H_3^+ Line Survey Towards the Galactic Center

M. Goto[1,2], B.J. McCall[3], T.R. Geballe[4], T. Usuda[2], and T. Oka[5]

[1] IfA, University of Hawaii mgoto@duke.ifa.hawaii.edu
[2] Subaru Telescope mgoto@duke.ifa.hawaii.edu
[3] University of California, Berkeley bjmccall@astron.berkeley.edu
[4] Gemini Observatory tgeballe@gemini.edu
[5] University of Chicago t-oka@uchicago.edu

1 H_3^+ Survey Towards the Galactic Center

The H_3^+ in the interstellar medium is a unique probe of physical and chemical environments in dense and diffuse clouds. As the observational study in many lines of sight is becoming matured, we have as many problems newly found. The overabundance of H_3^+ in diffuse clouds is one of them [3, 4]. We undertook the absorption line survey of H_3^+ toward the Galactic center sources to shed light on it [1].

The Galactic center sources are ideal line of sight to start the survey since they suffer heavy visual extinction of A_V=25–40, the highest in the Galaxy among those obscured by diffuse clouds. The intervening clouds have different radial velocities, and the nature of them have been studied in previous spectroscopic observations from near-infrared to radio wavelengths. We observed two infrared sources, GCS 3-2 in the Quintuplet cluster and GC IRS 3 near Sgr A*. Both have intrinsically featureless spectra, and sufficiently luminous to provide good continuum fluxes in the 3 μm region.

The observations were made in June 2001 using the Infrared Camera and Spectrograph (IRCS; Tokunaga et al. 1998; Kobayashi et al. 2000) at the 8.2 m Subaru Telescope. Subaru IRCS is equipped with an echelle and a cross-dispersing gratings. The high resolution (R=20,000) spectroscopy with wide wavelength coverage is unique characteristic of the instrument. It allows us to record one third of 3.2–4.0 μm with a single exposure. This makes the system very suitable for any line-survey projects, in particular for H_3^+ vibrational transition lines that scatter all over the 3 μm region.

2 Result and Discussion

2.1 Velocity Components

All transitions within our spectral coverage starting from the ground states $(J, K) = (1, 0)$ and $(1, 1)$ are successfully detected (Figure 1). At least four velocity components are resolved in both GCS 3-2 and GC IRS 3 (Figure 2).

The bluest component of GC IRS 3 at -140 km s^{-1} is attributed to the expanding molecular ring [7]. The expanding molecular ring is a chain of the

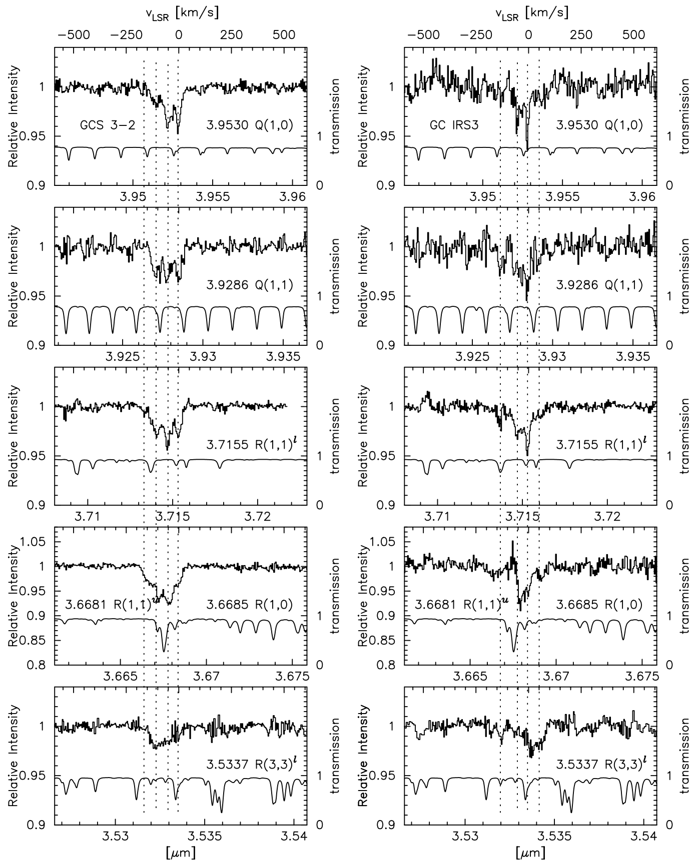

Fig. 1. H_3^+ absorption lines toward GCS 3-2 (right) and GC IRS 3 (left).

molecular clouds that rotates around the nucleus at 200 pc away from the Galactic center, slowly receding from it. The same component appears at -110 km s^{-1} in the line of sight toward GCS 3-2.

The two absorption minima at -60 km s^{-1} and 0 km s^{-1} toward GC IRS 3 closely match with those of H_2CO in the same line of sight. The HI spectrum toward Sgr A shows self-absorption at the same velocities. It indicates that those H_3^+ absorption to GC IRS 3 are originated from diffuse interstellar clouds. We attributed the -60 km s^{-1} component to the clouds in the 3 kpc arm because the radial velocity is consistent. The signature of the 3 kpc arm also appears at similar velocity in absorption in GCS 3-2.

The 0 km s^{-1} components are usually attributed to the local clouds within a few kps from the solar system. However, in contrast to the absorption features at 0 km s^{-1} ubiquitously seen in the HI 21 cm spectroscopy, the H_3^+ absorption at 0 km s^{-1} with this intensity has not been observed in many lines of sight. There could be a contribution from the low-velocity clouds close to the Galactic center region. Some of such clouds have been reported by [9] to be within about 50 pc of Sgr A.

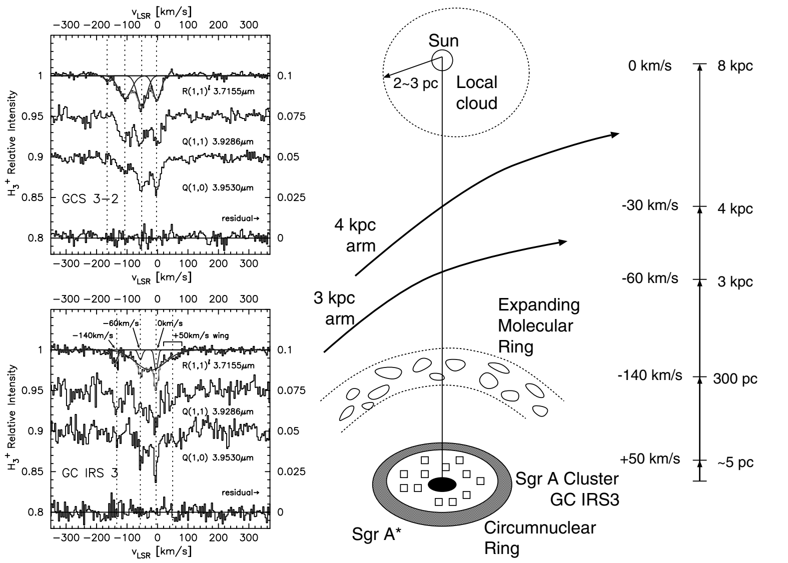

Fig. 2. Velocity components and their attribution.

2.2 Metastable H_3^+

The highlight of the present observation is the first detection of the absorption line starting from a metastable state $(J, K) = (3, 3)$. The only absorption line we detected, and is not starting from the ground state (1, 1) or (1, 0), is $R(3, 3)^l$ at 3.534 μm. The rotationally excited state (3, 3) is special because spontaneous emission from this level to lower levels is forbidden by the ortho–para selection rule. [6] predicted (3, 3) level of interstellar H_3^+ is excessively populated. Other transition lines starting from J >1 levels, $R(2, 1)^u$, $R(2, 2)^l$, $Q(2, 1)^l$, and $Q(3, 0)$, are also covered by our observation, but end up with negative detection. This clearly demonstrates the metastability of (3, 3) level, and theoretical prediction of [6].

However, the problem is that the kinematic temperature of the surrounding molecular hydrogen should be very hot in order to collisionally excite the H_3^+ to the (3, 3) level [5]. The (3, 3) level is higher than the lowest (1, 1) level by 361 K. The $R(3, 3)$ and $R(1, 1)$ have almost similar absorption depths and transition dipole moments. The kinetic temperature of hydrogen should be over 200 K to populate (3, 3) in the same extent with (1, 1). However, large population of clouds with so much warm molecular gas has not been recognized to date.

The nature of the warm cloud is still in mystery, however, a hint of it could be found in the comparison of the line profiles of H_3^+ and CO (Figure 3). The line profile of H_3^+ starting from (1, 1) and metastable state (3, 3) are apparently different. The velocity components of CO ν=2–0 and H_3^+ (1, 1) show reasonable agreement, and most likely two molecules are physically associated. However, a quantitative difference may be noticeable. The H_3^+ (1, 1) has broad and strong pedestal component, while the CO trace goes back to the continuum level in between the absorption lines. The last panel in Figure 3 is the differential spectrum of H_3^+(3, 3) and H_3^+(1, 1) overlaid with CO ν=2–0. The match between the two spectra is convincing. Our working hypothesis is that the CO ν=2–0 traces cold (10 K) and dense molecular cloud, while H_3^+(3, 3) traces hot (200 K) diffuse cloud, *exclusively*. Only H_3^+ (1, 1) absorption occurs in both of them, producing sharp absorption lines superposed on the broad pedestal absorption. The hypothesis provides *ad-hoc* accounts for the differences in the line profiles, however, we need more observations with higher spectral resolution to prove the presence of interstellar clouds as warm as about 200 K.

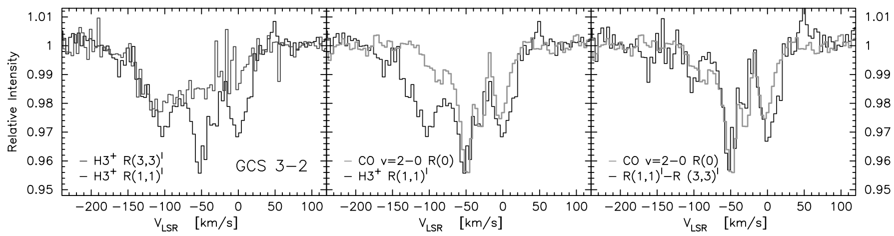

Fig. 3. Comparison of absorption line profiles.

References

1. Goto, M., McCall, B. J., Geballe, T. R., Usuda, T., Kobayashi, N., Terada, H., & Oka, T. 2002, PASJ, **54**, 951
2. Kobayashi, N., et al. 2000, Proc. SPIE, **4008**, 1056
3. McCall, B. J., et al. 2002, ApJ, **567**, 391
4. McCall, B. J., et al. 2003, Nature, **22**, 500
5. Oka, T., & Epp 2003, in this proceedings.
6. Pan, F.-S., & Oka, T. 1986, ApJ, **305**, 518
7. Scoville, N. Z. 1972, ApJ, **175**, L127
8. Tokunaga, A. T., et al. 1998, Proc. SPIE, **3354**, 512
9. Whiteoak, J. B., & Gardner, F. F. 1978, Proc. Astron. Soc. Australia. **3**, 266