Search for H_2 absorption lines toward the Galactic Center

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ABSTRACT

We have detected the H_3^+ absorption line from the $(J,K)=(3,3)$ metastable level toward the Galactic Center (Goto et al. 2002) and discovered that three-fourths of the total H_3^+ column density arises in the central molecular zone (CMZ) of the Galaxy (Fig.1, Oka et al. 2005).

In order to investigate the physical and chemical properties of the molecular gas toward the Galactic center and in various lines of sight in the Galactic plane, we made the Near Infrared Echelle spectroscopic observations (R=20,000) using IRCS (Fig.2) with 8.2 meter Subaru Telescope (Fig.3) and the adaptive optics system (Fig.2).

(1) Absorption lines of molecular hydrogen (H_2) and CO were searched for in foreground molecular clouds towards the IR continuum sources GCS 3-2 in the Quintaplet cluster and GC IRS16NE. **None of H_2 absorption lines was detected** with our sensitivity level (Fig.4). The 1 sigma error of equivalent width and column density of H_2 (v,J)=(0,0) level are 3.1×10^{-7} μm and **7.5×10^{21} cm^{-2}**, respectively. The **total H_2 column density is $<4.9\times10^{22}$ cm^{-2}** on the assumption of $T\sim250$ K which was estimated by the observed H_3^+ population ratios (Oka et al. 2005). It is consistent with the results by Rodriguez-Fernandez et al. (2001) toward 16 sources within 500 pc of the Galactic Center.

(2) The **H_2 v=0-1 S(0) absorption line was detected** together with CO v=0-2 absorption lines **toward NGC7538 IRS1** in the outer galaxy (Fig.5). The H_2/CO ratio is directly measured to be 4000±1300 on the assumption of H_2 ortho-to-para ratio of 3, in line of sight toward the Outer Galaxy for the first time. We found that it is as same as the one measured in nearby YSOs (e.g. H_2/CO =3700 toward NGC2024 IRS2 by Lacy et al. (1994). However, **no H_3^+ absorption lines including $R(1,0)$, $R(1,1)^l$, $R(3,3)^l$, etc. were detected** in the molecular clouds surrounding NGC7538 IRS1 (Fig.6), which means that the path length through the cloud is much shorter than in other ones (Table 1; e.g., Glactic Center, W33A).

0. Our GOAL

(1) **Establish H_2/CO abundance ratio** in various lines of sight in the Galactic plane, which enables us to estimate correctly mass of molecular clouds.

(2) **Study physical conditions of molecular clouds** such as gas density and kinetic temperature.

1. Introduction

(1) ***Metastable H_3^+ Absorption Lines toward the G.C.***

Using an absorption line from the metastable $(J, K) = (3, 3)$ level of H_3^+, which is 361 K above the (1, 1) ground level, together with other lines of H_3^+ and CO, we have discovered a vast amount of high-temperature ($T\sim250$ K) and low-density ($n\sim100$ cm^{-3}) gas with a large velocity dispersion in the central molecular zone (CMZ) of the Galaxy, i.e., within 200 pc of the center.

(2) ***CO Absorption Lines toward the G.C.***

The narrow $R(1, 1)^l$ and CO features arise in the in the intervening spiral arms and CO is not very abundant in the molecular clouds near the G.C.

How about H_2? What H_2 has physical conditions?

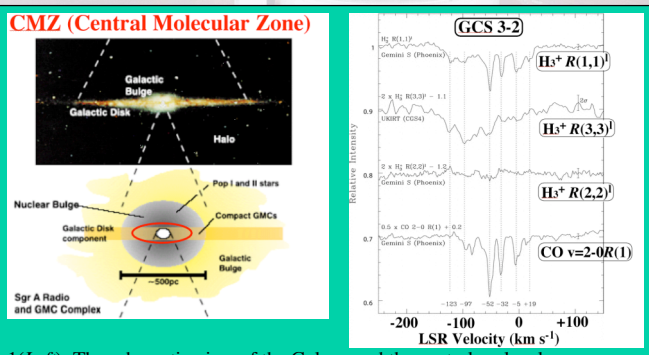

Fig. 1(*Left*): The schematic view of the Galaxy and the central molecular zone (CMZ) of the Galaxy (Mezger et al. 1996).
(*Right*): Observed H_3^+ and CO spectra toward GCS 3-2 (Oka et al. 2005).

2. Observations : K-band Echelle Spectroscopy

SUBARU Telescope 8.2m (Iye et al. 2004; Fig.1) **+ IRCS** (Tokunaga et al. 1998; Fig.2)**+AO** (Takami et al. 1998)

(1) Galactic Center: GCS 3-2 & IRS16NE
- May24, 2003 & Jun.14, 2005 UT, Seeing = 0.”5@2.2 μm
- ^{12}CO First overtone transitions $R(0)$-$R(18)$ & $P(1)$-$P(8)$
- H_2 v=1-0 $S(0)$ & $S(1)$
- **$R(\lambda/\Delta\lambda)$ = 20,000**, 0.”15 Slit width

(2) NGC7538 IRS1
- Sep.15 & Nov.2, 2003 UT, Seeing = 0.”3@2.2 μm
- ^{12}CO First overtone transitions $R(0)$-$R(18)$ & $P(1)$-$P(8)$
- H_2 v=1-0 $S(0)$ & $S(1)$
- **$R(\lambda/\Delta\lambda)$ = 20,000**, 0.”15 Slit width

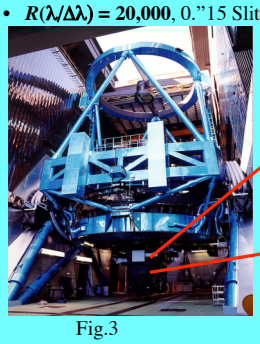

Fig.3

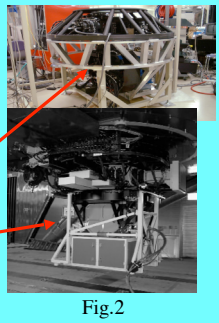

Fig.2

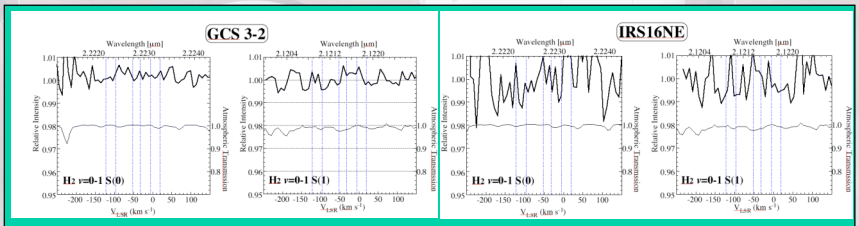

Fig. 4: Absorption spectra of H_2 v=0-1 $S(0)$ and $S(1)$ toward GCS3-2 (*Left*) and GC IRS16NE (*Right*). The dotted lines shows the velocity at V_{LSR} of the measured CO absorption lines (cf. Fig.1). The atmospheric transmission curve was computed with the ATRAN code (Lord 1992).

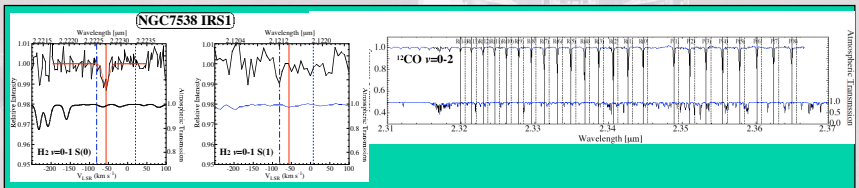

Fig. 5(*Left*): Absorption spectra of H_2 v=0-1 $S(0)$ and $S(1)$ toward NGC7538 IRS1. The solid lines shows Gaussian fitting curves and the velocity at V_{LSR}=-57 km s^{-1}. The dotted and dot-dashed vertical lines mark the wavelengths in vacuum and of emission line from the outflow.
(*Right*): First-overtone of the vibrational transition of ^{12}CO R- and P- branch absorption lines. The solid and dotted lines represent V_{LSR}=-57 km s^{-1} and wavelengths in vacuum, respectively.

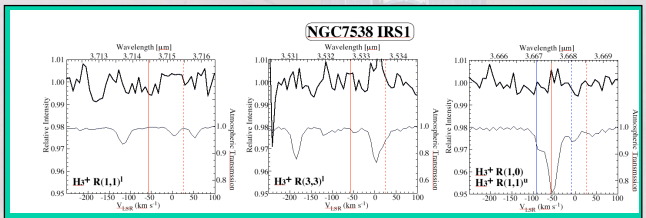

Fig. 6: Absorption spectra of H_3^+ $R(1,1)^l$, $R(3,3)^l$, $R(1,0)$, and $R(1,1)^u$ toward NGC7538 IRS1. The solid and dotted lines represent V_{LSR}=-57 km s^{-1} and wavelengths in vacuum, respectively.

Object	$N(R(1,1))$*	L [pc]	τ(9.7μm)	$N(^{12}CO)$*	$T(H_3^+)$ [K]	T(CO) [K]
AFGL2136	1.9E14	1.3	5.07	3.2E19	47	17 & 580
W33A	2.9E14	1.7	7.84	3.9	36	23 & 120
MonR2 IRS3	0.8E14	0.5	2	1.68	31	49 & 252
AFGL490	0.7E14	0.4	2.77	0.73	26	36 & 143
N7538 IRS1	**<0.69E14**	**<0.4**	**6.38**	**2.3**	**N/A**	**35 & 191**

(*): [cm^{-2}], (cf. McCall et al. 1999, Mitchell et al. 1990, Goto et al. 2003)

Table 1: Summary of clouds parameters (column density, path length, excitation temperature, Silicate optical depth) measured by H_3^+ and CO absorption lines.