Herschel far-IR and submm spectroscopy of the Galactic Center

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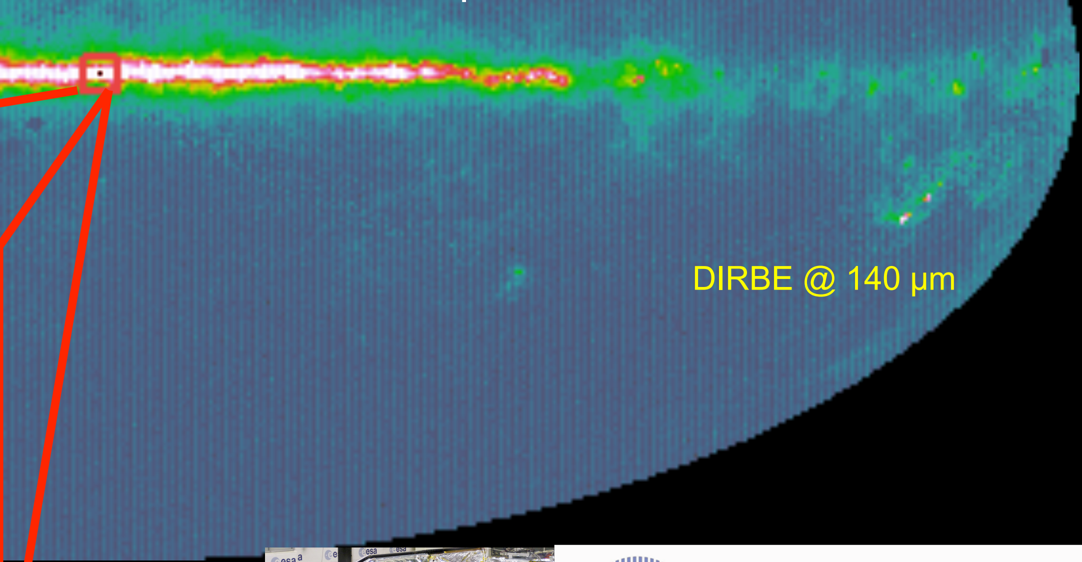
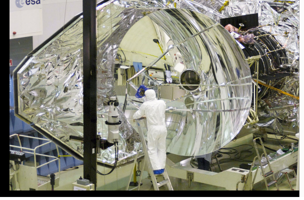
M. De Luca, P. Encrenaz, N. Indriolo, D.C. Lis, E. T. Polehampton, P. Sonnentrucker





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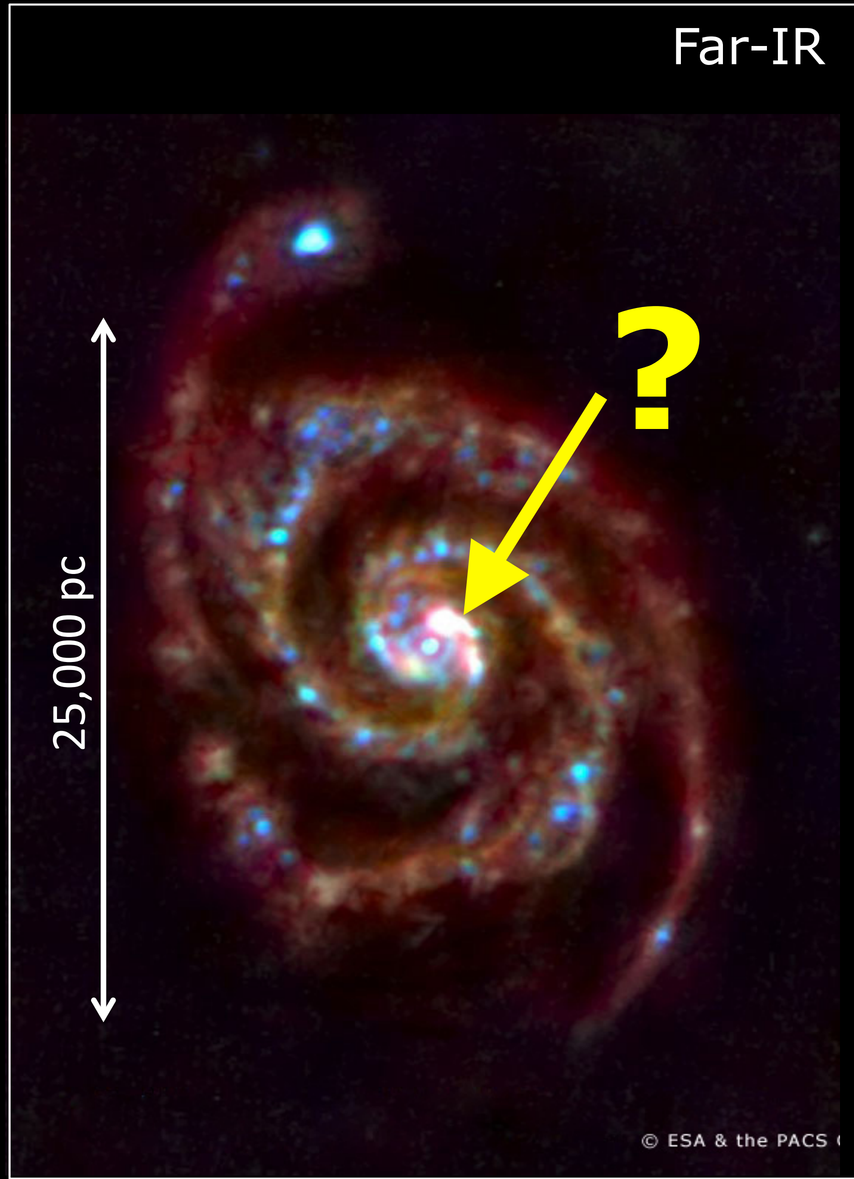
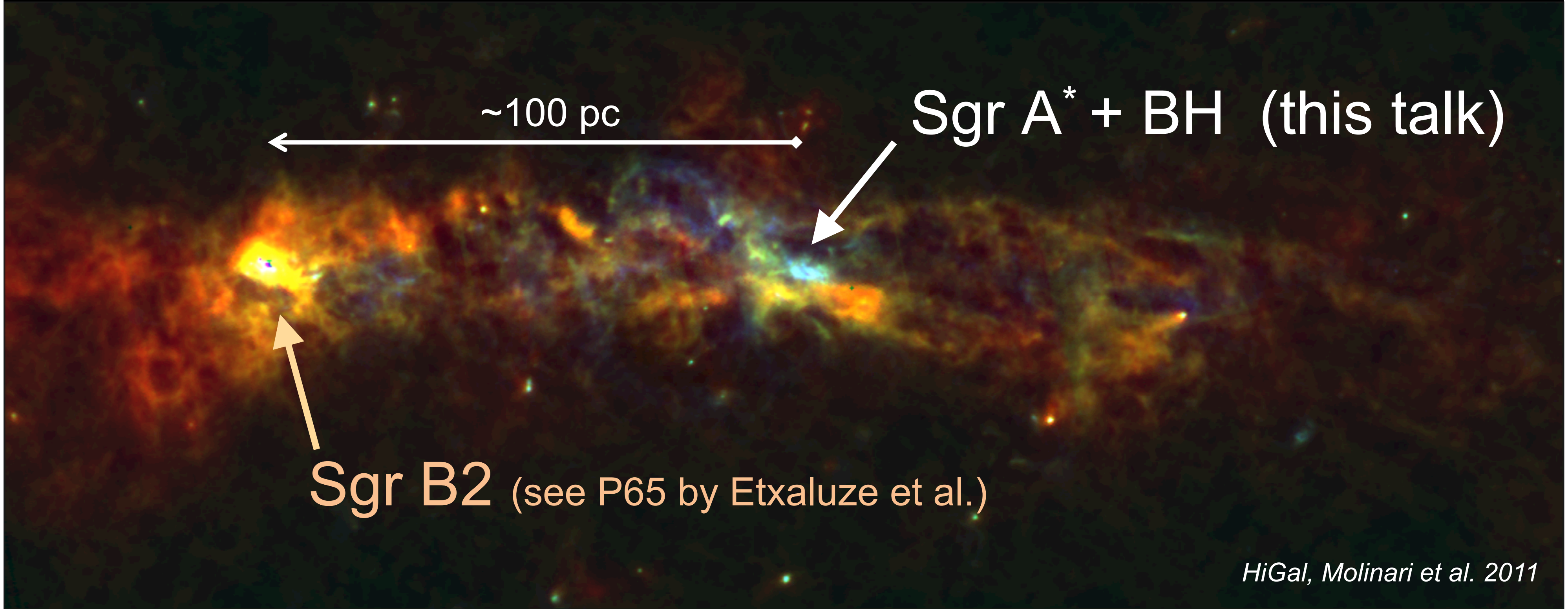
Spiral Galaxy M51 ("Whirlpool Galaxy")

NASA / JPL-Caltech / R. Kennicutt (Univ. of Arizona)



PACS 70/100/160

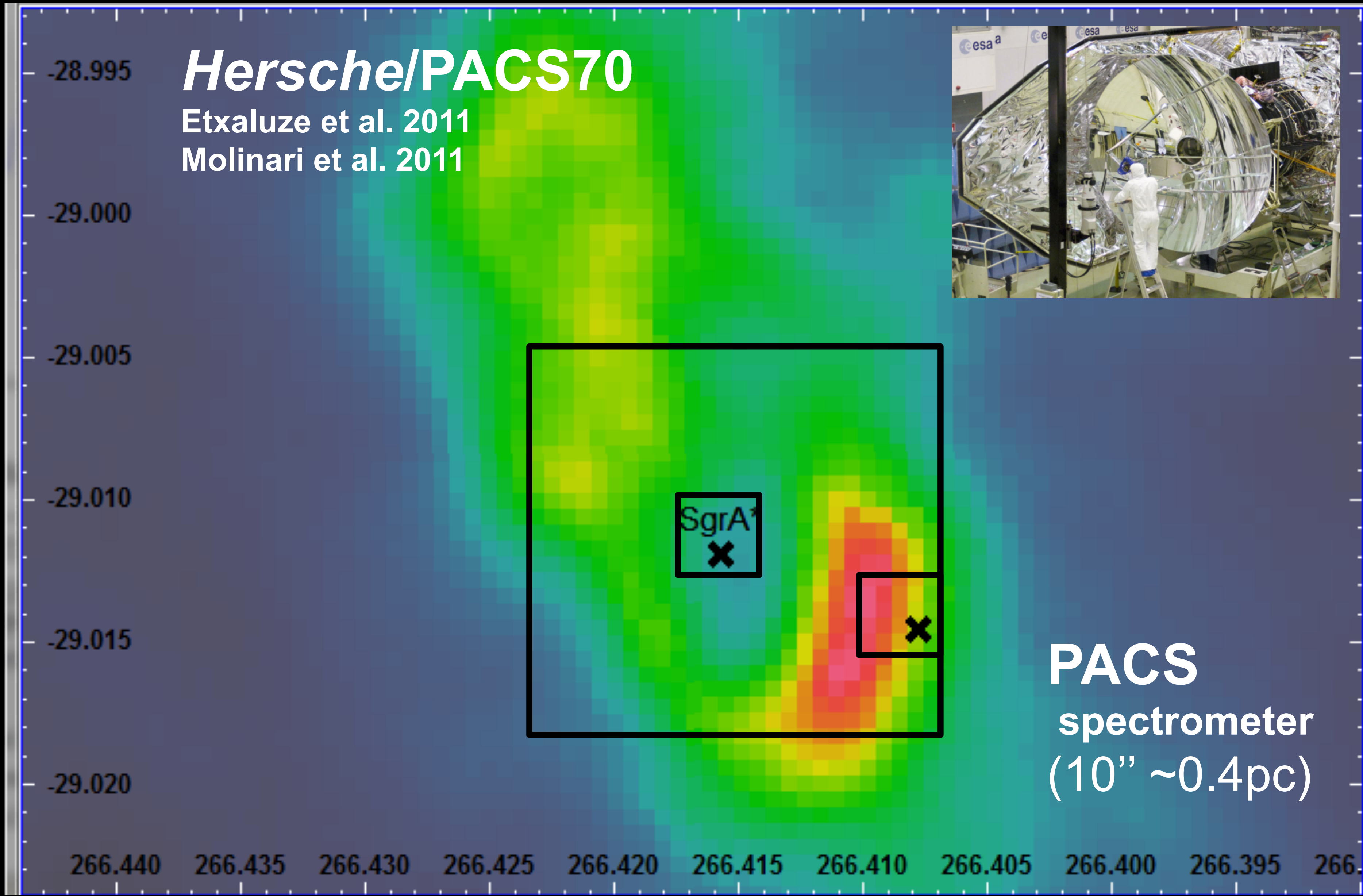
Herschel's far-IR view of the Galactic Center



- A few 100's times closer than the nearest AGN → high spatial resolution
- GC= 0.1% of the Galaxy volume but ~10% molecular gas mass
- GC ISM: on average higher n(H_2), T_k, Δv_{turb}, B, … gas heating mechanisms?

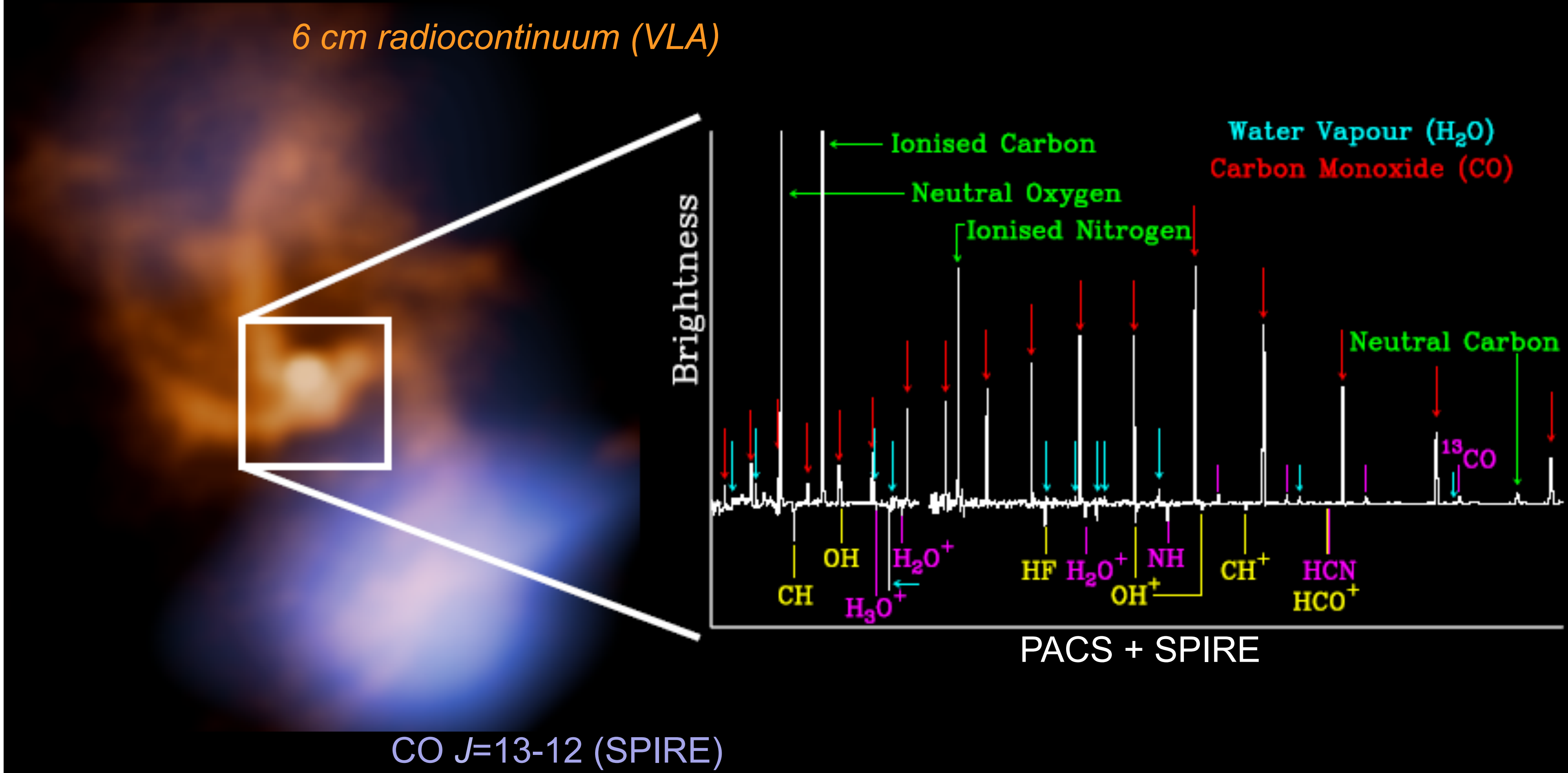
See reviews by Güsten et al. Genzel et al.

The inner central parsec of the Galaxy



Herschel PACS-SPIRE maps

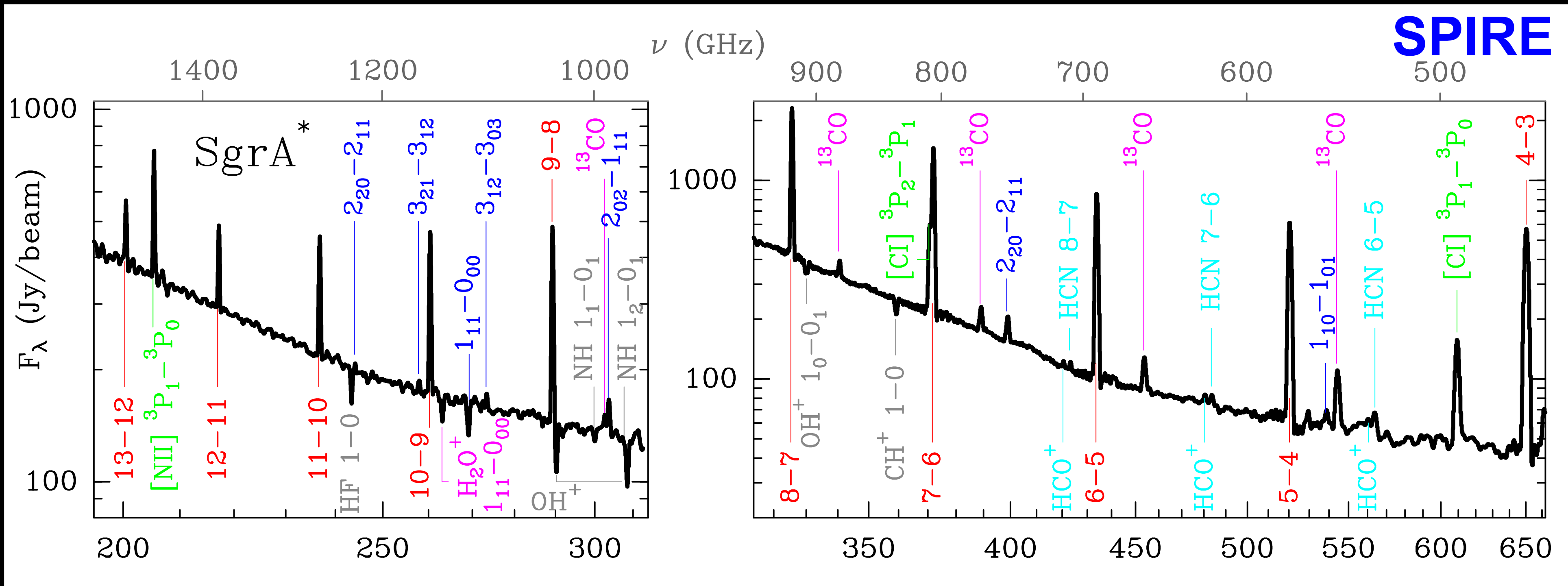
SgrA*, the central cavity and the CND



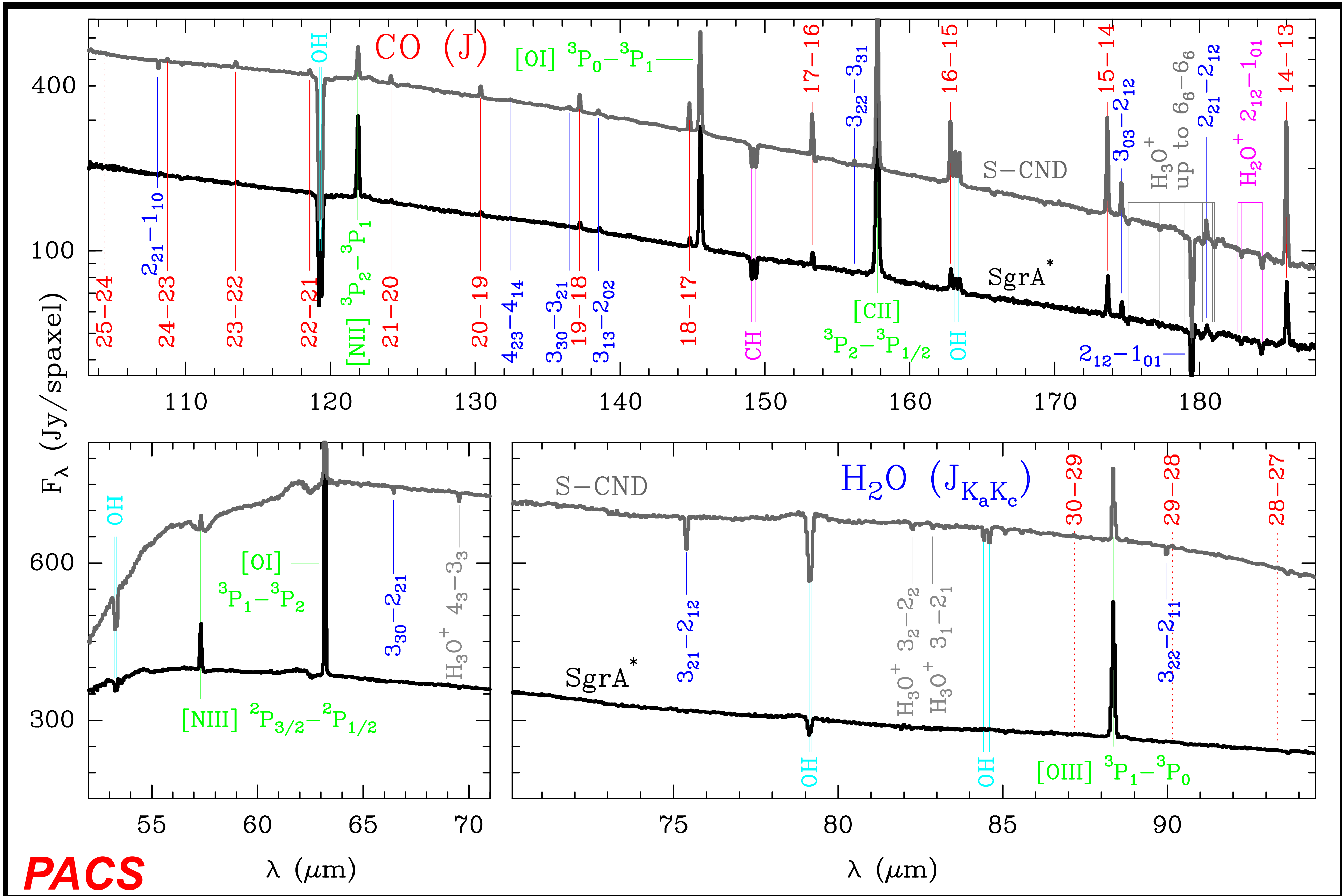
ESA Press release

*SPIRE+PACS spectrum towards SgrA**
(55-650um)

- Molecular lines of: OH^+, H_2O^+, H_3O^+, CH^+, HF, H_2O, OH, NH, NH_2, HCN, HCO^+…
- Atomic fine structure lines: [OIII], [OI], [CII], [NIII], [NII] and [CI]
- ^{12}CO rotational ladder (*J*=4-3 to 24-23 towards SgrA*, and *J*=30-29 towards CND)



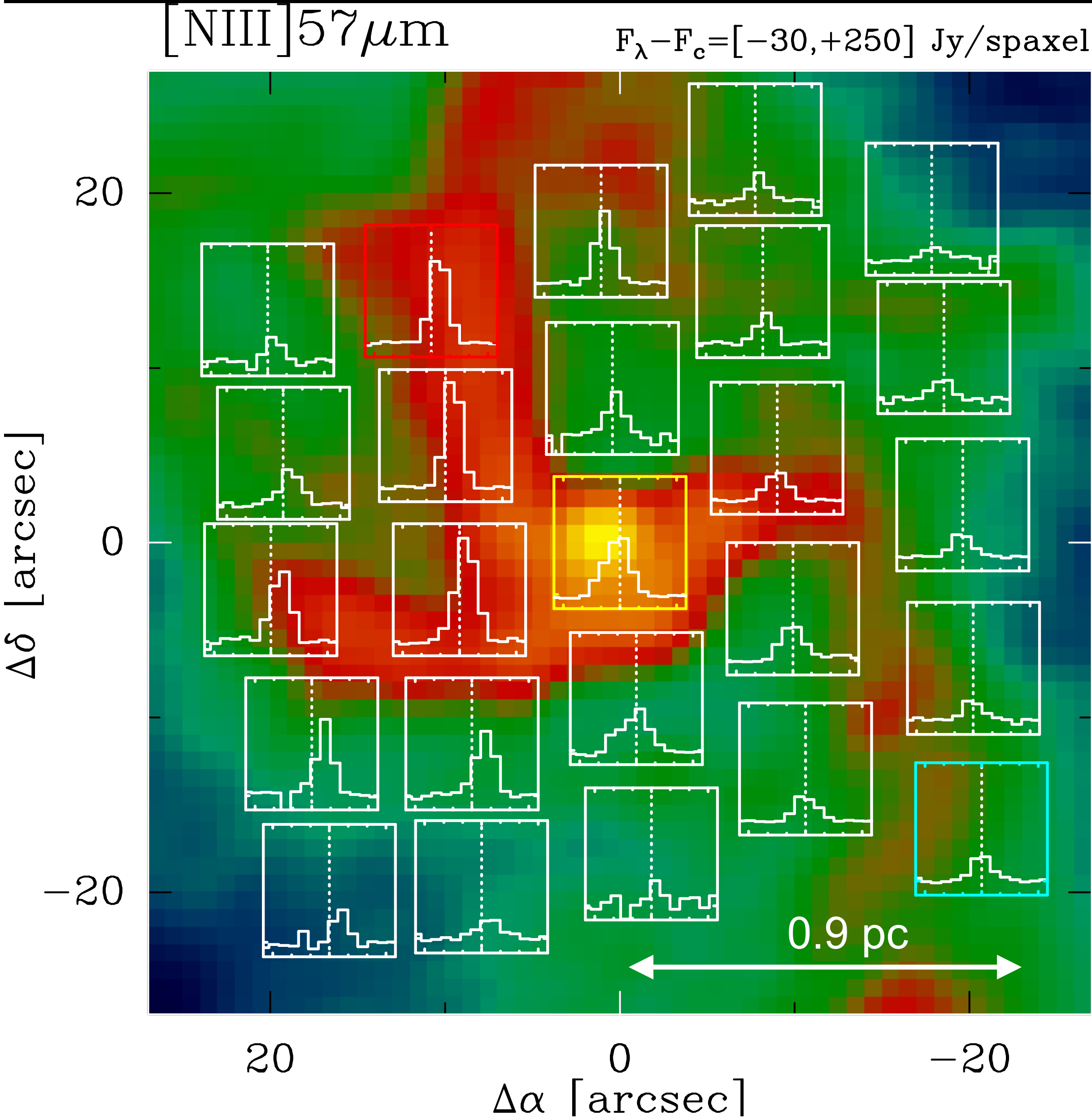
SgrA* spectrum: not as extreme as *e.g.,* Arp220 (Gonzalez-Alfonso et al. 2013)
or Mrk231 ULIRGs (van der Werf et al. 2010)



Powerful FIR diagnostic toolbox to characterize galaxy nuclei

The inner central parsec of the Galaxy

Central cavity and mini-spiral



e.g., [NIII] 57um

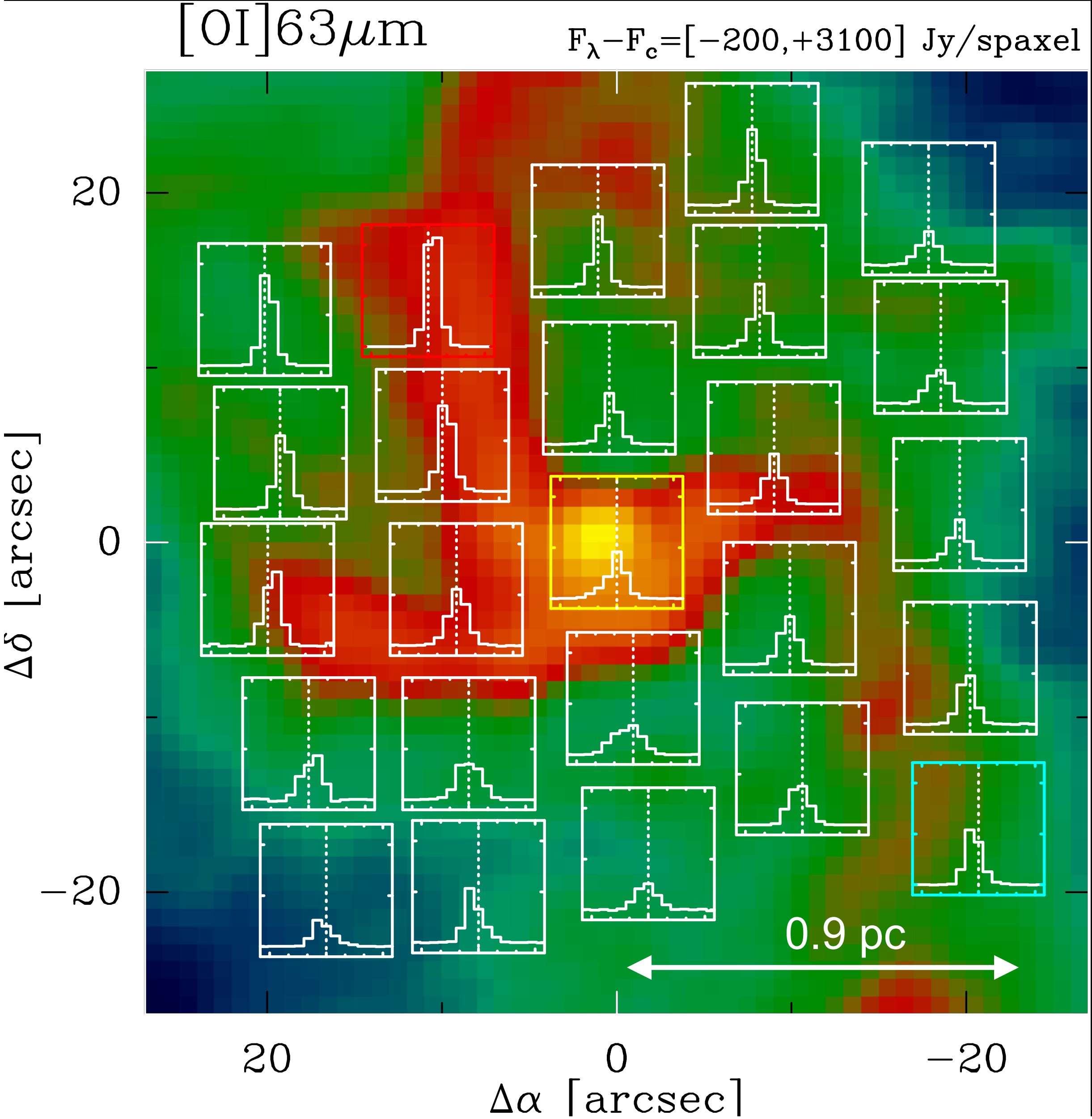
Ionized gas

Fine structure lines:

T_{eff} ~ 35,000 ± 1,000 K
(OB stars central cluster)
$n_e > 10^{3.5}$ cm^{-3} (from [OIII])

Background image is VLA radiocontinuum at 6cm (thanks to C. Lang & M. Requena)

The inner central parsec of the Galaxy
Strong [OI] emission



[OI] 63um
Neutral atomic gas

([OI] + [CII])/FIR ~ 0.008

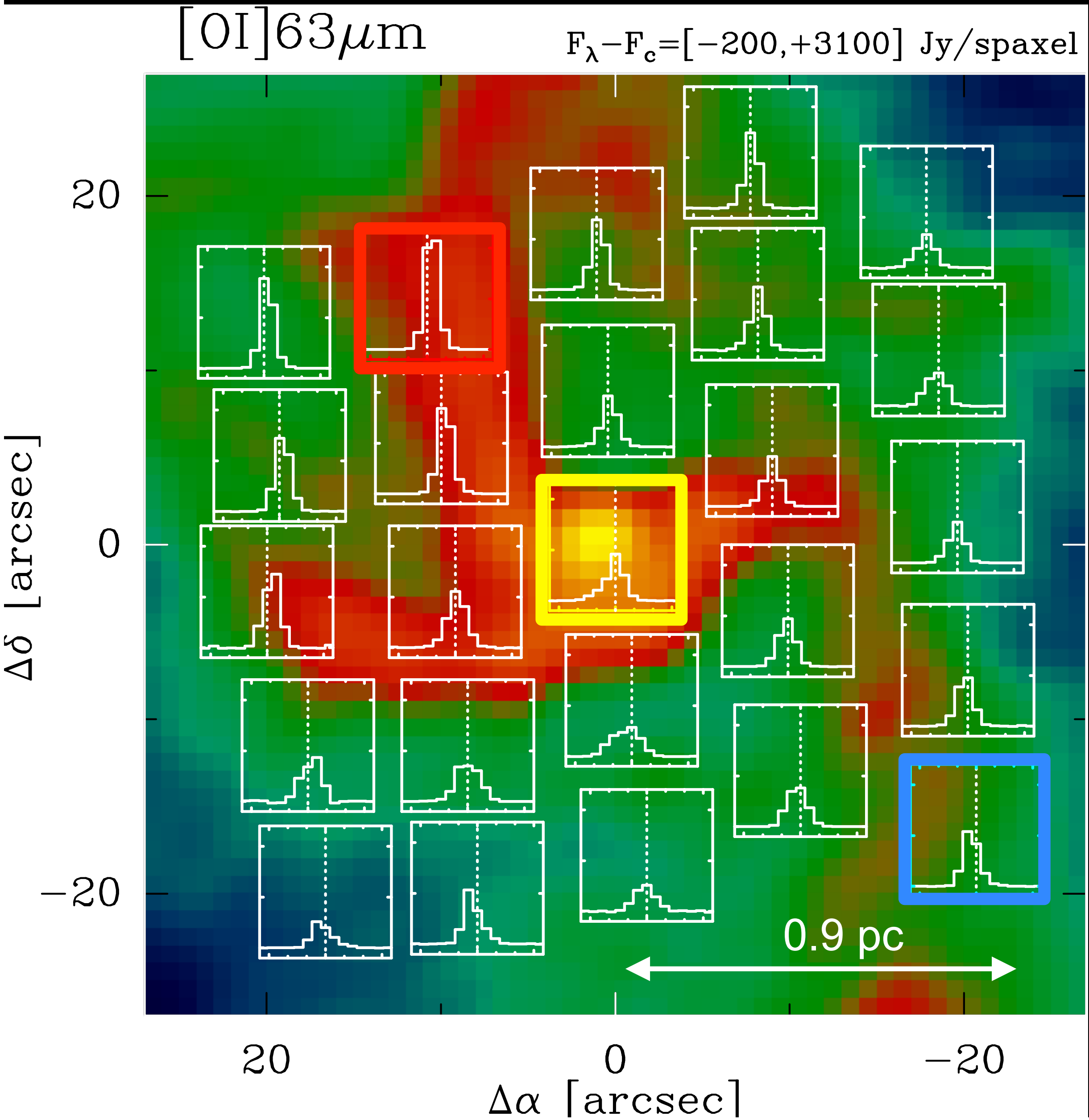
[OI]63/[CII]158 = 3.3±1.3

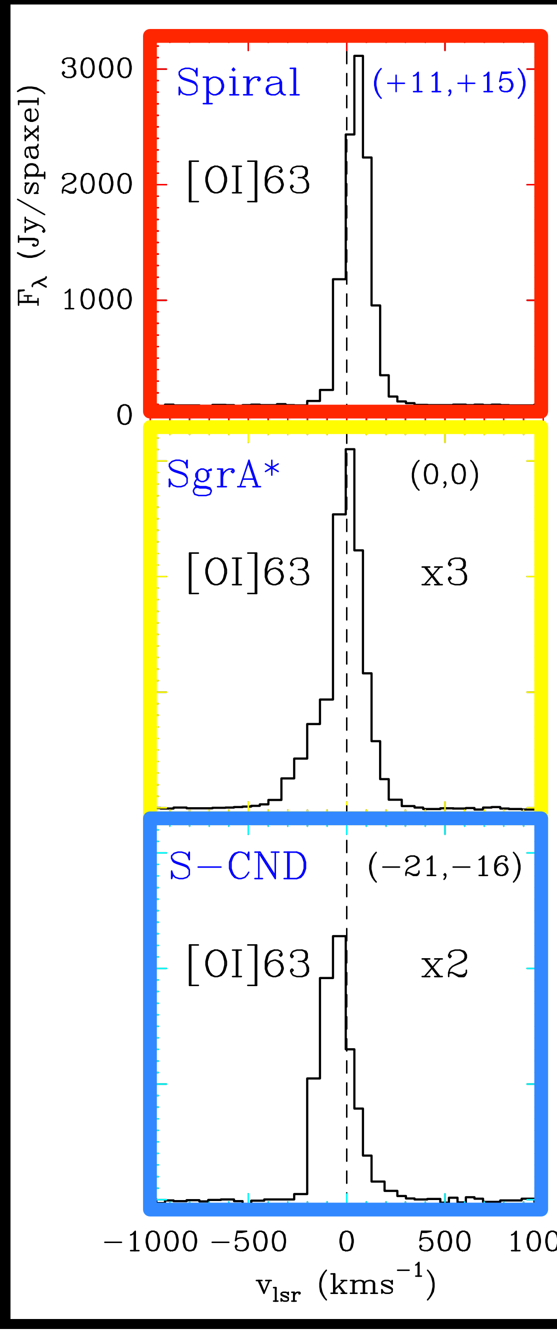
[OI]63/[OI]145 = 8.3±0.5

→ similar to PDRs

[OI]63μm velocity-shifts and broad line-wings in SgrA*

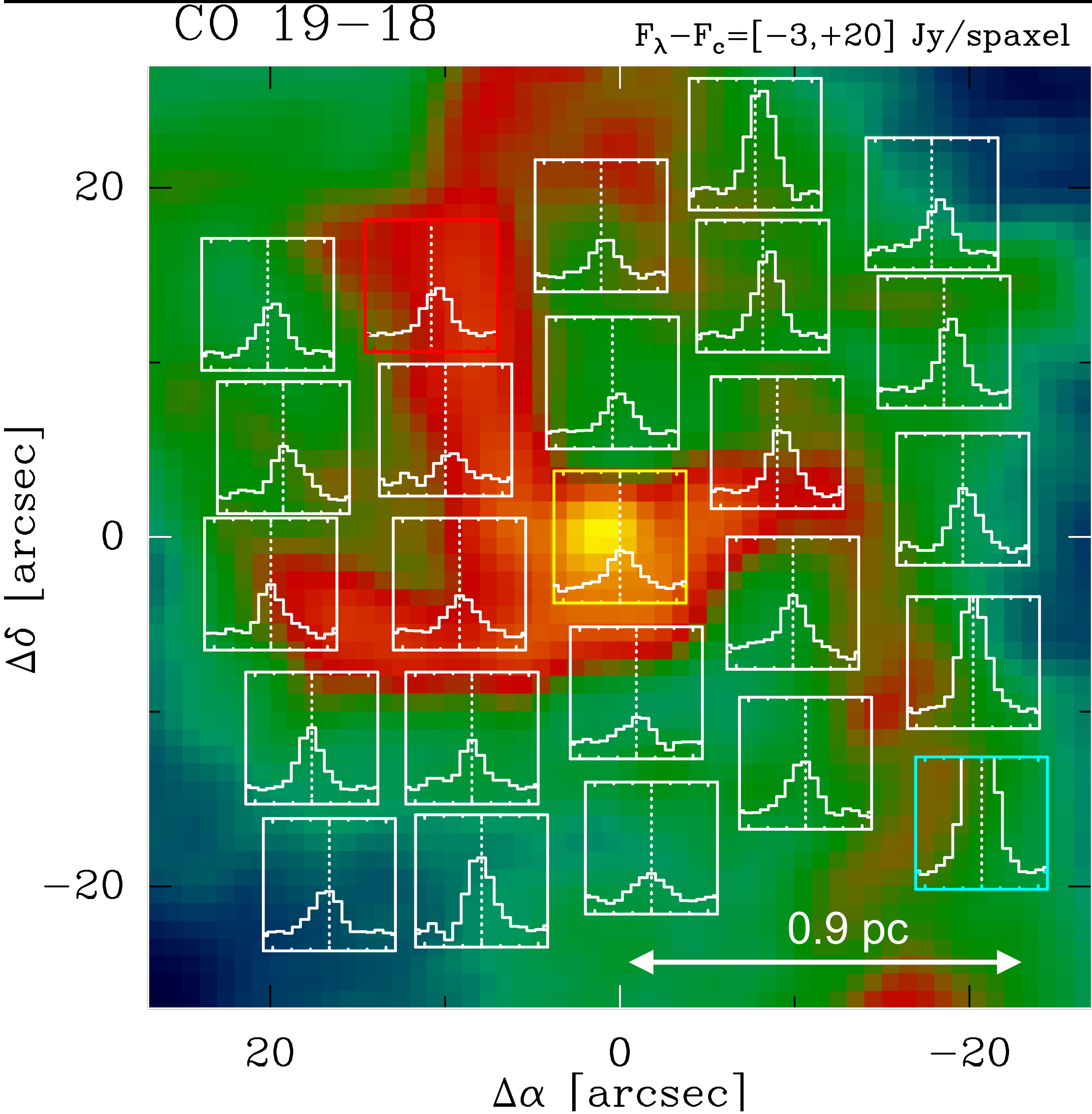
High-velocity gas motions





The inner central parsec of the Galaxy

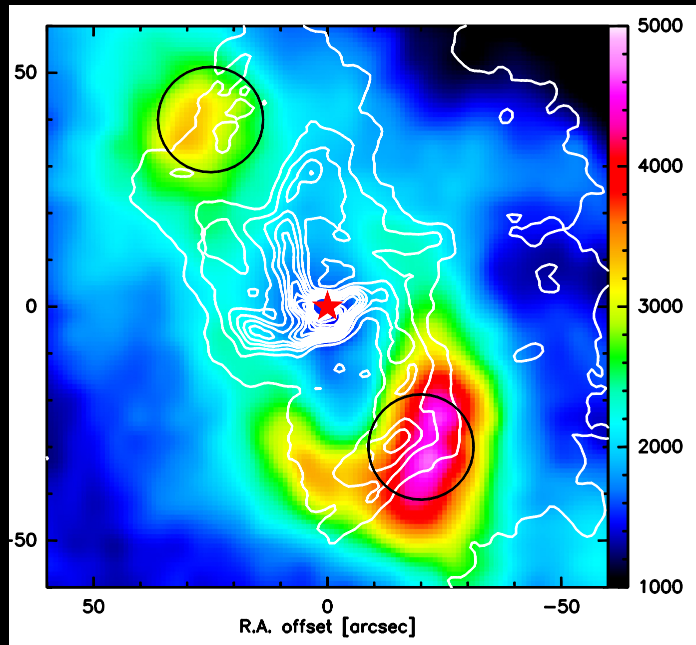
High-J CO peaks in the CND but detectable towards SgrA*



CO J=19-18

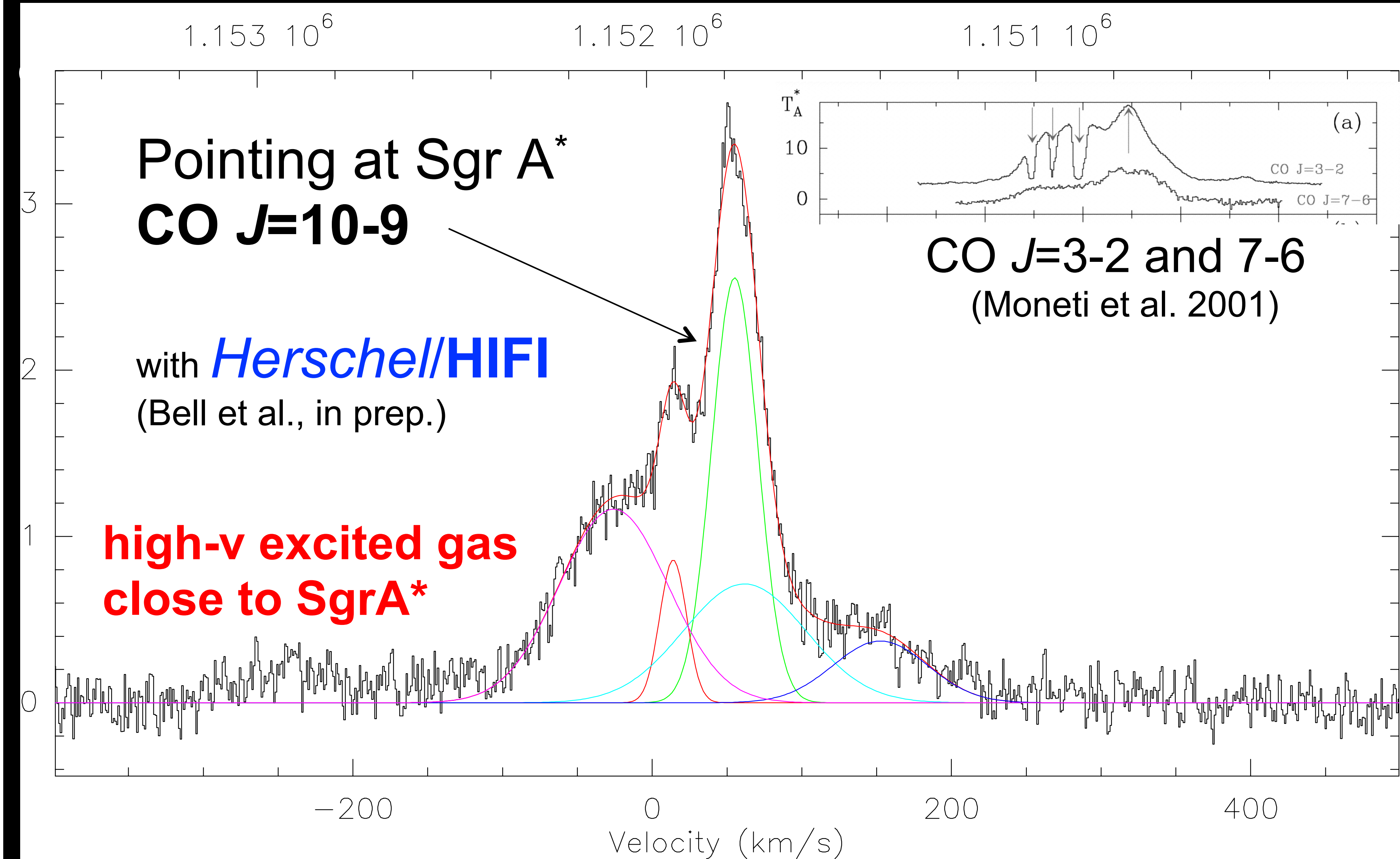
Hot molecular gas

APEX CO J=6-5



Requena-Torres et al. 2012

*Velocity-resolved CO observations towards SgA**



The inner central parsec of the Galaxy FIR luminosities

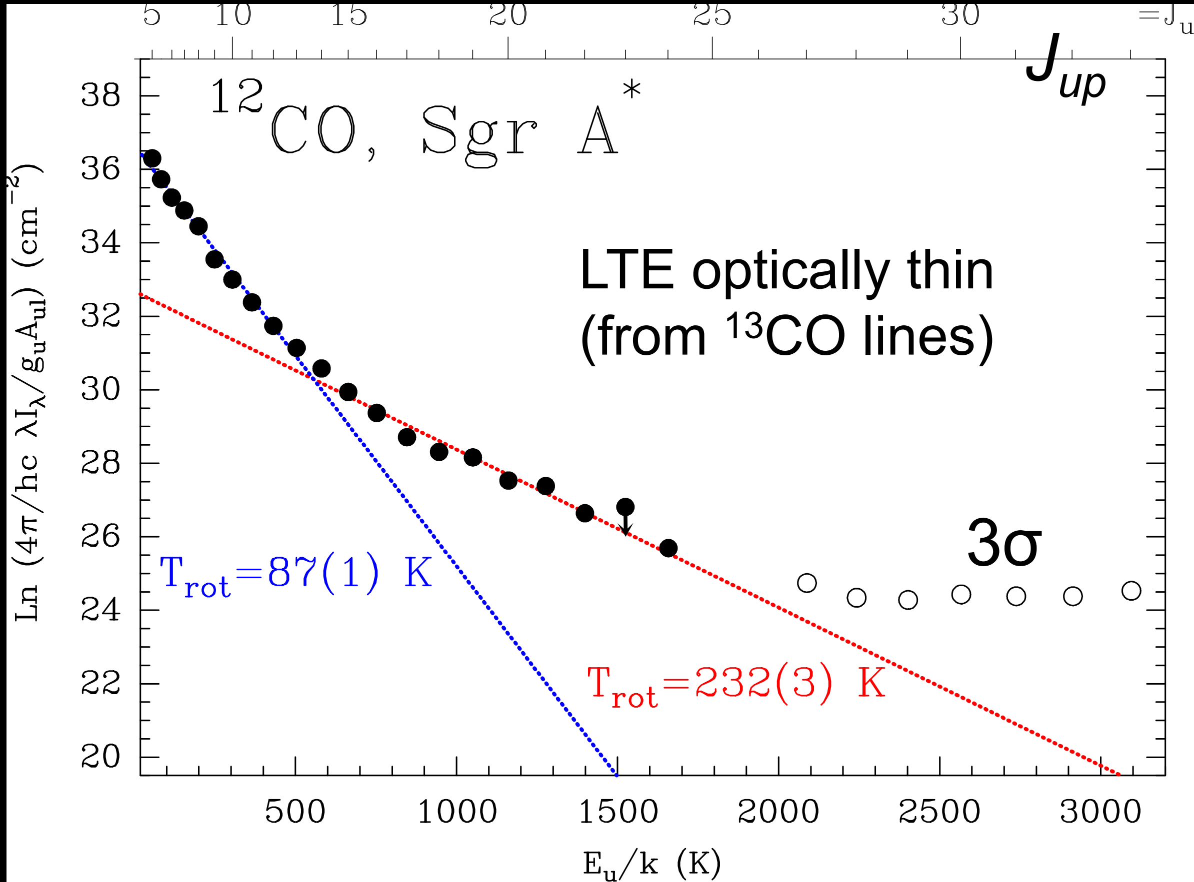
Inner 30”x30”

Species	Luminosity
[OIII]52,88μm	885 L_{SUN}
[OI]63,145μm	855 L_{SUN}
[CII]158μm	230 L_{SUN}
[NIII]57μm	130 L_{SUN}
[NII]121,206μm	120 L_{SUN}
^{12}CO (J=4 to 24)	125 L_{SUN}
[CI]370,609μm	6 L_{SUN}
^{13}CO (J=5 to 12)	4 L_{SUN}

FIR cooling:
Ionized gas ≈ 48%
Neutral atomic ≈ 46% → GC = HII region
CO molecular ≈ 6% + hot neutral component

NOTE: Line intensities corrected by the A_V=30 extinction towards the GC (corrections <15% in the FIR)
Extrapolation of the mid-IR extinction-law derived by Lutz (1999) for SgrA*.

*Properties and origin of hot molecular gas (traced by CO) towards SgrA**



- A moderate positive curvature in the rotational diagram can be explained either by:

  (a) multiple temperature components (that could be in LTE).

  e.g., Neufeld 2012, ApJ

  (b) a (subthermally excited) single-temperature non-LTE component ($T_k \gg T_{rot}$)

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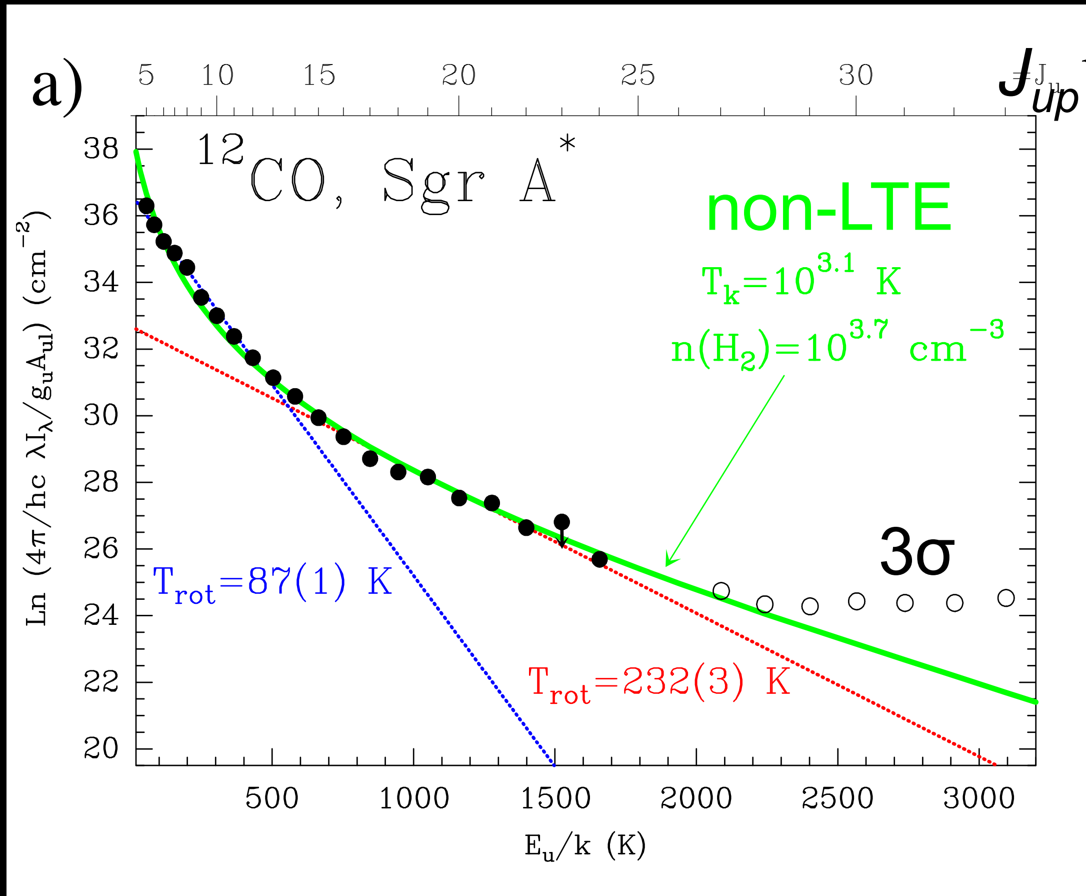

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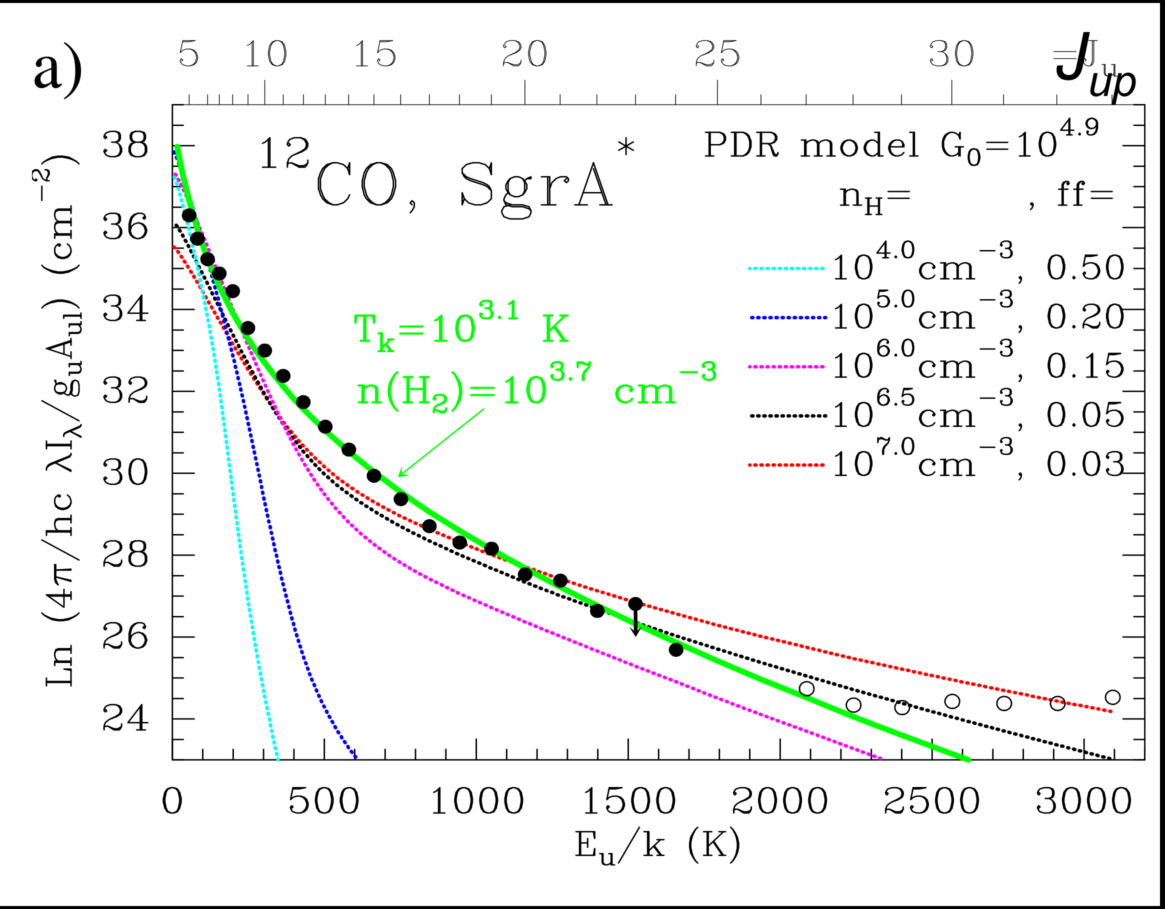
Meudon PDR code



$G_0=10^{4.9}$

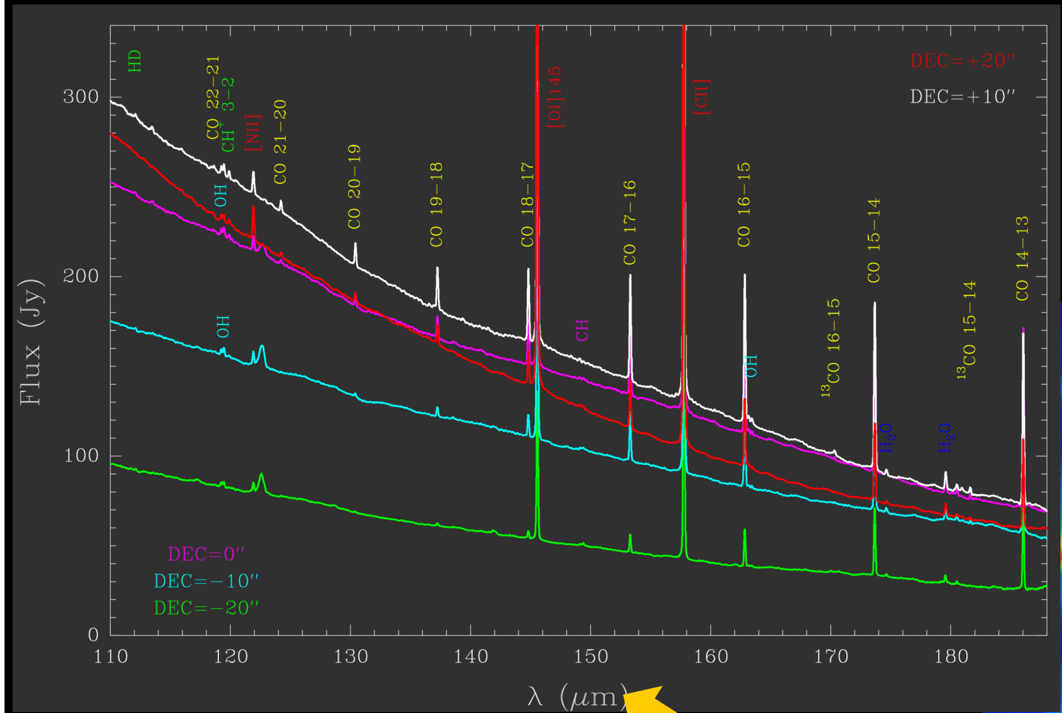
PDR models (crudely) reproduce the high-*J* CO lines
<u>only</u> if unresolved hot and dense clumps exist (n_H~10^7 cm^{-3})

Let's compare with a prototypical high-UV field PDR? The Orion Bar PDR…

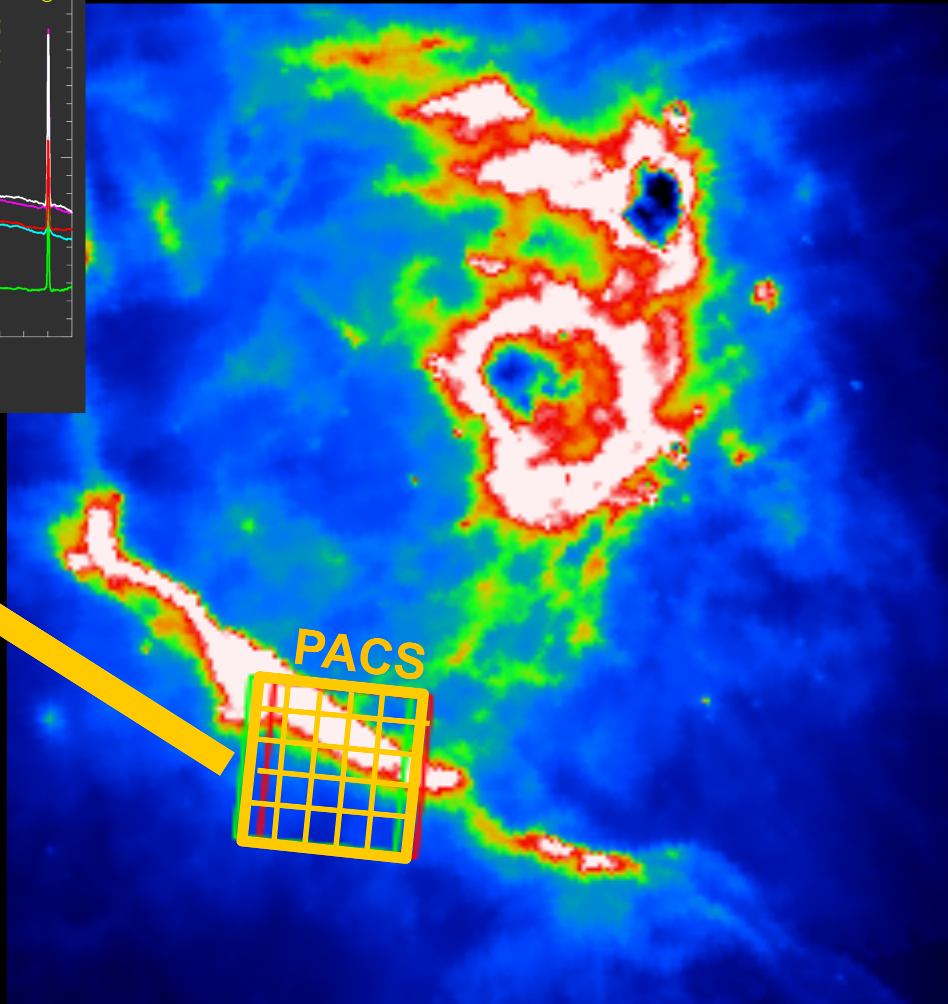
Strongly UV-irradiated PDRs

Joblin et al. In prep.

Goicoechea et al. 2011



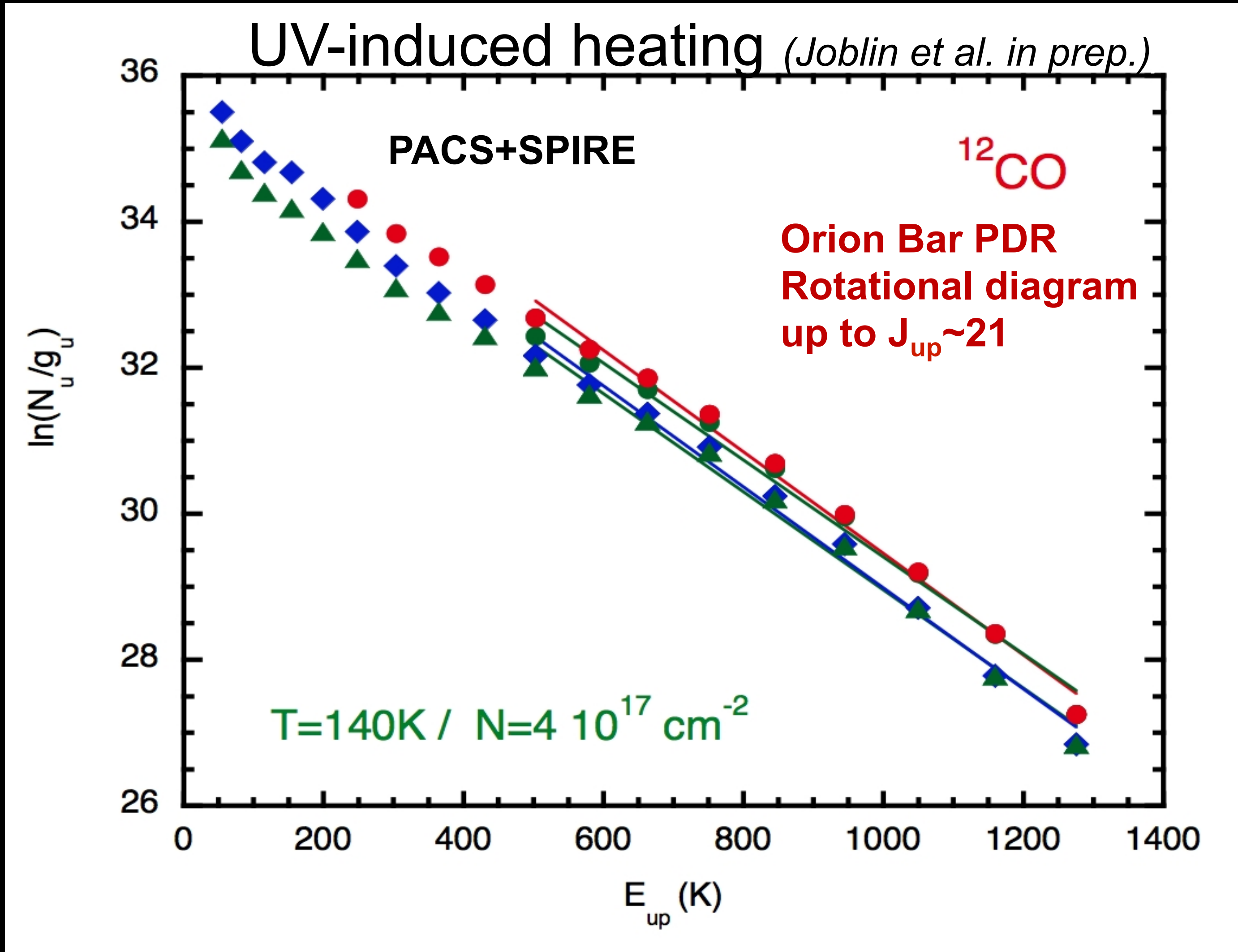
Excited CO emission from Photodissociation Regions



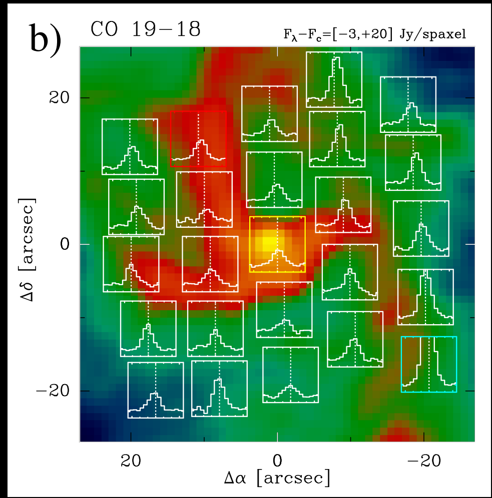
***Spitzer*-IRAC 8um**

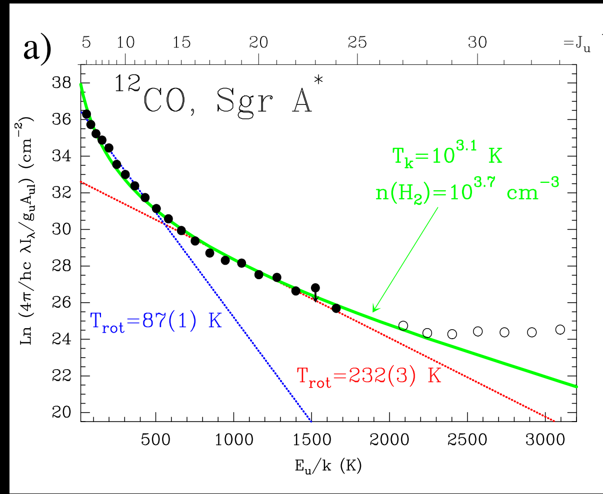
Orion Bar PDR vs. Sgr A*

T_{rot}(SgrA*) > T_{rot} (Orion Bar PDR) $L(CO)/L_{FIR}$ (SgrA*) > $L(CO)/L_{FIR}$ (Orion Bar).



NOT the same environment





2 SCENARIOS possible:

1) **Distribution of temperature components**, $dN(CO)/dT_k = aT_k^{-b}$, at $n(H_2)$~$10^{4\text{-}5}$ cm^{-3}, and *b* ~2.0-2.5 → with "most CO (>96%) at T_k <300 K".

→ UV heating can explain the lower-J CO emission but not the high-J CO line emission

→ Strongly irradiated dense clumps?

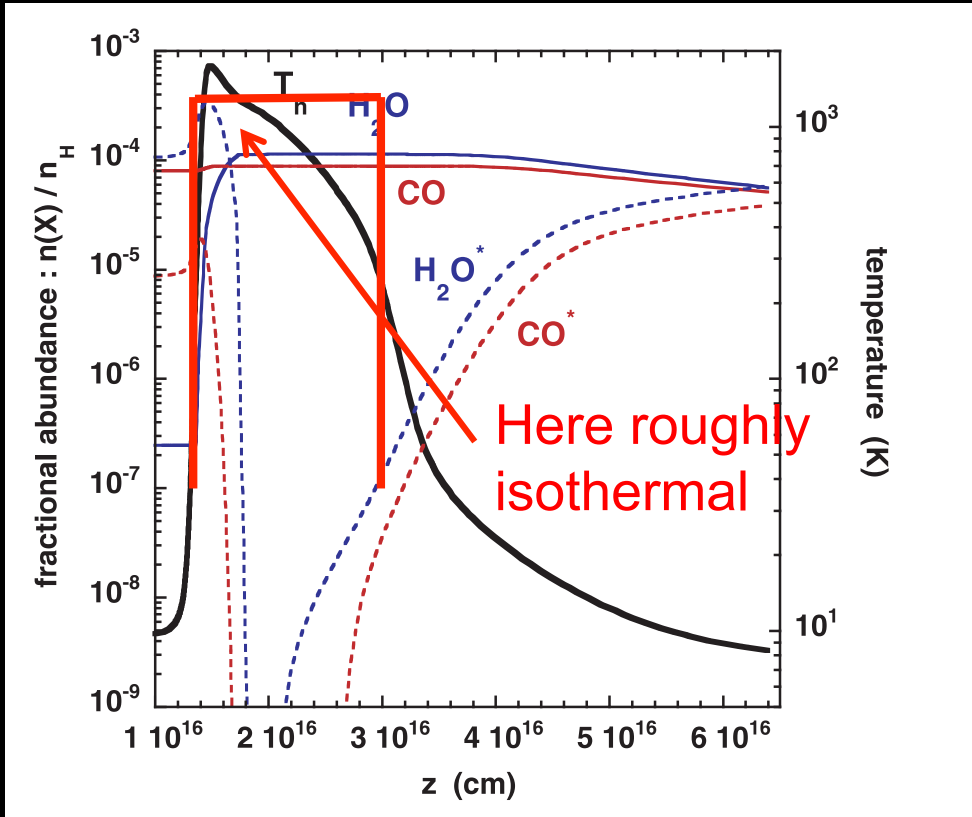
2) **Single**, ***hot*** (T_k≃$10^{3.1}$ K) **and low-density** ($n(H_2)<10^4$ cm^{-3}) **gas component**

→ "all CO is *hot*": PDRs, XDRs or enhanced CR flux heating NOT enough.

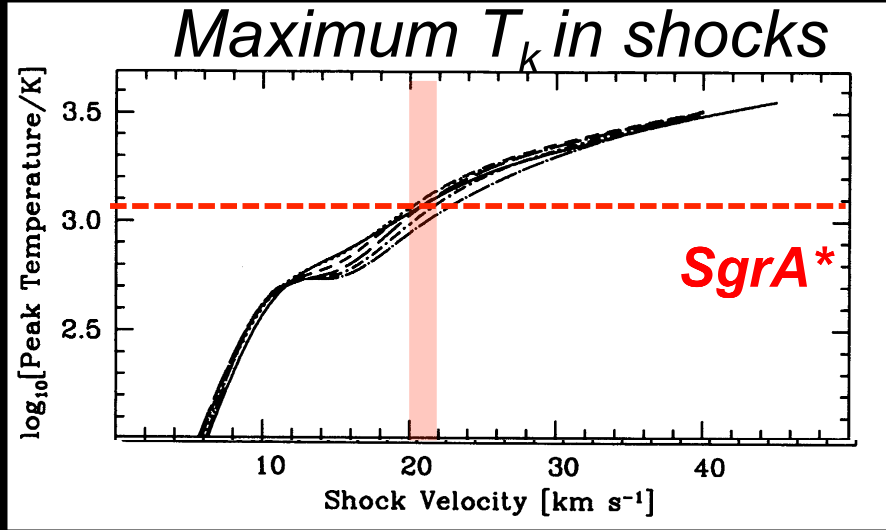
(also non detections of excited OH^+ or H_2O^+ lines)

→Low density shocks??

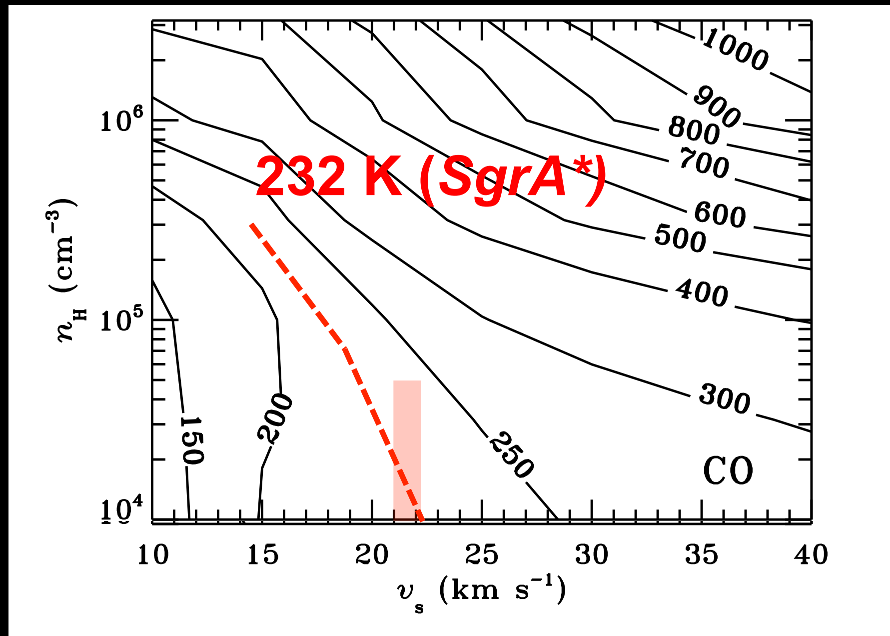
C-type MHD shocks models



(Flower & PdF 2010)



Kaufman & Neufeld 1996



T_{rot} (CO) (PACS domain)

Shocks near SgrA* consistent with the high velocity gas and with distorted velocity field in the region

Conclusions

- GC is a unique laboratory for extragalactic nuclei studies ← far-IR shifts to ALMA for high-z
- Spectral-mapping provides new insights on the gas physical conditions and on the main heating mechanisms at large scales (not with photometry).
- Irradiated warm (200-300K) dense clumps as possible explanation of the CO observations.
- A *hot* CO component (T_k~1000 K) could be alternatively inferred towards in the gas near SgrA*. In this case low-density shocks could dominate the heating (outflows? Infall? cloud-cloud collisions?)
- High angular resolution observations (ALMA) of high excitation lines of $HCN/HCO^+/CS$ could help in constraining the physical conditions of the gas.