ISAAC M-band spectroscopy of dust embedded sources at the Galactic Center

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Abstract. We present our most recent observations in the M-band, ranging from 4.4 to 5.1 micron, of the central parsec of the Galaxy, obtained with the ISAAC spectrograph of the VLT. These observations resulted in unprecedented high quality spectra of the brightest sources of the central parsec which allow us to analyse the spatial distribution, locally and along the line of sight, of the solid and gaseous phase of the CO molecule.

1. Introduction
At a distance of 8 kpc, the Galactic Center (GC) is the closest galactic central region. It can thus be studied in detail by the direct observation of individual stars, gas, and dust. It represents an ideal and unique case allowing us to analyse thoroughly the direct environment of a central supermassive black hole.

The Galactic Center cavity of about 3 pc in diameter, is obscured by extinction from the diffuse interstellar medium (ISM) present along the line of sight and is surrounded by a circumnuclear ring of dense gas and dust showing clumpy extinction [5]. The exact magnitude and spatial distribution of this obscuration are complex but a mean value of the visual extinction towards prominent sources within the central stellar cluster reaches $\sim 27$ mag [7, 13]. Moreover, the extinction across the central 10" to 20" is shown to be smoothly distributed [13].

Recently, we studied the distribution of the water ice and hydrocarbon features at 3.0 $\mu$m and 3.4-3.48 $\mu$m, respectively, in the central parsec. Our results show that most of these features are predominantly produced locally in the central parsec and are associated with individual bright sources [10, 11].

In this contribution, we present our most recent observations of the central parsec of the Galaxy, performed in the M-band spectral region using the ISAAC instrument at the ESO VLT UT1 (Antu) telescope. This allows us to analyse the spatial distribution of the CO molecule in its gas- and solid-phase.

2. Observations
We have observed about 20 bright sources of the central parsec using the ISAAC NIR spectrograph of the VLT. We used the long wavelength, low resolution (R=800) spectroscopic mode in the spectral range of the M filter from 4.4 $\mu$m to 5.1 $\mu$m.

To correct for sky emission, the chopping technique was used with chopper throws of $\sim 20$" along
Figure 1. M-band spectra of the He emission line stars of the IRS 16 complex. The CO gaseous and solid phase absorptions are also shown. All blanked spectral regions correspond to residuals from the telluric lines.

As it can be seen in figures 1, 2, 3 and 4, in addition to the Pfβ Hydrogen line at 4.65µm, two spectral features of the CO molecule are present in this spectral band:

- The absorption band of the $^{13}$CO gas-phase with its fundamental vibration-rotation P and R branch lines around 4.666µm.
- The absorption feature at 4.675µm of the solid-phase CO.

The interstellar solid CO at 4.675µm was detected for the first time in the deeply embedded young stellar object W33A by [6]. In the Galactic Center, the solid-phase CO feature was observed in IRS 12 by [8]. The authors also detected the absorption band of the gas-phase CO in
 IRS 3, IRS 7 and IRS 12 but the P and R branches were not resolved. The CO absorption in IRS 3 was also previously observed by [3]. However the $Pf_\beta$ Hydrogen emission line is absent in all three spectra.

From the solid-phase CO feature detection towards IRS 12 and its absence towards IRS 3 and IRS 7, [8] conclude that the distribution of the cold molecular clouds is not uniform in the central cluster. They also conclude that the molecular clouds cannot be close to the Galactic Center because the CO molecule cannot survive temperatures higher than 20K unless they are located in an environment of water ice and other molecules.

Here we present for the first time, good quality M-band spectra of 15 bright sources of the central parsec including the He emission-line stars of the IRS 16 complex, cool stars and the dust-embedded sources of the northern arm of the minispiral. Unlike [8], in our spectra, the P and R branches of the gas-phase absorption feature are resolved. This will allow us to derive column densities of the CO gas-phase. We also observe a prominent $Pf_\beta$ emission line in IRS 12 that was not detected previously and a CO solid-phase absorption feature in IRS 7 that was also absent in the IRS 7 spectrum published by [8].

In our spectra, all dust free He-stars of the IRS 16 complex show the solid CO feature that is probably present in the foreground material of the ISM. IRS 16C shows almost no gas-phase absorption, while IRS 16NE and IRS 16SW do. This can be due to the fact that the latter are closer to the minispiral by which the observed gas-phase feature is probably caused. Moreover,
Figure 3. M-band spectra of the dust embedded sources in the northern arm of the minispiral. All blanked spectral regions correspond to residuals from the telluric lines.

all cool stars (IRS2S, 2L, 9, 12N) also show the solid absorption in their spectra which looks deeper than in the spectra of the He-stars. This suggests that part of this absorption is local and associated with these sources, which is an expected result, since the solid-phase CO can survive in the direct environment of these stars. On the other hand, all the dust-embedded sources of the northern arm (IRS1W, 5 and 10W) of the minispiral, except IRS21, as well as IRS3, 29 and 13E (classified as dusty Wolf-Rayet stars), show the gas-phase feature in their spectra. The observed gas-phase CO is most probably located in the minispiral and heated by the hot massive dust-embedded sources.

This work is still in progress and will be pursued by a more detailed and quantitative study in Moultaka et al. (in preparation).

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Figure 4. M-band spectra of the IRS 13 complex, IRS 29, the dust embedded source IRS 21 and the cool supergiant IRS 7. All blanked spectral regions correspond to residuals from the telluric lines.

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