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The extremely sharp transition from H^+ to CO in the Horsehead nebula revealed by ALMA

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We present the most detailed image of the molecular gas in the photo-dissociation region (PDR) located at the edge of the Horsehead Nebula. The derived gas physical conditions and distances between the transition zones are consistent with stationary isobaric PDR models. However, dynamical effects can still be relevant in shaping the observed molecular cloud structure.

Massive stars can determine the evolution of molecular clouds by eroding and photo-evaporating their surfaces with strong UV radiation fields (e.g., Kim et al., 2018; Pabst et al., 2019). Thus, probing the fundamental structure of nearby molecular clouds is crucial to understand how massive stars shape their surrounding medium and how fast molecular clouds are destroyed. Although previous efforts have been made in well-known sources such as the Orion Bar PDR (Goicoechea et al., 2016), we must study the molecular gas exposed to more moderate UV radiation fields to obtain constraints representative of the molecular gas exposed to typical Milky Way illumination conditions.

Located at a distance of about 400 pc and viewed nearly edge-on, the illuminated edge of the Horsehead Nebula has been commonly considered a benchmark source for low-UV illuminated PDRs (Abergel et al., 2003). By combining CO $J = 3-2$ and HCO^+ $J = 4-3$ data from the ALMA 12m array, the Atacama Compact Array (ACA) and Total Power (single-dish), we present the highest angular resolution ($\sim$ $0\farcs5$, corresponding to 207 au) and velocity-resolved images of the molecular gas emission in the Horsehead nebula (Hernández-Vera et al., 2023).

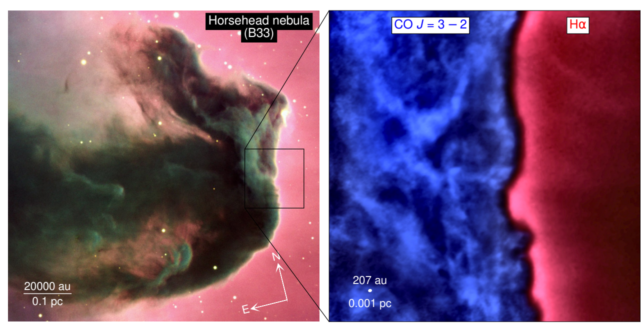

Figure 1. Multiphase view of the different gas phases at the edge of the Horsehead nebula, where the extremely sharp transition from ionized (traced by Hα in red) to molecular gas (traced by CO in blue) is clearly delimited. Figure extracted from Hernández-Vera et al. (2023).

We find that CO and HCO^+ are present at the edge of the cloud, very close to the ionization (H^+/H) and dissociation fronts (H/H_2), suggesting a very thin layer of neutral atomic gas and almost no CO-dark H_2 gas at the molecular cloud edge (see Fig. 1). Notably, the HCO^+ emission map exhibits a bimodal behavior, tracing the cold and dense gas shielded from UV radiation and a more diffuse gas component interacting directly with the UV radiation field. Additionally, using CO as a proxy of the C^+/C/CO front, we conclude that the distances between the fronts can be reproduced by isobaric stationary models, which confirms the presence of a steep density gradient, as suggested by previous observations (Habart et al., 2005). Still, dynamical effects cannot be completely ruled out, and even higher angular observations will be needed to unveil their role.

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