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Gas in the CMZ toward the Galactic Nucleus Studied by H_3^+ and CO Spectra

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Abstract. Infrared spectroscopy of H_3^+ toward the Galactic center uncovered the presence of vast amount of diffuse (100 cm^{-3}) and warm gas (250 K) filling the Central Molecular Zone of our Galaxy (CMZ; R< 200 pc). We present a detailed view of the cloud, with yet higher resolution spectroscopy of H_3^+ and ^{13}CO toward two bright sources in the Central cluster. H_3^+ $R(2,2)^l$ absorption is clearly detected toward GCIRS 3 at +60 km s^{-1}, and less significantly in GCIRS 1W at the positive velocity. $R(2,2)^l$ absorption represents warmer (> 200 K) and moderately dense gas (200 cm^{-3}) local in the Galactic nucleus. The absorption profiles of H_3^+ $R(1,1)^l$ consists of two components. The one is sharp absorption lines in the negative velocity, that represents the diffuse clouds in the foreground Galactic Arms. The other is the trough absorption spanning from -150 to +90 km s^{-1}. The absorption profile of the trough component has detailed structure with several absorption minima, which was not noticed in the previous lower resolution spectroscopy. The detailed coincidence in the trough absorption in $R(1,1)^l$ and $R(3,3)^l$ implies clumpy structure in the gas, yet with the uniform temperature throughout the CMZ.

Keywords: The Galactic Center; Interstellar Medium; Molecular Ion
PACS: 98.35.Jk; 98.38.Am; 98.38.Bn; 98.38.Dq; 98.38.Gt

H_3^+ OBSERVATION IN THE GALACTIC CENTER

The observation of the Galactic center with H_3^+ as astrophysical probe started with Geballe et al. [1], who unveiled that the Galactic center is the richest reservoir of the H_3^+ in the Milky Way showing an order of magnitude higher column densities than any other line of sights explored by then. Study of H_3^+ in the interstellar space has long relied on the transitions from the lowest rotational levels of the vibrational ground state, (J, K) = (1,0) and (1,1). The first H_3^+ absorption from a rotationally excited state, H_3^+ $R(3,3)^l$, was found by Goto et al. [3] in the line of sight to the bright infrared sources in the Galactic center, GCIRS 3 and GCS 3-2. (J, K)=(3,3) is a metastable state at 361 K above the lowest level of H_3^+ that does not decay further with the spontaneous emission to the lower levels. Oka et al. [7] quantitatively discussed the nature of the warm gas in the Galactic center for the first time, using the steady state analysis developed by Oka & Epp [8]. The density of H_3^+ cloud in the Galactic center is nothing different from that of the diffuse clouds in the other part of the Galaxy (~100 cm^{-3}), but the temperature is significantly higher (200-250 K). Most notable findings are however, (1) the path length of the H_3^+ clouds is 30 pc, at minimum. The filling factor in the Galactic center is likely higher than 0.2, which makes the clouds one of the major elements in the Central Molecular Zone (CMZ) of the Galaxy [6]. (2) The cosmic ray ionization rate is about 10^{-15} s^{-1} in the Galactic center, which is an order of magnitude higher than the Galactic disk. Goto et al. [4] confirmed that the new insights obtained by Oka et al. [7] is more a rule than an exception within 30 pc of the Galactic nucleus, as sources within that circle show clear $R(3,3)^l$ absorption without an exception with the high column density about ~10^{14} cm^{-2}.

^{13}CO OBSERVATION AT VLT

In order to better characterize the physical property of the warm and diffuse cloud reported by Oka et al. [7], we performed high resolution (dv=3-6 km s^{-1}) follow-up spectroscopy of CO fundamental band at 4.7 μm in addition to H_3^+, in the two bright sources in the Central cluster, GCIRS 3 and GCIRS 1W. The observation was carried out at

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the VLT using CRIRES spectrograph. As all fundamental lines of ^{12}CO lines are heavily saturated, ^{13}CO transitions of R(6)-R(0) and P(1)-P(4) were used in the spectral analysis. The representative absorption spectra in the Galactic center sources, ^{13}CO P(1), are shown in Figure 1. The absorption spectra toward both of the sources are deconvolved into three components.

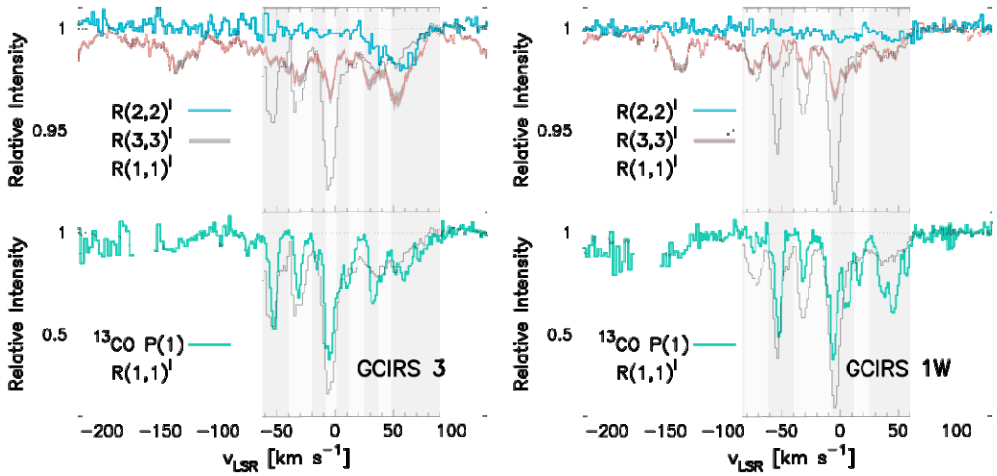

FIGURE 1. CO and H3+ spectra of GCIRS 3 (left) and GCIRS 1W (right).

The broad absorption lines commonly seen in GCIRS 3 and GCIRS 1W at -160 to -110 km s^{-1} represents the Expanding Molecular Ring (EMR; [10]). The EMR is a chain of molecular clouds that delineates the outer boundary of the Central Molecular Zone, expanding from the Galactic center with the radial velocity ~200 km s^{-1}.

The three sharp absorption lines at -55, -30, 0 km s^{-1} match to the radial velocities of the Galactic spiral arms: 3 kpc-Norma, Scutum-Crux, and Sagittarius-Carina, respectively, intervening the line of sight between the Galactic center and the Sun. The CO absorption takes place in the molecular clouds in the Arms of the Galactic disk.

The broad absorptions in the positive velocity supposedly arise in the gas in the Galactic center. The rotational temperatures of the CO in the positive velocity are significantly higher (>50 K), than the absorbing clouds in the Galactic arms (10-20 K), which is consistent with the warm clouds being in the the Galactic center, though CO there is likely sub-thermally excited.

The broad absorption at +60 km s^{-1} in GCIRS 3 is exceptional in showing highest rotational temperature (> 100 K) in the Galactic center, and being optically thick. The absorption component is peculiar as well, with H_3^+ R(2,2)^l absorption at the same velocity. The population in (J, K)= (2,2) decays to (1,1) in 27 days [9]. The significant population in that level testifies that the density in the absorbing clouds is $n_H \geq 200$ cm^{-3} [9]. Clear detection of H_3^+ R(2,2)^l has happened only two line of sights to date, GCIRS 3 and 2MASS J17470898-2829561 in the giant molecular clouds Sgr B, with marginal detection toward GCIRS 1W, among sources in the Galactic center searched so far. The origin of the dense gas is not clear, except it is likely local to the sources themselves. In the cases of GCIRS 3 and GCIRS 1W, the gas inside the Circumnuclear Disk [5], tidally distorted clouds orbiting around the central black hole Sgr A*, is the most likely source of the absorption of R(2,2)^l.

H_3^+ R(1,1)^l, R(3,3)^l and CO absorption, each has particular role as a probe of the medium in the Galactic center. The absorption profiles of H_3^+ R(1,1)^l is similar to that of ^{13}CO v=1-0 P(1) (Figure 1), except that there is additional broad absorption trough in R(1,1)^l. The "trough" component matches well with the absorption profile of R(3,3)^l. The simple rule is that CO v=1-0 traces molecular clouds in the Galactic center and the foreground Arms, R(3,3)^l traces warm and diffuse clouds in the Galactic center exclusively, while R(1,1)^l traces both of them.

The close coincidence between R(1,1)^l trough absorption and broad absorption profile of R(3,3)^l over the wide range of the velocity (from -150 km s^{-1} to +60 km s^{-1} in the case of GCIRS 1W) indicates that the warm and the

diffuse cloud in the Galactic center is somewhat clumpy, but isothermal in the large part of the CMZ. The ratio n(3,3)/n(1,1) is a good index of the temperature in the absorbing clouds, and is significantly higher in the Central cluster than the Quintuplet cluster at 30 pc away. It drops further in 2MASS J17432173−2951430 at 130 pc away to the west of the Galactic center [2]. Geballe et al. [2] has pushed forward the outer boundary of the warm and diffuse cloud upto >100 pc, but the whole extent of the cloud is yet to be explored. H_3^+ $R(3,3)^l$ and $R(1,1)^l$ will be the ideal probe to uncover the temperature structure in the warm and diffuse clouds in the Galactic center.

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REFERENCES

1. T. R. Geballe, B. J. McCall, K. H. Hinkle, & T. Oka, ApJ, 510, 251-257 (1999)
2. T. R. Geballe & T. Oka, ApJL, 709, L70-L73 (2010)
3. M. Goto, B. J. McCall, T. R. Geballe, T. Usuda, et al., PASJ, 54, 951-961 (2002)
4. M. Goto, T. Usuda, T. Nagata, T. R. Geballe, B. J. McCall, N. Indriolo et al., ApJ, 688, 306-319 (2008)
5. R. Güsten, "Atomic and molecular gas in the circumnuclear disk" in the Galactic Center-1986, edited by D. C. Backer, AIP Conference Proceedings 155, 1987, pp.19-29
6. M. Morris & E. Serabyn, ARA&A, 34, 645 (1996)
7. T. Oka, T. R. Geballe, M. Goto, T. Usuda, & B. J. McCall, ApJ, 632, 882 (2005)
8. T. Oka & Epp, ApJ, 613, 349 (2004)
9. F. Pan & T. Oka, ApJ, 305, 518 (1986)
10. N. Z. Scoville, ApJ, 175, L127 (1972)