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Possible evidence of a jet-induced explosion found from X-ray and radio observations of a peculiar SNR G0.61+0.01

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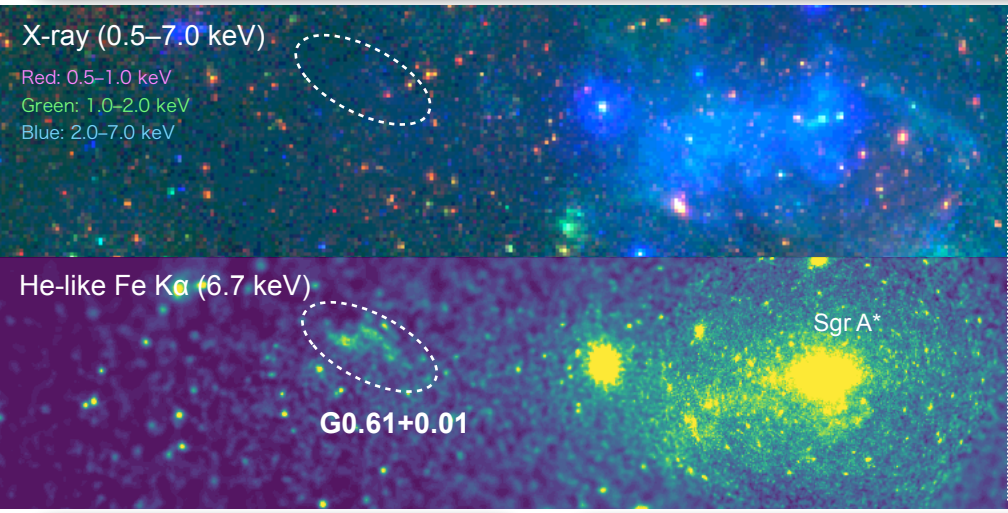
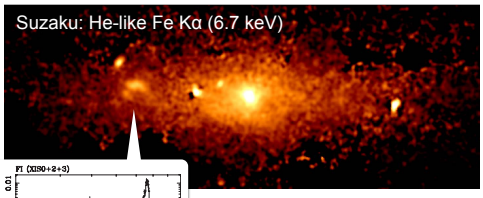


We report on the discovery of a jet-like bipolar motion of Fe-rich ejecta in a Galactic SNR G0.61+0.01. This remnant is located near Sgr B and known to be a remnant of a core-collapse SN (Koyama et al. 2007). Based on our XMM-Newton observations, we revealed that G0.61+0.01 has an elongated east-west bipolar structure, whose length exceeds ~15 pc. They are likely ejected from the core of a massive star. We also found a possible bipolar motion by measuring the line centroid of the Fe Ka line in each spectrum. We further discovered a clear anti-correlation between the plasma and a previously-reported high-velocity compact cloud (HVCC; Oka et al. 2022), suggesting an SNR-cloud interaction. Our follow-up survey for shock tracers such as SiO J=2-1 and HCN J=4-3 shows convincing evidence of gas motions with an opposite velocity direction toward the east and west. All the results support the idea that G0.61+0.01 is a remnant of a theoretically proposed jet-induced explosion (e.g., Maeda & Nomoto 2003; Tominaga et al. 2009). While similar scenarios have also been drawn for several SNRs (e.g., W49B; Lopez et al. 2013) based on their morphologies, our findings provide more direct evidence. Taking into account the lack of the detection of a compact object, we speculate that G0.61+0.01 was formed by a jet explosion driven by a central black hole in a massive star. This scenario is also consistent with the fact that G0.61+0.01 is located in the central molecular zone, where the star formation activity is relatively high. We conclude that G0.61+0.01 is a remnant of a jet-induced explosion, possibly an energetic hypernova or a low-energy faint supernova (Nomoto et al. 2006).

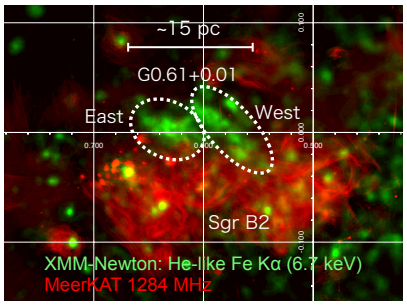
Peculiar SNR, G0.61+0.01

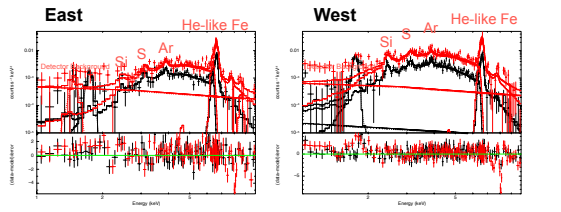


Koyama et al. 2007
Yamaguchi et al. 2014

- With Suzaku, Koyama et al. (2007) reported that an ionized Fe-rich plasma (G0.61+0.01) is found near the Galactic center.
- Although the X-ray spectrum suggests a supernova remnant (SNR), no clear shell structure is found and a peculiar elliptical morphology cannot be explained by a standard SNR categories.

X-ray spectroscopy with XMM-Newton

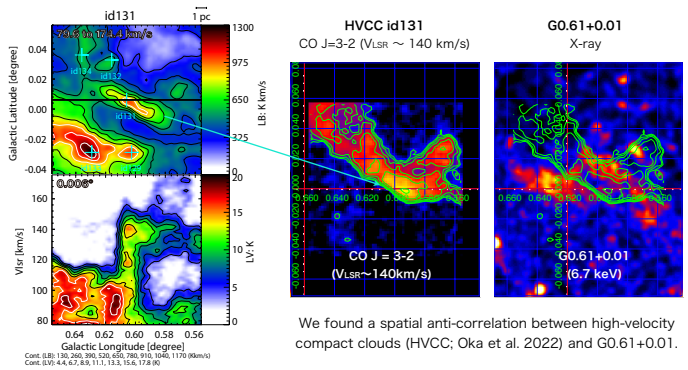




	N_H ($\times 10^{23}$ cm^{-2})	kT (keV)	Ca (= Si = S = Ar)	Fe (= Ni)	$n_e t$ ($\times 10^{10}$ s cm^{-3})
East	2.7 ± 0.3	4.2 ± 1.2	2.9 ± 0.8	6.5 ± 0.9	9 ± 1
West	1.8 ± 0.1	2.9 ± 0.4	1.4 ± 0.2	5.8 ± 0.7	9 ± 1

- Thanks to a better angular resolution of XMM-Newton than that of Suzaku, we revealed that G0.61+0.01 has a bipolar structure elongated from the east to west with a length of ~15 pc: **highly unusual morphology**.
- The spectra obtained from the east and west regions are quite similar to each other, suggesting G0.61+0.01 is a single SNR.
- The Fe-rich abundance implies its origin is a core-collapse SN.

Interaction with a High-Velocity Compact Cloud



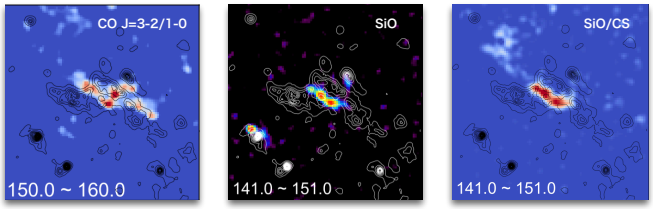
We found a spatial anti-correlation between high-velocity compact clouds (HVCC; Oka et al. 2022) and G0.61+0.01.

Is G0.61+0.01 interacting with HVCC id131?
or
Is HVCC id131 a foreground object? Is G0.61+0.01 obscured by id131?

We performed additional radio observations.

CO J=3-2:
JCMT (Eden et al. 2020)
CO J=1-0:
Nobeyama (Tokuyama et al. 2019)

SiO J=2-1, CS J=2-1:
Nobeyama (Takekawa et al., in prep.)



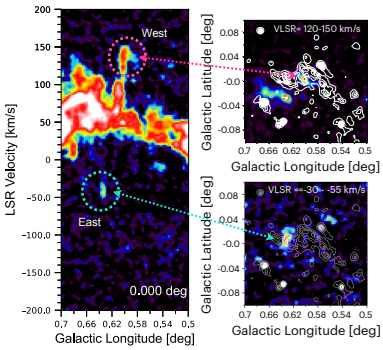
The intensity of this region is above ~1.0 (cf., an average in the CMZ is ~0.7)

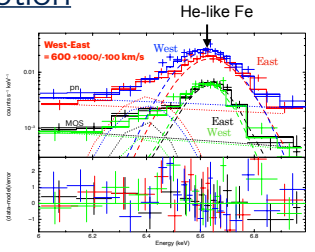
SiO: Shock Tracer

high SiO/CS = highly affected by a shock

We found strong evidence of shock-cloud interaction in G0.61+0.01.

Discovery of a bipolar motion

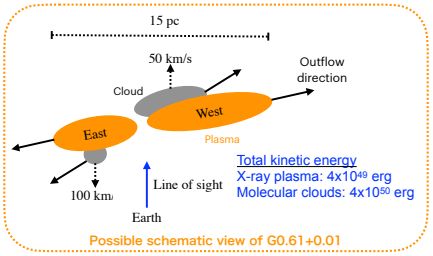


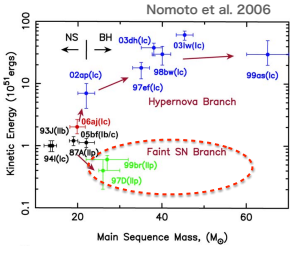


- We discovered molecular clouds with opposite line-of-sight velocity components in East and West.
- We also measured a Doppler velocity from line centroids of the Fe Kα lines in West and East
  → **significant difference is detected.**

G0.61+0.01 has a bipolar outflowing structure!

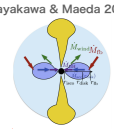
G0.61+0.01: a remnant of a jet-like explosion?





- Our observations strongly indicate that G0.61+0.01 has a bipolar outflowing structure.
- The Fe-rich, hot and low-ionized plasma strongly supports that G0.61+0.01 is a remnant of a core-collapse (but non-standard) SN.
- Estimated total kinetic energy (~10^{50} erg) suggests that the origin of G0.61+0.01 is a **jet-like explosion with a relatively low explosion energy**. This picture is consistent with a theoretically-predicted "faint SN" (e.g., Nomoto et al. 2006).

Hayakawa & Maeda 2018



G0.61+0.01 is possibly first evidence for faint (je-like) SNe.