The Warm ISM in the Sgr A Region: Mid-J CO, Atomic Carbon, Ionized Atomic Carbon, and Ionized Nitrogen Line Observations with the Herschel-HIFI and NANTEN2/SMART Telescopes

[1]García P., [1]Simon R., [1]Stutzki J., [2]Requena-Torres M., [2]Güsten R., [3]Fukui Y., [3]Yamamoto H., [4]Bertoldi F., [5]Burton M., [6]Bronfman L., [7]Ogawa H.

[1]I. Physikalisches Institut der Universität zu Köln, [2]Max-Plank-Institut für Radioastronomie, [3]Nagoya University, [4]Universität Bonn, [5]University of New South Wales, [6]Universidad de Chile, [7]Osaka Prefecture University.

contact: pablo@ph1.uni-koeln.de, Zülpicher Straße 77, 50937 Cologne - Germany, Phone: ++49 +221 4701334

This Program is supported by the BmbF Verbundforschung under grant number 05A08PK2

Overview

The interstellar medium (ISM) in the few central hundred parsecs of the Galaxy has physical properties that differ strongly from the rest of the ISM in the Galaxy: violent motions in dense high temperature gas, strong magnetic and radiation fields, and a rich chemistry make the Galactic Center (GC) of the Milky Way a unique testbed for studies of the ISM and star formation under such extreme conditions and a powerful tool in understanding the physical processes in the nuclei of other galaxies.

In order to study the warm ISM around the Sgr A Region in the GC, we present Herschel-HIFI sub-mm atomic carbon ([CI] $^3P_1$ - $^3P_0$ and [CI] $^3P_2$ - $^3P_1$), ionized carbon ([CII] $^2P_{3/2}$ - $^2P_{1/2}$), and ionized nitrogen ([NII] $^3P_1$ - $^3P_0$) line observations obtained in the frame of the Herschel Guaranteed Time HEXGAL (Herschel EXtraGAlactic) key program (P.I. Rolf Güsten, MPIfR), and NANTEN2/SMART carbon monoxide (CO J = 4 - 3) line observations, as part of NANTEN2/SMART CMZ Survey (P.I Pablo García, I. Physikalisches Institut, Universität zu Köln).

Observations

The 3.3 m Herschel Satellite, with the onboard Heterodyne Instrument for the Far-Infrared (HIFI) [5], and the 4 m NANTEN2 telescope, with the 16 pixel Sub-Mm Array for Two Frequencies (SMART) were used to detect the sub-mm emission tracing the warm (~50 K) component of the ISM. In Table 1, all relevant parameters for the lines observed, and the equivalent energy transition, measured from the ground state, are shown.

Table 1: Summary information of the observed datasets. From left to right: telescope, spectral line, observed frequency, telescope beam width, final spatial resolution, forward efficiency, rms noise temperature expressed in the $T_A{}^*$ antenna temperature scale, final velocity resolution, and energy of the upper level above ground of the given transition.

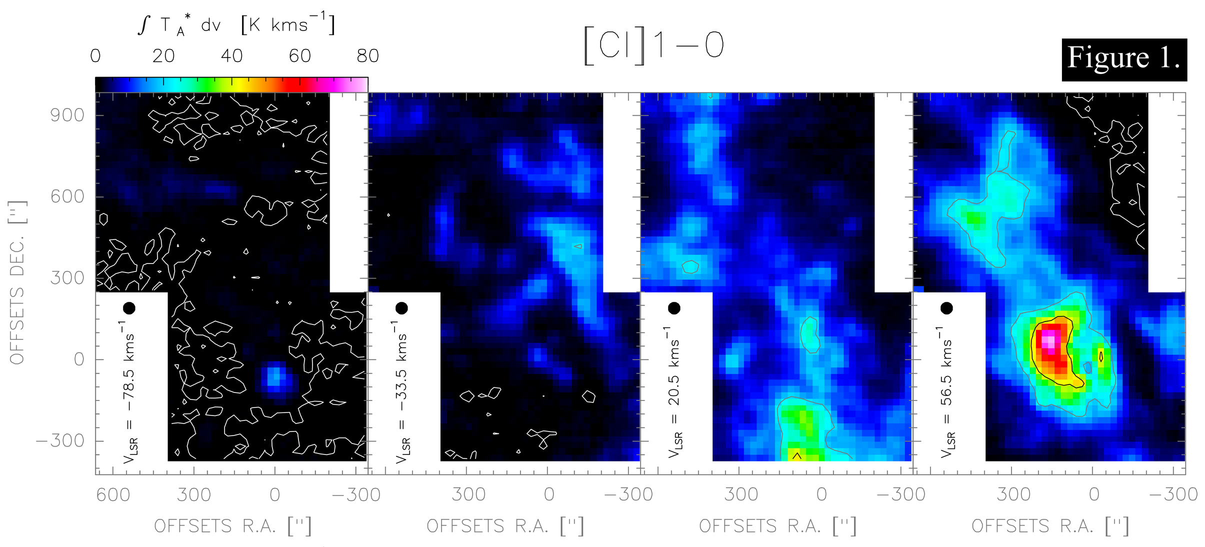
Telescope	Line	ν (GHz)	FWHM (")	Θ (")	F_{eff}	T_{rms} (K)	ΔV kms^{-1}	E_u (K)
NANTEN2/SMART	CO($J=4-J=3$)	461.0	37.4	40.0	0.86	0.13	1.0	55
HERSCHEL/HIFI	[CI] $^3P_1-{}^3P_0$	492.2	43.1	46.0	0.96	0.06	1.0	25
HERSCHEL/HIFI	[CI] $^3P_2-{}^3P_1$	809.3	26.2	27.6	0.96	0.13	1.0	60
HERSCHEL/HIFI	[NII] $^3P_1-{}^3P_0$	1461.1	14.5	46.0	0.96	0.28	1.0	70
HERSCHEL/HIFI	[CII] $^2P_{3/2}-{}^2P_{1/2}$	1900.5	11.2	46.0	0.96	0.42	1.0	90

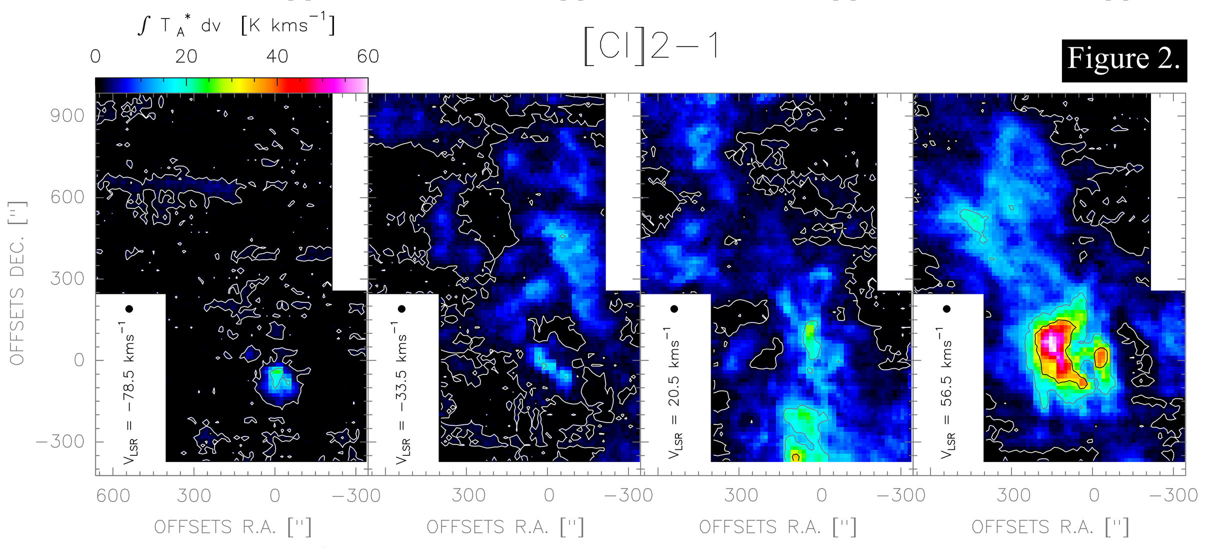
Spatial and Velocity Distribution of the Sub-mm Emission

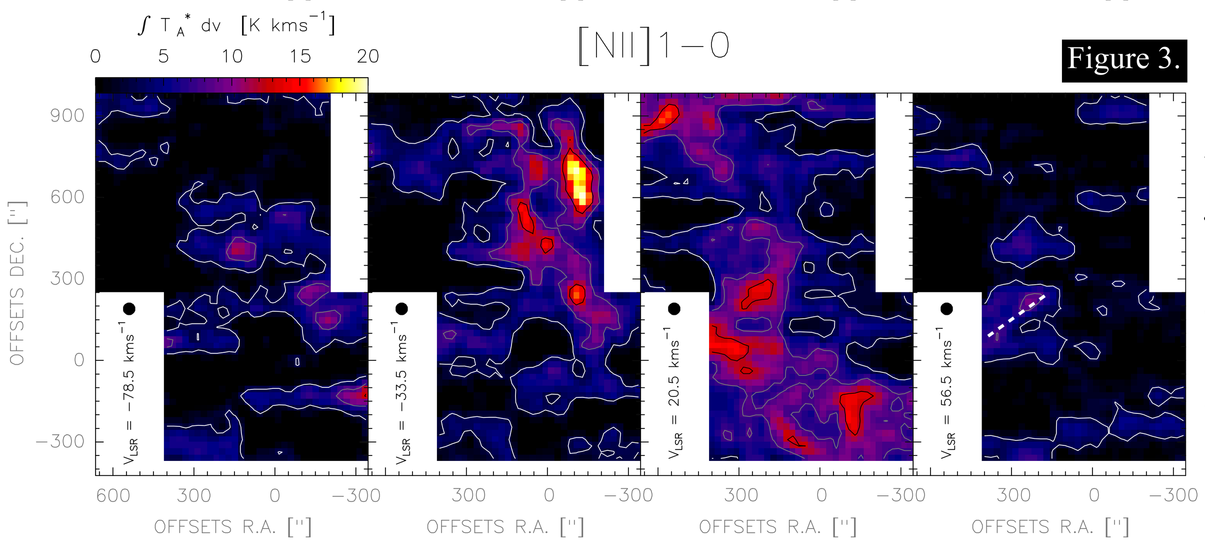
The spatial and LSR velocity distributions of the emission show large scale structures and complex line shapes over a wide velocity range from -200 kms^{-1} to +200 kms^{-1}. Figures 1 to 5 show the integrated intensity spatial distribution in each dataset for selected LSR velocities, where known prominent sources in the Sgr A Region are located. The integrated intensities are calculated by integrating a 10 kms^{-1} wide velocity interval, centered at the LSR velocity shown in each panel. The center position of all maps corresponds to 17^h:45′:39.9″; -29°:00′:28.1″ in Equatorial coordinates. The NANTEN2/SMART data shown in Figure 5 were observed in Galactic coordinates.

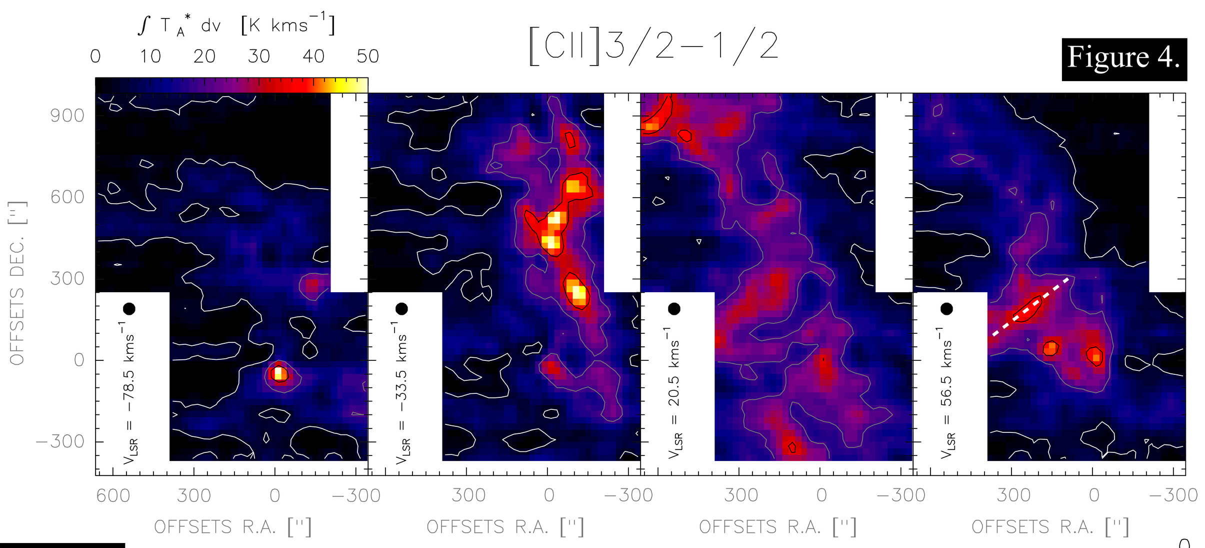
The first panel in the figures (from left to right for Figures 1 to 4, and from top to bottom in Figure 5) shows the integrated emission centered at -78.5 kms^{-1}. A circular shape structure, south of the *Central Nuclear Disk* (**CND,**[6]), around the (0″,-75″) position in Equatorial offsets, can be clearly seen in both [CI], CO(4-3), and [CII] lines. The lack of [NII] emission at the same position indicates a PDR-like region [1]. The second panel with the emission centered at -33.5 kms^{-1} shows very bright emission in the [CII] and [NII] lines, and their ring-like structure, in the square defined by the coordinates (+150″,+350″) and (-200″,+950″) in Equatorial offsets, matches the location of the known **Arched-Filaments**, also seen in 20 cm continuum [6] contours in Figure 7, within the same area. The ring-like structure is also seen in the lower frequency lines, but it is much weaker at that LSR velocity. The third panel shows the emission centered at +20.5 kms^{-1}, where the known **„+20 kms^{-1} Cloud**“ can be clearly identified specially in CO(4-3) centered at (-200″,-50″) in Galactic coordinates offsets, with very bright and widespread emission around it. For the [CI] lines, a local intensity maximum can be seen at the (+50″, -225″) position, but the extension of the emission is much less than in CO(4-3). The [NII] and [CII] emission does not correlate with the position of the source, but surrounds it.

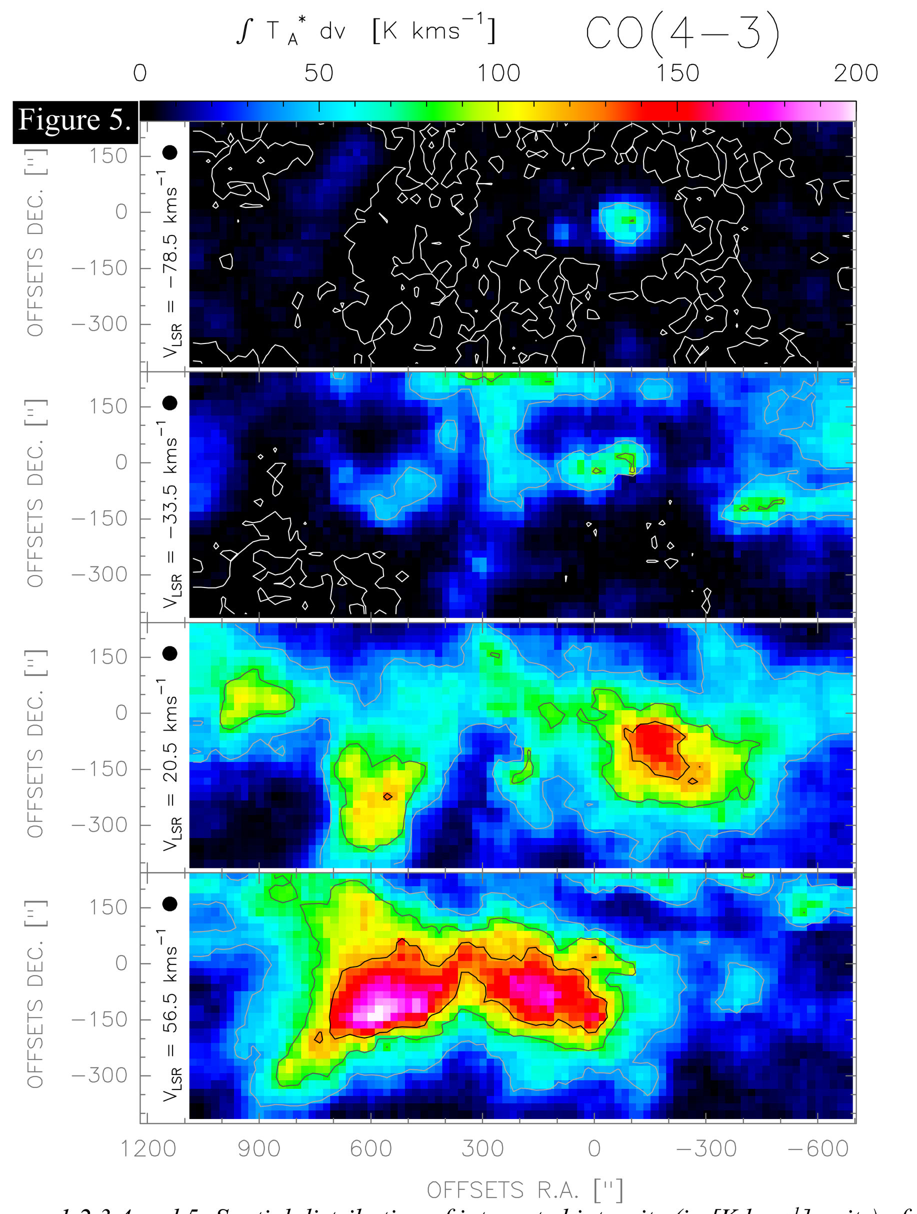
The last panel, centered at +56.5 kms^{-1} shows the known **„+50 kms^{-1} Cloud**“. It extends around the brightest [CI] emission in both lines as a „crescent-shape“ structure, surrounding the CND. It is also seen in CO(4-3) as the second brightest region on the map (material surrounding the intensity peak on the right of the map, around the (+150″, -75″) Galactic coordinates offsets). In Figure 6, the contours of the [CII] and [NII] overlaid on the [CI]1-0 emission (colours), show a lane of emission that goes from (+400″,+100″) to nearly (+100″,+250″) (dashed line in Figures 3, 4 and 6). The **CND** shown as red-square is plotted for reference. In Figure 7, the VLA 20 cm continuum data [6] is shown as contours. In the figure, it can be seen how the [CI] emission of the cloud wraps around the brightest continuum emission, while some bright [CII] spots fall inside the **CND** region.



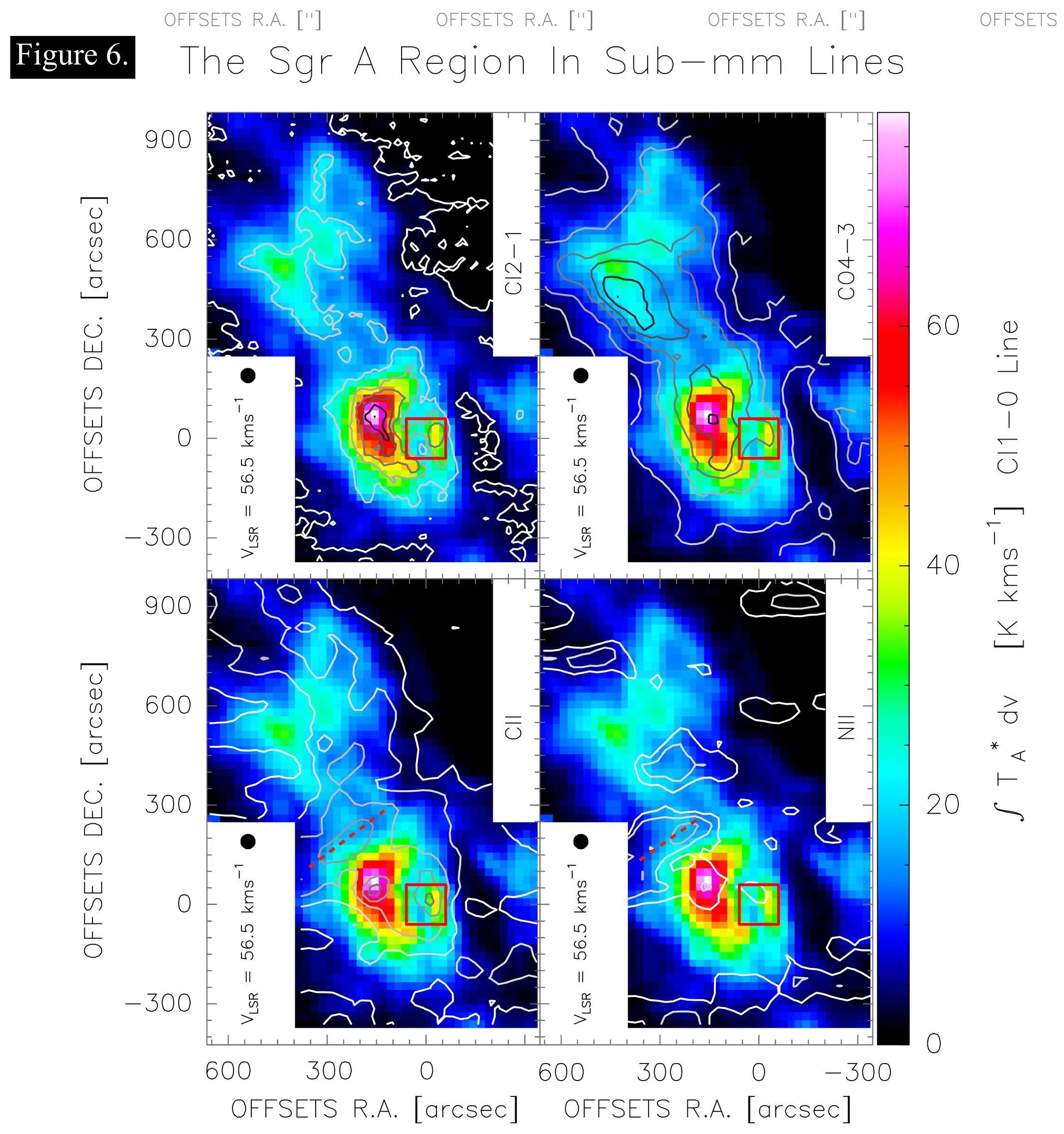








*Figures 1,2,3,4,and 5: Spatial distribution of integrated intensity (in [K kms^{-1}] units) of the observed [CI] $^3P_1$ - $^3P_0$, [CI] $^3P_2$ - $^3P_1$, [NII] $^3P_1$ - $^3P_0$, [CII] $^2P_{3/2}$ - $^2P_{1/2}$, and CO J=4-3 sub-millimeter lines. Each figure shows the integrated intensity in a 10 kms^{-1} wide velocity interval, centered at the selected velocities: -78.5 kms^{-1}, -33.5 kms^{-1}, +20.5 kms^{-1}, and +56.5 kms^{-1}, where some of the known sources in the Sgr A Region are located: emission related to the **CND**, the **Arched-Filaments**, the **„+20 kms^{-1} Cloud**“, and the **„+50 kms^{-1} Cloud**“, respectively. The first contour level in the figures is set at a 3×Trms×√N level, where Trms in the center of the rms noise distribution of each dataset and N is the number of spectral channels in the integration velocity interval. The black circle represents the spatial resolution of the data in colour scale.*



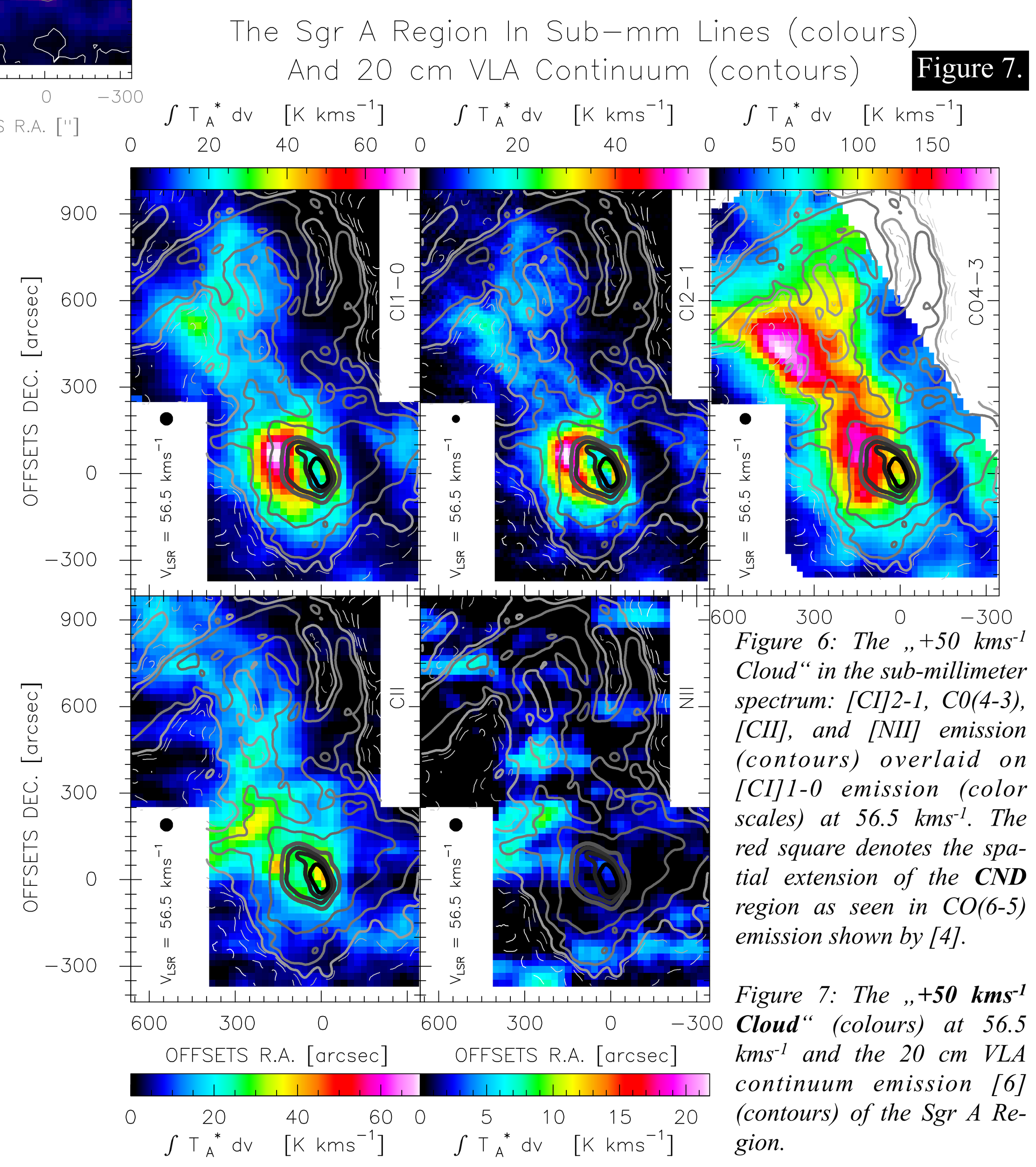
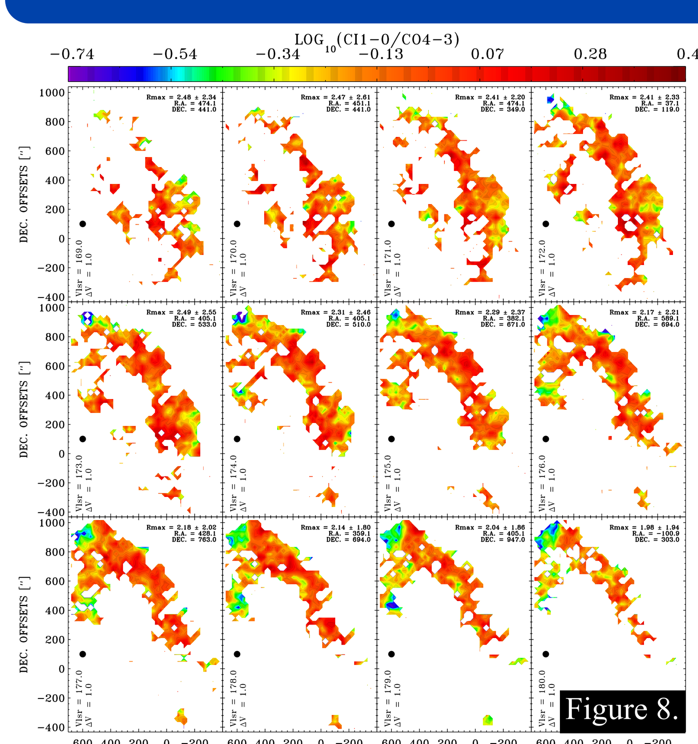


*Figure 6: The „+50 kms^{-1} Cloud“ in the sub-millimeter spectrum: [CI]2-1, C0(4-3), [CII], and [NII] emission (contours) overlaid on [CI]1-0 emission (color scales) at 56.5 kms^{-1}. The red square denotes the spatial extension of the **CND** region as seen in CO(6-5) emission shown by [4].*

*Figure 7: The **„+50 kms^{-1} Cloud**“ (colours) at 56.5 kms^{-1} and the 20 cm VLA continuum emission [6] (contours) of the Sgr A Region.*

[CI]1-0/CO(4-3) Integrated Intensity Ratios



In order to identify the different physical conditions of the gas, spatially as well as spectrally, we calculate integrated intensity ratios (IIRs) using different integrations intervals ΔV. In Figure 8, the velocity distribution of the IIRs for gas at high LSR velocities is shown as an example. In this case, we use a ΔV = 1 kms^{-1}. The IIRs distribution shows a large arc-like structure that extends from approximately +157 kms^{-1} to +188 kms^{-1} in LSR velocity. In the figure, only the most relevant IIRs channels are shown. The location of the gas in the Position-Velocity (PV) diagram coincides with the position of the **$X_{1,2}$ orbits**, that appear to be the response of the gas to the barred gravitational potential of the Galactic Bulge [2]. The CO(1-0) observations of [3] show a trapezoidal envelope in PV diagrams (see PV diagram at Galactic latitude b = 0° as example). The LSR velocities of this structure coincide with the ones of this source. The IIRs of this structure are much higher than any of the IIRs found along the line-of-sight, indicating physical conditions that differ strongly from the gas at other LSR velocities. This analysis is a work in progress and will be applied to all datasets.

[1] Abel, N. P., Ferland, G. J., Shaw, G., & van Hoof, P. A. M. 2005, ApJS, 161, 65; [2] Mezger, P.G., Duschl, W. J., & Zylka, R. 1996, A&AR, 7, 289; [3] Oka, T., Hasegawa, T., Sato, F., Tsuboi, M., & Miyazaki, A., 1998, ApJS, 118, 455; [4] Requena-Torres, M. A., Güsten, R., Weiß, A., et al. 2012, A&A, 542, L21; [5] Roelfsema, P. R., Helmich, F. P., Teyssier, D., et al. 2012, A&A, 537, A17; [6] Yusef-Zadeh, F., Morris, M., & Chance, D. 1984, Nature, 310, 557.