Molecules in Outflow Shocked Regions: JWST meets ALMA

Y. Okoda,[1] Y. Yang,[1] N. Sakai[1], and CORINOS team members

[1] *RIKEN Cluster for Pioneering Research, Japan*

How low-mass protostars at the earliest stage grow has still been veiled. As one approach to this problem, we study shock regions in the outflow structure of IRAS 15398-3359 by using some molecular lines observed with JWST (James Webb Space Telescope) and ALMA (Atacama Large Millimeter/submillimeter Array).

IRAS 15398-3359 is a Class 0 protostellar source (T_{bol} = 44 K) in the Lupus 1 molecular cloud (d= 156 pc). In the previous studies (e.g., [1][2][3][4]), some molecular lines, such as H_2CO, CS, and ^{12}CO etc, were found to trace the outflow structure extending from the northeast to southwest axis, which is almost parallel to the plane of the sky. The rotationally supported disk was detected in the SO emission, which is perpendicular to the outflow direction. The protostellar mass was estimated to be 0.007 solar mass on the assumption of a Keplerian rotation [5]. Based on the dust continuum data, the envelope mass was reported to be much larger, 0.5-1.2 solar mass[6][7], and hence, IRAS 15398-3359 should be a very young source.

CORINOS have conducted the JWST observation toward this source, and have detected the southern part of the outflow structure with the mid-infrared instrument (MIRI) [8]. The MIRI image shows the three shell structures and the front shock (Fig.1a). We compare the structure to molecular-line distributions observed with ALMA. The H_2CO and CS lines show the shell structures corresponding to those in the MIRI image, and the ^{12}CO line traces the whole structure including the front shock. We determine the outflow direction of P.A 235 degree, based on the structure in the MIRI image, which is slightly different from the outflow direction near the protostar (P.A 220 [5] and 230 degrees [1]). Furthermore, we detect eight lines of H_2 with JWST, mainly tracing the southern part of the outflow near the protostar (Fig. 1b). Assuming the LTE condition, we derive the temperature and the column density map to be ~700-800 K and ~10^{19} cm^{-2}, respectively. Comparing between the distributions of H_2 and those of the molecular lines (H_2CO, CS, and ^{12}CO), we find that the three molecular lines show a weak emission where the H_2 lines are enhanced with the high temperature. In the shock regions of the outflow cavity, the temperature is estimated to be 46-126 K when the H_2 density is assumed to be 10^6 cm^{-2}, by using the three H_2CO lines observed with ALMA. Our results suggest an episodic outflow ejecting with precession.

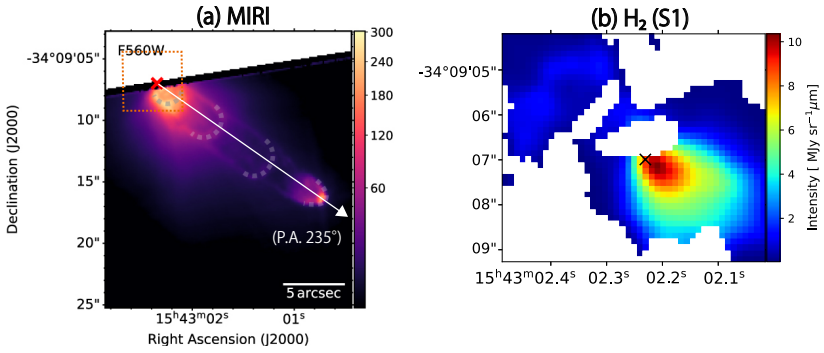

Figure 1: (a) MIRI image with JWST. Red cross mark shows the continuum peak. Dotted lines represent the shell structures and the front shock. The box with orange dotted lines corresponds to the area in the panel (b). (b) Integrated intensity map of H_2 (S1). Black cross mark shows the continuum peak.

References

[1] Y. Oya, et al. 2014, ApJ, 795, 152 [2] Y. Okoda et al. 2020, ApJ, 900, 40 [3] Y. Okoda et al. 2021, ApJ, 910, 11 [4] M.M.Vazzano et al. 2021, A&A, 648, A41 [5] Y. Okoda, 2018, ApJL, 864, L25 [6] L.E. Kristensen et al. 2012, A&A 542, A8 [7] Jes K. Jørgensen et al. 2013, ApJL, 779, L22 [8] Y. Yang, 2022, ApJL, 941, L13