We present results from interferometric image cubes of five deuterated ammonia (NH$_2$D) transitions in the Kleinmann-Low Nebula (Orion KL), a nearly $5	imes50$ parsec star-forming region at the high-powered heart of the Orion Nebula. Our multi-interferometer sample spatially and kinematically resolves NH$_2$D into distinct emitting regions, and features diverse upper excitation levels from $\sim$20 to 150 K above ground, a range sensitive to the source temperature in Orion KL. In these data, we find unambiguous evidence that NH$_2$D is not currently being produced in the gas phase, supporting the hypothesis that the NH$_2$D population may have been preserved on dust grains, desorbing into the gas as the nebula’s temperature increased.

Fig. 1: (top) Moment 0 (integrated spectrum) map of the seemingly uncontaminated 239 GHz NH$_2$D line. Synthesized beam resolution is demarcated in the lower left of each map. The locations of various IR and radio continuum sources (Source I, BN, IRC7, n, SMA1, H$_2$S), some of them young stellar objects, are marked. The fainter 43 and 25 GHz lines (not shown) are likewise uncontaminated and have similar morphologies.

Fig. 2 (left): Moment 0 map of the 25 GHz NH$_3$D line, overlaid with contours of the 239 GHz line. Though the moment 0 morphology is similar, this map shows 216 GHz in heavy contamination from formaldehyde (H$_2$CO). Fortunately, examination of an ortho-H$_2$CO line near 239 GHz, which is much stronger than the H$_2$CO line near 216 GHz, shows that the NH$_2$D peak near IRC7 is clear of contamination above $\sim$2 km/s. Thus, while there is some hope of deconvolving the lines’ contributions in the NE-SW filament, we focus on now on the peak near IRC7.

Fig. 3 (below): Moment 0 map of the 110 GHz NH$_2$D line, which is contaminated by methyl formate (HCOOCH$_3$) in the NE-SW filament and in the southern M1 peak. There is strong evidence to suggest, however, that the IRC7 NH$_2$D peak is relatively clear of contamination below $\sim$6 km/s. Point spectra near IRC7 and at M1 are extracted below; the HCOOCH$_3$ line at M1 is very narrow, and the synthesized beam near IRC7 is likely catching this line, adding an emission peak above $\sim$6 km/s. Together with Fig. 6, this helps us conclude that the HCOOCH$_3$ emission is very well contained.

Fig. 4 (left): Smoothed data for analysis: 239 GHz moment 0 is shown as an example. Our different data have very different synthesized beams, with comparatively low resolution at 110 and 25 GHz. We smoothed the images to a beam that approximates the native low resolutions (lower-right panel). But to regain some spatial information, we carry out our analyses with fewer low-resolution maps, three resolutions in each of the other panels.

Fig. 5 (below): Normalized spectral extractions from synthesized beam-sized regions centered on the IRC7 peak at different frequencies and resolutions, color-coded to match the beam colors from Fig. 4, to investigate the effect of smoothing on extracted line shapes. 239 GHz and 25 GHz line shapes showed no resolution dependence and are not shown.

Fig. 6 (above): Spectral extractions, at the lowest resolution smooth, from near IRC7; raw data (top) and re-interpolated + scaled by eye for comparison (bottom). Except for areas of previously noted contamination, and perhaps slight effects from hyperfine structure at 43 GHz, the line profiles have very similar shapes, suggesting that the $\sim$2 to 6 km/s range is uncontaminated in all lines. The 216 GHz line is scaled up by a factor of 3 to roughly match the 239 GHz line; since their $S_P$ line strengths are the same, this implies an ortho to para abundance ratio of 3, expected from spin statistical weights and suggesting they are optically thin. However, the ratio does seem to vary slightly across the profile.

The 43 GHz line, which has the second-strongest $S_Q$ after the 25 GHz line, might be expected to have more prominent structure or breadth from its three central components (separated by $\sim$0.5 and $\sim$1.5 km/s) if it were optically thick, which we do not observe.

Fig. 7 (left): Rotation diagrams for para NH$_2$D at three resolution smooths (color-coded as before), using integrated brightness temperature from $\sim$2.5 to 6 km/s and the equation below (assumes LTE, optically thin). Rotational temperatures are labeled.

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