

FIR Spectroscopy of the Galactic Center: Hot and Warm Molecular Gas

Javier R. Goicoechea¹, Mireya Etxaluze¹, José Cernicharo¹,
Maryvonne Gerin³, Jerome Pety⁴ and collaborators

¹ICMM-CSIC, Cantoblanco, Madrid. E-28049, Spain

³LERMA, Observatoire de Paris, CNRS UMR 8112, École Normale Supérieure, France.

⁴IRAM, F-38406, Saint Martin d'Hères, France.

Abstract. The angular resolution ($\sim 10''$) achieved by the Herschel Space Observatory ~ 3.5 m telescope at FIR wavelengths allowed us to roughly separate the emission toward the inner parsec of the galaxy (the central cavity) from that of the surrounding circumnuclear disk (the CND). The FIR spectrum toward Sgr A* is dominated by intense [O III], [O I], [C II], [N III], [N II], and [C I] fine-structure lines (in decreasing order of luminosity) arising in gas irradiated by the strong UV field from the central stellar cluster. The high- J CO rotational line intensities observed at the interface between the inner CND and the central cavity are consistent with a hot isothermal component at $T_k \approx 10^{3.1}$ K and $n(\text{H}_2) \approx 10^4 \text{ cm}^{-3}$. They are also consistent with a distribution of lower temperatures at higher gas density, with most CO at $T_k \approx 300$ K. The hot CO component (either the bulk of the CO column density or just a small fraction depending on the above scenario) likely results from a combination of UV and shock-driven heating. If UV-irradiated and heated dense clumps do not exist, shocks likely dominate the heating of the hot molecular gas component. Although this component is beam diluted in our FIR observations, it may be resolved at much higher angular resolution. An ALMA project using different molecular tracers to characterize UV-irradiated shocks in the innermost layers of the CND is ongoing.

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1. The neutral gas component of the Galactic Center

The interstellar material within a few parsecs from the central supermassive black hole of the Milky Way (near the Sgr A* radio source position) is a unique template for our understanding of galactic nuclei and galaxy evolution. Widespread shocks, high-energy radiation, enhanced magnetic fields and strong tidal forces, all shape a very singular environment. The distribution of interstellar gas and dust around Sgr A* consists of a central cavity of ~ 1 pc radius containing warm dust and ionized gas. Some of the ionized gas streamers (the “mini-spiral”) bring material close to the very center. Between ~ 1.5 pc and ~ 5 pc, a disk of dense molecular gas exists (the CND). However, its physical and kinematical properties are not fully constrained, thus it is not yet clear whether all the material in the CND is stable against the strong tidal forces in the region, or has a more transient nature (e.g., Requena-Torres *et al.* 2012 and references therein).

The interface between the inner CND and the central cavity likely contains a component of warm neutral gas, detectable through FIR atomic fine structure line emission and through molecular line emission/absorption features. The nature of this component, its ionization sources, heating mechanisms and kinematic patterns (in-falling gas from the CND? outflows? orbiting material?) are not known.

Owing to the small extinction effects at FIR wavelengths, and because of the strong emission from the ISM component related to AGN and star formation, the relevance of

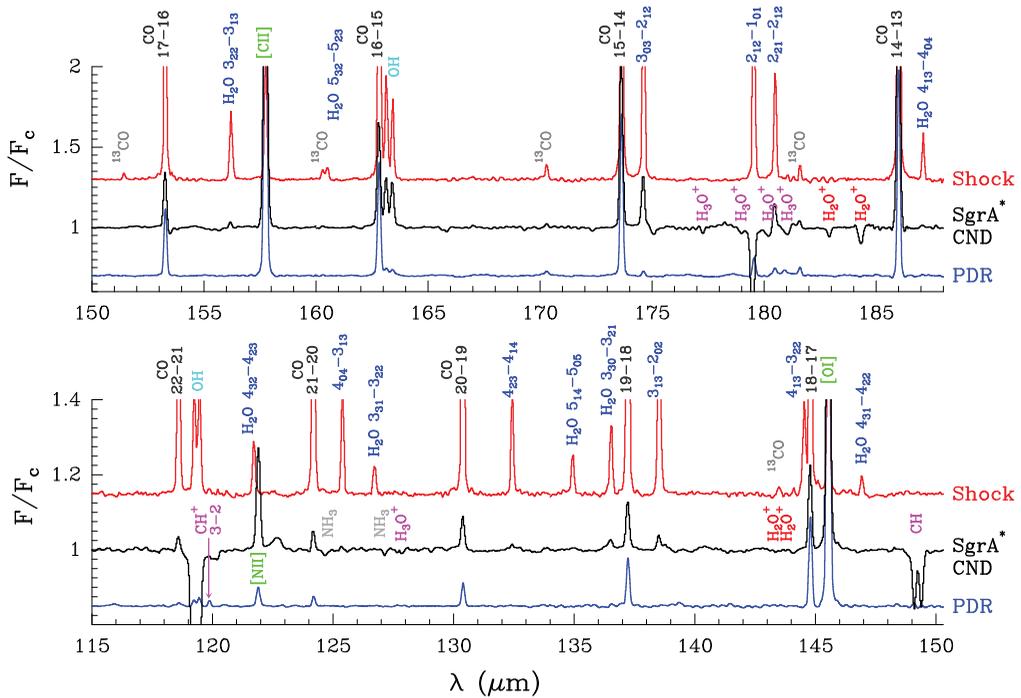


Figure 1. Comparative FIR spectra of three different template environments in the Milky Way taken with *Herschel*/PACS. They correspond, from top to bottom, to Orion BN/KL outflows (red; Goicoechea *et al.* 2015), the CND around Sgr A* (black; Goicoechea *et al.* 2013), and the Orion Bar PDR (blue). The ordinate scale refers to the line flux to continuum flux ratio.

FIR spectroscopy ($\sim 50\text{--}350\ \mu\text{m}$) to characterize extragalactic nuclei has notably increased thanks to *Herschel*, and now to ALMA observations of high- z galaxies. Goicoechea *et al.* (2013) presented the complete FIR/submm spectrum toward Sgr A*. The emission is dominated by strong [OIII], [OI], [CII], [NIII], [NII], and [CI] fine structure lines. In addition, rotationally excited lines of CO (from $J=4\text{--}3$ to $24\text{--}23$), H₂O, OH, H₃O⁺, HCN and HCO⁺ (up to $J=8\text{--}7$) as well as ground-state absorption lines of OH⁺, H₂O⁺, CH⁺ and HF are detected. Figure 1 shows a comparison of FIR spectra of three archetypal environments in the Milky Way: a protostellar outflow and associated shocked molecular gas, a sight line to the CND including dense gas and foreground absorption by diffuse gas, and a highly UV-irradiated dense PDR. Whereas the shocked region shows very intense rotationally excited CO, H₂O and OH emission lines (in decreasing order of luminosity), the PDR spectrum is dominated by strong [CII] and [OI] emission, with faint lines from H₂O. The warm neutral gas in the Galactic Center has a richer spectrum, with hydrides such as NH₃, OH, H₂O, H₃O⁺, and H₂O⁺ indicating the presence of UV- and CR-irradiated gas. These molecules are powerful tracers of the excitation conditions and ionization sources of the warm molecular gas (see review by Gerin *et al.* 2016).

References

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