S14 First Detection of a Bipolar Molecular Outflow Driven by the Microquasar 1E 1740.7-2942

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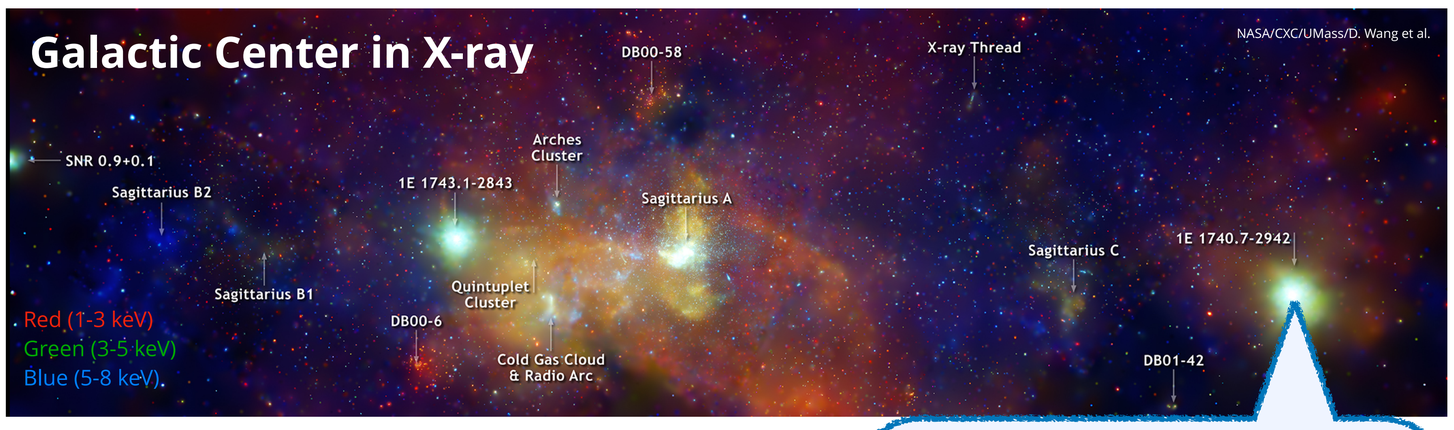


1E 1740.7–2942 may possibly be the most active stellar-mass black hole in the Central Molecular Zone.

Interaction between the jet and molecular gas has been discussed (Hodges-Kluck+09, Tetarenko+20).

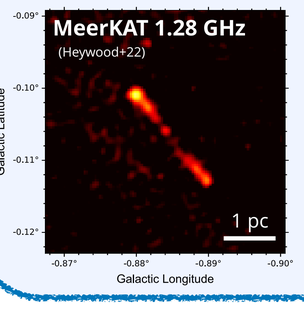
However, no definitive evidence has been found.

We conducted spectral line imaging observations toward 1E 1740.7–2942 to search for molecular gas interacting with the radio jet using the Nobeyama Radio Observatory 45-m telescope.

Microquasar 1E 1740.7–2942

(also known as **Great Annihilator**)

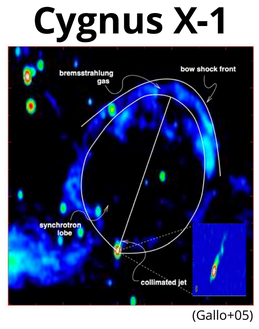
Brightest hard X-ray source in the Galactic center



- **Relativistic jet**
- $\sim 5M_\odot$ BH
- $L_{\rm bol} \sim 10^{37}$ erg s^{-1} ($\sim 0.02L_{\rm Edd}$)
- Maybe binary (no companion detected) (Bhuvana+23)

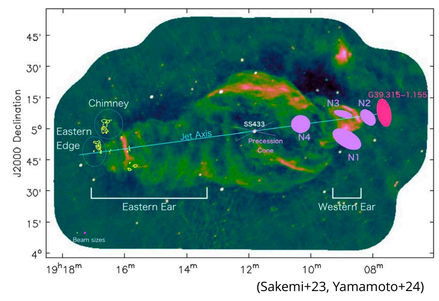
Possible jet-ISM interactions in microquasars

Cygnus X-1



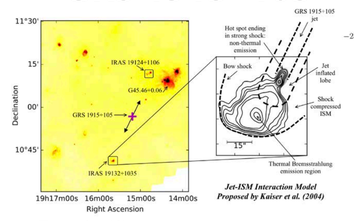
(Gallo+05)

SS433



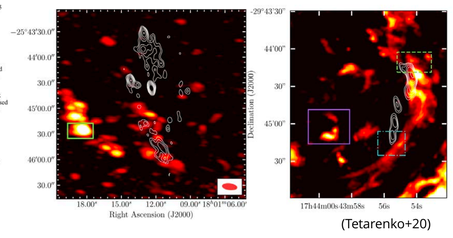
(Sakemi+23, Yamamoto+24)

GRS 1915+105



(Tetarenko+18)

GRS 1758–259 **1E 1740.7–2942**



(Tetarenko+20)

- Jets significantly influence the physical conditions and chemical compositions of the surrounding ISM.
- Important role for the **enhancement/suppression of star formation** and the **circulation of matter and energy** within galaxies.

Observations with the Nobeyama 45 m

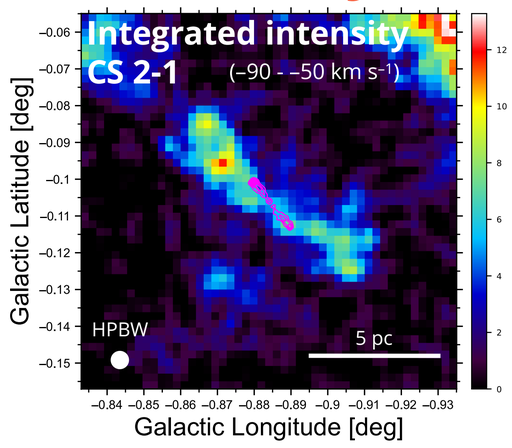
- Date: January 26-29, 2024 (25 hr)
- FOREST + SAM45 (OTF mode)

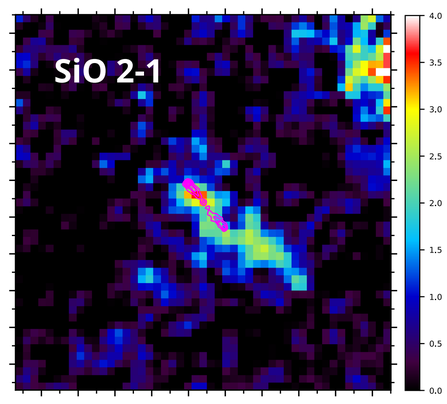
Target lines

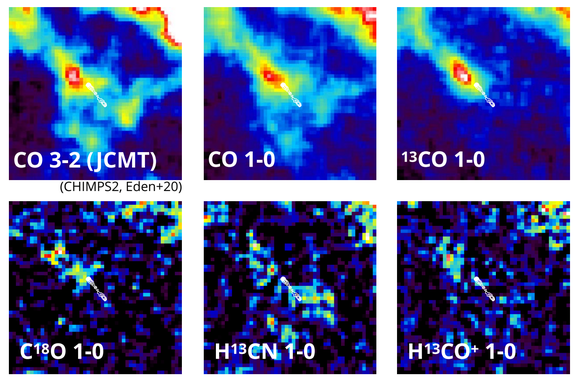
Molecule	Transition	Frequency
SiO	**J=2–1**	**86.8470 GHz**
CS	**J=2–1**	**97.9810 GHz**
$H^{13}CN$	J=1–0	86.3399 GHz
$H^{13}CO^+$	J=1–0	86.7543 GHz
CO	J=1–0	115.271 GHz
^{13}CO	J=1–0	110.201 GHz
$C^{18}O$	J=1–0	109.782 GHz

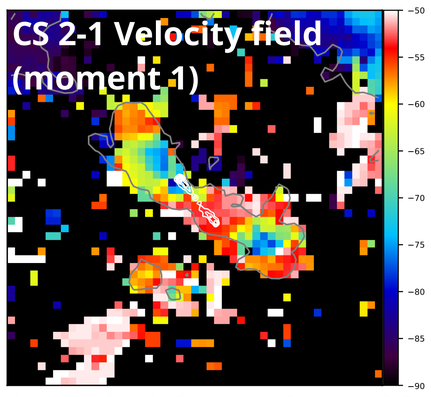
- **HPBW: 14″ - 18″** (~0.7 pc@8 kpc)
- **Area: 6′×6′**
- **$\Delta T_{\rm MB}$ = 0.1 K @1 km/s res.**

Discovery of molecular outflow









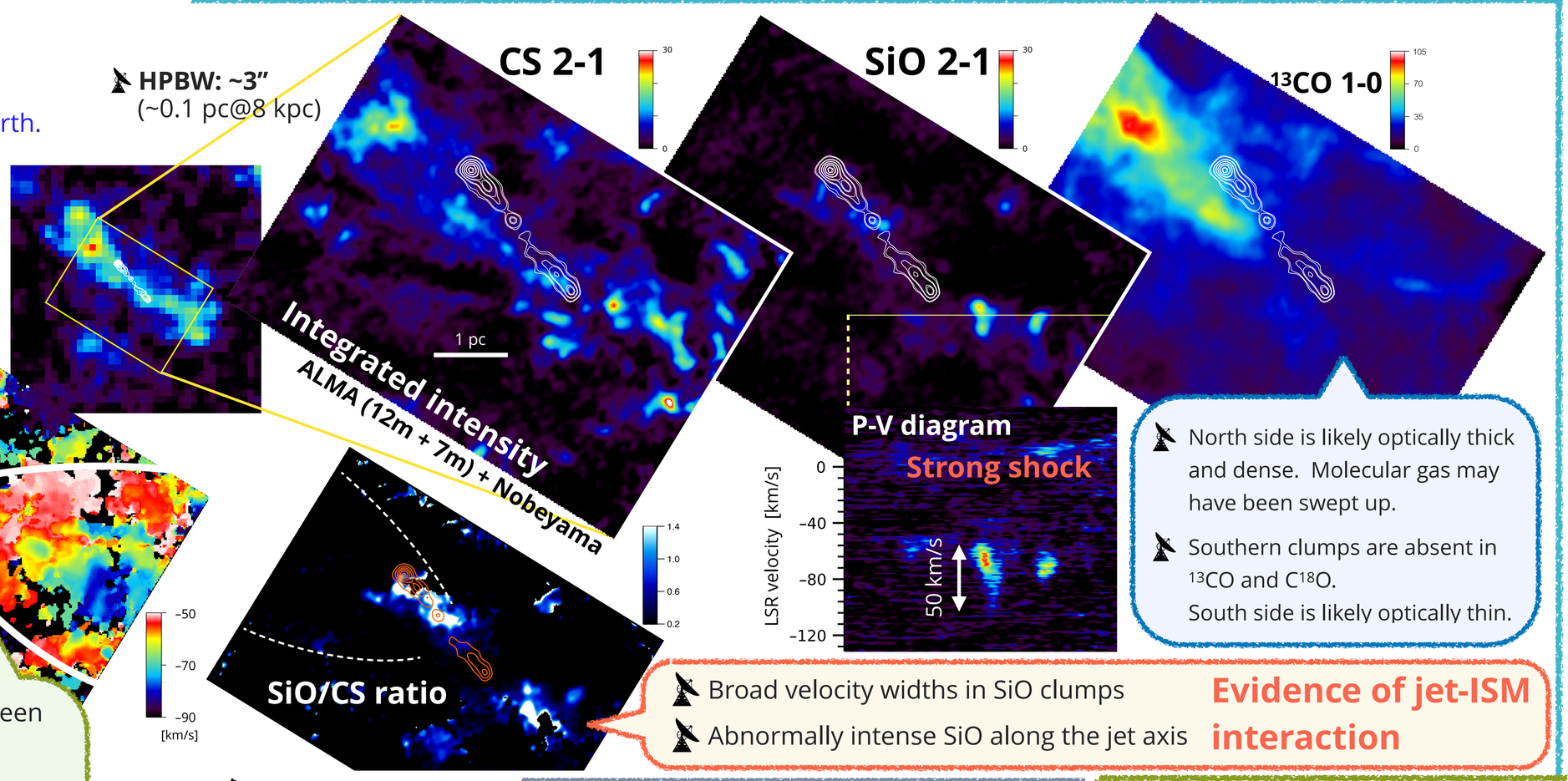
- Outflow extends over more than twice the length of the radio jet.
- Jet and outflow axes appear misaligned, indicating relative motion or jet precession or a sudden change in inclination.
- Outflow appearances vary between different molecules:
  - CS appears symmetrical with cone-like shapes.
  - SiO extends southward and does not appear conical.
  - CO is spatially widespread, while ^{13}CO and $C^{18}O$ are only in north.
- North/South exhibits blue (approaching)/red shift (receding).

Combined with ALMA

The jet-ISM interaction was investigated by ALMA (Tetarenko+20), but no definitive evidence has been found. Our Nobeyama data were combined as Total Power with the ALMA data (2017.1.00928.S, PI: A. Tetarenko) by Feathering.

- Internal structure and kinematics revealed on sub-pc scale.
- Clear cone-like structure in the north. Clumpy in the south.
- **SiO enhancement** around the radio core and southward.

- **HPBW: ~3″** (~0.1 pc@8 kpc)

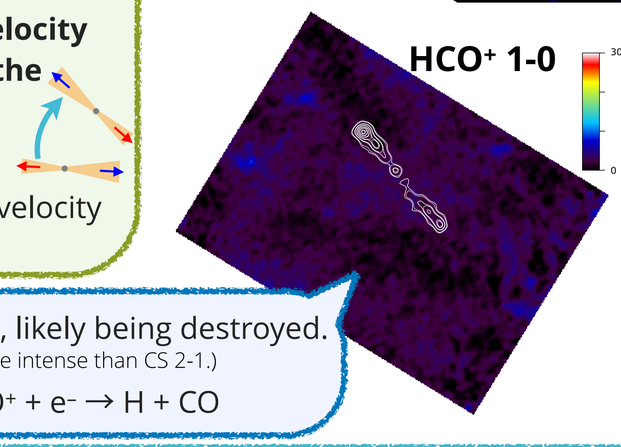


- North side is likely optically thick and dense. Molecular gas may have been swept up.
- Southern clumps are absent in ^{13}CO and $C^{18}O$. South side is likely optically thin.

- Broad velocity widths in SiO clumps
- Abnormally intense SiO along the jet axis

Evidence of jet-ISM interaction

- Typical velocity difference between north and south is ~20 km/s.
- North side exhibits a clear **velocity gradient perpendicular to the outflow axis.** → **Long-term precession ?**
- South side exhibits complex velocity structures.



- **HCO^+ is exceptionally weak**, likely being destroyed. (HCO^+ 1-0 from typical CMZ clouds is more intense than CS 2-1.)

Abundant electrons ? $HCO^+ + e^- \rightarrow H + CO$

Estimated physical properties using CS line

(assuming optically thin, LTE, $T_{\rm ex} = 15$ K, $[CS]/[H_2] = 10^{-8}$)

- Velocity dispersion: $\sigma_V \simeq 10$ km s^{-1}
- Gas mass: $M_{\rm outflow} \sim 1 \times 10^3\ M_\odot$
- Dynamical timescale: $\tau_{\rm dyn} \sim 2 \times 10^5$ yr
- Kinetic energy: $E_{\rm kin} \sim 4 \times 10^{48}$ erg
- Kinetic power: $P_{\rm kin} \sim 7 \times 10^{35}$ erg s^{-1} $\sim 0.07L_{\rm bol}$

Approximately 7% of the bolometric luminosity is transferred to the molecular gas.

Summary

- Conducted deep molecular line observations with the Nobeyama 45-m telescope, and combined our new data with ALMA archival data.
- **First example of a microquasar with bipolar molecular outflow.**
- Excellent target for detailed study of jet-ISM interaction.