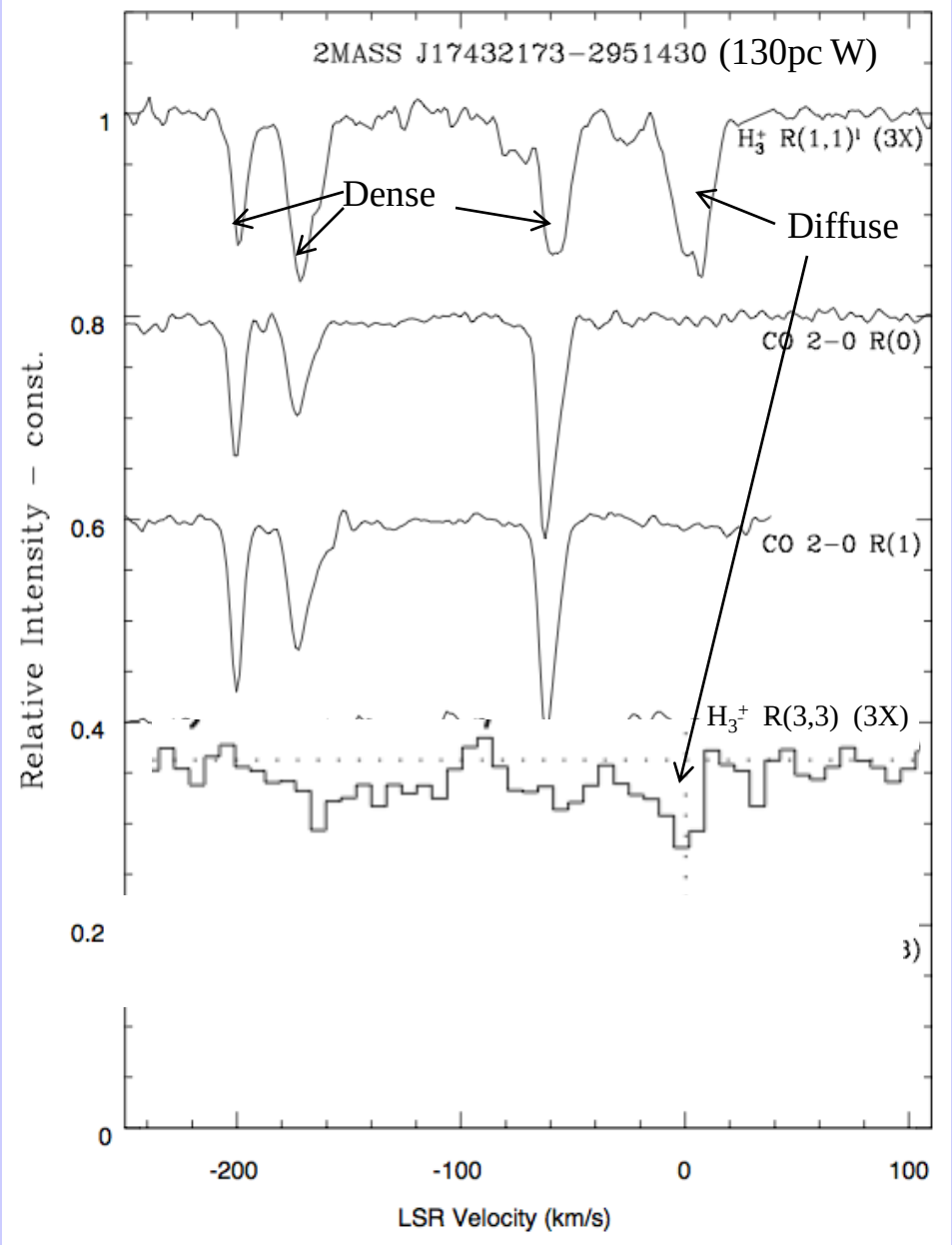


Need to find stars in or behind the CMZ that allow spectroscopy of the weak H_3^+ lines. (bright and with featureless spectra – not red giants).

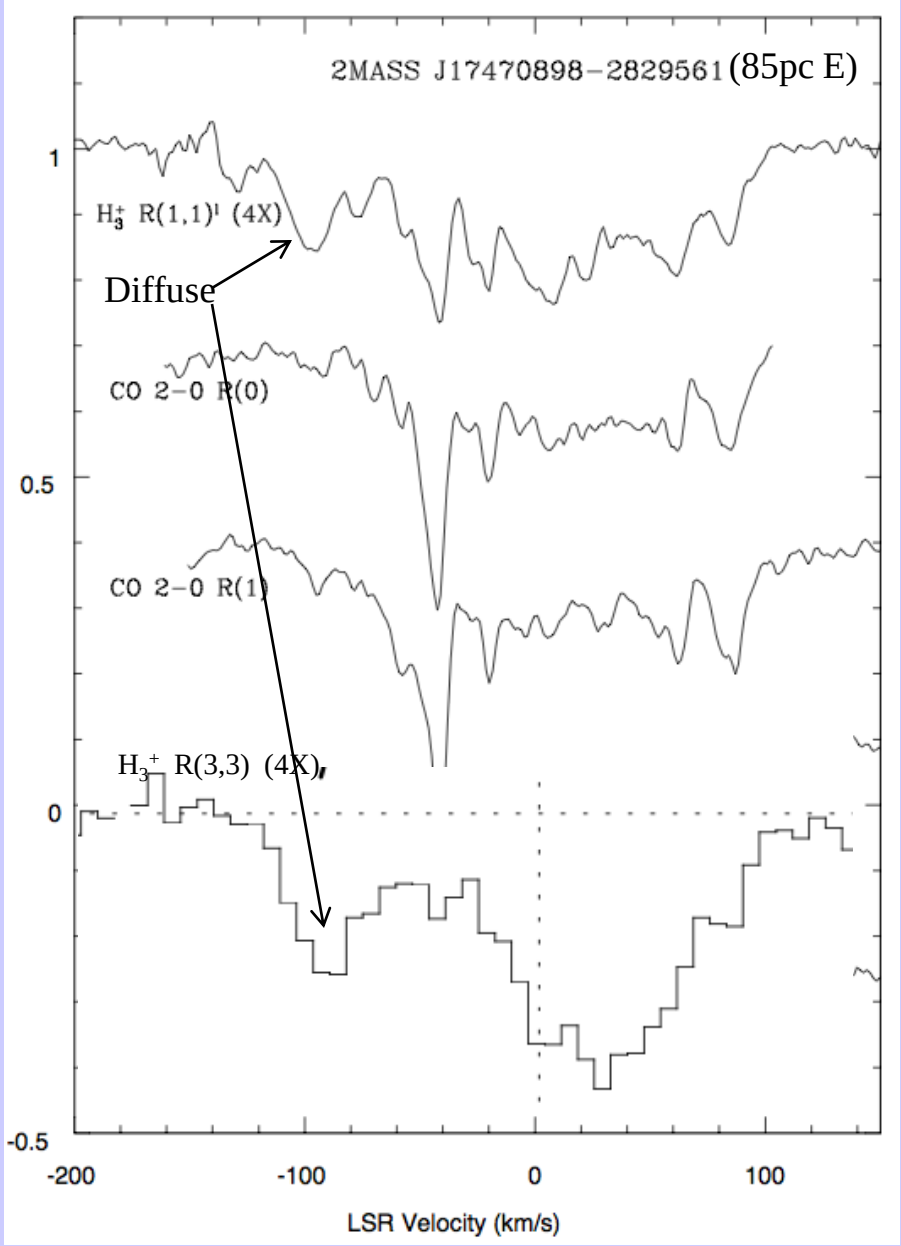
None previously known except in Central Cluster and clusters 30 pc E.

Use Spitzer & 2MASS catalogues to identify candidates.

Most are duds (RGs); some of remainder are in foreground, but a few are in or behind the CMZ.



Diffuse gas near $v_{LSR} = 0$
as expected if in CMZ
(gas motions should be largely in the plane of the sky)



Strongest H_3^+ absorption detected to date
Source probably located in Sgr B (first near IR source?)
Foreground diffuse gas near -100 km/s (as expected)

Results so far are consistent with the warm and diffuse gas present on all sightlines through the CMZ.

More sightlines needed.

H_3^+ COLUMN LENGTH AND IONIZATION RATE

$$\zeta \approx 2k_e\, N(H_3^+)\, [C^+/H] / f\, L$$

yields ζ L

(if we know f and [C/H])

f - assume 0.5

$[C^+/H]$ = C/H - 3 x Solar

(Sodroski et al. 1995; Arimoto, Sofue, & Tsujimoto 1996)

L - assume $0.5r_{CMZ}$ = 90 pc (ζ increases as L decreases)

Note:

ζ increases as f decreases.

ζ increases as [C/H] increases.

$\zeta \sim 2 \times 10^{-15}\ s^{-1}$

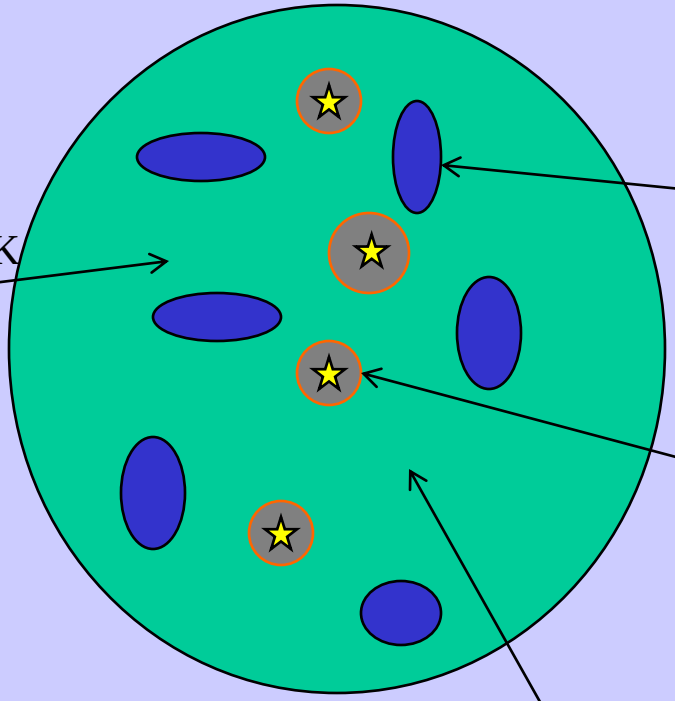
~5-10X higher than average value in Galactic diffuse clouds.

Especially impressive in view of the large dimensions of this region
(ζ is an average value over ~ 100pc)

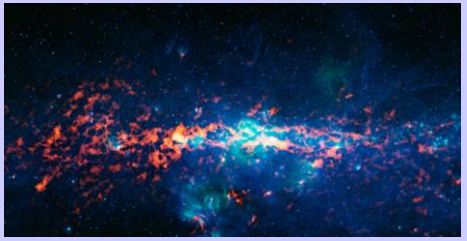
To maintain that high value over such a large region probably implies many nearby source(s) of low energy CR's (and X-rays).

(probably only possible in the Galactic center)

Current view of the CMZ

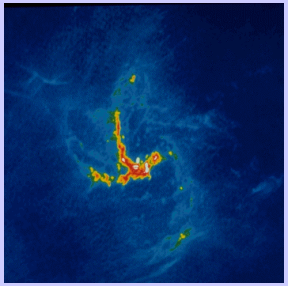


Molecular Clouds
(e.g., Sgr B2)
f ~ 0.1



X-ray plasma T~10^{7-8} K
f =?

Ionized gas T~10^{4} K
e.g. Sgr A West
f ~ 0.1



diffuse ISM, T~100 K
f =?

Based on:

(1) its presence on widely separated sightlines
(2) its presence at a wide range of velocities
(3) *its presence on many sightlines that do not include CMZ molecular clouds*

the warm and diffuse environment has a significant filling factor in the CMZ.

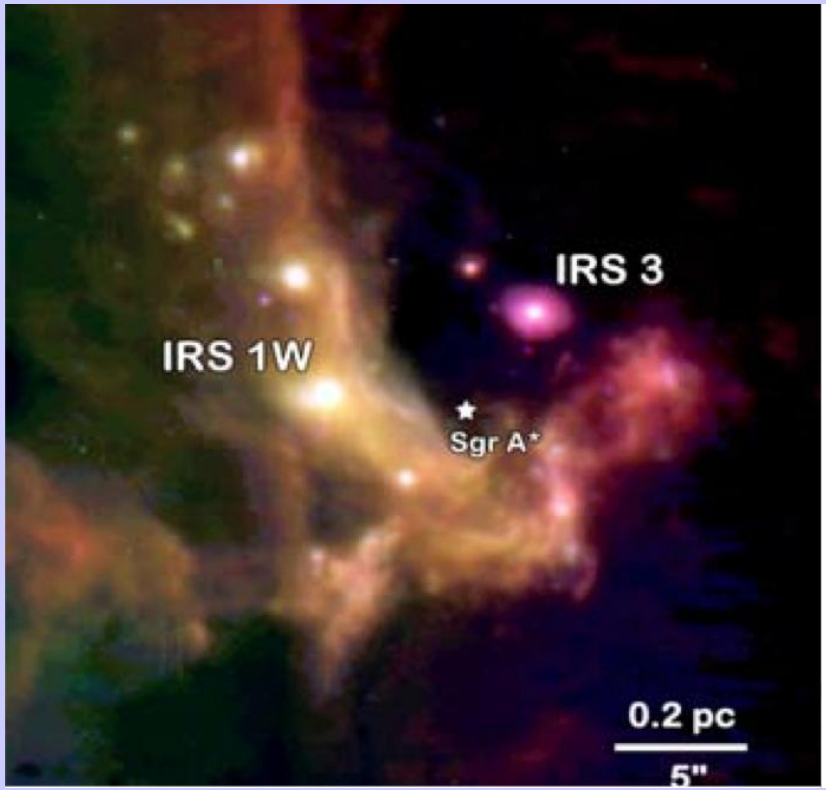
To do list

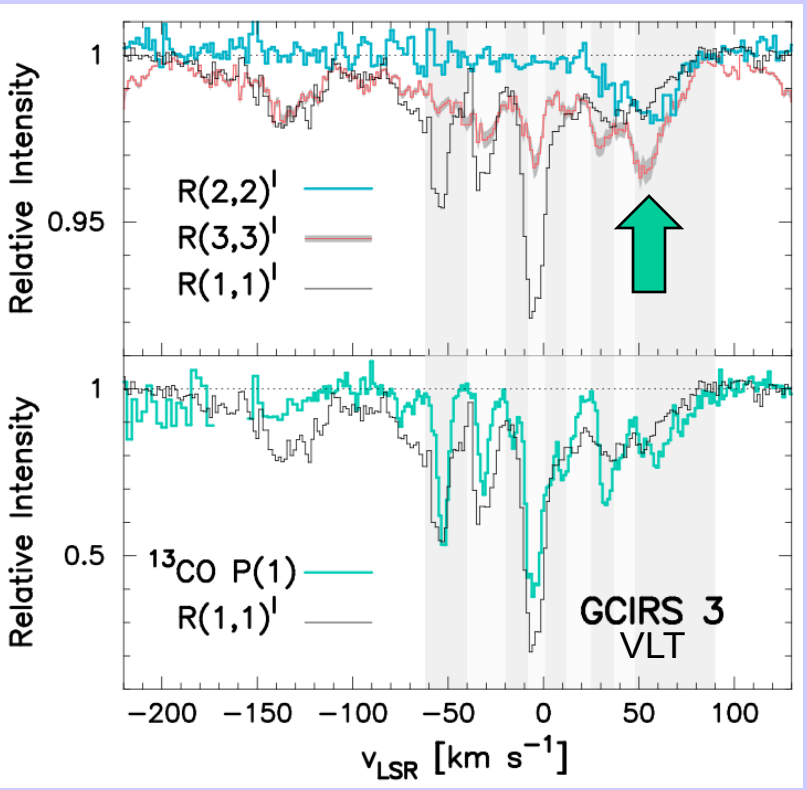
Identify and observe additional sightlines through the CMZ
in order to further constrain the extent of the diffuse gas.

Investigate sightlines close to diffuse cloud in front of GC/IRS3
(in Central Cluster near Sgr A*), which appears to have $\zeta \sim 2 \times 10^{-14}\ s^{-1}$.

Spitzer + VLA

The 60 km/s cloud in front of GC IRS3: A possible example of an extremely high ionization rate





- IRS3 – thought to be a member of the Central Cluster (closest bright compact source to Sgr A*)
- Only IRS3 spectra show the 60 km/s absorption (in CO and all three H_3^+ lines) - not seen toward nearby IRS1 & IRS2 suggests cloud is compact (< 1 pc)
- R(3,3) and R(2,2) imply higher density and temperature than elsewhere in the CMZ.

If IRS3 is indeed a member of the central cluster (rather than a background source behind a background cloud), ζ(60 km/s cloud) ~ 2 x 10^{-14} s^{-1} (Goto et al. 2007).

simple theory for H_3^+ may not apply in these extreme conditions