CN in the Sgr A* environment - first results

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Abstract.

The radical CN, through the CN/HCN ratio, has proven to be an exceptionally good tool to study the photodissociation regions (PDRs) dominated by FUV radiation. Our region of interest, the circumnuclear disk (CND) surrounding Sgr A*, is exposed to the strong UV radiation field originating from the central stellar cluster. It contains potentially star forming cores recently elucidated by interferometric HCN observations with OVRO by Christopher et al. (2005). We present the results of preliminary observations of CN (N=2–1) transitions with the IRAM 30-m telescope and report, for the first time, detection of CN emission in the GC region indicative of PDR activity. This work motivates the further investigation of the role of PDRs in the clumpy medium of the Galactic center (GC) environment in global photodissociation and in promoting or inhibiting star formation in the CND.

1. Introduction

Within the inner 10 pc of our Galaxy lie several fascinating structures not seen elsewhere in the Galaxy. The most prominent molecular gas feature surrounding Sgr A* is an asymmetric, clumpy ring of warm and dense molecular gas commonly referred to as the circumnuclear disk (CND), with outer radius 3–4 pc and inner radius 1.5–2 pc (e.g. [2, 4, 7]). It is immersed in a strong UV radiation field from massive stars in the central cluster responsible for ionizing gas inside the ring. The origin of these massive stars is not yet understood ([1] and references therein). This ionized gas component forms a remarkable system of streamers (the so-called minispiral) associated with gas accreting onto the central supermassive black hole. The non-ionizing (FUV) radiation, responsible for photodissociation of molecular species in the central cavity, diffuses farther out into the clumpy molecular ring, heating it and promoting gas phase chemical reactions, thereby producing photodissociation regions (PDRs). FUV photons not only govern in part the physical properties of associated PDRs, but they may also play an important role in regulating the star formation processes [9].

Recent interferometric studies of the CND in HCN and HCO+ at ~4″ resolution by [4] reveal the presence of exceedingly dense cloud cores (10^7 cm^{-3}) with an average diameter of 7″ (0.3 pc). These core densities are high enough to withstand tidal shear from Sgr A* and the central stellar concentration, thereby representing possible star forming zones that could provide a source for the young stars in the central parsec. Mid-IR observations of the CND by [15] show unexpectedly high dust temperatures in the regions of high optical depth, mostly in the southwestern lobe of the CND which contains some of the most massive cores discovered by [4]. Similarly, in their 30μm observations, [11] identify at least 16 color temperature peaks well
within the CND. These peaks may be young stellar sources embedded in the ring which locally heat the gas.

The PDR models predict ([6]) that FUV heating of molecular gas clumps generates photoevaporative outflows and drives strong shocks, compressing the gas to higher densities. These predictions indicate that investigation of the PDR structure in the GC region will significantly contribute to resolving persisting questions about the evolution of the CND and star formation in the hostile Sgr A* environment.

1.1. Diagnostic Properties of CN

The radical CN has proven to be an exceptionally good tool to study dense regions illuminated by a strong UV radiation field when supplemented by data from other selected molecular tracers [3, 5], and yet there are no published observations of CN in the GC region. CN is a by-product of HCN photodissociation and the photons of very high energy (>12.4 eV) are required to destroy this molecule. In particular, the CN/HCN intensity and abundance ratios have been identified as particularly good diagnostic probes of FUV irradiated molecular gas [3, 5, 13]: the CN molecules are more abundant in zones closer to the PDR surface where the UV radiation field is only partly attenuated, whereas HCN becomes abundant at larger (and more shielded) cloud depths closer to the cloud core, implying that large CN/HCN ratios arise naturally in the surface layers of dense PDRs [5, 13].

Observing the CN emission is a further benefit in such studies because the structure in the CN spectra shows fine and hyperfine structure components (Figure 1) that provide information on the physical parameters of the PDR zone. In particular, resolvable fine and hyperfine structure components are important to the interpretation of molecular observations because the optical depth of the observed transition, and hence the CN column density in PDR zones, can be obtained by comparing their relative intensities within a single rotational transition. For optically thin lines the intensity ratio is proportional to the ratio of the corresponding transition strengths; the ratio approaches unity for optically thick lines (assuming that all hyperfine levels have the same excitation temperature).

Figure 1. a) An illustration of resolved fine and hyperfine structure components in the CN spectra: the observed CN(N=2–1) transition toward CRL2688 (post AGB star) used as a calibrator source for our Galactic center observations. b) Energy level diagram for CN.
2. Observations and First Results

The observations were made with the 9 pixel dual-polarization heterodyne receiver array, HERA, on the IRAM 30-m telescope in the CN (N=2–1) line (226.875 GHz (2–1, J=5/2–3/2), 226.660 GHz (2–1, J=3/2–1/2)) in October 2005. The WILMA backend was operated in wideband mode offering a total bandwidth of 1 GHz (∼1300 km s$^{-1}$ at 230 GHz) sufficient to accommodate the velocity range of the GC structures, and channel separation of 2 MHz (∼2.5 km s$^{-1}$). The beamwidth (FWHM) of the IRAM 30-m telescope is 11″ at 230 GHz and the main beam efficiency is 0.51. We position-switched to an emission-free off position at Δα=120″, Δδ=−800″ relative to Sgr A*, integrating for a total of 4 minutes per point. This reference position was checked to be free of emission by comparison with other positions away from the GC.

The array receiver was centered on Sgr A* and four other pointing positions at offsets of Δα = ±2″ and Δδ = ±2″ with respect to Sgr A* (Figure 2a). Our observations show that the CN emission decreases away from the CND (Figure 2b). The strongest emission corresponds to the so called southwestern lobe of the CND, containing the most massive cores and showing enhanced HCN emission from the CND. This is also a region of a good spatial agreement between the HCN and H$_2$ emission at 2.12 μm [16], possibly excited either by UV fluorescence or shocks. We detect CN (N=2–1) emission towards Sgr A* as well, whereas other molecular species are photodissociated by the strong UV radiation originating from the central stellar cluster. Our spectra show resolvable fine structure components which provide an excellent diagnostic of the CN optical depth (Figure 2b). We are currently developing a method to deconvolve complex velocity structure of the GC region allowing us to distinguish between fine and possibly hyperfine structure components.

3. Future Work - Investigation of PDR structure in the GC region

In order to understand the fundamental problems of star formation in the GC region and the CND evolution, we intend to investigate the structure of the PDR in the CND and surrounding molecular clouds. PDRs unambiguously indicate the presence of young, massive stars in the central parsec, whose FUV radiation significantly influences the thermal balance and affects the chemistry and physical state of the gas [9]. The incident FUV heats up and pressurizes the surface layers, inducing the mass loss which causes photoevaporation of dense clumps, and drives shocks into the clumps, compressing them to higher densities and making them more stable against the strong tidal stresses from Sgr A* [6]. The compression of non-collapsing clumps driven by shock waves could possibly induce inner core instability and gravitational collapse, thereby triggering star formation. The clump parameters and state of the interclump medium will regulate the dynamical evolution and determine the timescale of photoevaporation of these clumps (and potentially of the entire CND), thereby influencing star formation, either by inhibiting or inducing it. The presence of atomic neutral gas in the central cavity (e.g. [10]), devoid of molecular gas, is already a signpost of ongoing photodissociation at the inner edge of the CND.

A detailed investigation of the PDR structure of the entire CND and its environs could readily lead to an estimate of the lifetime of the CND against complete dissociation of its individual clumps and whether some clumps may survive to form stars. An assessment of pressure confinement of the dense clumps by their surrounding diffuse gas will be necessary to test whether the interior conditions of the PDR associated clumps are favorable to collapse. The investigation of the PDR structure at the inner rim of the CND would help us to understand whether this zone represents an advancing front of dissociation into the CND. Comparisons with other data such as the H$_2$ fluorescence [16] in this region will be fruitful. It may be possible, from the estimated clump dissociation rates, to date the onset of the FUV continuum for comparison with the age of its source - the young massive stellar population in the central parsec.
Figure 2. a) Locations of the pointing positions observed with HERA at the IRAM 30-m telescope, superposed on a map of the Sgr A* region from [12]. The grey scale image shows the distribution of CI(1–0) 492 GHz emission, and the white contours the distribution of nonthermal continuum emission from Sgr A East. The western pointing position at $\Delta \alpha = -2'$ and $\Delta \delta = 0'$ is not shown in this figure. Open circles show the positions and beamwidth of the pixels of the HERA array for our CN(2–1) observations. b) CN(2–1) spectra shown in b1-b4, observed with HERA at the IRAM 30-m telescope at the positions indicated under a). Our spectra show resolvable fine structure components (as indicated for the spectrum at the central position under b4), leading to direct estimates of the line optical depth from measurements of a single rotational transition. We are currently developing a method to deconvolve the complex velocity profiles in the GC from these components.
The results reported here are based on test observations of CN and they motivate the further exploration of the PDR structure in the CND and surrounding molecular clouds. We intend to conduct a multi-transition survey of a $5' \times 5'$ region centered on Sgr A* that contains the CND and its environs, using a set of strategically selected lines at three different frequencies at a similar resolution (12''-15''). Such projects are now feasible because of the availability of new heterodyne array receivers at the JCMT, the IRAM 30-m and the NRO 45-m telescopes, and new PDR and radiative transfer codes permitting an increasingly sophisticated analysis of such data. This is ongoing work and we intend to start a larger survey in the coming fall semester of 2006 at the JCMT.

To investigate the PDR structure, densities and temperatures in different physical regimes need to be related by a constraining physical theory and we intend to use sophisticated PDR and radiative transfer models that can relate these nonuniform conditions by photochemical reactions in a PDR zone [8, 14]. In addition, to model the evolution of CND clumps we intend to fit the theory of clump evolution in [6] to the derived PDR clumps parameters, based on a geometric model involving simple spheres with a radial density gradient. For example, the basic clump photoevaporation timescale is set by the radius, the core density, and the density and sound speed in the outer clump PDR zone, all of which can be estimated from the PDR model. The theory also allows an estimate of whether part of the clump will survive, and the virial theorem with external pressure and tidal stresses included can be used to determine whether further contraction of the cold remnant to more extreme densities is likely.

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