Focal Plane Wavefront Correction for Dark Hole Creation With a Neural Network on PICTURE-D

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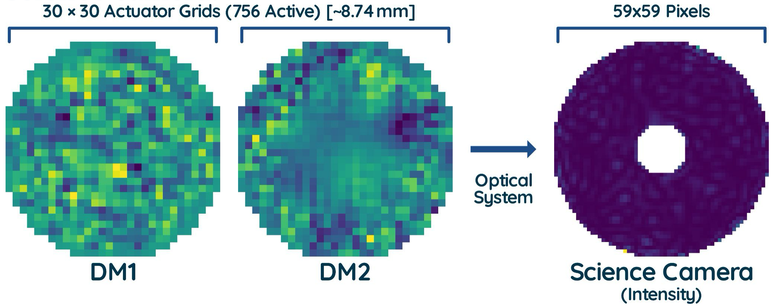
Background

- PICTURE-D is a balloon mission to detect exoplanets by direct imaging on science camera.
- Want to create a region on science camera, known as a Dark Hole (DH), with maximal contrast ratio.
- Use two Deformable Mirrors (DMs) to create DH.

Example set of DM commands that produce a DH in the science camera.



EFC + SVD

- Electric Field Conjugation (EFC) used to zero-out electric field (EF) to create DH (many iterations).
- DM and EF relationship: $E = MD$. $E \equiv$ EF, $D \equiv$ DM commands, $M \equiv$ EF from poking DM actuators.
- M^+ found via Singular Value Decomposition (SVD). Enables solving EFC equation $D = M^+E$.
- SVD does factorization $M = U\Sigma V^T$.
- U and V are orthogonal basis sets (EF + DM modes).

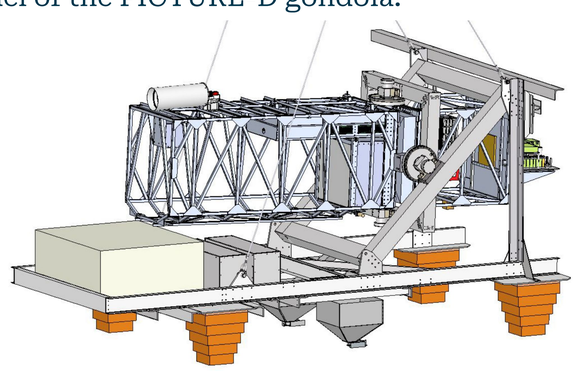
Method

- Run EFC in simulation on rows with random surface errors using a simplified optical system. The EF is perfectly known in the simulations.
- Data uses a single wavelength – not broadband.
- Save the initial EF and the DM commands associated with the final DH. ~108k rows in total.

Potential inputs and outputs that a neural network can be trained on.

Direct Values		
Name	**Description**	**Shape**
EF Input	Real(EF) and Imaginary(EF) each on their own channel.	2×59×59
DM Output	756 active actuators of each DM stacked together.	1,512
SVD Mode Basis		
Name	**Description**	**Shape**
SVD Input	500 $_U$ mode coefficients for each component of EF.	1,000
SVD Output	500 $_V$ mode coefficients for each DM.	1,000

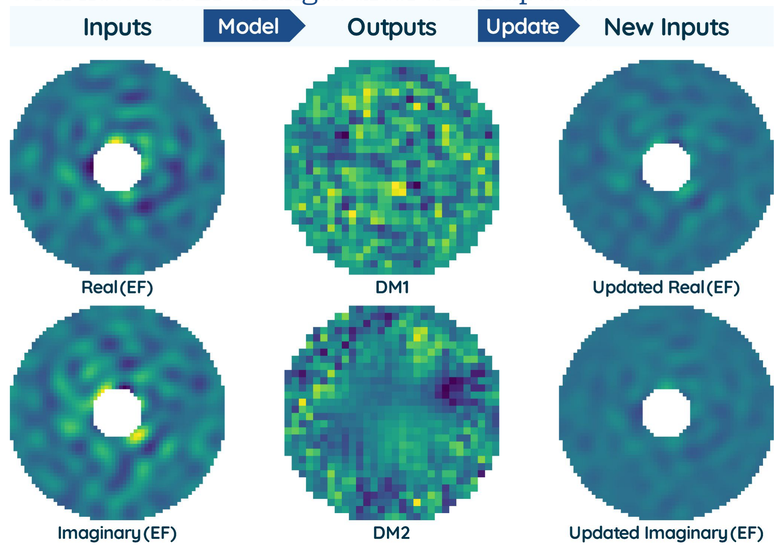
A model of the PICTURE-D gondola.



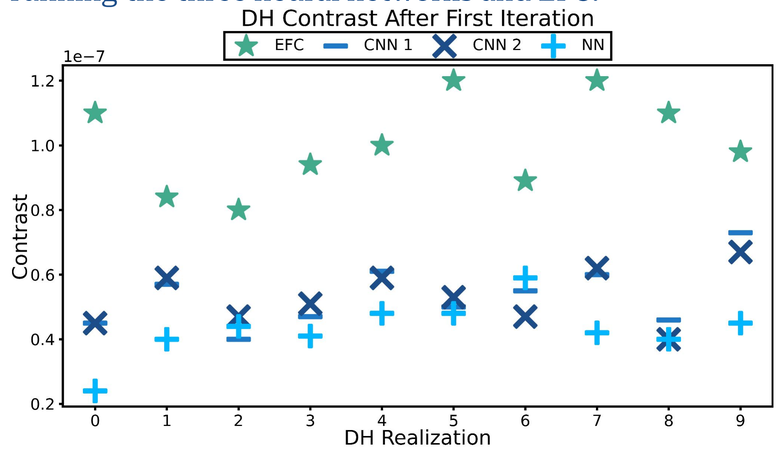
Summary of the three neural network models that are created and compared to EFC.

Neural Network Models		
Name	**Trainable Parameters**	**Input → Output** ***Shape*** ***Shape***
CNN 1	140,245,992	EF Input → DM Output *2×59×59* *1,1512*
CNN 2	138,148,328	EF Input → SVD Output *2×59×59* *1,000*
NN	12,501,992	SVD Input → SVD Output *1,000* *1,000*

Example inputs and outputs to a neural network, along with how the EF changes after a DM update.



Comparison of DH contrasts after one iteration of running the three neural networks and EFC.



Conclusion + Next Steps

- A neural network can achieve a higher contrast after one iteration when compared with EFC.
- The next steps will be to use broadband data along with EF estimates.

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