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Observation of Interstellar H_3^+ Using Subaru IRCS: The Galactic Center

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Abstract. High resolution infrared absorption spectrum of H_3^+ has been observed toward the luminous Galactic center sources GCS 3-2 and GC IRS 3. With the wide wavelength coverage of Subaru IRCS, six absorption lines of H_3^+ have been detected from 3.5 to 4.0 μm, three of which are new. In particular the $R(3, 3)^l$ transition arising from the metastable (3, 3) level has been detected indicating the existence of high temperature cloud. At least four velocity components are found in the H_3^+ absorption profile. The observations have revealed a striking difference between the absorption profiles of H_3^+ and CO, demonstrating the complementary nature of the H_3^+ and CO as astrophysical probes.

1. Introduction

H_3^+ is the third pure hydrogenic species after H and H_2 that can be used for astronomical observations. Since its discovery toward young stellar objects that are deeply embedded in molecular clouds (Geballe and Oka 1996), H_3^+ has been observed in many dense molecular clouds (McCall et al. 1999). Quite unexpectedly, H_3^+ has also been observed in diffuse clouds with similar column densities as in dense clouds (McCall et al. 1998; Geballe et al. 1999; McCall et al. 2002). This ubiquity and abundance makes H_3^+ a powerful astrophysical probe more generally applicable for the study of interstellar matter than H_2.

H_3^+ is produced by cosmic ray-ionization of H_2 into H_2^+ followed by the very efficient Langevin reaction $H_2^+ + H_2 \rightarrow H_3^+ + H$. It plays the pivotal role in interstellar chemistry as a universal proton donor (acid) and it initiates network of chemical reactions. The simple chemistry of H_3^+ has the special characteristic that its number density is constant and is independent of the cloud density for typically dense or diffuse clouds (Fig. 1). Thus H_3^+ can be used to measure the dimension of the cloud (Gaballe & Oka 1996; McCall et al. 1998, 1999, 2002). This in turn gives the average number density of the cloud if the column density of H_2 is estimated from extinction. The presence of two rotational levels $(J,\ K) = (1,\ 0)$ and $(1,\ 1)$ separated by 32.87 K, and the rapid equilibration between the two states by Langevin reaction allows H_3^+ to be used to measure the temperature of the cloud.

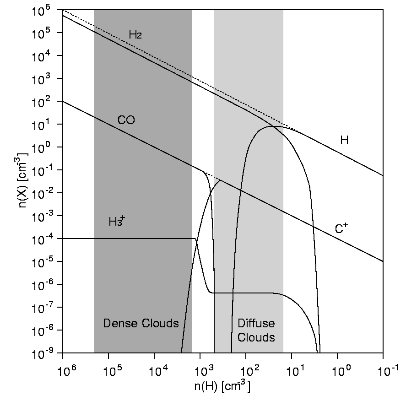

Figure 1. A schematic number density variation of H_3^+ with respect to hydrogen along with that of major molecules and ions in the interstellar medium.

These excellent characteristics of H_3^+ as a yardstick, densitometer, and thermometer of clouds are being applied to the survey of the Galactic center whose lines of sight contain diffuse and dense clouds in intervening spiral arms as well as the molecular complex close to the nucleus. Two infrared sources, GCS 3-2 in the Quintuplet cluster and GC IRS 3 near Sgr A have been selected because of their high luminosity in the L-band. We report the initial findings of the study (Goto et al. submitted to PASJ).

2. Observations and Results

The H_3^+ spectra were observed using the Infrared Camera and Spectrograph (IRCS) with the 8.2 m Subaru Telescope on Mauna Kea. The IRCS with an echelle and a cross dispersing grating allowed us to cover a wide wavelength region containing not only 5 of the 6 lines arising from the lowest $J = 1$ levels but also many spectral lines from higher J levels with two grating settings. A 0."15 × 4."5 slit width was used to achieve the spectral resolution of 20,000.

Observed spectra are shown in Fig. 2 for GCS 3-2 (left column) and GC IRS 3 (right column). The atmospheric transmission curves are also shown. All 5 absorption lines in our coverage starting from the lowest $J = 1$ levels [$R(1,\ 0)$, $Q(1,\ 0)$, $R(1,\ 1)^l$, $R(1,\ 1)^u$ and $Q(1,\ 1)$] are detected while those starting from higher J levels are negative except $R(3,\ 3)^l$ which arise from the (3, 3) metastable rotational level.

The lines with $J = 1$ show several discrete kinematic components with peaks at LSR velocities of -110 – -140 km s^{-1}, -50 – -60 km s^{-1}, and 0 km s^{-1}. GC IRS 3 shows and additional broad pedestal peak at 20 km s^{-1} and a wing at + 50 km s^{-1} on the pedestal. A weak absorption is seen at -170 km s^{-1}.

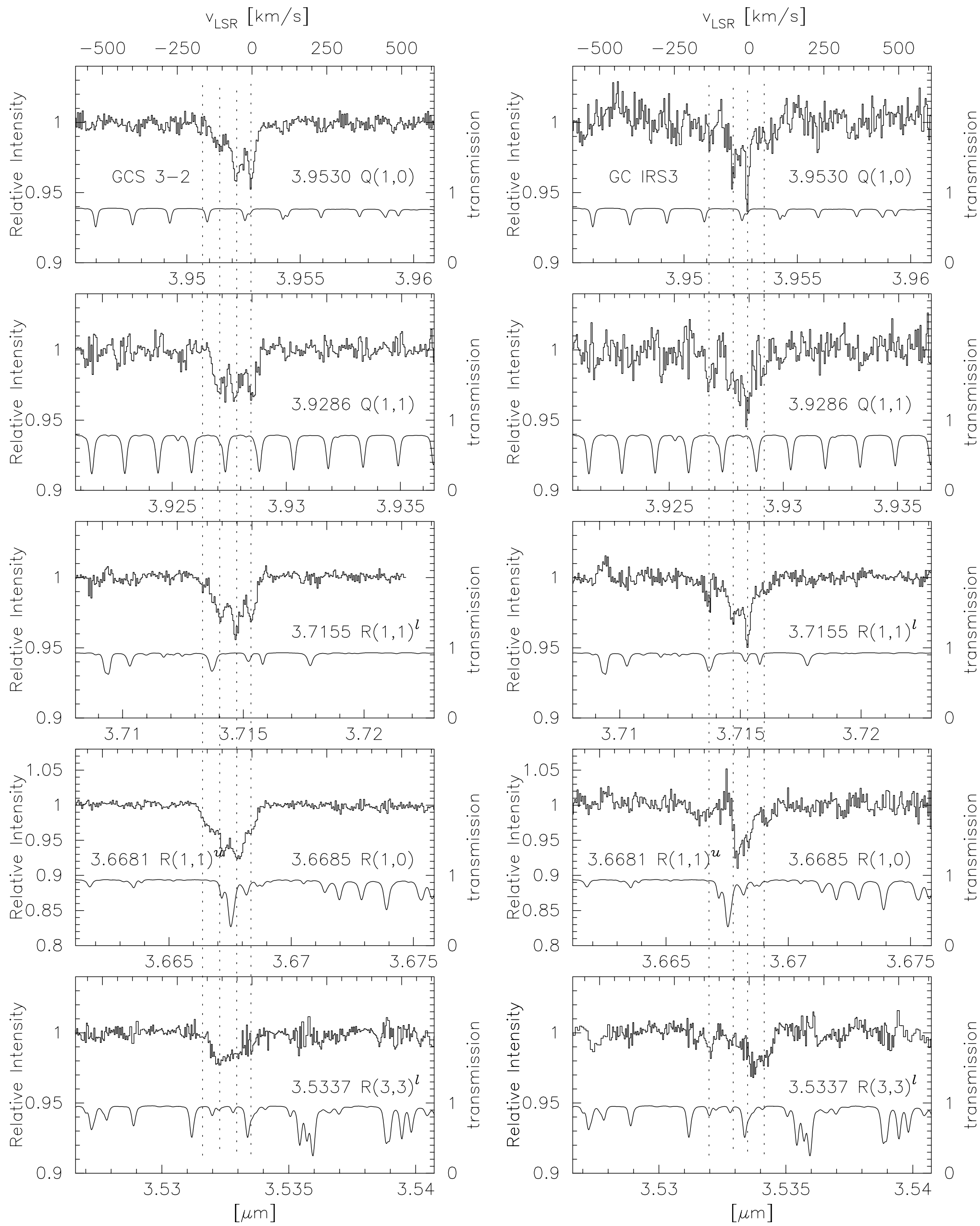

Figure 2. The total detected H_3^+ absorption spectra toward GCS 3-2 (left column) and GC IRS 3 (right column) .

3. Discussions

3.1. Cloud components

Observed spectral lines of the $R(1,\,1)^l$ and the $R(3,\,3)^u$ transitions of H_3^+ in GC IRS 3 are compared with spectra of H (Liszt et al. 1985) , CO (Geballe et al. 1989) and H_2CO (Güsten & Downes 1981) in Fig. 3. The three sharp lines of H_3^+ at -140 km s^{-1}, -60 km s^{-1} and 0 km s^{-1} have corresponding peaks in H and H_2CO and perhaps in CO. The weakness of the H_2CO and CO spectra suggests that those H_3^+ are in the diffuse interstellar medium in the "expanding molecular ring" (Kaifu, Kato, & Iguchi 1972; Scoville 1972) the"3 kpc arm" and local clouds, respectively.

The strong and saturated infrared CO absorption toward GC IRS 3 and radio H_2CO absorption in Sgr A at the velocity of +50 km s^{-1} clearly represent dense clouds. It is remarkable that the H_3^+ lines arising from the J = 1 levels are weak at this velocity (Fig. 2 and 3). This indicate presence of a dense cloud with a short pathlength in front of the infrared source. The complementary nature of CO and H_3^+, the former representing the total amount of molecules while the latter simply the pathlength, is clearly seen here. It is surprising that the intensity of the $R(3, 3)$ absorption is the strongest at this velocity. This is also noted for the spectrum of GCS 3-2.

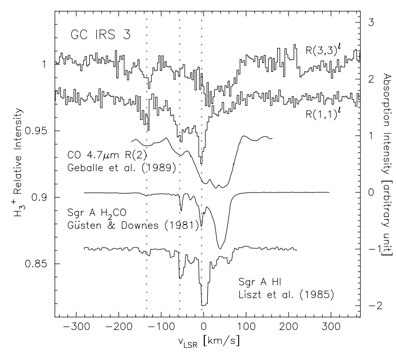

Figure 3. Comparison of the line profiles of H_3^+ $R(1,\ 1)^l$ and $R(3,\ 3)^l$ lines along with those of CO , H_2CO and toward GC IRS 3.

3.2. The (3, 3) Metastable State

The detection of the $R(3, 3)$ line is a breakthrough and it introduces a new dimension into the study of interstellar H_3^+. The detection and our non-detection of other high J transitions is reasonable since the (3, 3) level is metastable, that is, the spontaneous emission from this level to lower level by centrifugal distortion induced dipole moment (Pan & Oka 1986) is forbidden.

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