The Nucleus of our Galaxy

Javier R. Goicoechea

CAB (CSIC-INTA), Madrid.

Herschel collaborators:
Mireya **Etxaluze**, Tom A. **Bell**, Maryvonne **Gerin**, Pepe **Cernicharo**

DIRBE @ 140 μm

CENTRO DE ASTROBIOLOGÍA
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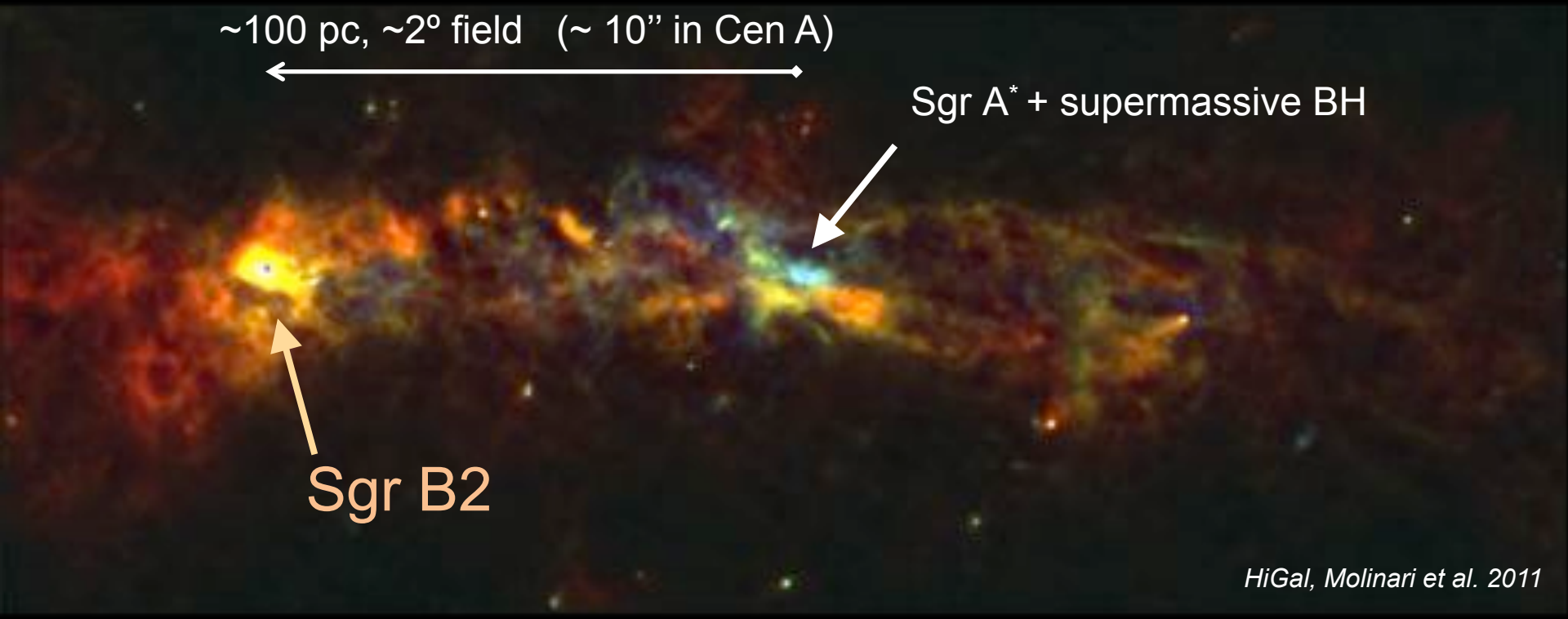
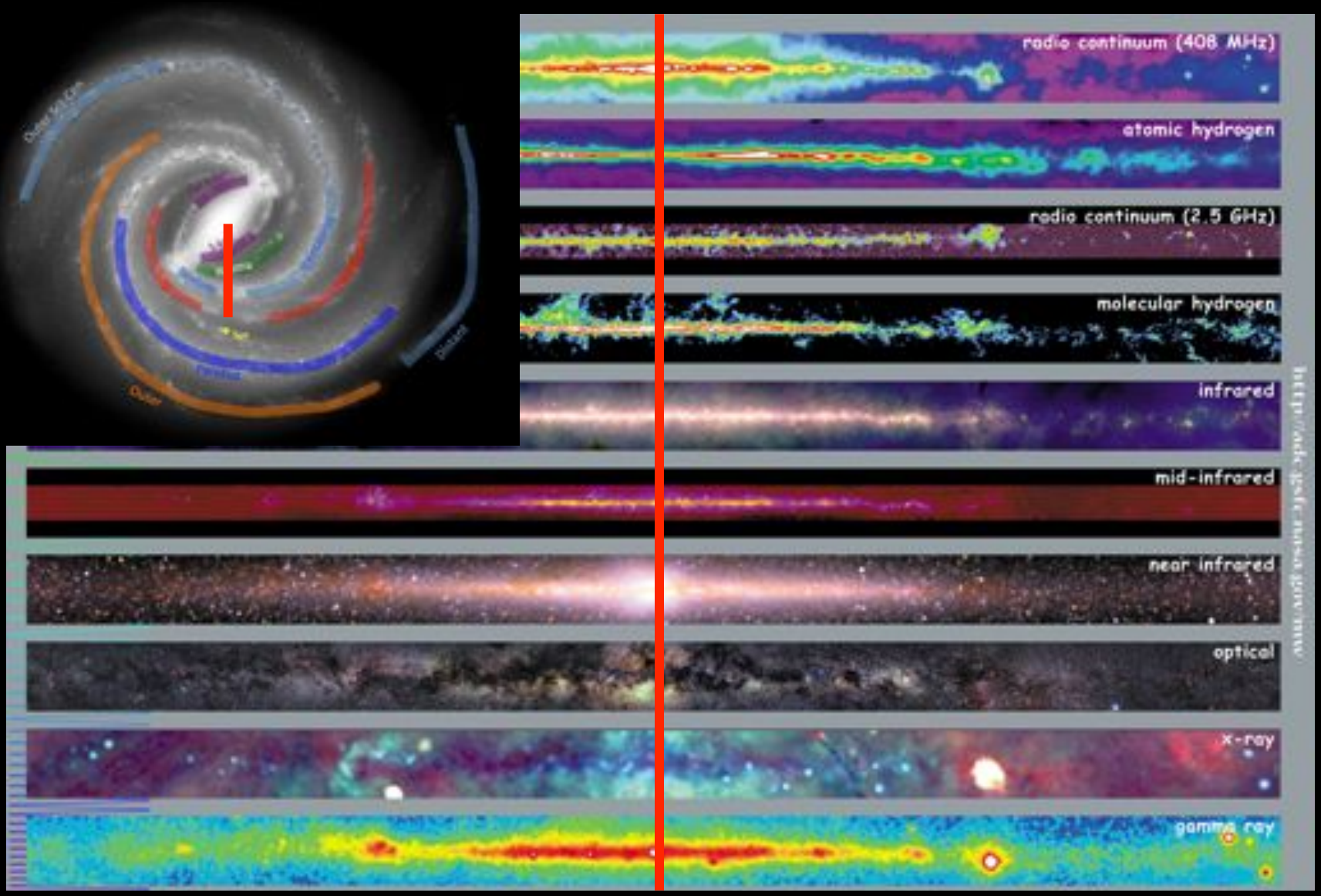
Herschel's far-IR view of the Galactic Center (GC)



- A few 100's times closer than the nearest AGN → high spatial resolution
- GC ISM: on average higher $n(H_2)$, T_k, Δv_{turb}, B, …
- What heats the neutral ISM? How do stars form in the GC?

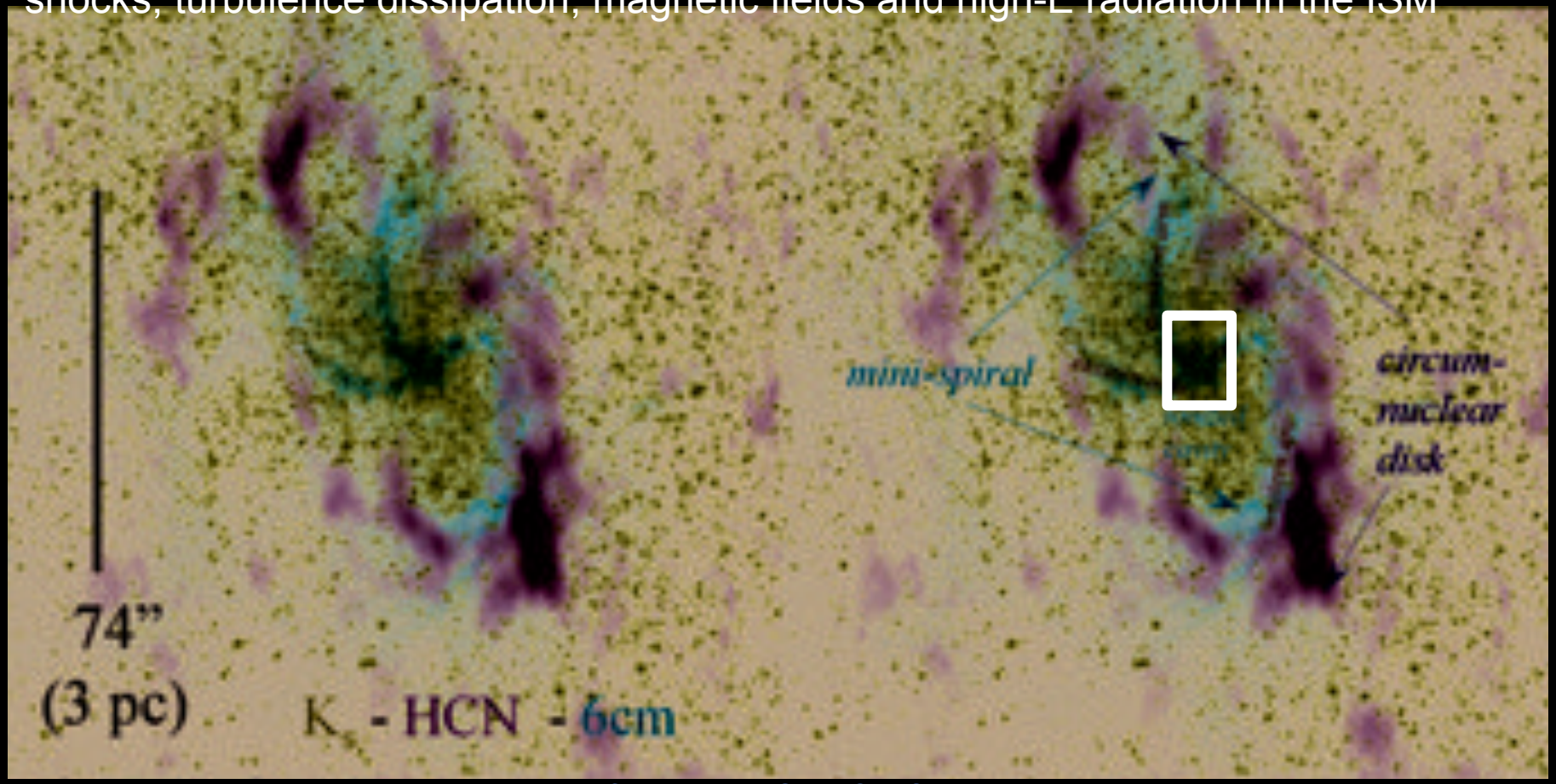
[See reviews by Güsten 1989 and Genzel et al. 2010]

- The majority of the radiation energy from the GC comes as infrared photons (A_V=30) → almost transparent at far-IR wavelengths.



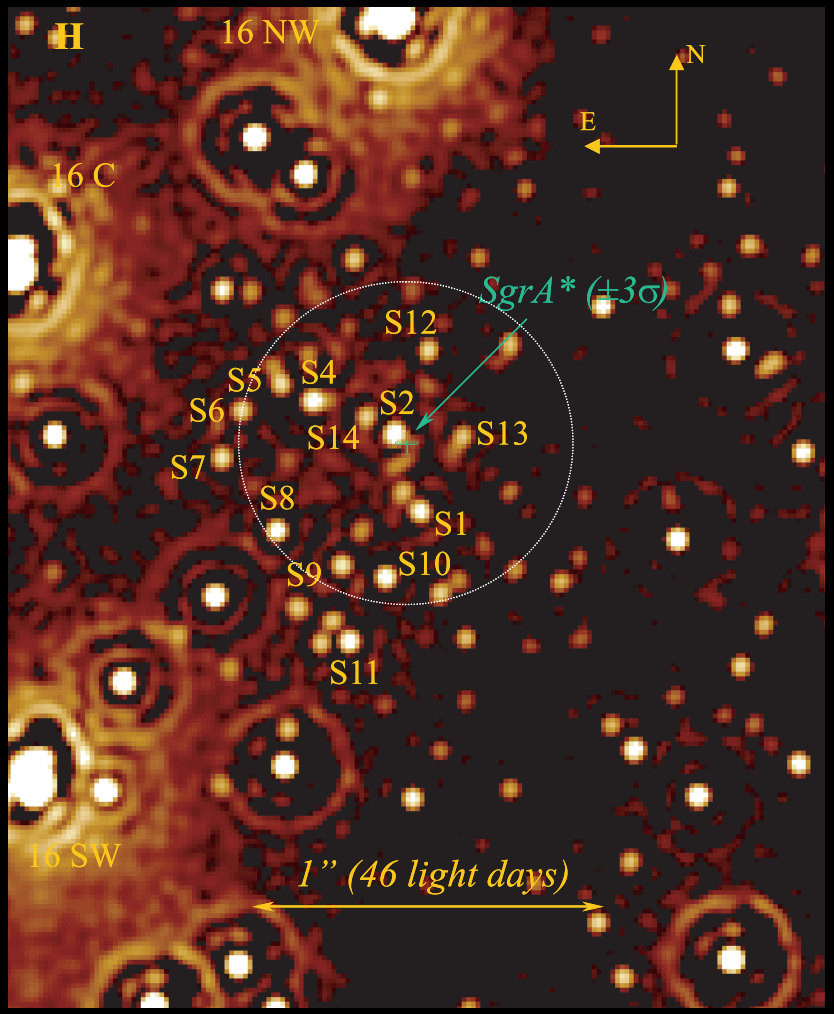
Inner 3 parsec of the Milky Way

Laboratory for extragalactic CNDs, black hole accretion, extreme star formation: shocks, turbulence dissipation, magnetic fields and high-E radiation in the ISM



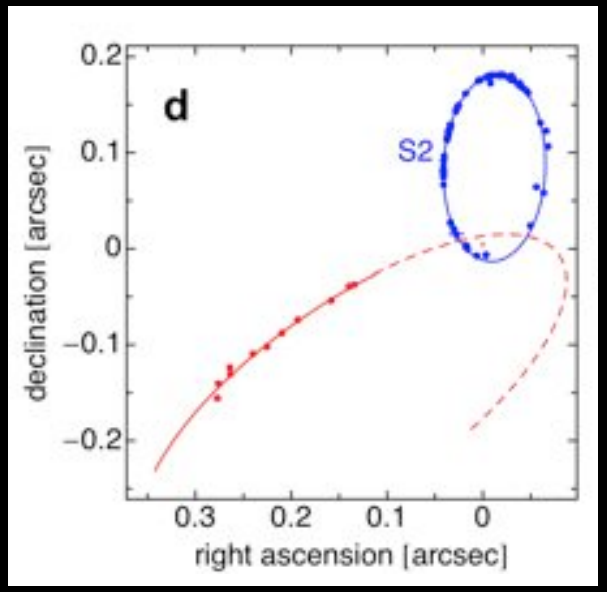
K_s band (2.2um) from VLT-ISAAC (Schödel et al. 2007)
HCN 1-0 from OVRO interferometer, 4" (Christopher et al. 2005)
Radio 6cm from VLA interferometer, 3" (Yusef-Zadeh & Morris 1987)

Stars orbiting the central supermasive black hole



- Enclosed mass in $r < 6$ light-hours

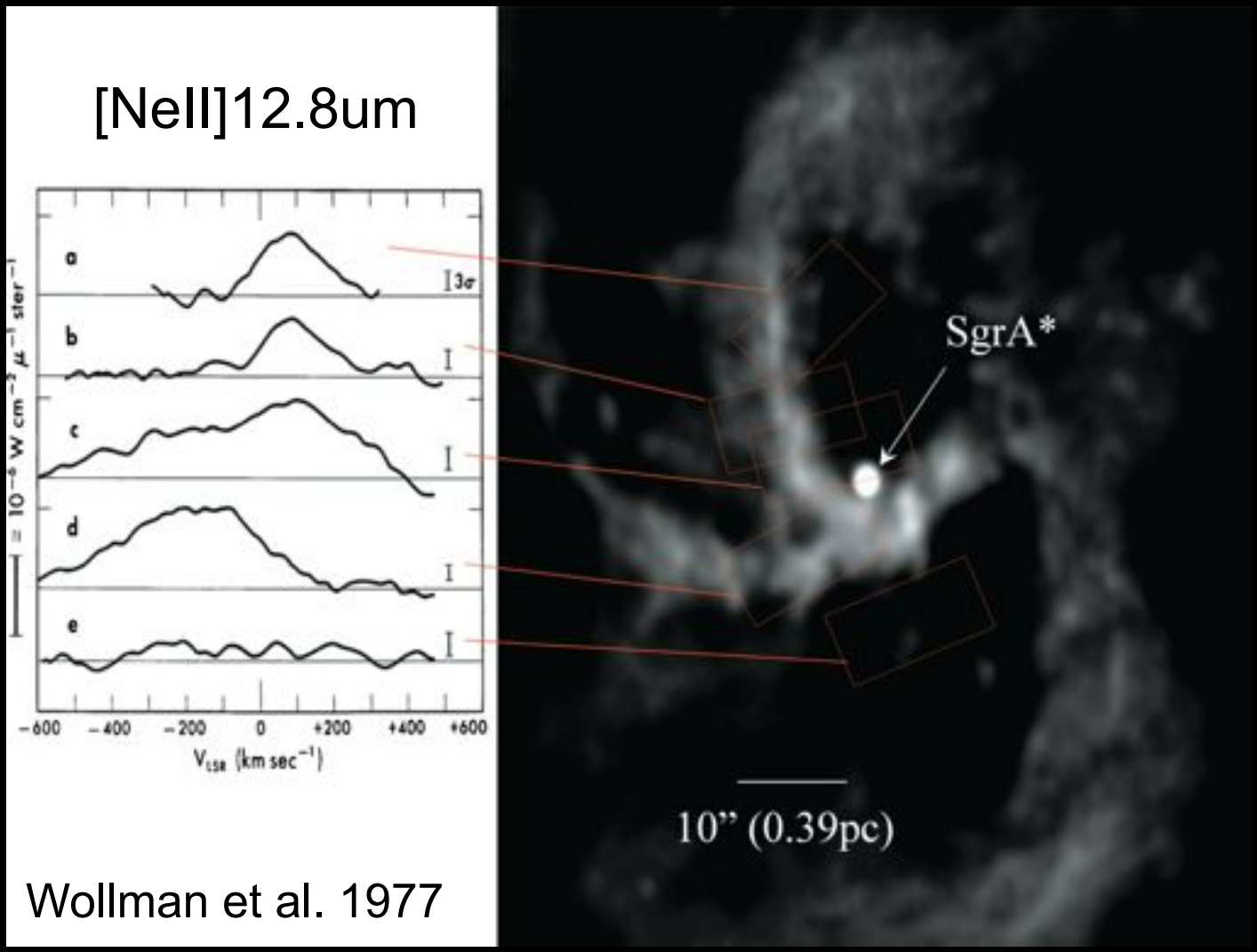
  ~ 4 x 10^6 M_{sun} (BH!)



How were the stars formed??

H band (1.6um) from VLT- NAOS/CONICA, adaptive optics (Genzel et al. 2003)
Diffraction-limited resolution ~ 0.05"

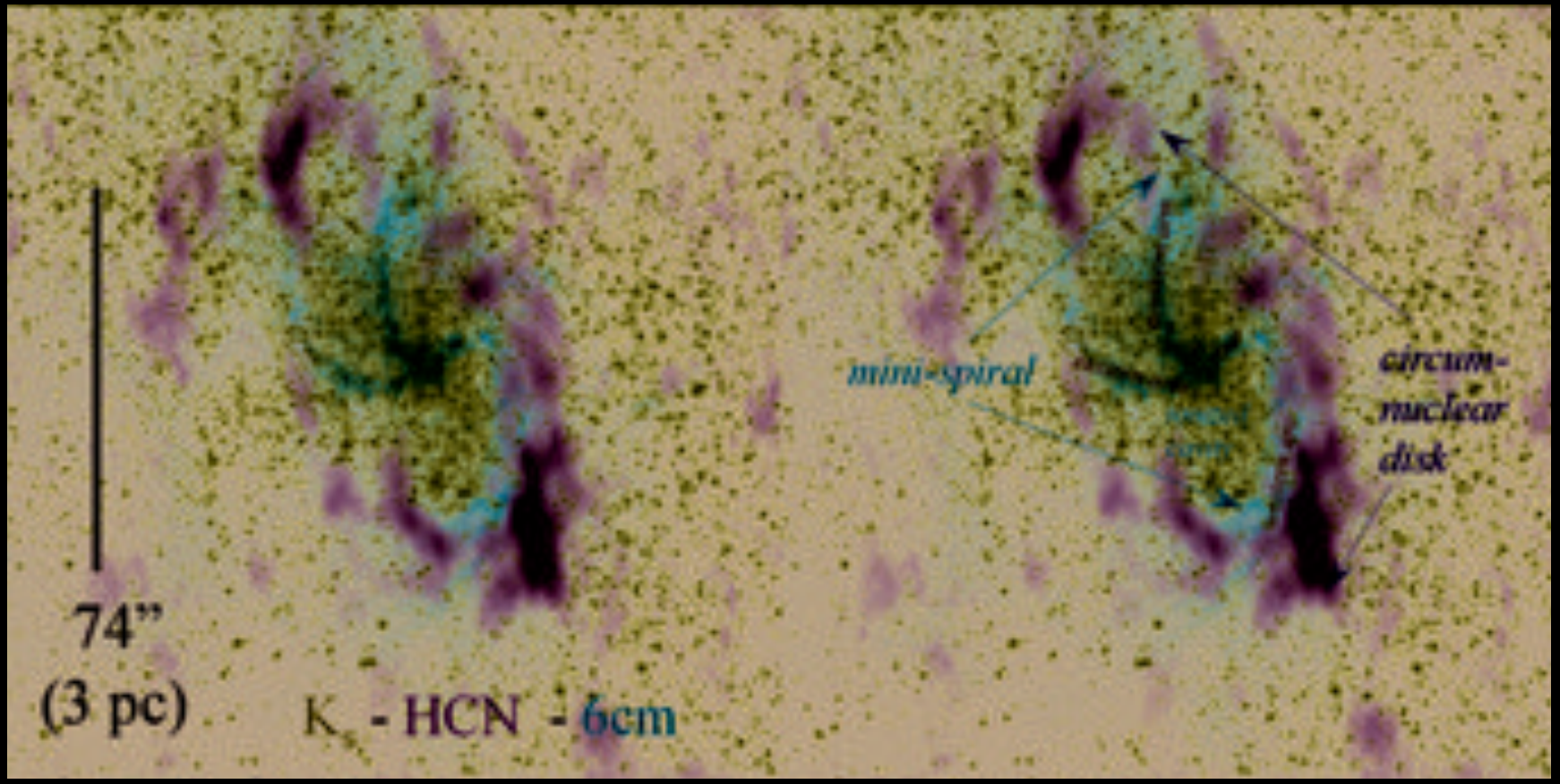
Ionized Gas streamers feeding SgrA ?*



First dynamic evidence from large gas velocities perhaps hidden a mass of 2-4x10^6 M_{sun} near SgrA*

3.6cm VLA interferometer radio continuum map, 0.5” resolution (Robert & Goss 1993)

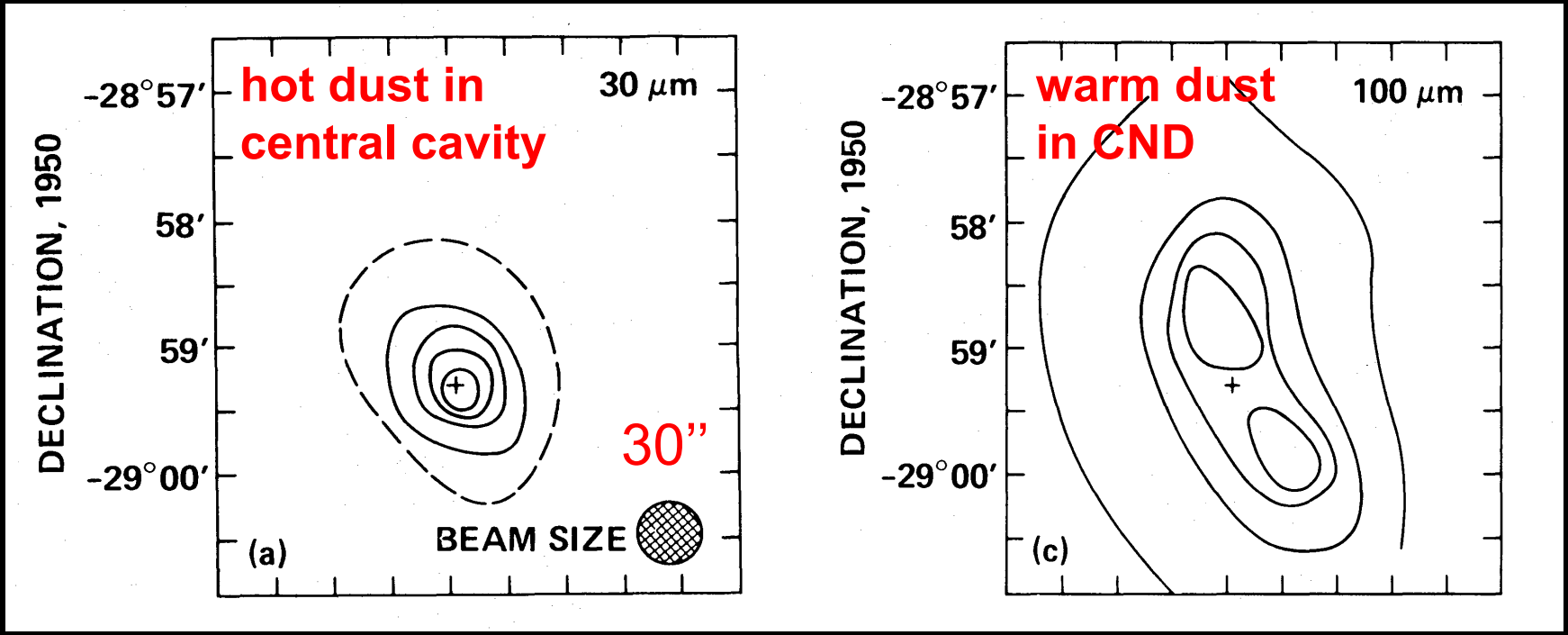
Multi-λ observations of stars and ISM around SgrA*
have changed our view of the Galactic Center



All had <5" angular resolution and were sensitive to the extended emission

What about the far-IR?

Circumnuclear disk (CND) first detected at far-IR wavelengths with KAO (Becklin et al. 1982)



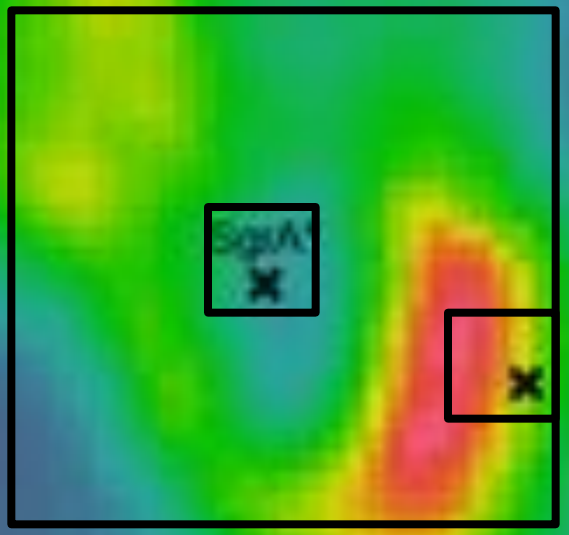
Reservoir of material accreting onto central parsec:

→ **star formation & accretion onto SgrA***

The inner parsecs of the Galaxy in the far-IR…

***Hersche*/PACS70**

Etxaluze et al. 2011
Molinari et al. 2011



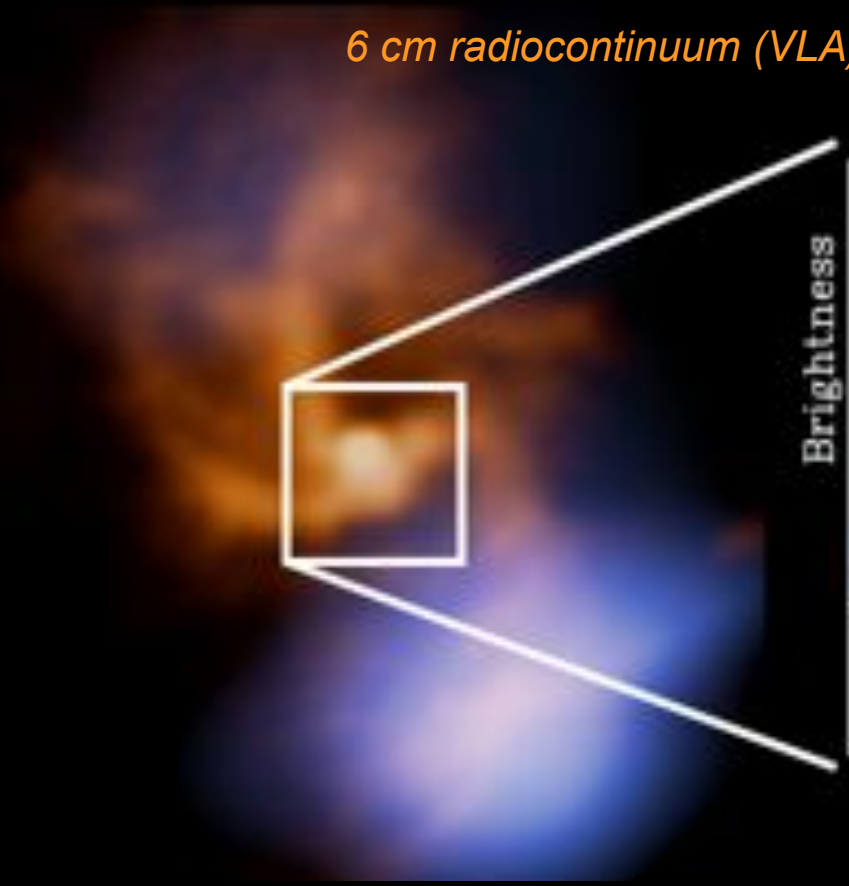
PACS
spectrometer
(10” ~0.4pc)

[See recent interferometric works: Montero-Castaño+2009; Martín+2012; Yusef-Zadeh+2013 …]

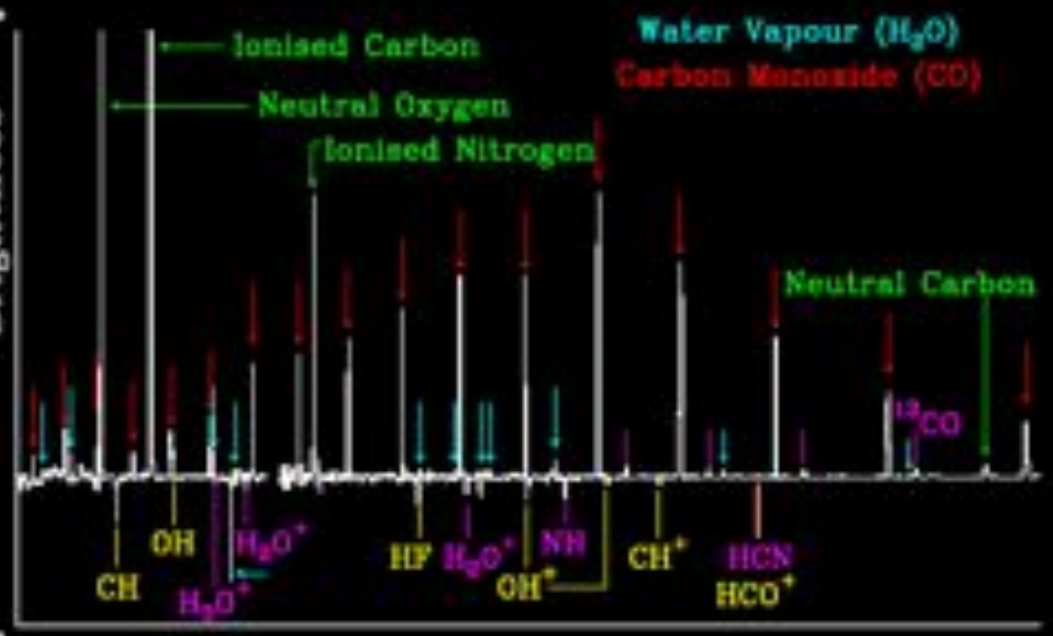
Far-IR spectroscopy!

Properties of material around SgrA*

6 cm radiocontinuum (VLA)



CO *J*=13-12 (SPIRE)

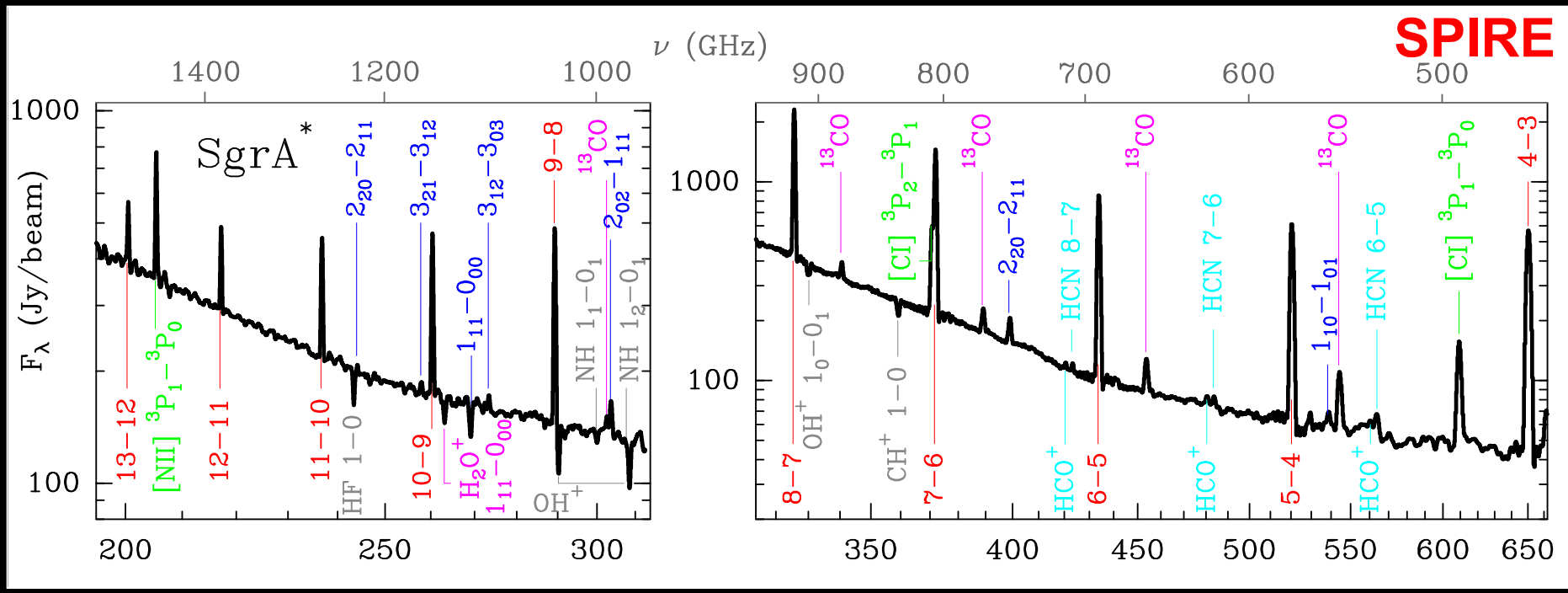


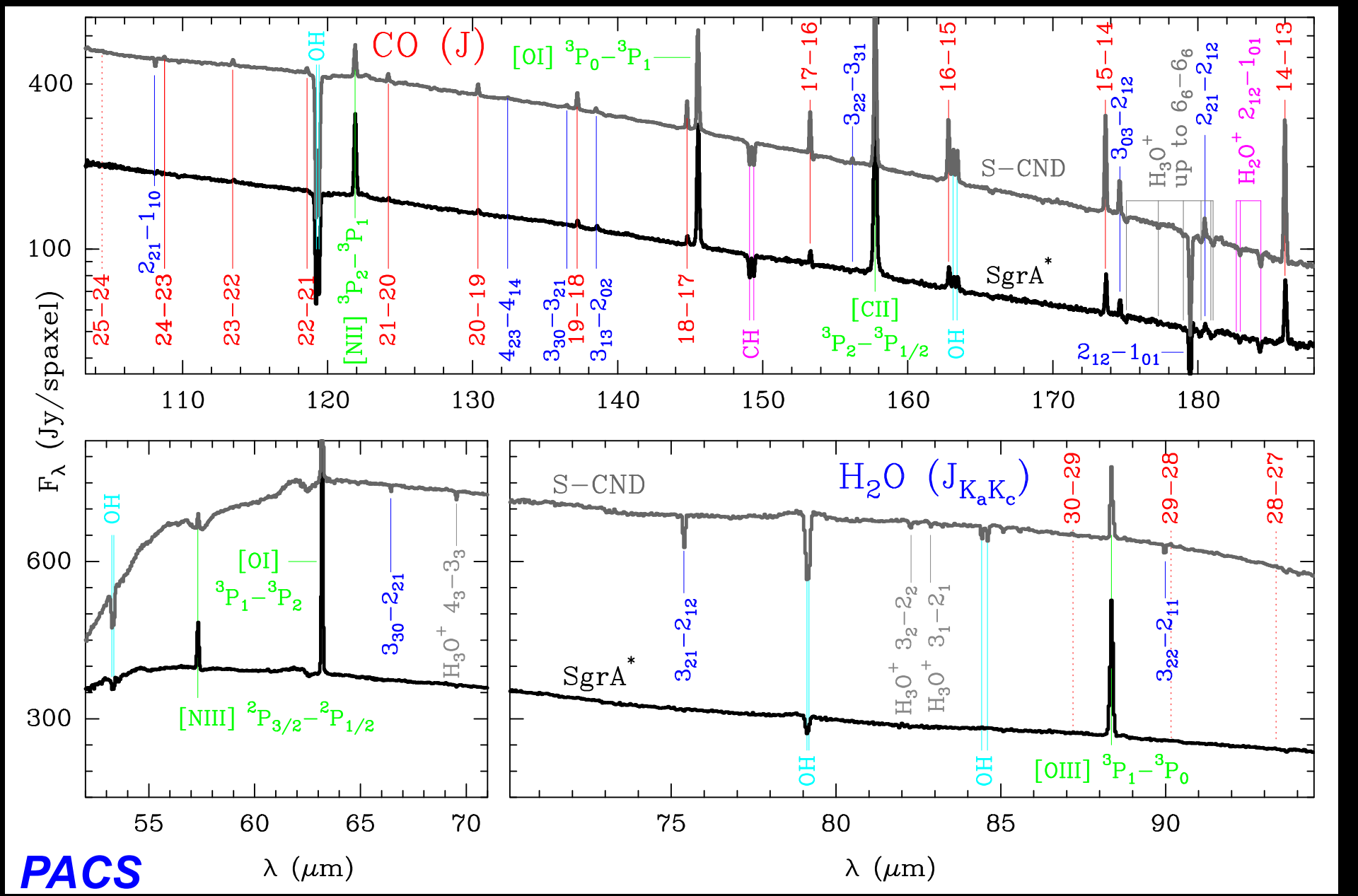
Herschel/PACS + SPIRE
(Goicoechea et al. 2013)

ESA Press release

*SPIRE+PACS spectrum toward SgrA**
(55-650μm)

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




CO (J)
[OI] $^3P_0-^3P_1$
OH
$2_{21}-1_{10}$
25−24
24−23
23−22
22−21
$^3P_2-^3P_1$
[NII]
21−20
20−19
$4_{23}-4_{14}$
$3_{30}-3_{21}$
19−18
$3_{13}-2_{02}$
18−17
CH
17−16
$3_{22}-3_{31}$
[CII]
$^3P_2-^3P_{1/2}$
16−15
OH
15−14
$3_{03}-2_{12}$
H_3O^+ up to 6_6-6_6
$2_{21}-2_{12}$
H_2O^+ $2_{12}-1_{01}$
14−13
S−CND
SgrA*
$2_{12}-1_{01}$
400
100
F_λ (Jy/spaxel)
110
120
130
140
150
160
170
180
OH
[OI] $^3P_1-^3P_2$
$3_{30}-2_{21}$
H_3O^+ 4_3-3_3
[NIII] $^2P_{3/2}-^2P_{1/2}$
600
300
55
60
65
70
S−CND
H_2O ($J_{K_aK_c}$)
30−29
29−28
28−27
$3_{21}-2_{12}$
H_3O^+ 3_2-2_2
H_3O^+ 3_1-2_1
$3_{22}-2_{11}$
SgrA*
OH
OH
[OIII] $^3P_1-^3P_0$
75
80
85
90
λ (μm)
λ (μm)
PACS

Powerful Far-IR diagnostic toolbox to characterize galaxy nuclei:

Atomic fine structure lines

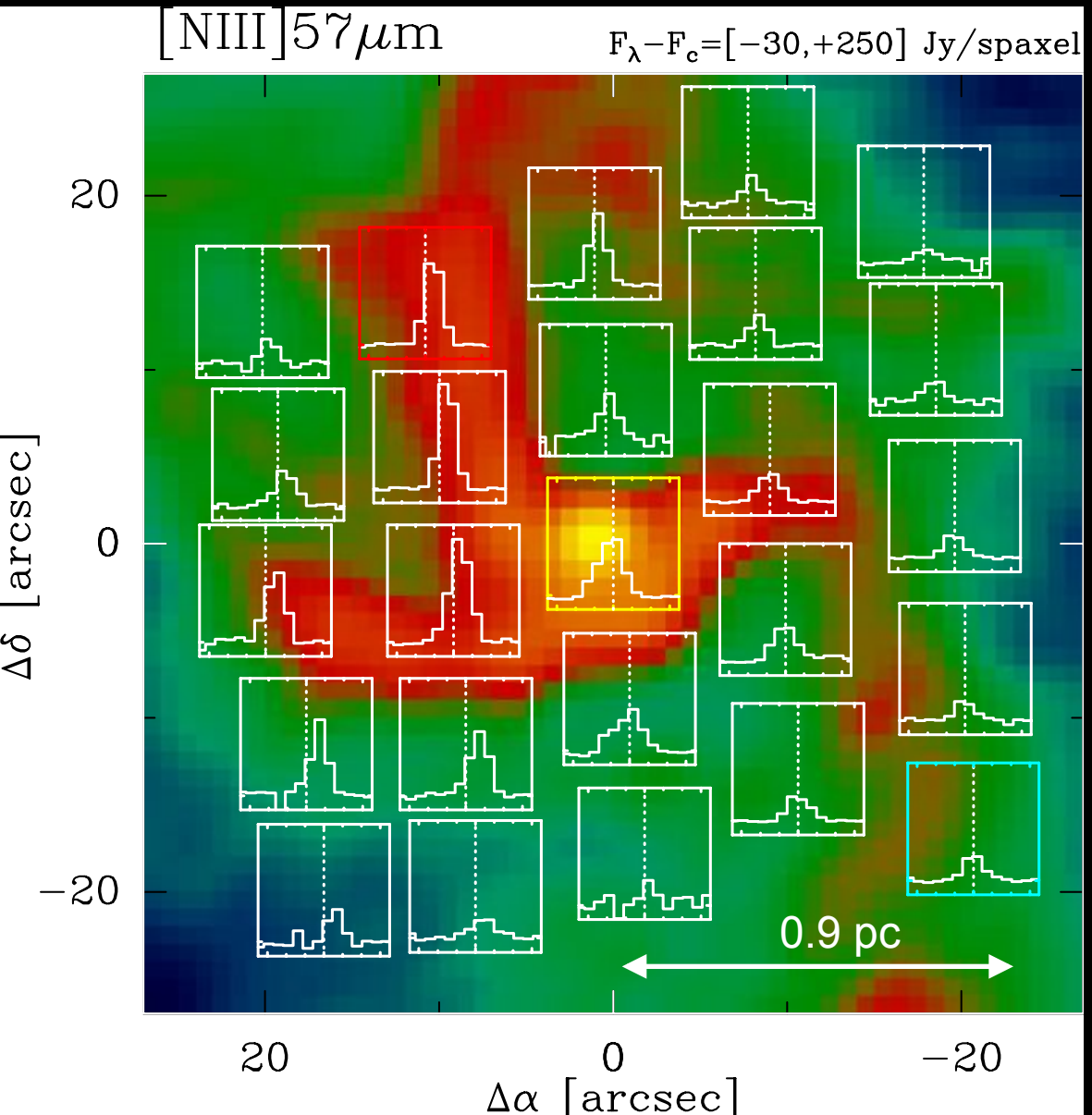
High-J CO, light hydrides…

(NOT with ALMA or JWST !)

The inner central parsec of the Galaxy

Central cavity and mini-spiral

10” resolution



e.g., [NIII] 57um
Ionized gas

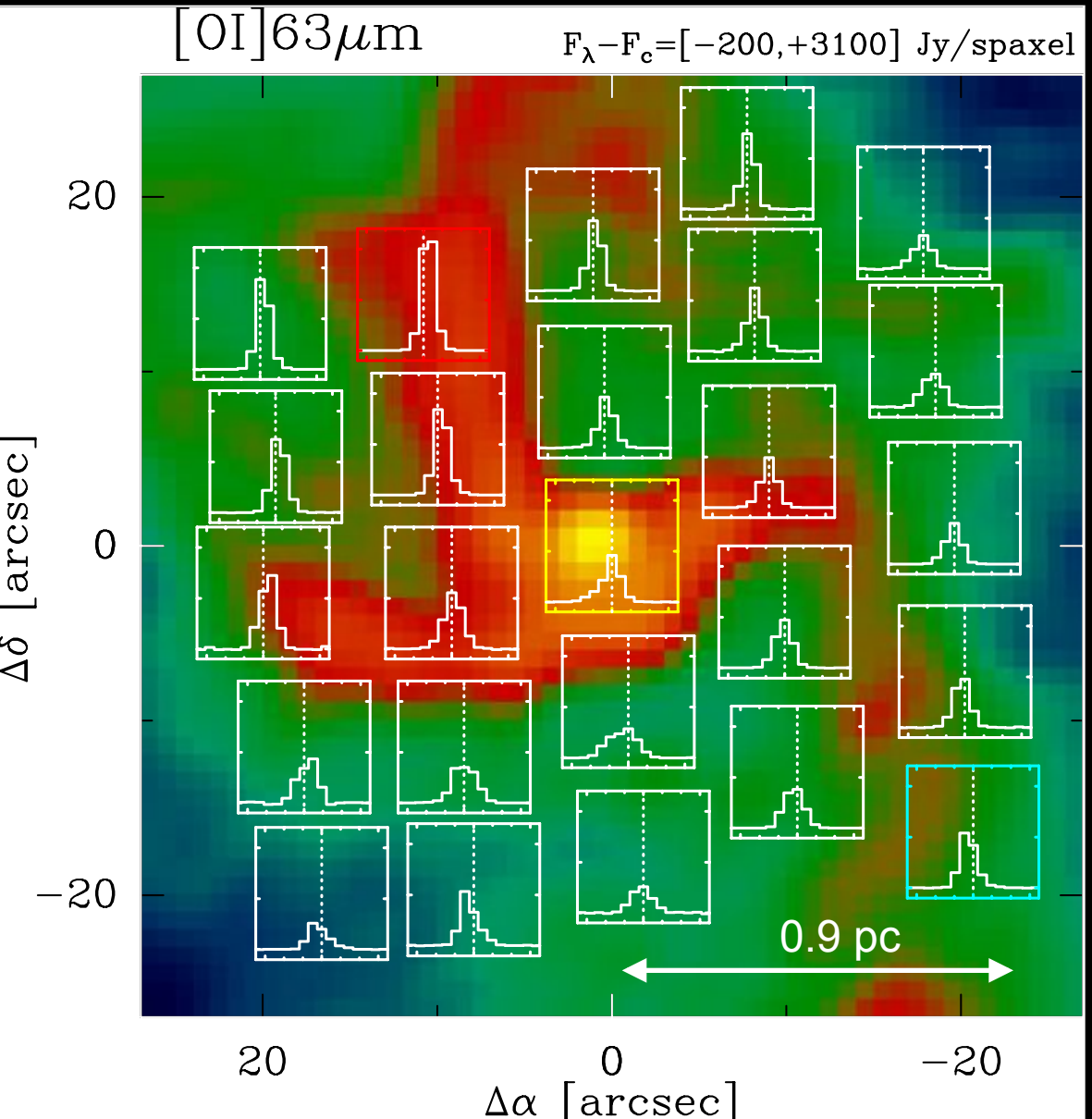
Fine structure lines:

T_{eff} ~ 35,000 ± 1,000 K
(OB stars central cluster)
$n_e > 10^{3.5}$ cm^{-3}
(from [OIII]52,88μm)

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

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

10” resolution



[OI] 63um
Neutral atomic gas

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

[OI]63/[CII]158 = 3.3±1.3

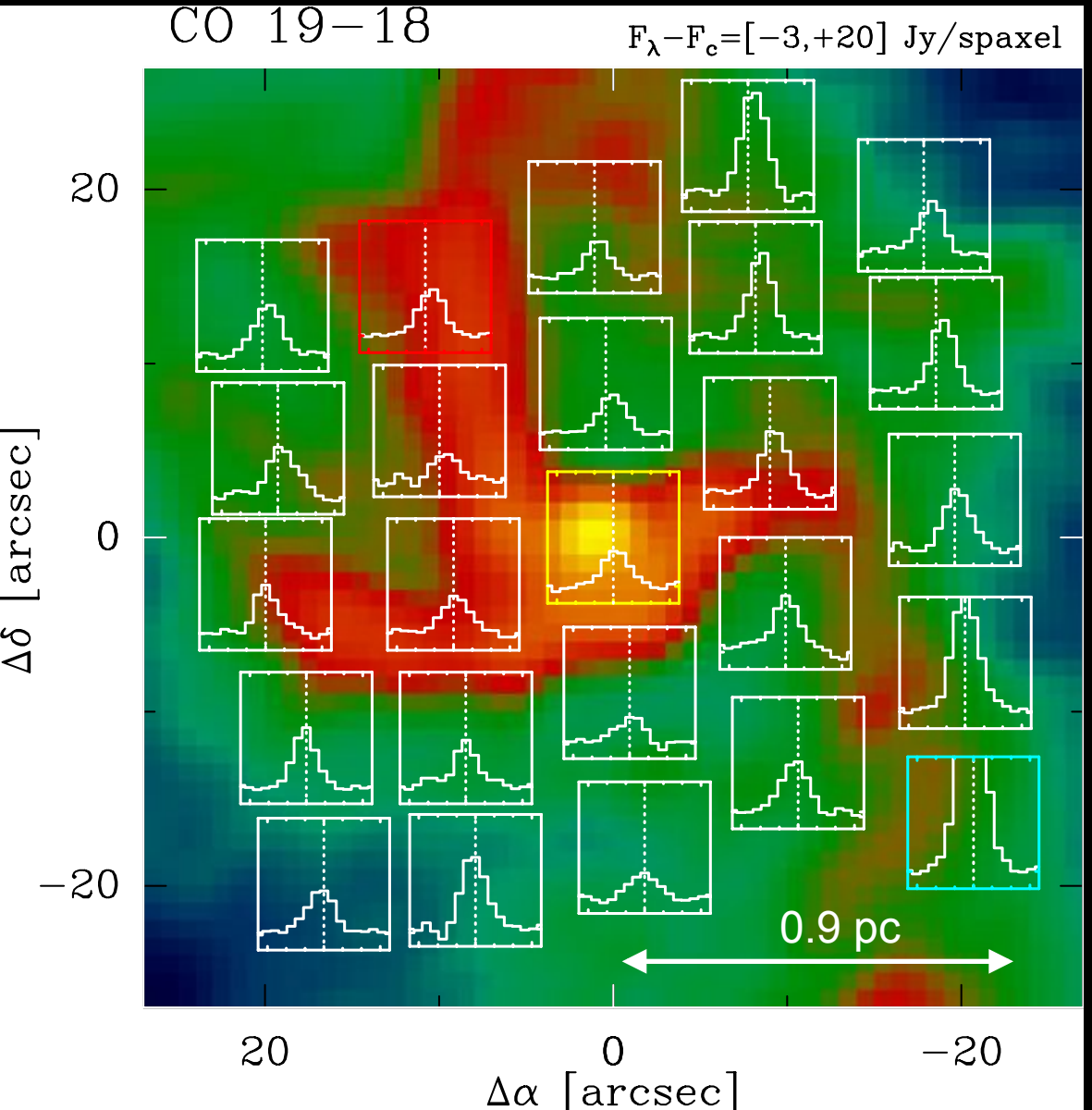
[OI]63/[OI]145 = 8.3±0.5

→ similar to PDRs …

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

The inner central parsec of the Galaxy
High-J CO peaks towards CND

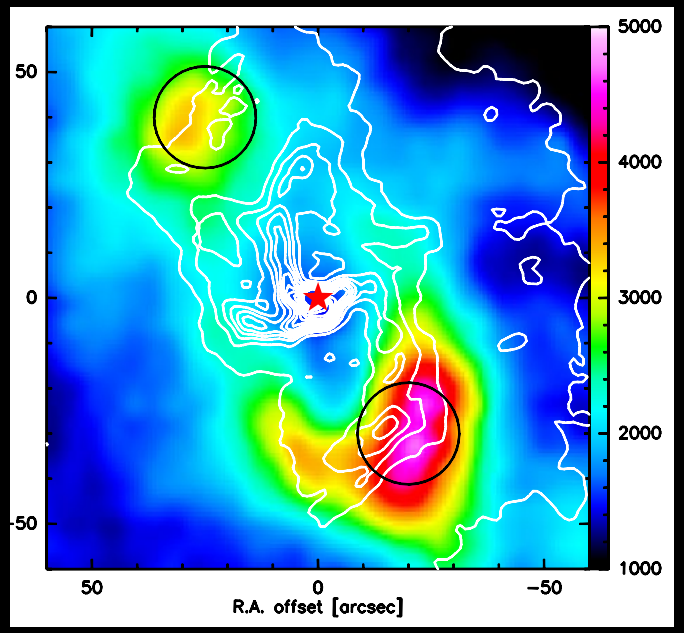
10” resolution



CO *J*=19-18

Hot molecular gas

APEX CO J=6-5



Requena-Torres et al. 2012

The inner central parsec

Inner 30”x30”

Far-IR luminosities

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}

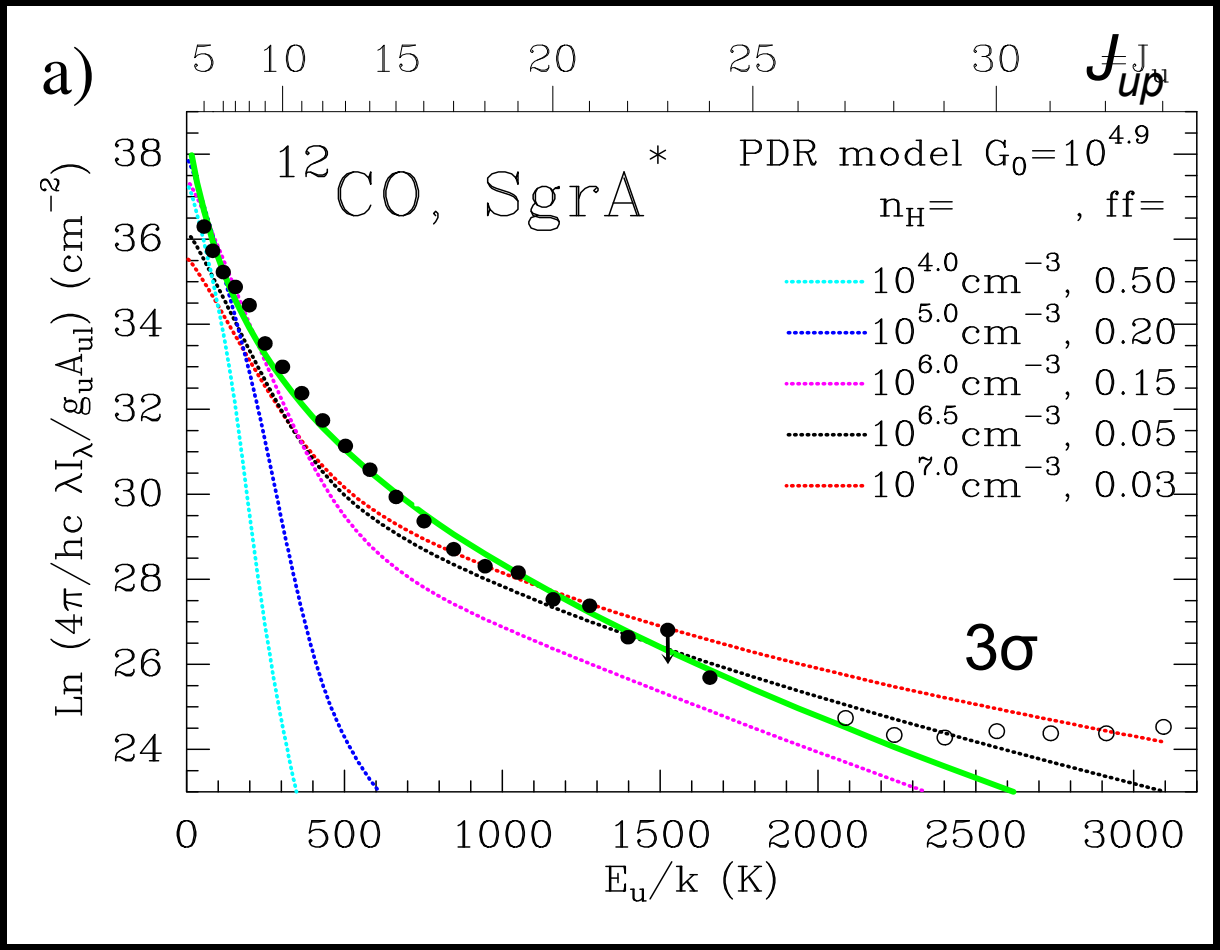
FIR cooling: Ionized gas ≈ 48%
Neutral atomic ≈ 46%
CO molecular ≈ 6%

→ GC = HII region + PDR + hot neutral component

Origin of the hot neutral component?

PDR view: warm gas heated by UV photons from central stellar cluster

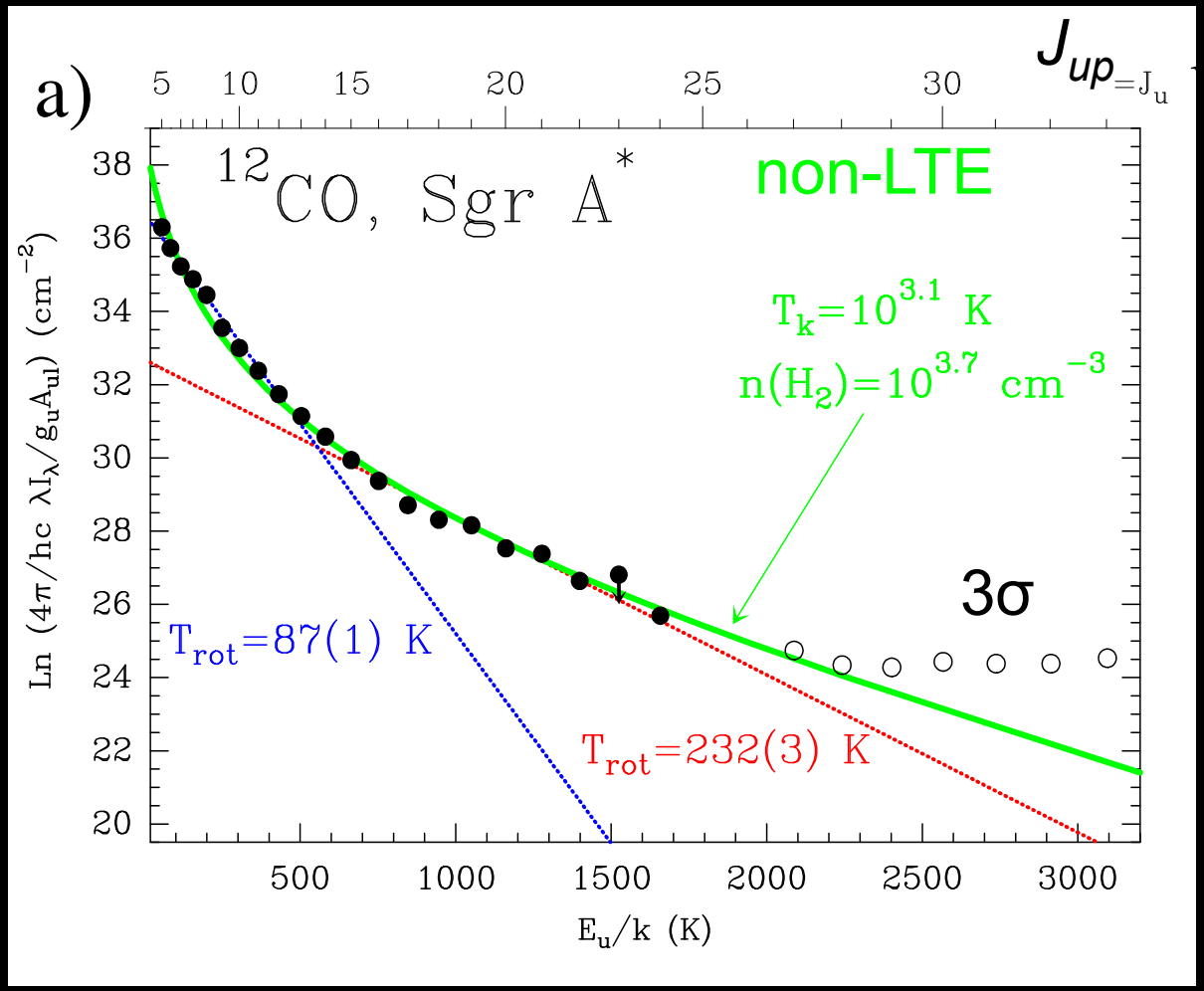
Meudon PDR code



$G_0^{FUV}=10^{4.9}$

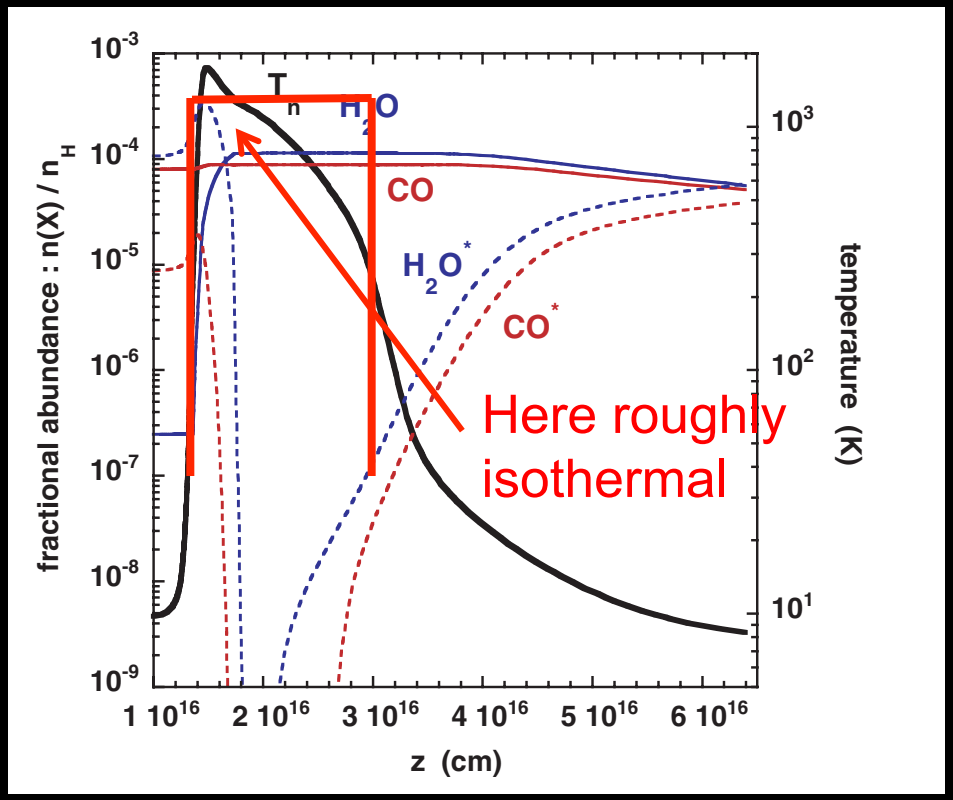
PDR models can reproduce the high-*J* CO lines
only if **unresolved** hot and dense **irradiated clumps** exist (n_H~10^7 cm^{-3})

Shock view: hot gas heated low-density shocks and turbulence dissipation

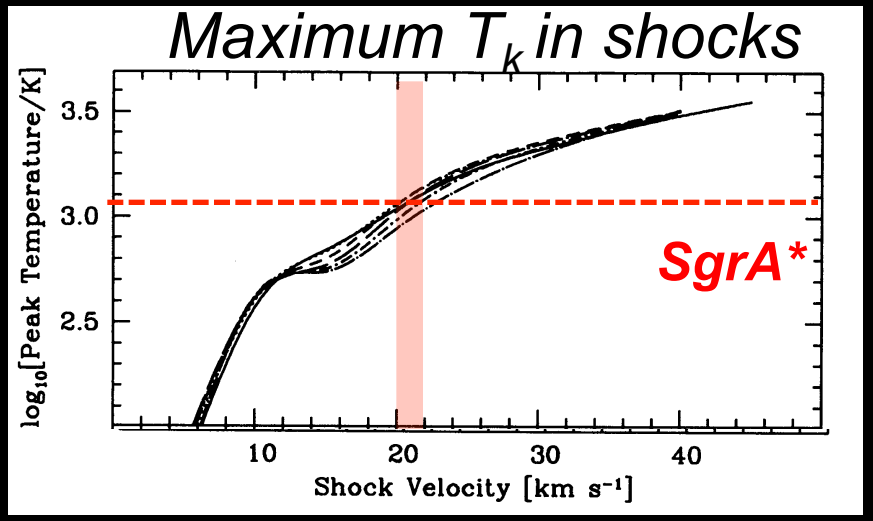


Isothermal component: T_k ~1000 K $n(H_2) \leq 10^4$ cm^{-3}

Non-dissociative C-type shocks
high-*J* CO, H_2O …



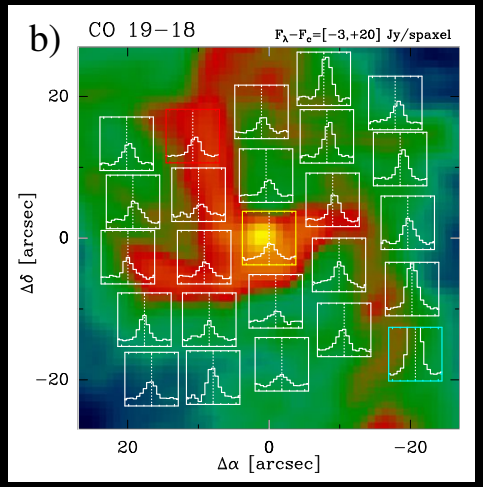
(Flower & PdF 2010)

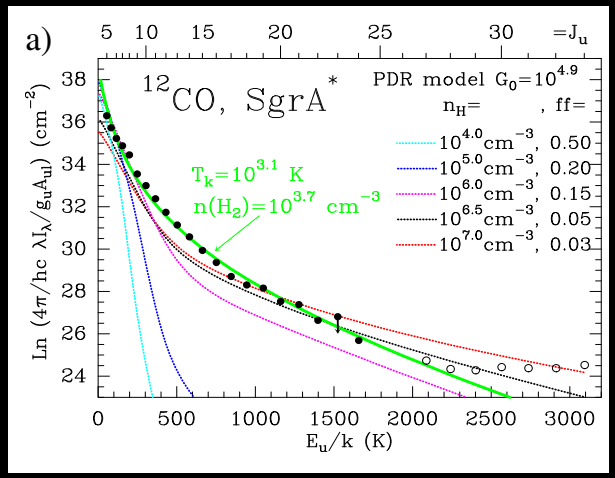


Kaufman & Neufeld 1996, models

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

Need much higher angular resolution to resolve the true gas morphology





2 SCENARIOS (SgrA*):

1) **Distribution of temperature components** "95% of CO column density at T_k<300 K".

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

→ Irradiated dense clumps?

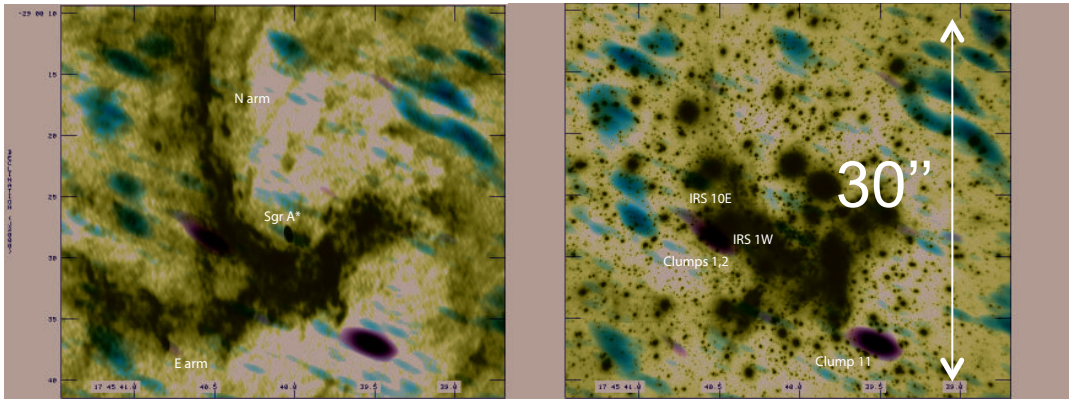
2) **Single, *hot*** (T_k≈1000 K) **and low-density** ($n(H_2)<10^4$ cm^{-3}) **gas component**

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

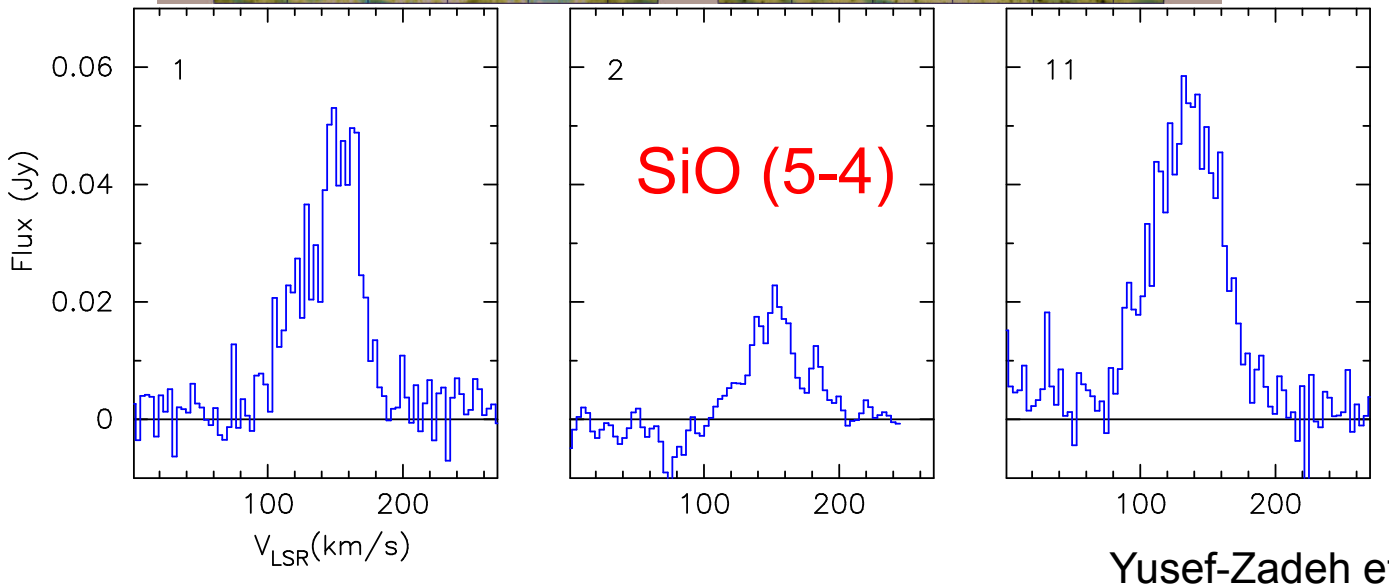
→Low density shocks??

First ALMA observations toward Sgr A (~2")*

SiO (5-4)
3.6cm VLA



SiO (5-4)
3.6um VLT

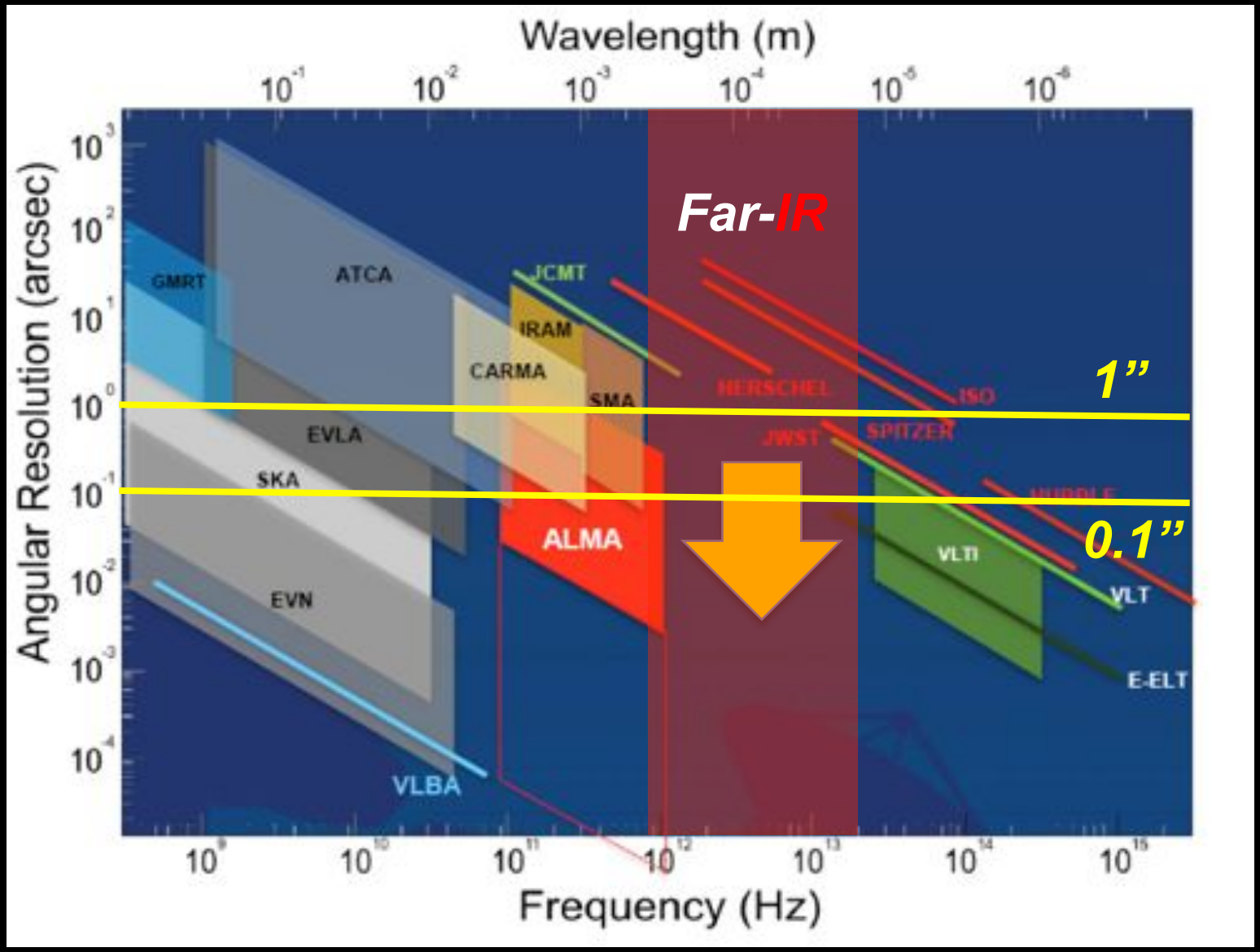


Yusef-Zadeh et al. 2013

embedded massive protostellar outflows??

Most important PDR & shock & protostar's diagnostics in the Far-IR !!

Far-IR: not playing the same league…

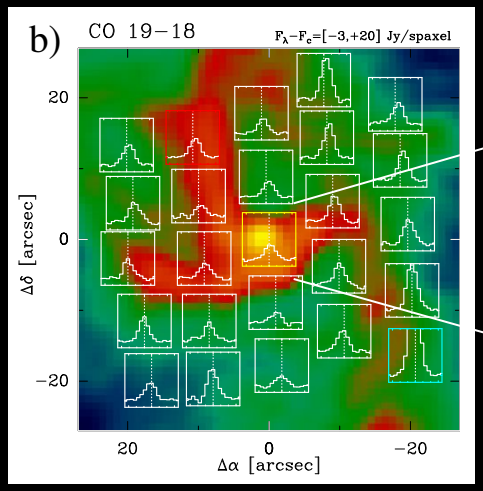


From T. de Graauw

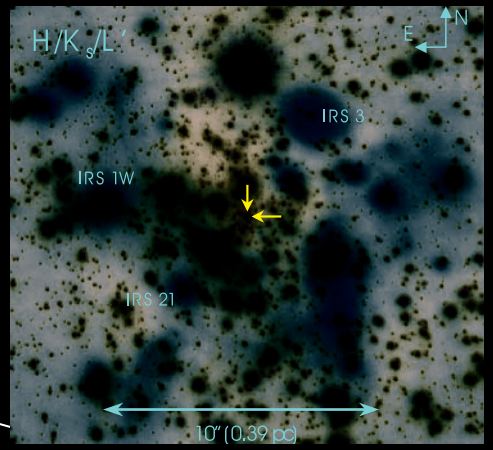
Limits our understanding…

Far-IR: requirements for GC studies

Herschel/PACS (Goicoechea et al.)



ISM & SF



VLT (Genzel et al.)

stars

- Angular resolution: 1''-0.3'' @ 100 μm → a few thousands AU at 8 kpc

- Fundamental structures and sources (in-falling clumps?, protostellar envelope/disk/outflows?)

- Spectral resolution:
- Heterodyne or R ≥ 30,000 for studies of gas kinematics

- Sensitivity: e.g., Flux([OI]63)~2.5E-17 W/m^2/0.3'' Flux(CO 14-13)~ 2E-19 W/m^2/0.3''

- Mapping semi-extended sources?: ~1'x1' FoV (mosaicing?) (short spacings?)