The Second Galactic Center Black Hole? A Possible Detection of Ionized Gas Orbiting around an IMBH Embedded in the Galactic Center IRS13E Complex

Masato Tsuboi, Yoshimi Kitamura, Takahiro Tsutsumi, Kenta Uehara, Makoto Miyoshi, Ryosuke Miyawaki, and Atsushi Miyazaki

1 Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa 252-5210, Japan; tsuboi@vsop.isas.jaxa.jp
2 Department of Astronomy, The University of Tokyo, Bunkyo, Tokyo 113-0033, Japan
3 National Radio Astronomy Observatory, Socorro, NM 87801-0387, USA
4 National Astronomical Observatory of Japan, Mitaka, Tokyo 181-8588, Japan
5 College of Arts and Sciences, J.F. Oberlin University, Machida, Tokyo 194-0294, Japan
6 Japan Space Forum, Kanda-surugadai, Chiyoda-ku, Tokyo, 101-0062, Japan

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Abstract

The Galactic Center is the nuclear region of the nearest spiral galaxy, the Milky Way, and contains the supermassive black hole with $M \sim 4 \times 10^6 M_\odot$, Sagittarius A* (Sgr A*). One of the basic questions about the Galactic Center is whether or not Sgr A* is the only "massive" black hole in the region. The IRS13E complex is a very intriguing infrared (IR) object that contains a large dark mass comparable to the mass of an intermediate mass black hole (IMBH) from the proper motions of the main member stars. However, the existence of the IMBH remains controversial. There are some objections to accepting the existence of the IMBH. In this study, we detected ionized gas with a very large velocity width ($\Delta V_{FWZI} \sim 650$ km s$^{-1}$) and a very compact size ($r \sim 400$ au) in the complex using the Atacama Large Millimeter/submillimeter Array (ALMA). We also found an extended component connecting with the compact ionized gas. The properties suggest that this is an ionized gas flow on the Keplerian orbit with high eccentricity. The enclosed mass is estimated to be $10^4 M_\odot$ by the analysis of the orbit. The mass does not conflict with the upper limit mass of the IMBH around Sgr A*, which is derived by the long-term astrometry with the Very Long Baseline Array (VLBA). In addition, the object probably has an X-ray counterpart. Consequently, a very fascinating possibility is that the detected ionized gas is rotating around an IMBH embedded in the IRS13E complex.

Key words: accretion, accretion disks – Galaxy: center – stars: formation

1. Introduction

The Galactic Center is the nuclear region of the nearest spiral galaxy, the Milky Way, and harbors the Galactic Center black hole, Sagittarius A* (Sgr A*; $M \sim 4 \times 10^6 M_\odot$; e.g., Ghez et al. 2008; Gillessen et al. 2009; Schödel et al. 2009; Boehler et al. 2016). Its environment is unique in the galaxy, as it contains several peculiar objects. One of basic questions about the Galactic Center is whether or not Sgr A* is the only "massive" black hole ($\geq 10^4 M_\odot$) in the region.

The IRS13E complex is a very intriguing infrared-radiation (IR) object in the vicinity of Sgr A*, which was identified in the early days of the Galactic Center observations. It is located approximately 3.75 southwest of Sgr A* in projection ($r = 0.13$ pc; e.g., Genzel et al. 1996; Maillard et al. 2004). The center position of the complex corresponds to the west edge of the Minicavity, which is a hook-like substructure of the Galactic Center Minispiral (GCMS; e.g., Lacy et al. 1980; Ekers et al. 1983; Lo & Claussen 1983). The IR observations at the time suggested that the IRS13E complex contains several massive stars including Wolf–Rayet (WR) and O stars in a diameter of about 0.55, which have a common direction and similar amplitude to the proper motions (westward proper motion with $v_{\text{mean}} \sim 280$ km s$^{-1}$; e.g., Maillard et al. 2004). This fact indicates that the main members of the complex are physically bound, although the complex should be disrupted by the strong tidal force of Sgr A* (e.g., Gerhard 2001). One possible speculation was that a dark mass, such as an intermediate mass black hole (IMBH), in the complex may prevent its tidal disruption (e.g., Maillard et al. 2004). The mass of the IMBH was estimated to be $10^4 M_\odot$ from the proper motions of the member stars (e.g., Maillard et al. 2004; Schödel et al. 2005; Paumard et al. 2006). However, some objections to the existence of the IMBH emerged from new observations and environmental evidence (e.g., Schödel et al. 2005; Fritz et al. 2010). A recent IR spectroscopic observation indicated that most stars previously detected in the central area of the IRS13E complex are not massive stars but ionized gas blobs, although a few massive stars are certainly identified in the outer area (Fritz et al. 2010).

We consider the existence of the IMBH in the IRS13E complex to be an open question. If the IMBH exists, the Atacama Large Millimeter/submillimeter Array (ALMA) can detect the ionized gas accreting onto the IMBH in the IRS13E complex. The accreting ionized gas is expected to have a very large velocity width and a very compact size. We searched such ionized gas with ALMA in order to prove the IMBH hypothesis. Throughout this Letter, we adopt 8.0 kpc as the distance to the Galactic center (e.g., Ghez et al. 2008; Gillessen et al. 2009; Schödel et al. 2009; Boehler et al. 2016), and 1″ corresponds to 0.04 pc at the distance.

2. Observation and Data Reduction

We performed the following observation and analysis. The calibration and imaging of both data sets were done using the Common Astronomy Software Applications (CASA; McMullin et al. 2007).
2.1. 340 GHz Continuum

We observed the continuum emission of Sgr A* and the GCMS at 340 GHz as an ALMA Cy.3 program (2015.1.01080. S.; P.I.: M.Tsuboi). The observations were performed in three days (2016 April 23, August 30/31, and September 08). The observation in April was for the detection of extended emission. The field of view in FWHM (FOV) is 18", which is centered on Sgr A*. αCRS = 17°45'40.04" and δCRS = -29°00'28.20". J1717-3342 was used as a phase calibrator. The flux density scale was determined using Titan and J1733-1304. We used the self-calibration method in CASA to improve the dynamic range of the map. The angular resolutions using "natural weighting" and "uniform weighting" are 0".14 × 0".13, PA = 82.5° and 0".101 × 0".090, PA = 3.8°, respectively. The sensitivities are 1σ = 0.10 and 0.18 mJy beam -1 in the emission-free areas, respectively. The dynamic ranges are ~28,000 and ~16,000, respectively. These values are several times worse than the expected values generated by the ALMA sensitivity calculator. We will present the improvement of the analysis and the full results in another paper (M. Tsuboi et al. 2017, in preparation).

2.2. H30α Recombination Line

We analyzed the Director’s Discretionary Time (DDT) observation toward the Galactic Center with ALMA, which was released in the autumn of 2016 (Project code: 2015.A.00021.S). The data set contains two-day observations (2016 July 12/13 and 18/19) of the Galactic Center in the H30α recombination line (νrest = 231.9 GHz). The FOV is 25"., which is centered on Sgr A*. Since the original observations aimed for the measurement of the time variation of Sgr A*, the time spans of the observations are 22:40 UT – 03:40 UT for the first day and 23:00 UT – 05:45 UT for the second day, providing good coverages on the spatial frequency plane (uv plane) for imaging. J1744-3116 was used as a phase calibrator. The flux density scale was determined using Titan and J1733-1304. Before spectral line imaging, the time variation of Sgr A* was noted in the Introduction (Fritz et al. 2010). The positions and angular sizes of these objects are estimated by the 2D Gaussian fit of CASA (see Table 1). The relative position of IRS13E referring to Sgr A* is estimated to be Δα = -3°.19 ± 0°.01, Δδ = -1°.55 ± 0°.01. The error is derived nominally according to the ALMA Technical Handbook (10.6.6). The beam-deconvolved angular size of IRS13E is derived to be 800 au × 800 au at 430 GHz by the Gaussian fit. Compared to Sν = 13.1 mJy at 42 GHz (Yusef-Zadeh et al. 2014), the spectrum index is estimated to be α = log(Sν/ν) / log(Sν/ν°) ~ -0.1. The flat spectrum suggests that the emission from IRS13E3 is an optically thin free-free emission and the sign of dust thermal emission is not clear. The derived parameters of the IR objects are also summarized in Table 1. Note that our derived values are similar to those in the previous observations (e.g., Maillard et al. 2004; Schödel et al. 2005; Paumard et al. 2006), including IRS13E3 which is a main member of the IRS13E complex but an ionized gas blob as noted in the Introduction (Fritz et al. 2010). The beam-deconvolved angular size of IRS13E is derived to be 800 au × 800 au at 430 GHz by the Gaussian fit. Compared to Sν = 13.1 mJy at 42 GHz (Yusef-Zadeh et al. 2014), the spectrum index is estimated to be α = log(Sν/ν) / log(Sν/ν°) ~ -0.1. The flat spectrum suggests that the emission from IRS13E3 is an optically thin free-free emission and the sign of dust thermal emission is not clear. The derived parameters of the IR objects are also summarized in Table 1. Note that our derived values are similar to those in the previous observations (e.g., Paumard et al. 2006; Yusef-Zadeh et al. 2014).

Although the flux density of Sgr A* was Sν = 2.8 Jy at 340 GHz, Sgr A* itself was not detected in the recombination line. The IRS13E complex is the most prominent in both of the maps. We concentrate on the IRS13E complex in this Letter, although we detected several fascinating objects in these maps, for example magnetar PSR J1745-2900 (e.g., Eatough et al. 2013) in the vicinity of Sgr A*, which is labeled “Magnetar” in the upper panel.

Figure 2 shows the close-up continuum map of the IRS13E complex at 340 GHz. The IRS13E complex is resolved into a group of compact objects in the map. Most of these are the IR-identified objects (e.g., Maillard et al. 2004; Schödel et al. 2005; Paumard et al. 2006), including IRS13E3 which is a main member of the IRS13E complex but an ionized gas blob as noted in the Introduction (Fritz et al. 2010). The positions and angular sizes of these objects are estimated by the 2D Gaussian fit of CASA (see Table 1). The relative position of IRS13E referring to Sgr A* is estimated to be Δα = -3°.19 ± 0°.01, Δδ = -1°.55 ± 0°.01. The error is derived nominally according to the ALMA Technical Handbook (10.6.6). The beam-deconvolved angular size of IRS13E is derived to be 800 au × 800 au at 430 GHz by the Gaussian fit. Compared to Sν = 13.1 mJy at 42 GHz (Yusef-Zadeh et al. 2014), the spectrum index is estimated to be α = log(Sν/ν) / log(Sν/ν°) ~ -0.1. The flat spectrum suggests that the emission from IRS13E3 is an optically thin free-free emission and the sign of dust thermal emission is not clear. The derived parameters of the IR objects are also summarized in Table 1. Note that our derived values are similar to those in the previous observations (e.g., Paumard et al. 2006; Yusef-Zadeh et al. 2014).

Figure 3 shows the channel maps of the IRS13E complex in the H30α recombination line with the central velocities of VLSR = -390 to +310 km s -1 (the map area corresponds to the red rectangle in Figure 1, lower panel). The velocity range of the channel maps is Δν = 50 km s -1. Figure 4(a) shows the integrated intensity map of the H30α recombination line with the integrated velocity range of VLSR = -400 to +400 km s -1. These maps also show the 340 GHz continuum emission as the contours. The ionized gas seen in the panels with VLSR ~ -340 to +260 km s -1 seems to be along a continuum north-south ridge including the IRS13E complex. Figure 4(b) shows the position–velocity diagram of the H30α recombination line through the IRS13E complex along the red rectangle shown in Figure 4(a).

There is a compact component located at ~1" south of IRS13E3 in the panel with VLSR = -340 km s -1 of Figure 3, which is labeled “D.” The compact component is approaching to IRS13E3 with increasing velocity (see the panels with VLSR = -340, -290, and -240 km s -1). This is also identified as a component in the position–velocity diagram. An extended component appears around ~2" south of IRS13E3 in the panel with VLSR = -290 km s -1, which is labeled “A.” The component also shifts to the north with increasing velocity and reaches IRS13E3 in the panel with VLSR ~ -190 km s -1. The components “D” and “A” seem to be combined at IRS13E3 and the combined compact component stays in the velocity range of VLSR = -90 to +260 km s -1. The peak position seems to shift monotonically to the north across the

5 https://casa.nrao.edu/casadocs/casa-5.0.0/synthesis-imaging/masks-for-deconvolution
IRS13E3 in the velocity range of $-90$ to $+210\ km_s^{-1}$. The peak shift is shown clearly in Figure 4(d). The behavior is also identified as a prominent curved ridge with a wide velocity width in Figure 4(b). The negative angular offset part of the curved ridge corresponds to the south-extended component in the panels with $V_{LSR} \sim -290$ to $-190\ km_s^{-1}$ of Figure 3. The velocity width of the ionized gas toward IRS13E3 reaches $\Delta v_{FWZI} \sim 650\ km_s^{-1}$ at IRS13E3.

A nearly vertical ridge with $V_{LSR} \sim -50$ to $+50\ km_s^{-1}$ is identified in the position–velocity diagram of Figure 4(b), which is labeled “B.” This corresponds to an extended component surrounding the IRS13E and IRS13N complexes seen in the channel map of $V_{LSR} = -90$ to $10\ km_s^{-1}$ of Figure 3. The component is a part of the Bar, which is a substructure of the GCMS (also see Figure 1). The ionized gas that is probably associated with the IRS13N complex is also

Figure 1. Finding charts of the structures around Sgr A' including the IRS13E complex. Upper panel: continuum map of Sgr A' and the GCMS at 340 GHz in units of Jy beam$^{-1}$. The FWHM beam size is $0\'\'14 \times 0\'\'13$, $PA = 82.5\ degrees$ shown at the lower-left corner. A red square indicates the area shown in Figure 2. Lower panel: integrated intensity (moment 0) map of the H30$\alpha$ recombination line with the integrated velocity range from $V_{LSR} = -400$ to $+400\ km_s^{-1}$ in units of Jy beam$^{-1}\ km_s^{-1}$. The FWHM beam size is $0\'\'41 \times 0\'\'30$, $PA = -77\ degrees$ shown in the lower-left corner. Sgr A' itself (cross) was not detected in the recombination line. A red rectangle indicates the area shown in Figure 3.
identified in the panels with $V_{\text{LSR}} \sim -90$ to $+110$ km s$^{-1}$ of Figure 3.

In addition, a faint ridge is seen in the position–velocity diagram of Figure 4(b), which is labeled “C.” This component is the counterpart to the He30$\alpha$ recombination line of the negative velocity vertical part of component “A,” because the velocity shift is exactly equal to the velocity difference between the H30$\alpha$ and He30$\alpha$ recombination lines: $\Delta v = c [\nu(\text{He30}\alpha) - \nu(\text{H30}\alpha)] / \nu(\text{H30}\alpha) \sim -122$ km s$^{-1}$. This component is also identified as a faint extended component $\sim 2''$ south of IRS13E3 in the channel map of $V_{\text{LSR}} \sim -390$ km s$^{-1}$ (see Figure 3). The intensity ratio of $I(\text{He30}\alpha) / I(\text{H30}\alpha)$ has a reasonable value of $\sim 0.05$ in galactic disk HII regions (e.g., Roshi et al. 2017).

Figure 4(c) shows the position–velocity diagram of the H30$\alpha$ recombination line along the cut adjacent and parallel to the cut for Figure 4(b) for comparison. This indicates the relations between the ionized gas associated with the IRS13E complex and the arms of the GCMS. The tip of the Eastern Arm (EA) is located around $\alpha_{\text{ICRS}} = 17^h 45^m 40.0^s$; $\delta_{\text{ICRS}} = -29^\circ 00' 30.5''$ (see the lower panel of Figure 1), which is far from the ionized gas associated with the IRS13E complex. Therefore, there is no connection between the EA and the ionized gas. The ionized gas is independent from the EA. On the other hand, the relation between the ionized gas and the Northern Arm (NA) is complicated. The tip of the NA crosses the ionized gas around $2''$ south of IRS13E as shown in Figure 4(a); (yellow arrows, see also the panels with $V_{\text{LSR}} \sim -290$ to $-190$ km s$^{-1}$ of Figure 3). Although the tip of the NA is partially blended with the ionized gas, this is barely identified in the position–velocity diagram of Figure 4(c); (yellow arrow). The ionized gas would be independent from the NA.

4. Discussion

4.1. Compactness of the Ionized Gas toward IRS13E3

The angular source size of the ionized gas toward IRS13E3 is derived to be $\theta_{\text{maj,obs.}} \times \theta_{\text{min,obs.}} = 0''41 \times 0''31 \sim 0''31 \pm 0''02$, $PA \sim 127^\circ$ by the 2D Gaussian fit to the total integrated velocity map (see Figure 1, lower panel). Because this is as large as the clean beam size of the H30$\alpha$ recombination line, the beam-deconvolved source size is estimated to be much less than the beam size. The peak position is also estimated to be $\alpha_{\text{ICRS}} = 17^h 45^m 39.7^s$; $\delta_{\text{ICRS}} = -29^\circ 00' 29.84''$ \pm $0''.01$. This position is almost equal to that of IRS13E3 in the 340 GHz continuum map within the FWHM beam size. The positional differences are $\Delta \alpha \sim 0''005$ and $\Delta \delta \sim 0''028$ according to the comparison between the 340 GHz continuum and H30$\alpha$ moment 0 positions of IRS16NE, of which images are compact in both of the maps (see Figure 1). The positional correspondence between both the observation is better than 10% of the FWHM beam size of the H30$\alpha$ moment 0 map (~0''4).

Because IRS13E3 is emitting the 340 GHz continuum through thin free–free emission mechanism as mentioned above, IRS13E3 is emitting the H30$\alpha$ recombination line simultaneously. The area emitting the recombination line should be identical to IRS13E3 itself, as shown in the continuum map (see Figure 2). The size of the ionized gas would be $\theta_{\text{maj,obs.}} \times \theta_{\text{min,obs.}} = 0''.102 \times 0''.090$, $PA \sim 27^\circ$ or $r_{\text{maj}} \times r_{\text{min,obs.}} = 0.0020$ pc $\times 0.0018$ pc (400 au $\times$ 350 au). Although our estimated radius, $r$, is an upper limit, this radius is considered to be close to the real radius because the continuum observation of IRS13E3 with JVLA at 34 GHz shows a similar source size; $0''.08 \times 0''.04$ (Yusef-Zadeh et al. 2014). The
compactness and large velocity width suggest the presence of an IMBH in the IRS13E complex.

### 4.2. Keplerian Orbit with High Eccentricity around IRS13E3?

There is a bright ridge connecting IRS13E3 with the extended component around ~2″ south of IRS13E3 in Figure 4(a). This corresponds to the curved ridge from \( V_{\text{LSR}} \sim -300 \) to \( +250 \text{ km s}^{-1} \) ("A") in the position–velocity diagram of Figure 4(b). In addition, there is a weak component at \( V_{\text{LSR}} \sim -350 \text{ km s}^{-1} \) at the offset of \( \sim -0.5' \) ("D"; white arrow) in the position–velocity diagram. The weak component is identified as a compact component at 0.6″ south of IRS13E3 in the channel map of \( V_{\text{LSR}} = -340 \text{ km s}^{-1} \), as mentioned in the previous section (see Figure 3). These observed features suggest the presence of a Keplerian orbit with high eccentricity around IRS13E3. Such Keplerian orbits have a nearly linear part with a large velocity gradient, and double-curved ridges with a relatively small velocity gradient, in the position–velocity diagram (see Figure 12 in Tsuboi et al. 2017). In this case, the line intensity of the orbit decreases with increasing velocity, as shown in Figure 4(b), because the line intensity should be in inverse proportion to the orbital velocity. Note that the thermal velocity broadening for ionized Hydrogen gas of \( 10^4 \text{ K} \) is \( \Delta v \sim 20 \text{ km s}^{-1} \) in FWHM, which is negligible compared with the rotation velocity.

Another hypothesis to explain the weak component "D" may be that the component is the counterpart in the He3α recombination line. However, the intensity ratio of the bright ridge and the weak component is up to \( \sim 0.3 \). This is too high, as \( \frac{I(\text{He3}\alpha)}{I(\text{H3}\alpha)} \). In addition, the velocity shift between these components is \( \Delta v \sim -100 \text{ km s}^{-1} \) which is less than the velocity difference between the H3α and He3α recombination lines, \( \Delta v \sim -122 \text{ km s}^{-1} \), as mentioned previously. Therefore, the weak component would be a part of the Keplerian orbit with a high eccentricity around IRS13E3.

An example of the orbits describing well the observed features is shown in the position–velocity diagram (see the black broken line in Figure 4(b)). Note that it is difficult to determine exclusively the accurate orbital parameters by fitting in the position–velocity diagram, because the full orbit is not completely occupied by ionized gas and/or the observed features do not always belong to a single orbit. The apoapron of the orbit would be located in the bright extended ionized gas component seen \( \sim 2″ \) south of the IRS13E complex in projection. The angle between the direction of the semimajor axis and the line of sight is \( PA \sim 60° \). The observed major axis is \( 2a \sin 60° \sim 2.5 \times 10^{17} \text{ cm} \) and the semimajor axis of the orbit is estimated to be \( a \sim 1.4 \times 10^{17} \text{ cm} = 1 \times 10^{14} \text{ au} \). The inclination angle of the orbit would be \( i \sim 0° \) because of the elongated feature with a narrow width of orbiting ionized gas shown in Figure 4(a). Comparing the observed shape in the position–velocity diagram and the calculated Keplerian orbits, the eccentricity of the orbit is estimated to be \( e \sim 0.97 \).

### 4.3. The Enclosed Mass of IRS13E3

The presence of an IMBH in the IRS13E complex is strongly supported by a large enclosed mass of IRS13E3. In the case of nearly edge-on view, the velocity width of the Keplerian orbit is estimated by

\[
\Delta V \sim \left( \frac{1 + e}{1 - e} \right)^{1/2} \left( \frac{1 + e}{1 - e} \right)^{1/2} \left( \frac{GM}{a} \right)^{1/2}
\]

Then the enclosed mass is estimated to be

\[
M \sim a \Delta V^2 \left( \frac{1 + e}{1 - e} \right) \left( \frac{1 - e}{1 + e} \right)^{2} G^{-1}.
\]

The observed velocity width is \( \Delta V \sim 600 \text{ km s}^{-1} \), and the enclosed mass of the object is estimated to be \( M \sim (4-7) \times 10^4 M_\odot \), comparable to the mass of an IMBH, for \( e = 0.96-0.98 \) and \( a \sim 1.4 \times 10^{17} \text{ cm} \). Although the Keplerian orbit has large ambiguities in the orbit parameters, the mass would be consistent with \( M \sim 10^4 M_\odot \) in the IRS13E complex (e.g., Maillard et al. 2004; Schödel et al. 2005; Paumard et al. 2006). Even if the compact ionized gas does not belong to the Keplerian orbit, the compactness and large velocity width would indicate \( 10^4 M_\odot \) in the IRS13E complex.

If there is an IMBH orbiting Sgr A*, the position of Sgr A* must be affected by it. The position of Sgr A* on the celestial sphere has been monitored using VLBA for over 15 years (e.g., Reid & Brunthaler 2004). The positional shift along the Galactic plane is as large as \( -6.4 \text{ mas year}^{-1} \). However, one can not distinguish between the perturbation by the massive object and the proper motion by the Galactic rotation. On the
other hand, the positional shift crossing the Galactic plane is found to be as small as $-0.2 \text{ mas year}^{-1}$. This indicates that the upper limit mass of the second black hole is $\lesssim M_{10^4} \epsilon M_{\odot}$ in the area of $\sim r_{10^{10}} \text{ au}$ from Sgr A* (Reid & Brunthaler 2004). Therefore, there is no conflict between our derived enclosed mass and the upper limit mass of the second black hole inferred from the VLBA observations.

The periastron distance is estimated to be $a(1 - e) = 4.3 \times 10^{15}$ cm and the projected distance from Sgr A* is $r_{\text{proj}} \sim 4 \times 10^{17}$ cm. Because the mass of the IMBH is only 1% of the mass of Sgr A*, the gravity of the IMBH associated with IRS13E3 is comparable to that of Sgr A*, even around the periastron of the Keplerian orbit around IRS13E3. However, the flow of the ionized gas, which is extended to the south, seems to be described by a Keplerian orbit as mentioned above. This means that the gravity of the IMBH would be dominant there, and the IMBH might be located fairly far from Sgr A* than the projected distance.

The ionized gas mass on the orbit is estimated to be $\sim 10^{6} M_{\odot}$ based on this observation assuming the electron temperature of $T_e \sim 1 \times 10^4 \text{ K}$ and the electron density of $n_e \sim 1 \times 10^6 \text{ cm}^{-3}$ (e.g., Murchikova 2017; Tsuboi et al. 2017). When all of the ionized gas falls to the IMBH associated with IRS13E3 within one orbital period,

Figure 3. Channel maps of the IRS13E complex in the H$_3$O$^+$ recombination line from $-415$ to $+335 \text{ km s}^{-1}$ in $V_{\text{LSR}}$ (red rectangle in Figure 1, lower panel). The velocity width of each panel is $50 \text{ km s}^{-1}$. The central velocity and the FWHM beam size, $0.041 \times 0.030$, $PA = -74^\circ$, are shown at the upper-right and lower-left corners of each panel, respectively. The 340 GHz continuum emission is also shown as contours for comparison. The FWHM beam size, $0.14 \times 0.13$, $PA = 82.5^\circ$, at 340 GHz is also shown at the lower-left corner of each panel. The contour levels are 0.4, 0.8, 1.6, 2.4, 4.0, 4.8, 5.6, and 6.4 mJy beam$^{-1}$. The capitals show the components shown in Figure 4.

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\[ T = 2\pi \sqrt{\frac{a}{GM}} \approx 4 \times 10^{3}\text{ years} \]

The upper limit of the mass accretion rate is estimated to be \( M/T \leq 1 \times 10^{-6} \text{ } M_\odot \text{ yr}^{-1} \). However, because both the gas approaching IRS13E3 (probably “D”) and going away from it (probably “A”) are observed on the orbit (see Oka et al. 2016), it would be overestimation to say that all of the gas falls into it within an orbital period. If the efficiency of the accretion is assumed to be 1% as a likely value, the mass accretion rate becomes comparable to the mass accretion rate of Sgr A* (e.g., Quataert & Gruzinov 2000; Genzel et al. 2010).

### 4.4. X-Ray Counterpart of IRS13E3?

Figure 2 also shows the position of a discrete X-ray source detected in the IRS13E complex, CXOGCI\(174539.7-290029 \ (\alpha_{\text{ICRS}} = 17^\text{h}45^\text{m}39.7^\text{s}, \delta_{\text{ICRS}} = -29^\circ00'29.5'\text{'}; \text{e.g.,} \)

Baganoff et al. 2003; Muno et al. 2009). The statistical error and absolute uncertainty of the position are \( 0'^{0.16} \) and \( 0'^{0.76} \) in radius, respectively (Baganoff et al. 2003). The X-ray source is located near the 340 GHz continuum peak position of IRS13E3, and a relatively narrow velocity width component around \( V_{\text{LSR}} \approx -50 \) to \( +50 \text{ km} \text{s}^{-1} \) ("B"). A black broken line shows an example of the Keplerian orbits that describe well the observed features. The eccentricity, the semimajor axis, and the position angle are \( e \approx 0.97, a \approx 1.4 \times 10^{17} \text{ cm}, \text{and } PA \approx 60^\circ \), respectively.

The X-ray photon flux is \( F_{\text{0.3 keV}} = 3.092 \times 10^{-7} \text{ cm}^{-2} \text{ s}^{-1} \) at 1999.72 years, which is a half that of Sgr A* (e.g., Muno et al. 2009). The spectrum of this bright X-ray source resembles...
that of the quiescent emission from the hot plasma around Sgr A*, and the source has no long- and short-timescale variabilities (Muno et al. 2009). The X-ray emission should be originated in the hot plasma located at IRS13E3 through bremsstrahlung, rather than those from the usual X-ray binaries, cataclysmic variables, and so on. Thus we consider that this source is the X-ray counterpart of IRS13E3. The large X-ray photon flux may be consistent with the mass accretion rate estimated in the previous subsection.

5. Conclusions

We detected the ionized gas associated with IRS13E3 in the H30α recombination line using ALMA, which has a wide velocity width (ΔvFWZI ~ 650 km s⁻¹) and compactness (r ~ 0.002 pc = 400 au). The enclosed mass is estimated to be 10⁴ M☉ in the case of the Keplerian orbit with high eccentricity around IRS13E3. The mass does not conflict with the upper-limit mass of the IMBH around Sgr A*, which is derived by the long-term astrometry with VLBA. This object presumably has an X-ray counterpart. Consequently, a very fascinating possibility is that the detected ionized gas is orbiting around an IMBH with 10⁴ M☉ embedded in the IRS13E complex.

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Facility: ALMA.
Software: CASA.

ORCID iDs
Masato Tsuboi https://orcid.org/0000-0001-8185-8954
Takahiro Tsutsumi https://orcid.org/0000-0002-4298-4461

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