Cosmic Masers: Proper Motion toward the Next-Generation Large Projects
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Jet and Outflows in Massive Star Forming Region: G10.34−0.14

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Abstract. The ALMA observations of the high-mass star-forming region G10.34−0.14 reveal the existence of three massive hot cores. The most massive of these cores, core S1, exhibits both high and low-velocity jet/outflow in the CO, SiO, and CH_3OH. It is associated with water and Class I methanol masers. The core N shows a low-velocity CO outflow and is associated with an Extended Green Object, along with Class I and II methanol masers. The characteristics of the outflows and masers in these two cores suggest they are in different stage of evolution and varying physical conditions.

Keywords. stars: formation, stars: winds, outflows, stars: jets

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1. Kinematics in G10.34−0.14

The massive star forming region G10.34−0.14, situated a distance of 2.9kpc away (Li *et al.* 2022), consists of 3 protostars with core masses of 4 − 10 Ms, all currently in hot molecular core stages (Baek *et al.* 2022). By analyzing the ALMA data (2015.1.01288.S: P.I. M.-K. Kim), we report the detections of jet and outflows in the high mass star forming region, G10.34−0.14, in the SiO (5 − 4, 217.104980 GHz), CO (2 − 1, 230.538 GHz), and CH_3OH ($8_{-1} - 7_0$ E, 229.758811 GHz) molecular transitions.

1.1. *Core S1/S2 system*

Core S1 (RA, Dec = 18:08:59.98, −20:03:39.1) and S2 constitute a binary system within the same envelope. They are located in the southern part of the observed field. Core S1 is the brightest in the continuum emission, and the collimated jet and outflow originating from Core S1 are detected in SiO and CO emission at velocities ($|V - V_{\rm sys}| <$ 70 km s^{-1}), where $V_{\rm sys} = +11$ km s^{-1} (see the left panel of Fig. 1). The high-velocity (HV; $30 < |V - V_{\rm sys}| < 70$ km s^{-1}) CO/SiO jet is well-collimated and manifests as a regularly spaced bullet-like feature in the position-velocity diagram cut along the jet axis, suggesting episodic ejections. The dynamic age of the B1 bullet as shown in Fig. 1 is approximately 500 yrs, assuming an inclination of 45°. The dynamic timescale of the outflow, estimated from the lobe extent and terminal speed of outflows, is about 6600 yrs. The mass loss rate estimated from the CO emission is 8.8×10^{-5} Ms/yr, which is 10-100 times greater than that of low mass protostellar objects, which ranges $0.1 - 5.5\times^{-6}$ Ms/yr (Li *et al.* 2020; Dutta *et al.* 2022).

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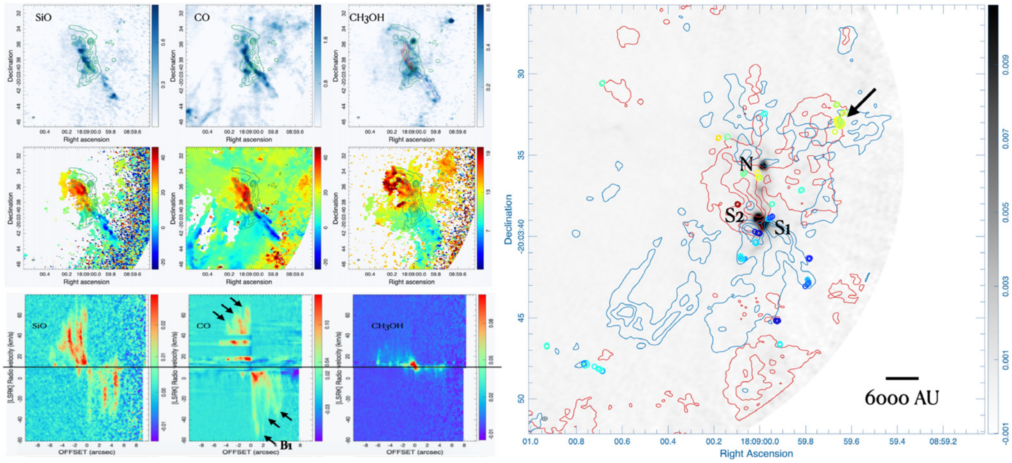

Figure 1. (Left) The top and middle images display moment 0 and 1 maps in SiO, CO, and CH_3OH from left to right. The continuum emission in green contours is overlaid on the moment maps of each molecular transitions. The HV CO jet ($30 < |V - V_{\rm sys}| < 70$ km s^{-1}) is presented with blue and red contours in the moment 0 map of CH_3OH. The PV diagrams along the collimated CO jet for each molecular lines are shown at the bottom. Note that the jet axis shown in the moment 1 map of CO differs slightly between the blue- and red-shifted components. The systemic velocity of +11 km s^{-1} is marked by a black horizontal line. The bullet-like features are indicated by black arrows. (Right) Blue- and red-shifted LV CO outflows ($7 < |V - V_{\rm sys}| < 15$ km s^{-1}) are overlaid on the 1.3 mm dust continuum emission. The open circles represent the positions of the 44 GHz methanol masers, adopted from Cyganowski *et al.* (2009). The symbol area corresponds to the intensity and the color indicates the velocity, ranging from +7.8 km s^{-1} (purple) to +19.7 km s^{-1} (red).

The low-velocity (LV; $|V - V_{\rm sys}| < 20$ km s^{-1}) outflow lobes are also observed in the CH_3OH emission, and the rim of CH_3OH outflow encapsulates the HV CO jet (as presented in the moment 0 map of CH_3OH in Fig. 1), suggesting that the LV outflow could be induced by the energetic jet. The Class I 44 GHz methanol masers are also observed near Core S1 and at the tip of shocked outflow regions (right panel in Fig. 1)

1.2. *Core N*

Core N is positioned in the northern part of the field (RA, Dec = 18:08:59.98, −20:03:35.7). The LV blue-shifted CO lobe in the southeast and the red-shifted CO blob in northwest (right panel of Fig. 1) possibly originate from Core N. The red-shifted blob appears to compress the surrounding medium and generate strong methanol masers at 44, 95, and 229 GHz (Kang *et al.* 2016, this paper), as indicated by an arrow in the right panel of Fig. 1.

We note that the 6.7 GHz Class II methanol maser is situated at the center of Core N, and the Extended Green Object, a 4.5 μ m infrared excess resulting from the high-temperature CO outflow or shocked H2 gas, is located in core N and extends in the SE-NW direction (Cyganowski *et al.* 2009), which aligns with the direction of the CO outflow.

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