

Supplemental Materials for

“Tracking normal fluid flow in He II with unsupervised machine learning”

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Materials and Methods

An Oxford OptistatCF2 cryostat (Static Exchange Gas Continuous Flow Cryostat) provided a reservoir (bath) of liquid He that could be viewed through any of 5 quartz windows. Quartz was chosen for its transparency to 640-1100 nm light and to neutrons.

A 10 mm × 10 mm × 35mm quartz cuvette by FireflySci with same transparency was immersed at the bottom of the cryostat. The cuvette was connected to a 3.5-liter tank filled with a ³He / ⁴He gas mixture. Two heater coils made of LakeShore Nichrome heater wire WNC-32 were wrapped around a 1.6 mm diameter G-10 fiber glass rod. Power to the heater coil was supplied by a DC power source. The G-10 rod was fed through the cuvette.

The experiment required a pulsed laser and two continuous wave lasers. An EKSPLA brand laser produced the pulsed 905 nm laser light. Two custom-made fiber lasers by AdValue Photonics produced the 1073 and 1099 nm continuous wave light. The light from the three lasers was focused to a cross-section 1 mm wide (along the camera axis) × 10 mm tall that illuminated the 20 mm length of the cryostat with the largest dimension parallel to the axis of the neutron beam.

We used a Princeton Instruments PI-MAX3 1024i ICCD camera to record images with resolution of 256 × 256 pixels mapped onto a field of view measuring 10 mm × 10 mm. The field of view was between two heater coils. The camera used a P46 phosphor image intensifier. The lens of the camera was focused onto the plane illuminated by the lasers. The axis of the camera was perpendicular to this plane and to the neutron and laser beams. Data were exported using the vendor’s LightField software.

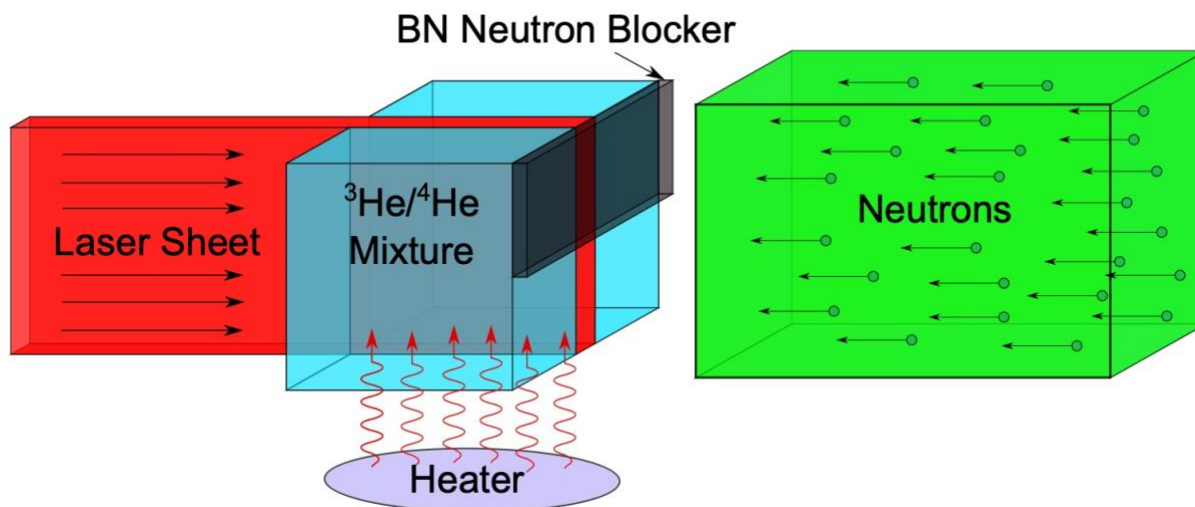


Fig. S1 A laser sheet (red) ~10 mm high by 1mm thick illuminated a quartz cell of liquid ^3He / ^4He mixture (cyan) from the left. A collimated neutron beam (green) ~12mm high by 8mm thick consisting of wavelengths ranging from 2.8 Å to 5.8 Å irradiate the liquid from the right. The focal plane of the camera lies within the laser sheet, and the field of view was adjusted to be 1cm by 1cm. A neutron blocker (gray) made of Boron Nitride (BN) shadows the upper half of the liquid mixture so that He_2^* excimers are only created in lower half of the cell. He_2^* excimers. A heater (purple) installed below the field view is the source of heat that causes flow of normal component upwards. The excimers track the motion of the normal component flow and so drift upwards. Only excimers illuminated by the laser can fluoresce.

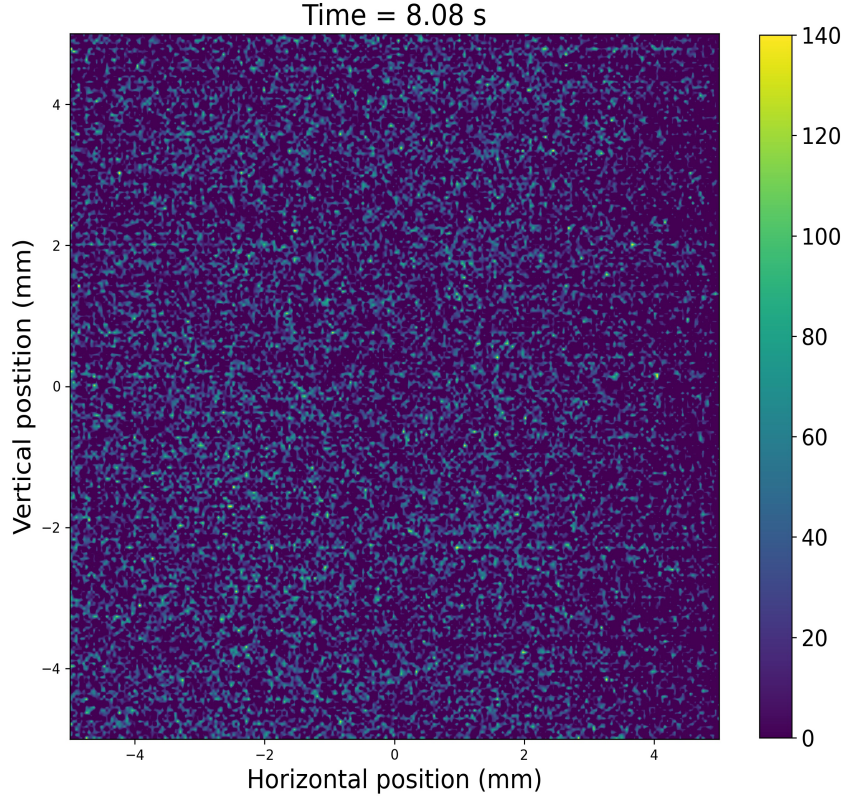


Fig. S2 A movie of the fluorescence recorded by the camera's field of view as a function of time. The background noise has been subtracted. The neutron shutter was opened at 5 s, the laser shutter opened at $t_l = 10$ s, and the bottom heater energized at $t_h = 12$ s. All excimers are first seen in the region where the vertical position is < 0 because no neutrons enter the vertical region > 0 . After the bottom heater was energized, the thermal gradient caused the normal component of He II to move upwards. The vertical shadow near the center of field of view is the shadow of our sample rod that holds the heaters. The color bar scale represents the net signal (above background) of a pixel recorded by the camera.

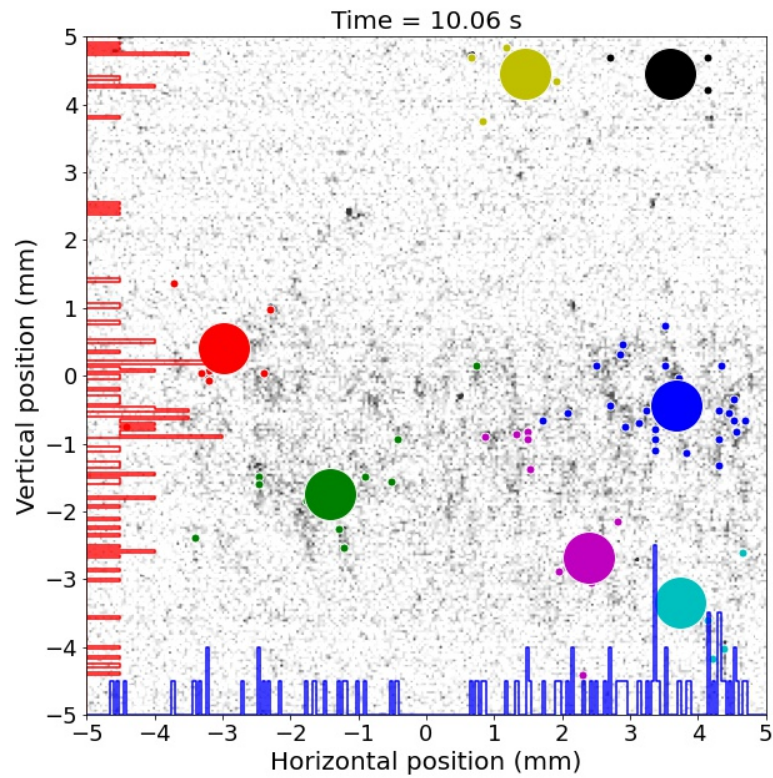


Fig. S3 A movie of the clusters vs. time showing upward motion of the clusters for the condition of the bottom heater being energized at 7.5 mW. The large circles represent the centroids of the clusters, and the small circles are the fluorescence events recorded by the camera and identified as comprising a cluster by the machine learning algorithm. A typical cluster contains 20 to 30 events.

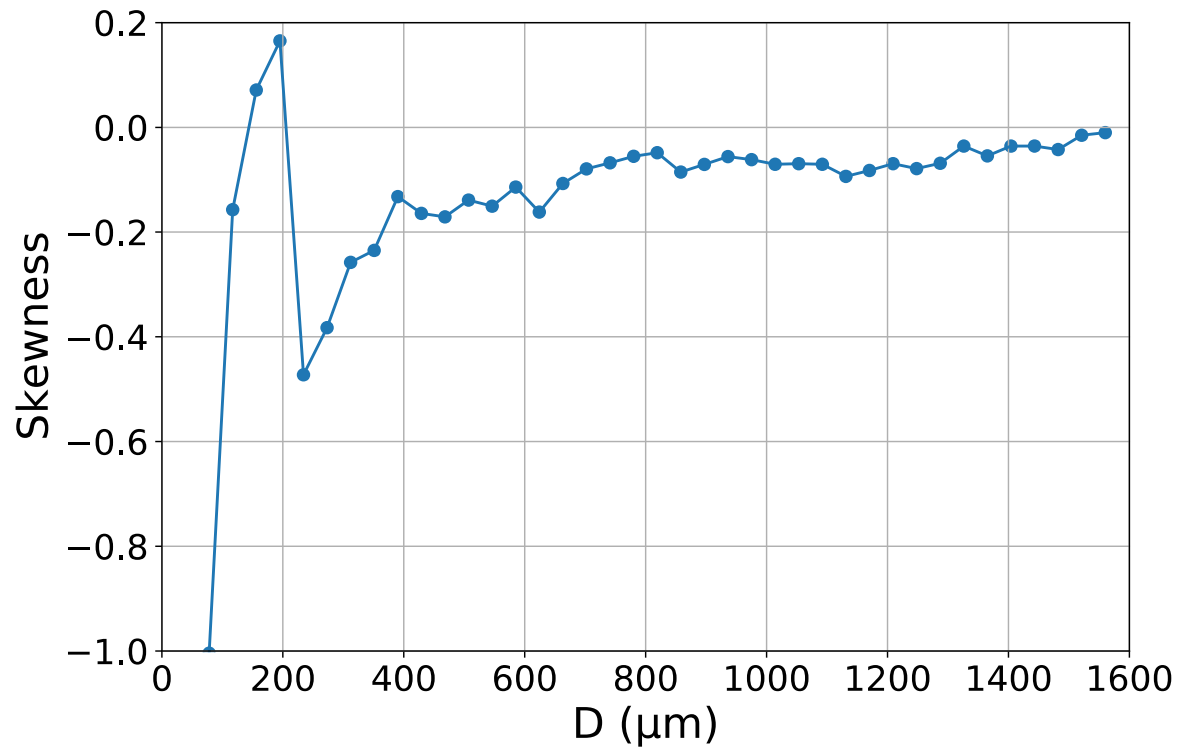


Fig. S4 The influence of choice of D (separation between centroids appearing in sequential frames) on the skewness of distribution of the vertical displacements of fluorescence. Skewness is a measure of the asymmetry of the distribution. A negative skewness means more excimers move upwards than downwards. For a given heater power, the velocity of the flow will have an upper limit, v_u , so for frames taken $dt = 1$ ms apart values of $D > v_u dt$ there can be no correlation between clusters in sequential frames. Thus, skewness tends to zero as D becomes large. We chose $D = 234 \mu\text{m}$, and the skewness is consistent with our observation that the fluorescence moves upwards.

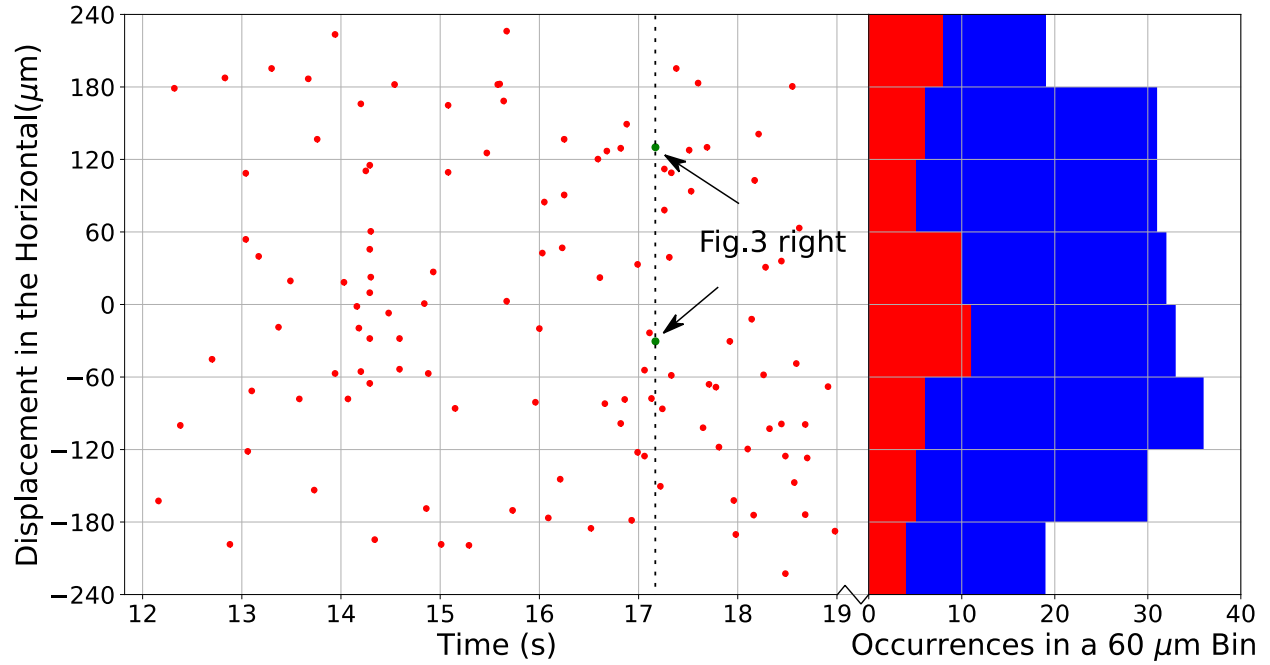


Fig. S5 (left) Horizontal displacements (vertical in Fig. 4) of clusters (within one period between consecutive exposures = $\frac{1}{55.6}$ s) vs. time for conditions with the bottom heater power = 7.5 mW. **(right)** Histograms of the horizontal displacements for times of (red) 12 to 15 s and (blue) 12 to 19 s. The red histogram shows skewness near 0, i.e., no net flow along the horizontal direction. The two green dots (see arrows) at 17.17s correspond to the horizontal displacements shown in Fig. 3 (right).

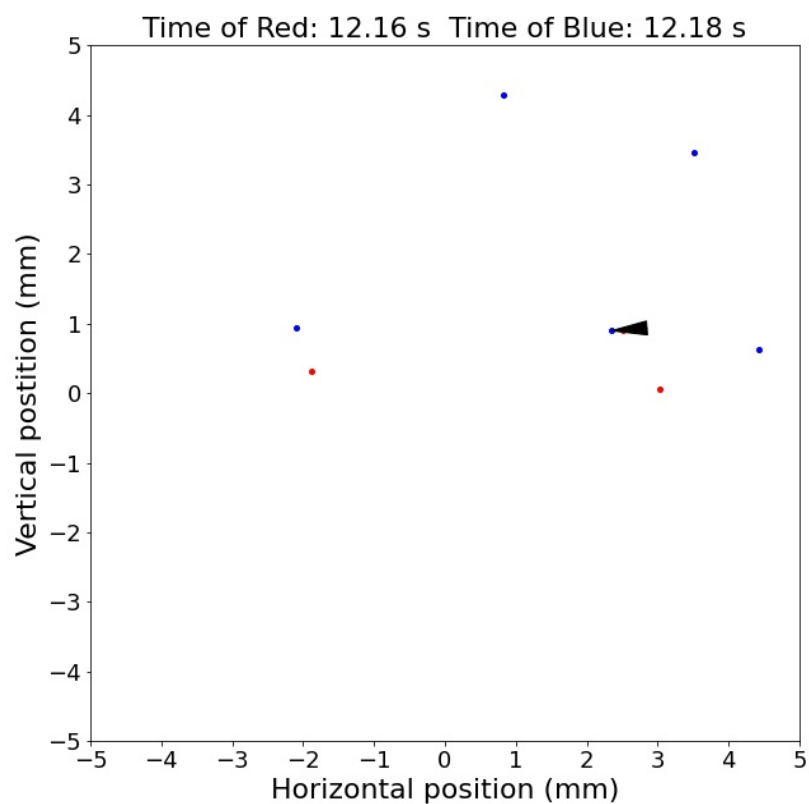


Fig. S6 Motion of the excimer clusters identified with machine learning. The red dots represent the cluster centroids of the first frame of an image pair, and the blue dots represent centroids in the second frame. If the distance between a red dot and a blue dot is $\leq D$, the pair are identified as the same centroid in the two frames.