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Ionized Gas Ring Rotating Around the Galactic Center IMBH, IRS13E3

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Abstract. We found an ionized gas rotating around IRS13E3 using ALMA (2017.1.00503.S), which is an intermediate mass black hole (IMBH) candidate in the Galactic center. The continuum emission map at 232 GHz shows an oval-like structure with the angular size of $0\farcs093 \times 0\farcs061$ (1.1×10^{16} cm $\times 0.74 \times 10^{16}$ cm). The structure is also identified in the H30α recombination line, which is seen as an inclined linear feature in the position-velocity diagram along the major axis. Such feature is usually a defining characteristic of a gas ring rotating around a massive object. The rotating velocity and orbit radius are estimated to be $V_{\rm rot} \simeq 230$ km s^{-1} and $r \simeq 6 \times 10^{15}$ cm, respectively. The enclosed mass is derived to be $M_{\rm encl.} \simeq 2.4 \times 10^4\ M_\odot$, which is within the astrometric upper limit mass when it is at the projection distance from Sgr A*. Moreover, IRS13E3 has an X-ray counterpart. These would be supporting evidences that an IMBH is embedded in IRS13E3. The electron temperature, density, and mass of the ionized gas ring are estimated to be $\bar{T}_{\rm e} \simeq 6800$ K, $\bar{n}_{\rm e} \simeq 6 \times 10^5$ cm^{-3}, and $M_{\rm gas} \simeq 4 \times 10^{-4} M_\odot$, respectively.

1. Introduction

The IRS 13E cluster is a conspicuous IR object located within 0.2 pc from Sagittarius A*(Sgr A*) in projection distance (e.g. Genzel et al. 1996). The cluster was thought to contain several WR and O stars in the early observations. The common direction and similar amplitude of these proper motions suggest that the main members of the cluster are physically bound (e.g. Maillard et al. 2004) although the strong tidal force of Sgr A* should disrupt the cluster easily (e.g. Gerhard 2001). One of the possible speculation is that a dark mass like an intermediate mass black hole (IMBH), $M \sim 10^{4-5}\ M_\odot$, in the cluster would prevent the cluster disruption (e.g. Maillard et al. 2004). However, there are some objections to accept the existence of the IMBH. The upper limit mass of the object around Sgr A* is derived on long-term VLBA astrometry (Reid&Brunthaler 2004). If the IMBH is at the observed projection distance from Sgr A*, the mass must not be larger than $M \lesssim 3 \times 10^4\ M_\odot$. IR spectroscopic observations show that almost all the member stars in the cluster are not real stars but gas blobs although a few massive stars may be contained. Therefore, there is an argument that the IMBH is not always necessary (e.g. Genzel et al. 2010).

It is an open question how Sgr A* acquires the material up to the present mass. There is a possibility that IMBHs had fallen and merged into Sgr A*. The high concentration of gas blobs in the IRS 13E cluster is peculiar even in the Galactic center region. Any unusual object may be exist. If the object is located farther than the projection distance, the astrometric upper limit mass becomes larger according to the physical distance. Therefore there is still a possibility that an IMBH exists in the IRS 13E cluster. The associated gas with such object must have very large velocity width and very high compactness, which is possibly detected by ALMA. In our first attempt, we had detected the ionized gas stream associated with the IRS 13E cluster and the southern extension (Tsuboi et al. 2017). The velocity width around IRS13E3 reaches to ~ 650 km s^{-1} in the H30α recombination line. The stream is presumably depicted by a high-eccentricity Keplerian orbit. However, the enclosed mass is slightly larger than the astrometric upper limit mass. A highly excited CH_3OH emission line is also detected in the stream. Because the molecule is easily destroyed by cosmic ray around Sgr A*, the detection indicates that the stream is located farther than the projection distance. Nevertheless we should accept the existence of an IMBH is still controversial and need more precise mass estimation. Then we have attempted to observe IRS13E3 using ALMA at the longest baseline. If the rotating gas ring around IRS13E3 is detected, it provides the stronger evidence that the IMBH exists.

2. Observation and Results

We have observed the area including the IRS 13E cluster in the continuum emission at 232 GHz and the H30α recombination line as an ALMA Cy.5 program (2017.1.00503.S.) (Tsuboi et al. 2019). The diameters of the FOV is ~ 25″ at 232 GHz in FWHM. The observations were performed in the period of the longest baseline antenna configuration of ALMA. J1744-3116 and J1752-2956 were used as a phase calibrator in the 230 GHz observation. The flux density scale was determined using J1924-2914. We performed the data analysis by CASA 5.5 (McMullin et al. 2007). We used the "self-calibration" method to obtain a high dynamic range in the continuum map. The imaging to obtain the continuum and recombination line maps was done using `tclean` task. The angular resolution using "natural weighting" is $0''.037 \times 0''.025$, $PA = 85°$ in FWHM.

Figure 1a shows the continuum map at 232 GHz of the IRS 13E cluster. IRS13E3 is clearly resolved into an inclined oval-like structure which is elongated in the direction of northeast to southwest. The angular size is $0\farcs093 \times 0\farcs061$ which corresponds to 1.1×10^{16} cm $\times 0.74 \times 10^{16}$ cm at the Galactic center distance. The peak position is $\alpha_{\rm ICRS} = 17^{\rm h}45^{\rm m}39^{\rm s}.789$, $\delta_{\rm ICRS} = -29°00'29''.759$. The peak flux density is $S_\nu = 1.712 \pm 0.054$ mJy beam^{-1}. The structure around IRS13E3 is also identified in the H30α recombination line. Figure 1b shows the position-velocity (PV) diagram in the H30α recombination line along the major axis of the ionized gas structure. The integration area is shown as a white rectangle in Figure 1a. The structure is seen as an inclined linear feature in the PV diagram.

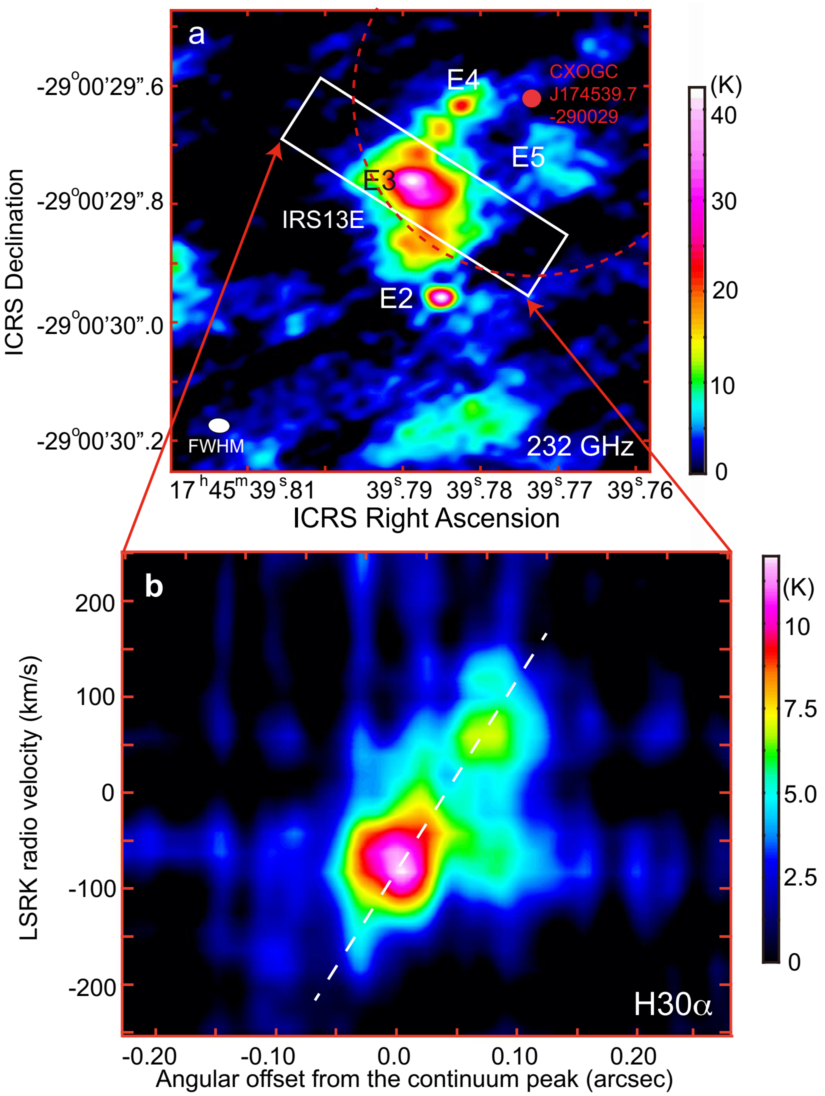

Figure 1. **(a)** Continuum map at 232 GHz of the IRS 13E cluster. The angular resolution is $0''.037 \times 0''.025, PA = 85^\circ$ in FWHM. IRS13E3 is clearly resolved into an inclined oval-like structure which is elongated in the direction of northeast to southwest. The position of a X-ray source, CXOGC174539.7-290029 ($\alpha_{\rm ICRS} = 17^{\rm h}45^{\rm m}39^{\rm s}.773$, $\delta_{\rm ICRS} = -29^\circ 00' 29''.622$), is shown as a white filled circle. The broken circle is the 95% position error circle which has the radius of $0''.3$. **(b)** Position-velocity (PV) diagram in the H30α recombination line along the major axis of the inclined oval-like ionized gas around IRS13E3. The integration area is shown as a white rectangle in **(a).** The inclined oval-like structure is seen as an inclined linear feature.

3. Discussion

An inclined linear feature in the PV diagram is usually thought to be a defining characteristic of a gas ring rotating around a massive object. From the aspect ratio and semi-major axis of the feature, the inclination angle and radius of the ionized gas ring are derived to be $i \simeq 50^\circ$ and $r \simeq 6 \times 10^{15}$ cm, respectively. After the inclination angle correction, the rotating velocity is estimated to be $V_{\rm rot} \simeq 230$ km s^{-1}. Assuming that the ionized gas obeys a single circular orbit, the enclosed mass is derived to be $M_{\rm encl.} \simeq 2.4 \times 10^4\ M_\odot$, which is within the astrometric upper limit mass (see also Tsuboi et al. 2019). From the continuum flux desnity at 232 GHz and the integrated intensity of the H30α recombination line, the electron temperature, density, and mass of the ionized gas ring are estimated to be $\bar{T}_{\rm e} \simeq 6800$ K, $\bar{n}_{\rm e} \simeq 6 \times 10^5$ cm^{-3}, and $M_{\rm gas} \simeq 4 \times 10^{-4} M_\odot$, respectively (see also Tsuboi et al. 2019).

If a modest amount of gas accretes onto an IMBH, strong X-ray emission is expected to be produced. The X-ray point source, CXOGC174539.7-290029, has been detected around IRS13E3 by CHANDRA (Muno et al. 2009). The position is $\alpha_{\rm ICRS} = 17^{\rm h}45^{\rm m}39^{\rm s}.773$, $\delta_{\rm ICRS} = -29^\circ 00' 29''.622$, which is shown as a white filled circle in Figure 1a. The broken line circle is the 95% position error circle which has the radius of $0''.3$. Because IRS13E3 is within the circle, this object has presumably an X-ray counterpart. Therefore, a very fascinated possibility is that an IMBH is embedded in IRS13E3.

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