

Supplementary Materials for

“Observing flow of He II with unsupervised machine learning”

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The supplementary material contains figures and movies that are a crucial component of our manuscript. We recommend using Adobe Acrobat to view this document or the movies may not play correctly. The movies can be played from this document and are also available in mp4 format.

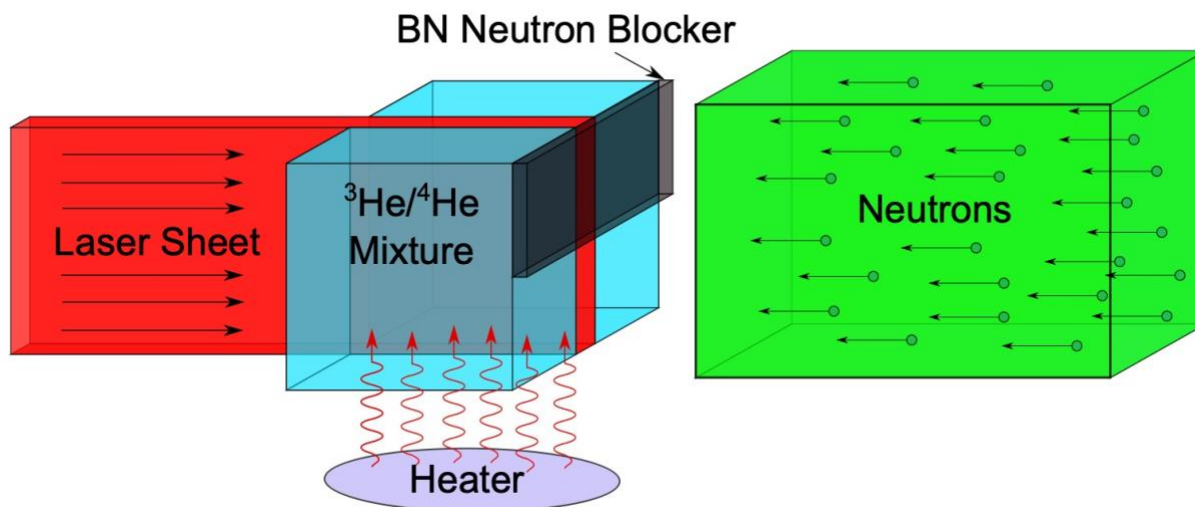


Fig. S1 A laser sheet (red) ~10 mm high by 1mm thick illuminated a quartz cell of liquid ^3He / ^4He mixture (cyan) from the left. A collimated neutron beam (green) ~12mm high by 8mm thick consisting of wavelengths ranging from 2.8 Å to 5.8 Å irradiate the liquid from the right. The focal plane of the 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. 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.

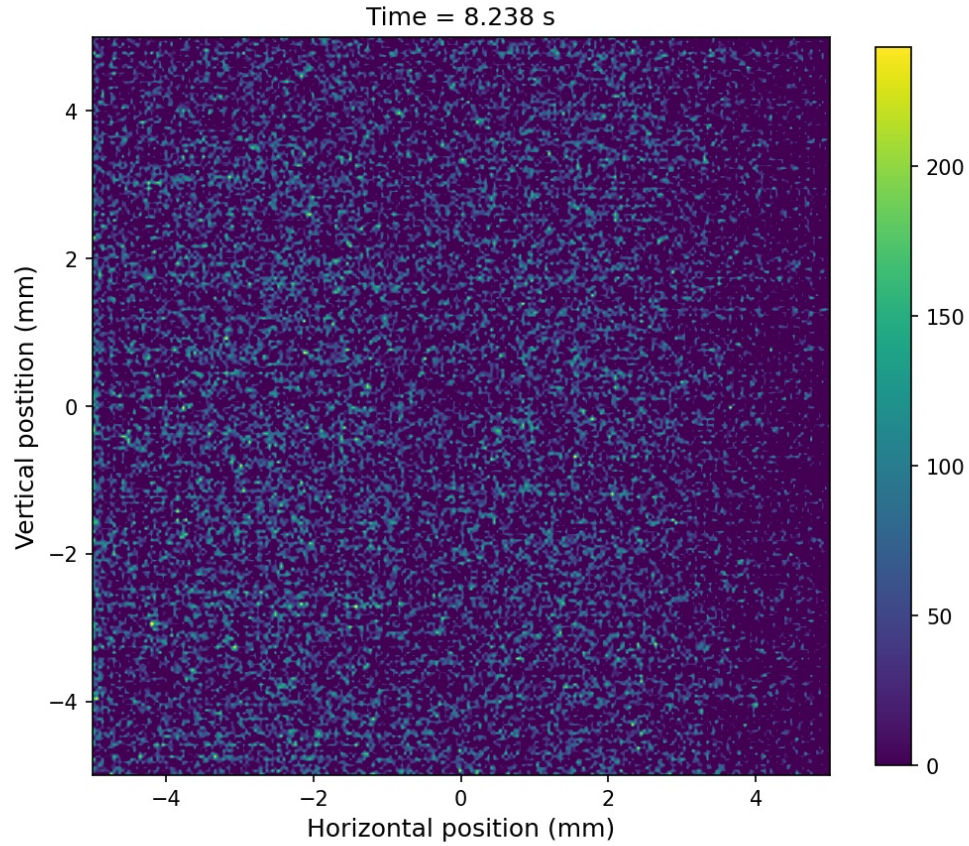


Fig. S2 A movie of the fluorescence recorded by the camera's field of view as a function of time. The background noise has been subtracted. The neutron shutter was opened at 5 s, the laser shutter opened at $t_l = 10$ s, and the bottom heater energized at $t_h = 12$ s. All excimers are first seen in 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.

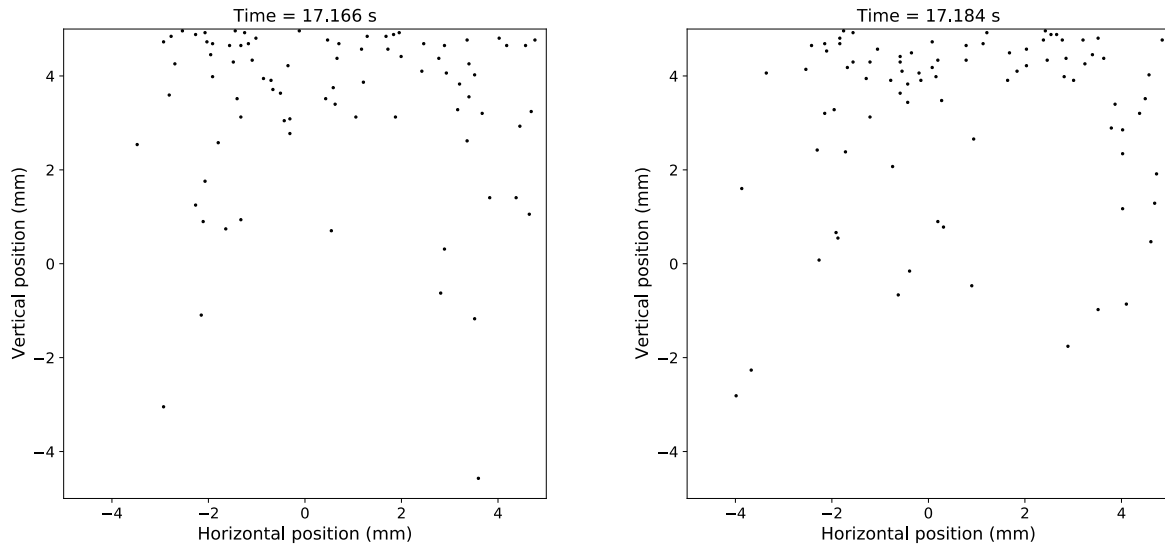


Fig. S3 Images of events identified in two sequential frames. Each frame contains ~ 80 events (or records of 80 photons) over the 1 cm^2 view. These events all have intensity greater than 4-sigma above the background. Given that the trajectory of an emitted photon is random, an excimer that produce a photon captured in Fig. S3 (left) has only a 1 in 42 chance to produce a photon in the second frame, Fig. S3 (right).

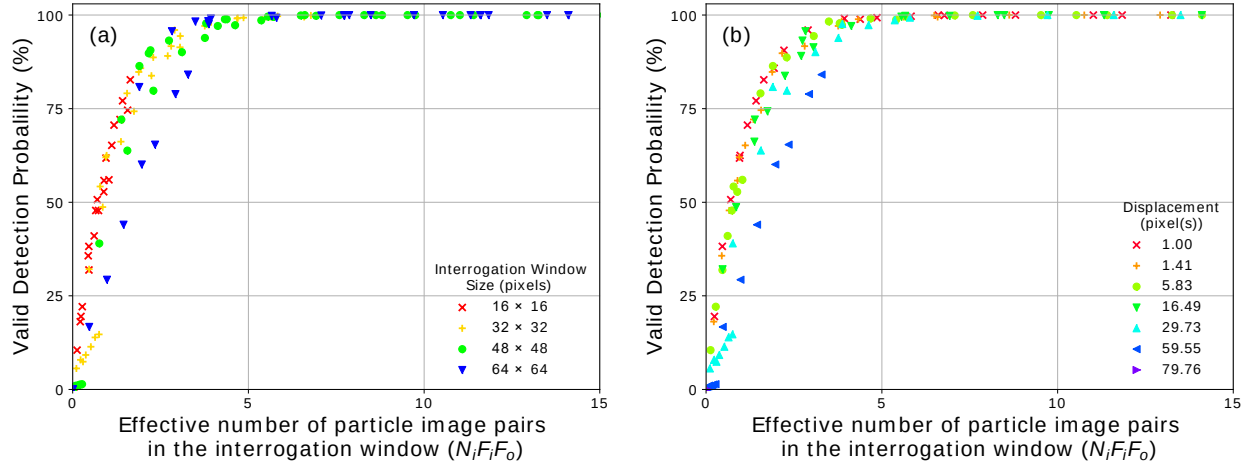


Fig. S4 A simple simulation results of Valid Detection Probability (VDP) vs. the effective number of particle-image-pairs in the interrogation window using a cross-correlation function. Fig. S4 (a) shows the effect of interrogation window size on the VDP, and Fig. S4 (b) shows the VDP with different imposed displacements of the tracer particles. The reliability of cross-correlation scales with the “Valid Detection Probability” (VDP). Even with the best choice of interrogation window size and the smallest tracer displacement, the effective number of particles image pairs $N_i f_i f_o$ should be > 3 . For our experiment, if we regard individual excimer events, the effective number of image pairs is only $N_i f_i f_o \sim \mathcal{O}(10^{-2})$ per grid element. Thus, we cannot apply PIV and cross-correlation to individual excimers. Instead, we are motivated to apply PTV techniques to track flow represented by motion of excimer clusters.

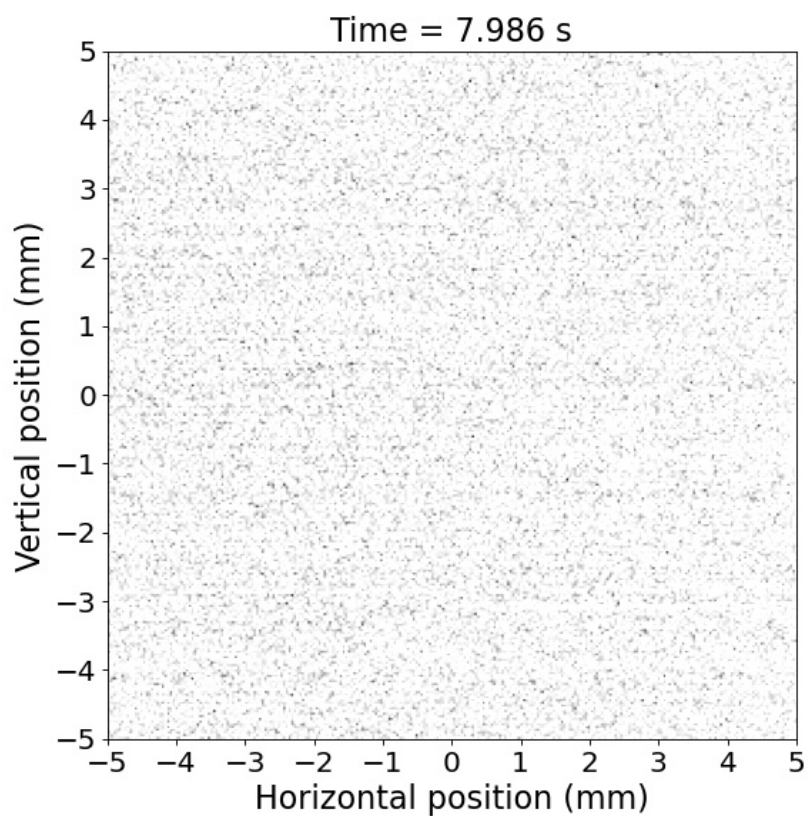


Fig. S5 A movie of the clusters vs. time showing upward motion of the clusters for the condition of the bottom heater being energized at 7.32 mW. The large circles represent the centroids of the clusters, and the small circles are the fluorescence events recorded by the camera and identified as comprising a cluster by the machine learning algorithm. A typical cluster contains $\sim \mathcal{O}(10^2)$ events.

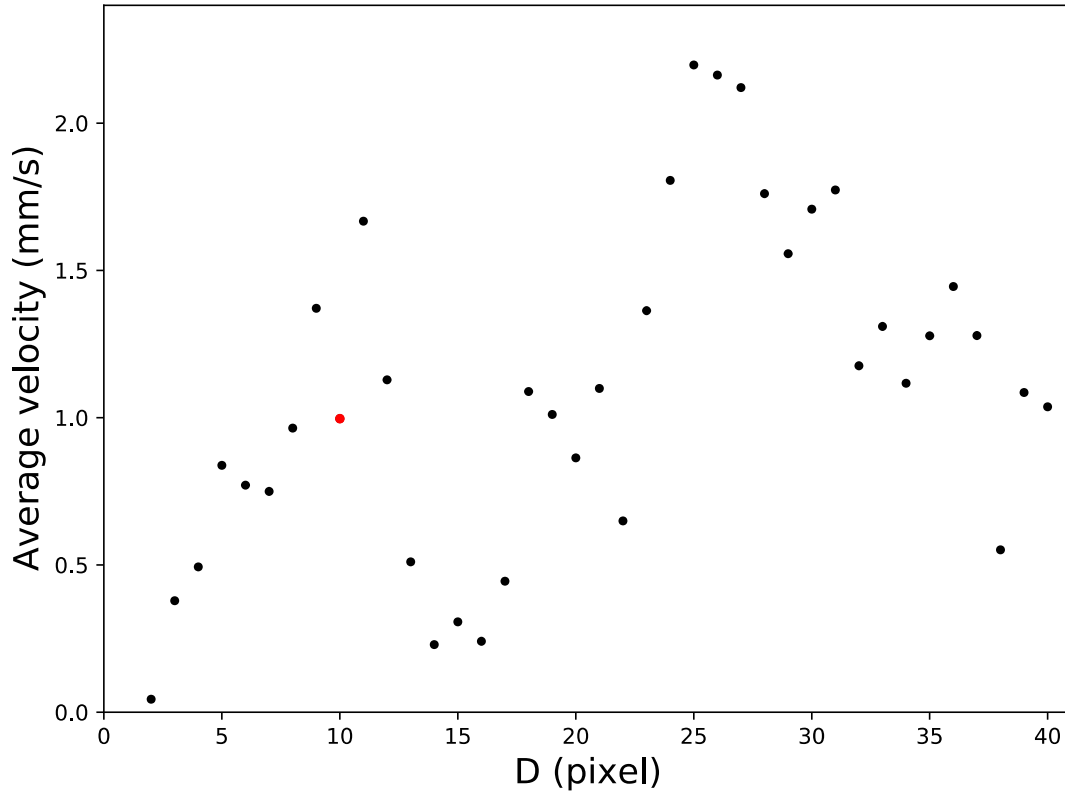


Fig. S6 The influence of choice of D on the correlator metric. The vertical-axis shows the average velocity of all the image pairs identified with our metric when choosing D as a search radius limit. With 7.32 mW heater power applied, we can directly measure the average velocity to be 0.985 mm/s from the motion of the excimer fluorescence (shown in Fig. 2). We choose $D = 10$ pixels ($390 \mu\text{m}$) to achieve a similar average velocity of 0.996 mm/s when integrated over the same field-of-view and same range of time used to obtain the mean velocity from the motion of the fluorescence. The value of D is proportional to the mean velocity. Using $D = 10$ pixels for 7.32 mW data and the slope of the blue line in Fig. 3, we obtain $D = 377 \mu\text{m}$ for 3.69 mW, $D = 418 \mu\text{m}$ for 14.69 mW, $D = 445 \mu\text{m}$ for 22 mW and $D = 472 \mu\text{m}$ for 29.41 mW data.

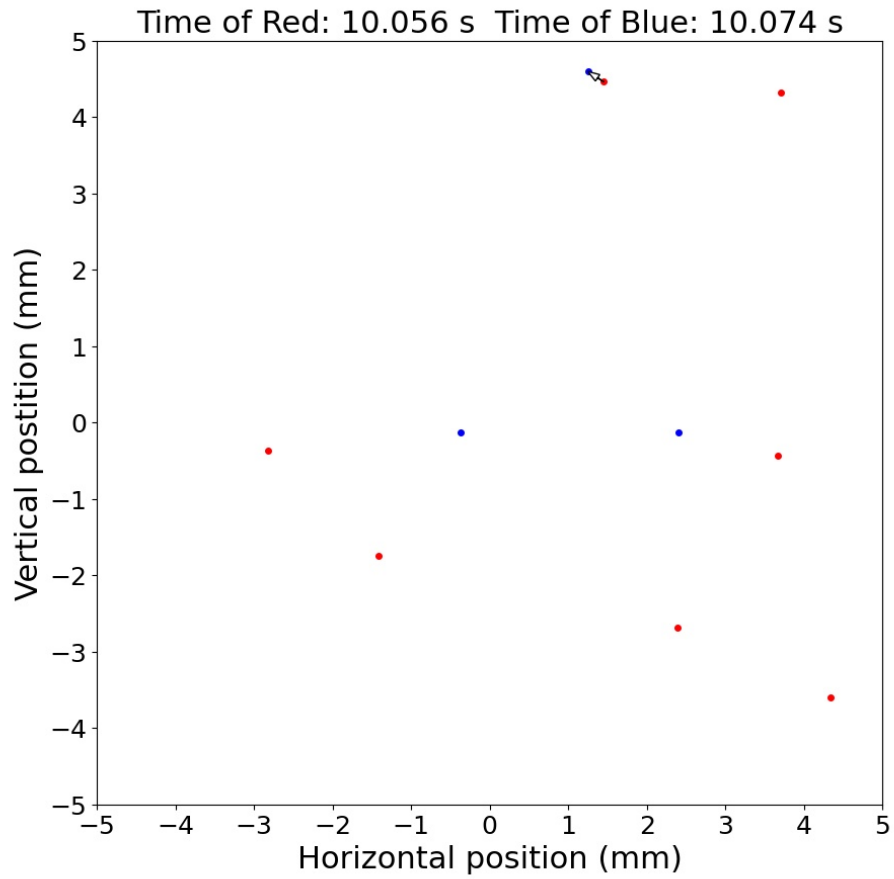


Fig. S7 Motion of the excimer clusters identified with machine learning. The red dots represent the cluster centroids of the first frame of an image pair, and the blue dots represent centroids in the second frame. If the distance between a red dot and a blue dot is $\leq D$, the pair are identified as the same centroid in the two frames.