"The Tornado" and "the Chimney"

– Two Peculiar Diffuse X-ray Objects with Outflowing Structures in the Galactic Center Region. –

Takeshi Go Tsuru[1], Masayoshi Nobukawa[1], Hiroshi Nakajima[2], Makoto Sawada[1], Hironori Matsumoto[1], Katsuji Koyama[1], Tomoharu Oka[3], Kunihiko Tanaka[3], Shinji Matsumura[3]

[1] Department of Physics, Kyoto University, Kitashirakawa, Sakyo, Kyoto, JAPAN, 606-8502
[2] Department of Earth and Space Science, Osaka University, Toyonaka, Osaka, 560-0043
[3] Department of Physics, Keio University, 3-14-1 Hiyoshi, Kohoku-ku, Yokohama, Kanagawa 223-8522
E-mail(TGT): tsuru@cr.scphys.kyoto-u.ac.jp

Abstract

From the Suzaku observation of the Galactic center region, we successfully detected two peculiar objects, the Tornado and the Chimney, with spatially outflowing structures. Both of the objects have the spectra described by a thin-thermal plasma model with the temperature and thermal energy consistent with an SNR. However, their outflowing structures are very unusual as a galactic SNR. The mechanism forming the structures is mystery, although it would be related with the high energy activities of the Galactic center region.

Key words: workshop: the Galactic center region — SNR — Tornado — Sgr C

1. The Tornado

The Tornado is an unusual highly polarized non-thermal radio object consisting of an extended (35pc × 18pc) bizarre head-tail structure (tornado) and its eye (eg. Manchester 1987; Shull et al. 1989; Stewart et al. 1994; Brogan et al. 2003). It has been suggested that the source is extragalactic, an exotic SNR, a pulsar wind nebula, results from precessing jets from an X-ray binary. However, no satisfactory explanation has yet been found.

Gaensler et al. (2003) detected three sources of X-ray emission from the Tornado with Chandra: a relatively bright region of $2' \times 1'$ coincident with the brightest radio emission at the head of the Tornado, and two fainter extended regions possibly associated with the Tornado's tail. No X-ray point source associated with the Tornado was detected.

We made a 50 ksec exposure with Suzaku for the Tornado. We successfully detected the head-tail structure in X-ray for the first time (Fig. 1). The spectra of the head center and the head surroundings are well described by a thin-thermal plasma model with $kT \sim 0.5$ keV (Fig. 2). The absorption column of $N_{\rm H} \sim 7 \times 10^{22}$ cm^{-2} suggests the Tornado is located in the Galactic center region. The total thermal energy of the head (center plus surroundings) is estimated $\sim (1-2) \times 10^{50}$ ergs. The results suggest that the Tornado is an SNR candidate.

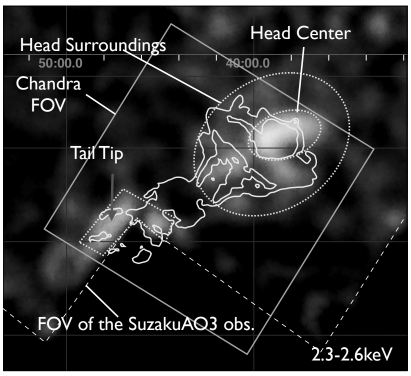

Fig. 1. The 2.45 keV-line (He-like S Kα) image of the Tornado with Suzaku. Diffuse X-ray emission of the whole head region and the tail-tip is successfully detected for the first time.

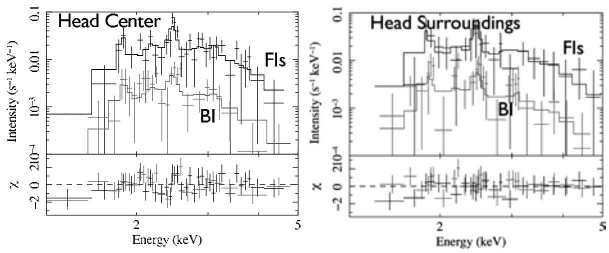

Fig. 2. The Suzaku spectra of the head center (left) and surroundings (right) of the Tornado with the best-fit thin thermal models. They show strong ionized He-like Si and S K lines.

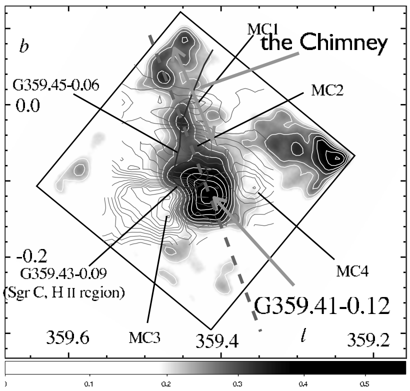

Fig. 3. The 2.45 keV-line (He-like S Kα) image of the Sgr C region (gray). Contours of ^{13}CO at -84 to -24 km s^{-1} (red) and the schematic diagram of the radio continuum sources of G359.45-0.06 and G359.43-0.09 (blue) are overlaid on the 2.45 keV-line image (Liszt et al. 1995). MC1, 2, 3, and 4 indicate molecular clouds.

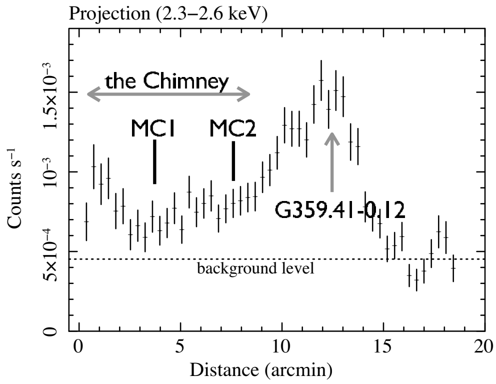

Fig. 4. The one-dimensional profile at 2.45 keV along the red dashed line given in the Fig. 3. "MC1" and "MC2" show the positions of ridges of the molecular clouds crossing the Chimney shown in Fig. 3. The dips would be due to absorption by the molecular clouds and the unabsorbed one-dimensional profile in the Chimney would decrease monotonically from G359.41-0.12 without a significant dip.

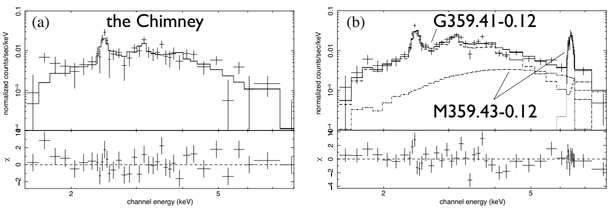

Fig. 5. The background subtracted FIs spectra of the Chimney (left) and G359.41-0.12 (right) with the best-fit model spectra. We included the best-fit model spectrum of M359.43-0.12, which is the contaminating source for G359.41-0.12 (Nakajima et al. 2009).

2. Outflowing SNR in the Sgr C region

Sgr C is one of the brightest radio complexes in the Galactic center region. There are well-defined non-thermal radio filaments (NTFs), some compact and evolved H_{II} regions, far-IR and submillimeter sources, and giant molecular clouds (Liszt 1985; Tsuboi et al. 1991; Lis et al. 1994; Liszt et al. 1995). Accordingly, a rich variety of X-ray features may be expected. However, the X-ray studies have been concentrated on the diffuse 6.4 keV line emission (Fe I Kα) (Murakami et al. 2001; Yusef-Zadeh et al. 2007; Nakajima et al. 2008). Few results on thermal diffuse emissions have been reported so far. Thus, we conducted the studies of thermal emissions from the Sgr C region with Suzaku. The results given here has been already published as Tsuru et al. (2009). We here describe them in short.

We discovered an elongated chimney-like structure. the Chimney, with the dimension of 20pc $\times$ 7.4pc, and an elliptical shape object, G359.41-0.12, in the Sgr C region (Fig. 3). One-dimensional profile at the He-like S Kα band shows that the Chimney is emanating smoothly from G359.41-0.12 (Fig. 4). The spectra of the both of the Chimney and G359.41-0.12 can be fitted with a thin thermal plasma model of $kT \sim 1$ keV (Fig. 5). Therefore these two objects are physically connected with each other. The sum of thermal energies of the two objects is $\sim 1.4 \times 10^{50}$ ergs, typical for a Galactic SNR. G359.41-0.12 is likely a new SNR candidate and the Chimney is an associated outflow.

The molecular clouds of MC3 and MC4 can block the plasma from expanding except in the northern direction. Then, the outflow in the direction of the north may be formed. In any case, the morphology of single SNR plus a chimney-like thermal outflow with the dimension of $\sim$ 8pc $\times$ 8pc $\times$ 34pc is very unusual as a SNR.

References

Brogan C.L. et al. 2003 AJ., 125, 272
Gaensler B.M. et al. 2003 ApJL., 594, L35
Lis D.C. et al. 1994 ApJ., 424, 189
Liszt H.S. 1985 ApJL., 293, L65
Liszt H.S. et al. 1995 ApJS., 98, 259
Manchester R.N. 1987 A&A., 171, 205
Murakami H. et al. 2001 ApJ., 550, 297
Nakajima H. et al. 2009 PASJ., 61, S233
Stewart R.T. et al. 1994 ApJ., 432, L39
Sull J.M. et al. 1989 ApJ., 346, 860
Tsuru T.G. et al. 2009 PASJ., 61, S219
Tsuboi M. et al. 1991 PASJ., 43, 27
Yusef-Zadeh et al. 2007 ApJ., 656, 847