

File Name: Supplementary Movie 1

Description: **Movie 1. Continuous motion of Cdc48 revealed by 3DVA.** Simple mode output of cryoSPARC 3DVA from the consensus reconstruction revealed motion in subunits F (blue) and E (cyan). Consensus model fitted in map for clarity.

File Name: Supplementary Movie 2

Description: **Movie 2. Output of 3DVA split into multiple clusters along the principal component.** Continuous motion was parsed into nine discrete clusters, denoted as models 1-9.

File Name: Supplementary Movie 3

Description: **Movie 3. Sequence of Cdc48 subunit motion during substrate translocation.** Movie generated by morphing between models 1-9. Helix axis shown as purple rod.

File Name: Supplementary Movie 4

Description: **Movie 4. Trajectory of pore loop movement during substrate translocation.** Overlay of pore loops from models 1-9. Note how the movements in D1 (top half) and D2 (bottom half) are out of phase with each other.