

Extremely Noisy 4-D STEM Strain Mapping Using CC-ST-AE



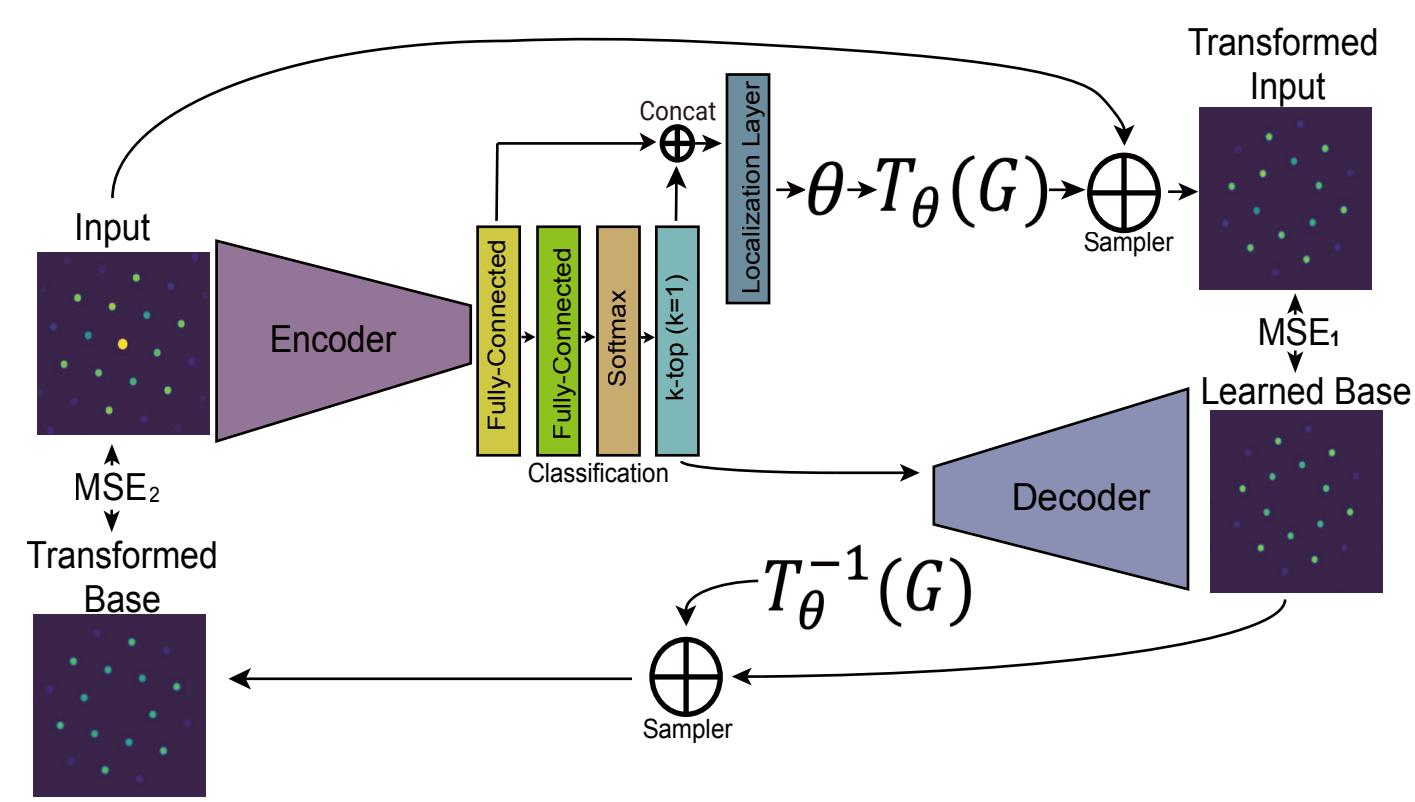
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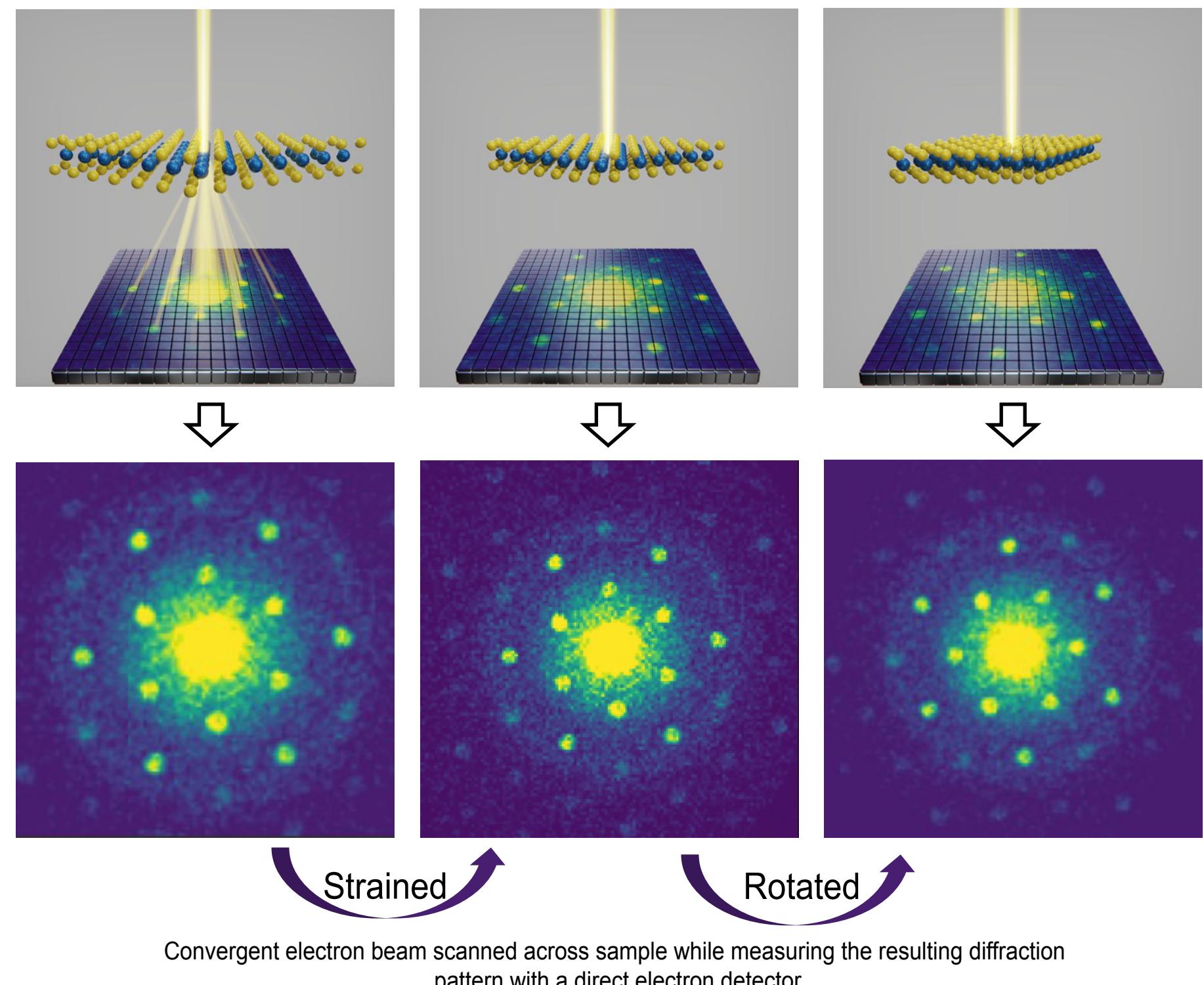


Cycle Consistent Spatial Transforming Autoencoder (CC-ST-AE)



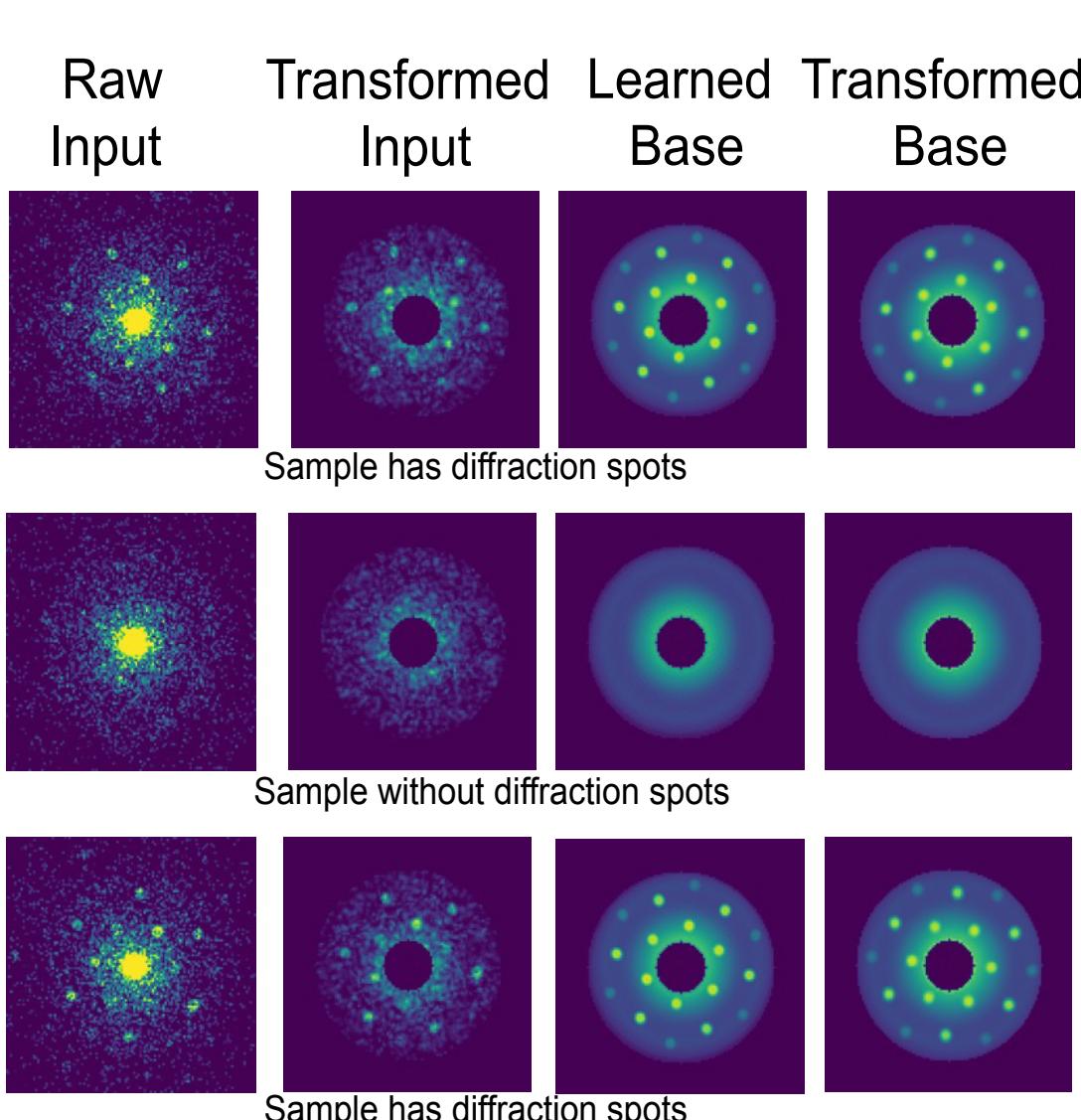
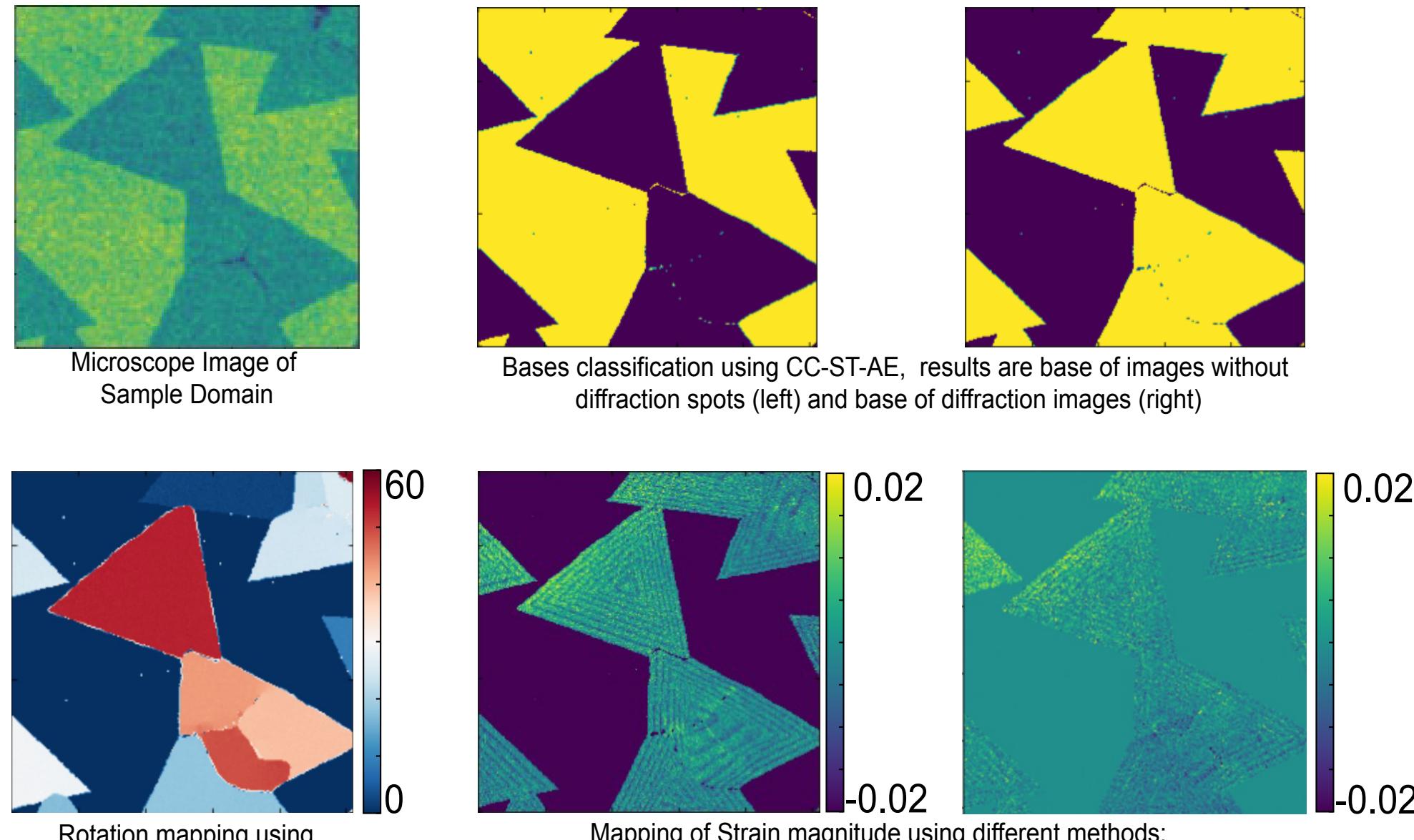
Transformation Name	Affine Matrix	Example		
Identity	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$		Shear	$\begin{bmatrix} 1 & C_x=0.5 & 0 \\ C_y=2 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$
Scale	$\begin{bmatrix} C_x=2 & 0 & 0 \\ 0 & C_y=1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$		Rotate	$\begin{bmatrix} \cos(\theta) & -\sin(\theta) & 0 \\ \sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix}$

4-Dimensional Scanning Transmission Electron Microscopy



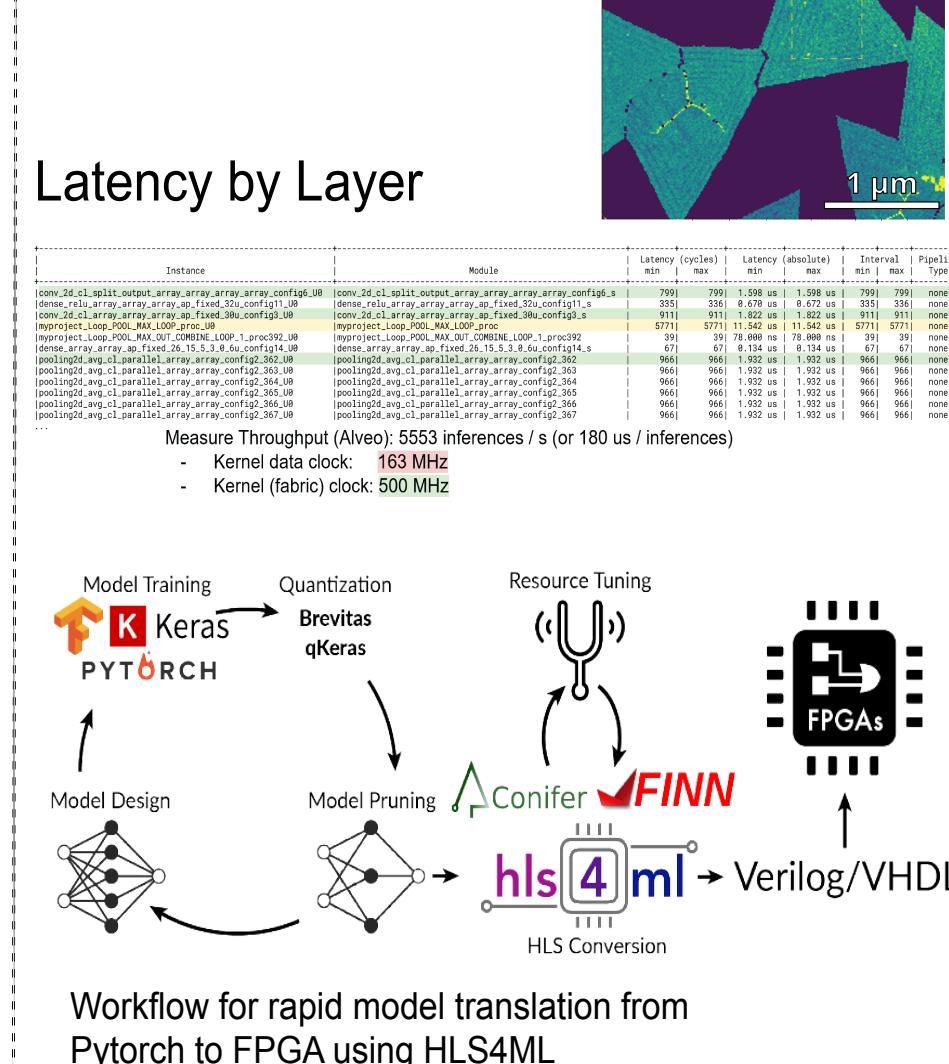
Convergent electron beam scanned across sample while measuring the resulting diffraction pattern with a direct electron detector

Results on WS₂WSe₂ 4-D STEM

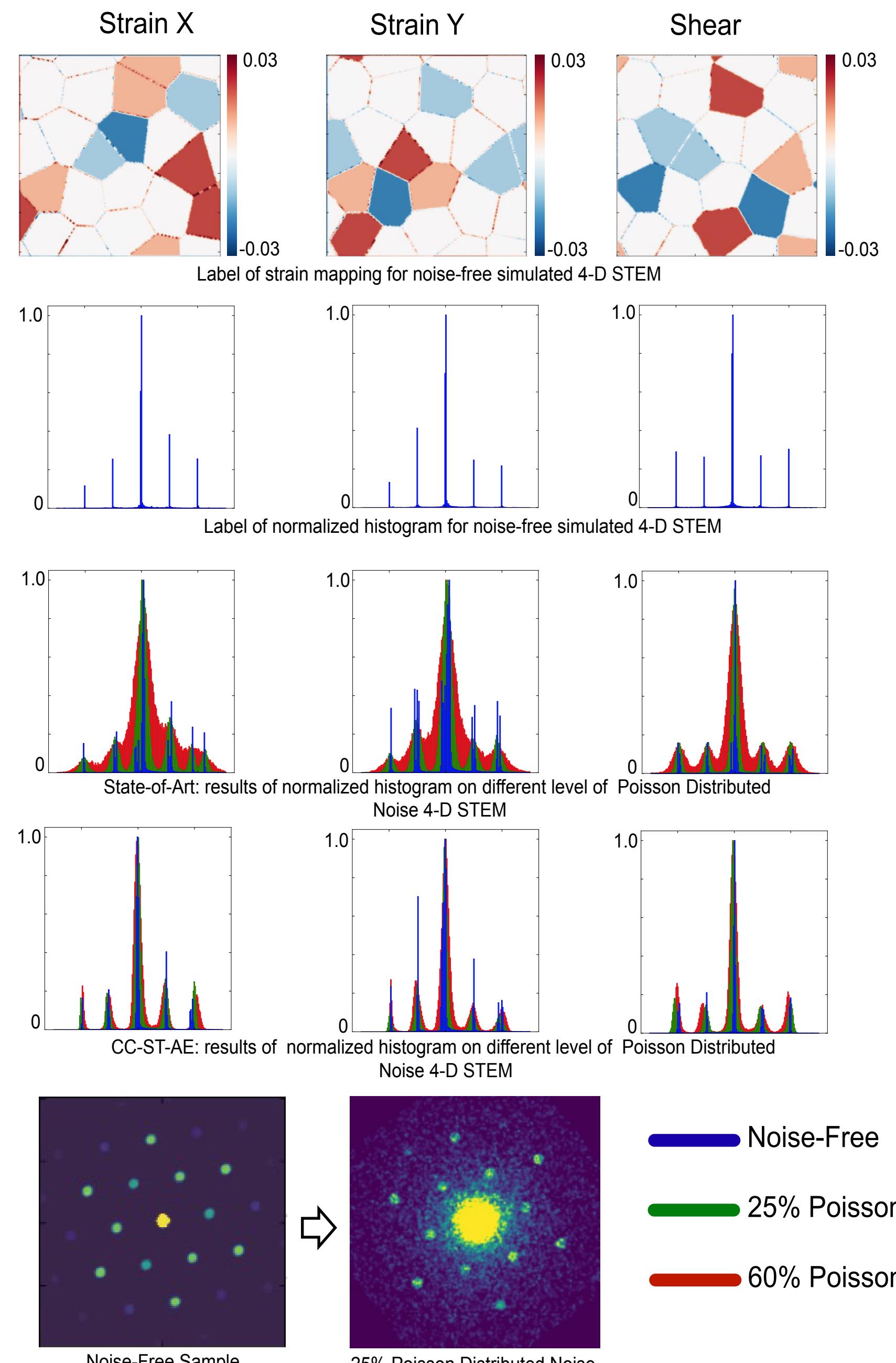


Visualization of random samples' results using CC-ST-AE

Future Work



Results on Simulated 4-D STEM



Poisson Noise Intensity (% of total Intensity)	Strain X MAE compared with Label ($\times 10^{-3}$)		Strain Y MAE compared with Label ($\times 10^{-3}$)		Shear MAE compared with Label ($\times 10^{-3}$)	
	State-of-Art	CC-ST-AE	State-of-Art	CC-ST-AE	State-of-Art	CC-ST-AE
0	2.0	1.5	2.0	1.8	0.9	0.7
5%	2.3	1.5	2.4	1.6	1.2	1.2
10%	2.3	1.5	2.4	1.6	1.3	1.0
15%	2.3	1.6	2.4	1.7	1.3	0.9
20%	2.4	1.7	2.5	1.7	1.4	1.0
25%	2.5	1.6	2.5	1.9	1.4	1.1
30%	2.5	1.6	2.6	1.7	1.4	1.2
35%	2.6	1.8	2.7	1.8	1.5	1.1
40%	2.7	1.7	2.7	1.8	1.6	1.4
45%	2.8	1.8	2.9	2.0	1.7	1.2
50%	3.2	1.8	3.2L	1.9	1.9	1.5
60%	3.9	2.1	4.0	2.4	2.5	1.6
70%	5.4	2.2	5.5	2.6	3.6	2.1

Table of Mean Absolute Error (MAE) for state-of-art (py4DSTEM) and CC-ST-AE results compared with label, evaluated on different level of Poisson Distributed noisy simulated 4-D STEM

References

- [1] Colin Ophus. Four-dimensional scanning transmission electron microscopy (4d-stem): From scanning nanodiffraction to ptychography and beyond. *Microscopy and Microanalysis*, 25(3):563–582, 2019.
- [2] Yimo Han, Kayla Nguyen, Michael Cao, Paul Cueva, Saien Xie, Mark W Tate, Prafull Purohit, Sol M Gruner, Jiwoong Park, and David A Muller. Strain mapping of two-dimensional heterostructures with subpicometer precision. *Nano letters*, 18(6):3746–3751, 2018.
- [3] Colin Ophus, Steven E Zeltmann, Alexandra Bruefach, Alexander Rakowski, Benjamin H Savitzky, Andrew M Minor, and Mary C Scott. Automated crystal orientation mapping in py4dstem using sparse correlation matching. *Microscopy and microanalysis*, 28(2):390–403, 2022.

