Hot molecular gas in the central region around Sgr A*  

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Abstract. We present our latest Submillimeter Array1 (SMA) results on HCN(4-3) in the Sgr A* vicinity. We have produced a 37-pointing mosaic, covering a 2' × 2' area around Sgr A*. The angular resolution is 2.5" and the spectral window covered the velocity range of -180 - 1490 km s\(^{-1}\). We compare our results to the HCN(1-0) observations from the Owens Valley Radio Observatory (OVRO) by [1]. Because of the higher excitation of the (4-3) transition, we find that absorption by lower density foreground material is not important. By comparing the (4-3) and (1-0) results, we find that the excitation is not uniform within the circumnuclear disk (CND). The southern part is stronger in the higher-excitation line. This result was previously suggested by single-dish observations from [2]. We discuss our results in the context of the structure and stability of the CND.  

1. Introduction  
One of the most fascinating characteristics of the Galactic Center is the type of interstellar medium (ISM) it is composed of. This ISM is very dense, warm and turbulent, much more than in other regions of the Milky Way, and it is mostly concentrated in giant molecular clouds (GMCs) ([3]). Because the temperature is higher, the molecular species detected in this region are highly excited, and even rare species, hardly observed anywhere else in the Galaxy, are present.  

Different molecular studies have demonstrated that the central 10 pc of the Galaxy have a very remarkable geometry, as can be seen in figure 1. Many different features have been detected in this region, surrounding the central black hole, Sgr A*. The close proximity of all of these structures implies that powerful interactions are taking place between them. The study of these interactions should shed light on our understanding of the dynamics of the Galactic Center.  

Previous studies have addressed the study of this region using different molecular tracers, with both interferometers and single-dish antennas. [4] studied the central 10 pc of the Milky Way.
Way using a high-density molecular tracer, NH₃ (∼10⁵ cm⁻³), in four different transitions, (1,1), (2,2), (3,3) and (6,6), using the Very Large Array (VLA). The lower transitions, (1,1) and (2,2), do not show very strong emission and this is mostly extended. (3,3), on the other hand, seems to trace quite well most of the structures in this region marked in figure 1. The explanation of these different behaviors is that (1,1) and (2,2) are suffering absorption from cold material in the line of sight, while the higher transitions are not affected by this problem. (6,6), which traces material at a very high temperature, ∼400 K, is detected very close to Sgr A*, but it is mostly absent everywhere else. These results confirm that really hot and dense material can be found in the close proximity of Sgr A*. This interesting conclusion brings the necessity to expand the study using another high-density molecular tracer, hence HCN (∼10⁶ cm⁻³).

[5] used the Hat-Creek Interferometer to observe the Galactic Center in HCN(1-0). Their results showed that (1-0) traces nicely the CND but for a gap in the eastern part, being the southern part stronger than the northern, and even emission to the south, outside of the CND, is seen. A few years later [6] observed the same region with the Berkeley-Illinois-Maryland Association (BIMA), producing a very similar emission map, where the emission coming from the southern part of the CND is stronger than the emission from the northern part. The latest and most improved results in HCN(1-0), in terms of angular resolution, were obtained using OVRO by [1]. In the emission map produced by these results (Fig. 2), we can appreciate the different structures more clearly than in the previous studies, even seeing the southwest lobe and the northeast lobe as separated structures. But HCN(1-0) is affected by self-absorption, as it has been reported by [7]. Therefore, the necessity to find a transition that is not affected by this problem. HCN(4-3) fulfills this requirement. HCN(4-3) was not available before for high-resolution interferometric studies, since no array had a receiver that covered the 354 GHz frequency. Nowadays, the SMA has solved this problem, allowing us to continue our study.
2. Observations
Observations of the central 2 pc of the Milky Way (which cover Sgr A*, the ionizing gas forming the mini-spiral and the CND surrounding them both, see figure 1) in HCN(4-3) ($\nu = 354.505$ GHz) were made with the SMA in the compact configuration on 2004 July 9 and 2005 July 1 and 7 and August 13. The primary beam for the 354 GHz frequency is 36", therefore to cover the central 2 pc ($\sim 2' \times 2'$) we needed a mosaic. We produced a 37-pointing mosaic in 2004 and a 25-pointing mosaic in 2005, both centered on Sgr A*. The data were reduced using the MIR package developed for the SMA calibration and consequently imaged using MIRIAD (Multichannel Image Reconstruction, Image Analysis and Display). The synthesized beam is $2.5'' \times 1.7''$.

3. Results
Figure 3 shows the integrated intensity map obtained combining the four nights of data. There is a very clear detection of the southern part of the CND, but the emission from the northern part is almost non-existent. This result is somehow not surprising since previous single-dish studies by [2] showed the same pattern (Fig. 5): the emission from the southern part of the CND is much stronger than the emission from the northern part.

[2] explained this behavior by distinguishing the northern and the southern lobes of the CND as independent structures following the same rotation pattern. While most of the material in the southern part of the CND follows this pattern, only the high velocity material of the north does, since emission at lower velocities seems to be dominated by material that does not belong to the CND, but that it is rather in the line of sight. By plotting the spectra at the different peaks marked in figure 3 (Fig. 4), we can see that the trend followed is certainly that of a rotation around Sgr A*, with the northern part receding and the southern part approaching.

Comparing the (4-3) results with the (1-0) emission map from [1] (Fig. 6) we can see that the emission from the lower-excitation line traces the CND more efficiently, but also that (1-0), as well as (4-3), is stronger in the southern part of the CND (Fig. 2). This result means that not only the northern and the southern parts of the CND are independent structures, but also
that they have different excitation levels, being the material composing the southern part of the CND warmer than the material in the northern part.

**Figure 5.** HCN(4-3) integrated intensity adapted from [2]. The contour levels are in steps of 25 K km s\(^{-1}\) from 75 K km s\(^{-1}\).

**Figure 6.** HCN(4-3) integrated intensity in contours and HCN(1-0) integrated intensity in false-color scale from [1]. The HCN(4-3) map has been smoothed to match the HCN(1-0) resolution. The contour levels are in steps of 3\(\sigma\), from 3 to 12\(\sigma\), and the last contour level is at 14\(\sigma\).

We also compare our results with those obtained from another high-density tracer, NH\(_3\), in its two highest mapped transitions, (3,3) and (6,6), ([7] and [8], respectively) observed with the Very Large Array (VLA) (Fig. 7 and 9). NH\(_3\) traces material at higher temperature but less dense than the material traced by HCN. More precisely, NH\(_3\)(3,3) traces material at \(\sim 125\) K and (6,6) at \(\sim 412\) K, while HCN(4-3) traces material at \(\sim 25\) K, but with a density one order of magnitude higher than that of the material traced by NH\(_3\). The first remarkable feature observed in both figures (7 and 9), is that NH\(_3\), in both transitions, is mostly absent from the northern part of the CND, a behavior also observed in HCN(4-3). Apart from that similarity, the maps look really different. NH\(_3\)(3,3) seems to trace the western part of the CND, but it is not very strong, in fact, it is stronger towards the southeast of the CND. It seems to trace the southern streamer that connects the “20 km s\(^{-1}\) GMC” with the CND (see figure 1), but it disappears once it reaches the CND. In order to see if the NH\(_3\)(3,3) and the HCN(4-3) are really “connected”, we plot the spectra at the same peaks or at least close by. We can observe that the peaks are not exactly coincident in the western peak (named H). The emission peak for NH\(_3\)(3,3) is red-shifted, indicating that HCN(4-3) and NH\(_3\)(3,3) are not tracing the same material. The spectra corresponding to the eastern peaks (since they are not really coincident for NH\(_3\)(3,3) and HCN(4-3), named K and L) show that the NH\(_3\)(3,3) does not have a large velocity gradient, unlike the HCN(4-3), and it is also red-shifted. This means that the material traced by both molecular transitions is probably unrelated and what we see as a “connection” between the CND and the southern streamer might be a projection effect.

NH\(_3\)(6,6) is mostly absent from the southern lobe of the CND, but it appears on the eastern
Figure 7. HCN(4-3) integrated intensity in contours and NH$_3$(3,3) integrated intensity in false-color scale from [7]. Contour levels are as in figure 3. Sgr A* is marked by a star.

Figure 8. Spectra at the positions marked in figure 7. The left-side spectra correspond to our HCN(4-3) results. The right-side spectra are NH$_3$(3,3) spectra in thick lines and HCN(1-0) spectra in thin lines adapted from [7] and [6] (the self-absorption suffered by HCN(1-0) is clearly seen in the bottom-right spectrum).

part of the CND, looking as a continuation towards the north of the southern extension of the CND. But, unlike HCN(4-3), NH$_3$(6,6) is detected inside the CND. This situation could happen because the conditions inside the CND allow gas at 412 K to survive, but not at 25 K. Looking at the spectra, we can observe that the spectra of the western peak (named E), both in HCN(4-3) and NH$_3$(6,6), have a similar linewidth and are centered at the same velocity, therefore NH$_3$(6,6) and HCN(4-3) seem to be tracing the same kind of material. The situation is completely different for the eastern peak (named D). The NH$_3$(6,6) line is very broad, which means that it is being affected by some kind of interaction, most likely related to the central black hole, while the HCN(4-3) seems to be merely following the rotation pattern mentioned previously.

4. Conclusions
We have successfully detected and mapped the emission corresponding to a high-density molecular tracer in a high-excitation state, HCN(4-3), in the Galactic Center, using the SMA. The detected emission shows that the CND might be composed by material in different excitation states, being the northern part of the CND colder than the southern part. Also, the connection that seems to be present between the southern streamer and the CND is most likely a projection effect. HCN(4-3) is not detected inside the CND, unlike the less dense but warmer NH$_3$(6,6). The interactions that the material inside the CND might be undergoing could prevent the colder gas from surviving there.

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Figure 9. HCN(4-3) integrated intensity in contours and NH$_3$(6,6) integrated intensity in false-color scale from [8]. Contour levels are as in figure 3. Sgr A* is marked by a star.

Figure 10. Spectra at the positions marked in figure 9. The left-side spectra correspond to our HCN(4-3) results. The right-side spectra are NH$_3$(6,6) spectra adapted from [8].

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