The Galactic Center: Feeding and Feedback in a Normal Galactic Nucleus
Proceedings IAU Symposium No. 303, 2013
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doi:10.1017/S1743921314000544

Large–scale and high–sensitivity multi–line CO surveys toward the Galactic center

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Abstract. We carried out large–scale (4 × 2 degree) CO multi–line observations toward the central molecular zone (CMZ) in the Galactic center (GC) with the NANTEN2 4m telescope and mapped several diffuse molecular features located at relatively high Galactic latitudes above $0^\circ\!.6$. These high–latitude features are composed of diffuse molecular halo gas and molecular filaments according to their morphological aspects. Their high velocities and high intensity ratios between ^{12}CO $J = (2-1)$ and $J = (1-0)$ clearly indicate their location in the GC, and their total mass amount to $\sim$ 10 % of that of the CMZ. We discuss that magnetic field is a possible mechanism of these high–latitude molecular features lifting up toward high galactic latitude.

Keywords. ISM: clouds — Radio lines: ISM — Galaxy: Galactic center

1. Introduction

The Galactic center (GC) is still the most enigmatic region in the Galaxy and thus many ground–based and satellite telescopes have intensively tried to focus their eyes on the region over the past few decades (e.g., Oka *et al.* 1998; Stolovy *et al.* 2006). Nevertheless, an unified point of view through multi wavelengths has not yet been acquired. Lack of a rational picture of the highly compressed and turbulent molecular cloud complex in the central few hundred parsecs – the central molecular zone (CMZ, Morris & Serabyn 1996) – is one of most important issues researchers are facing. This large reservoir of gas fuels current and past star formation activity and associated with high energy phenomena, including cosmic ray acceleration. For these reasons, it is naturally important to compare high quality CO data with emission in all other wavelength ranges. A few tens of non–thermal filaments have been discovered to extend vertically to the Galactic plane within the central 100 pc of the GC (Yusef-Zadeh, Morris & Chance 1984; LaRosa *et al.* 2004). At infrared wavelengths, Morris *et al.* (2006) discovered the Double Helix Nebula (DHN), located $0^\circ\!.6$ to $0^\circ\!.8$ above Sgr A*. The DHN appears to have two intertwined helical strands reminiscent of DNA and seems to be a magnetic event according to their morphological aspects. In fact, Tsuboi & Handa (2010) reported that magnetic field lines observed by the polarization measurements of 10 GHz and 5 GHz radio continuum radiation follow the helical patterns observed in the infrared wavelengths. Moreover, Crocker *et al.* (2010) discussed that the typical large–scale magnetic field is relatively stronger

	^{12}CO $J = (1-0)$	^{13}CO $J = (1-0)$	^{12}CO $J = (2-1)$
HPBW (arcsec)	190	190	100
Velocity resolution (km s^{-1})	0.16	0.16	0.08
Sensitivity (K/channel)	0.58	0.43	0.25
Covered area (degree)	-10°.0 $\leqslant l \leqslant$ 10°.0 -1°.0 $\leqslant b \leqslant$ 1°.0	-10°.0 $\leqslant l \leqslant$ 10°.0 -1°.0 $\leqslant b \leqslant$ 1°.0	-2°.0 $\leqslant l \leqslant$ 2°.0 -1°.0 $\leqslant b \leqslant$ 1°.0

Table 1. A summary of NANTEN2 observations

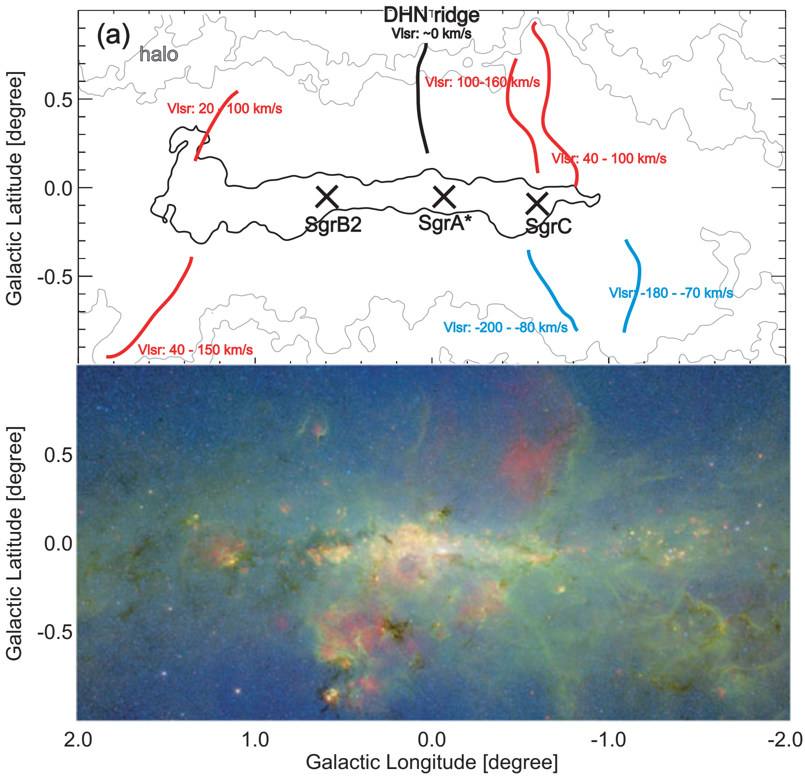

Figure 1. (a) A schematic image of distribution of molecular features around CMZ. The black contour shows the main molecular complex CMZ. Gray contours show diffuse high–latitude gases. The red, blue and black lines show the molecular filaments. **(b)** Superpositions of CO contours shown in **(a)** on the *Spitzer* composite image consists of 3.6 μm (blue), 8 μm (green) and 24 μm (red). [A COLOR VERSION IS AVAILABLE ONLINE.]

and at least 50 μG within 200 pc of the GC. These observational results indicate that the magnetic field may play a crucial role in the gas kinematics in the GC.

2. High latitude molecular features

Recently, we carried out large–scale and high–sensitivity CO multi–line observations toward the CMZ with the NANTEN2 telescope and detected diffuse molecular features located at relatively high galactic latitudes above 0°.6. Table 1 summarizes these observations.

The high–latitude molecular features can be sorted into molecular halos and molecular filaments according to their morphological aspects. Their high velocities and high intensity ratios between ^{12}CO $J = (2-1)$ and $J = (1-0)$ clearly indicate their location within the GC (Torii *et al.* 2013). Figure 1(a) shows a schematic image of distribution

https://doi.org/10.1017/S1743921314000544 Published online by Cambridge University Press

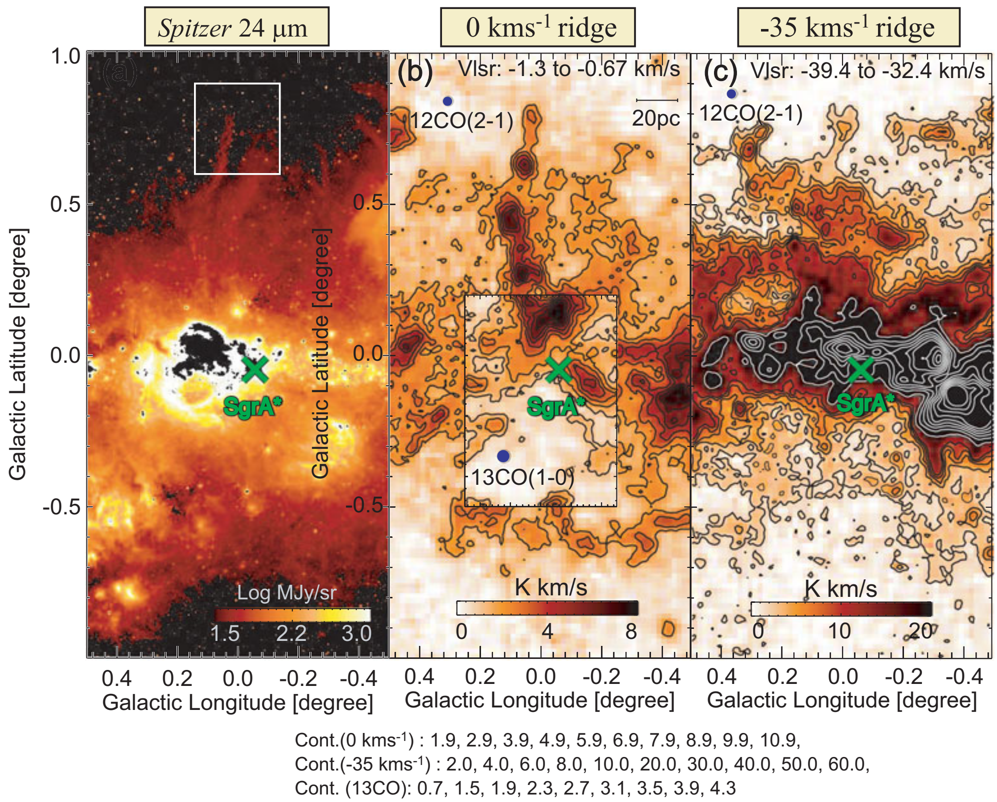

Figure 2. **(a)** *Spitzer* 24 μm image toward the DHN molecular ridges. The white box shows the location where the DHN is distributed. **(b)** The integrated intensity distribution of ^{12}CO $J = (2-1)$ and ^{13}CO $J = (1-0)$ emission. The velocity integrated range and contour levels are shown in the figure. **(c)** The integrated intensity distribution of ^{12}CO $J = (2-1)$ emission. The velocity integrated range and contour levels are shown in the figure. [A COLOR VERSION IS AVAILABLE ONLINE.]

of the high–latitude molecular features. They are extending by $\sim$50 – 100 pc from the Galactic plane and the typical mass of each filament is $\sim$ several $\times 10^5 M_\odot$, if we use an X factor (7.0×10^{19} ; Torii *et al.* 2010b). Therefore, the total mass of high-latitude molecular features are $\sim 4 \times 10^6 M_\odot$, corresponding to $\sim$ 10 % of that of the CMZ. It remains a puzzle what process is responsible for levitating the molecular gas against the strong gravity of the central 200 pc. We discuss possible origins of these high–latitude features focusing especially on the molecular filaments.

3. Possible origins of the molecular filaments

Among the seven filamentary features, five features have been reported elsewhere; they are the cloud associated with AFGL5376 (Uchida 1994), the GC molecular tornados (Sofue 2007), and the molecular counterparts of the infrared DHN (Enokiya *et al.* 2013). It is suggested that the infrared nebula AFGL5376 is a remnant of star formation triggered by cloud–cloud collision at high latitude (Uchida 1994), and the GC molecular tornados are magnetic twisted feature by the Galactic rotation of the cloud at $l = 1\overset{\circ}{.}3$ (Sofue 2007). Enokiya *et al.* (2013) discovered two molecular counterparts to the DHN (0 km s^{-1} and -35 km s^{-1} features) and at least the 0 km s^{-1} feature has molecular ridges linking Sgr A*

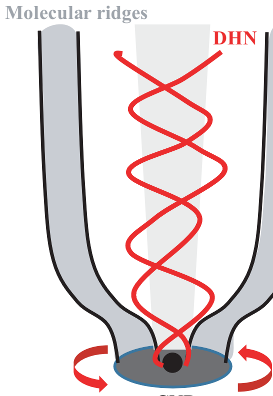

Figure 3. A schematic image of molecular tower jet model applied to the molecular ridges and the infrared DHN. The red lines show magnetic field lines surrounded by molecular ridges colored in gray. The rotating CND twists the magnetic fields and blows up the ISM upward from the Galactic plane. On the other had, dense HI gas above the CND will grow into molecular clouds by the compression of the central outflow which also helps to form molecular ridges. [A color version is available online.]

and the DHN (see Figure 2b). They suggest that twisted helical magnetic fields may be driven by the circumnuclear disk around Sgr A* (see Figure 3 for a schematic view of the model).

The present study has revealed the kinematic properties of all these high latitude features. The linewidths of these filaments are generally very broad like 100 $\mathrm{km\,s^{-1}}$, except for the DHN feature which has a linewidth less than 50 $\mathrm{km\,s^{-1}}$. The typical kinetic energy involved in a filament is roughly estimated to be 10^{51} erg. The stellar energy injection is not large enough to explain this energy by considering the small solid angle subtended by the filaments relative to the stars in the CMZ. As an alternative, we suggest the Parker instability (Parker 1966) as a more probable driving mechanism. Fukui *et al.* (2006) present an interpretation based on the Parker instability for the two molecular loops, loops 1 and 2, within 1 kpc of the Galactic center and suggest that the associated magnetic field is of the order of 100 μG. This picture is consistent with the MHD numerical simulations of the central magnetized gas disk (Machida *et al.* 2009). We suggest that a similar mechanism may be working to lift up the filamentary molecular gas within the central 200 pc. The large linewidths are similar to those of loops 1 and 2. The filaments do not show a complete loop–like shape as expected in the Parker instability, which may be due to blow out of a loop at high latitude. Detailed account of this work will be published elsewhere.

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