Emulating X-Ray Spectroscopy Utilizing Machine Learning

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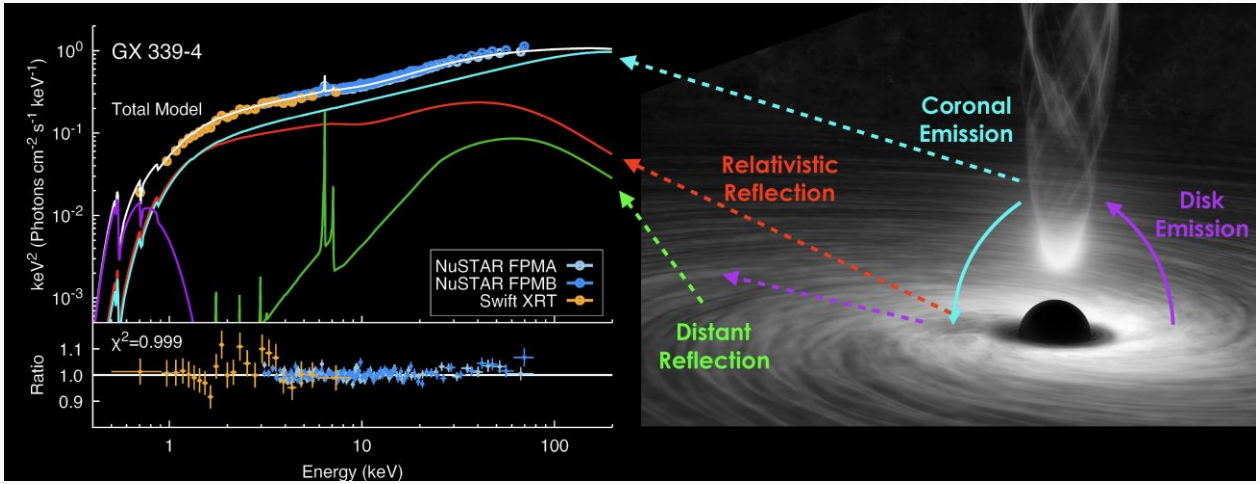
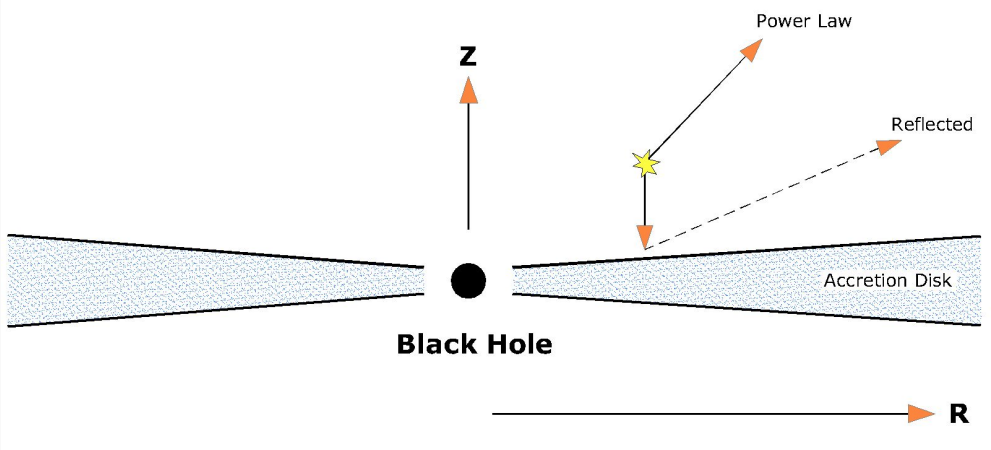
Mentors: Dr. Joanna Piotrowska, Professor Fiona Harrison

Black Hole X-Ray Spectra



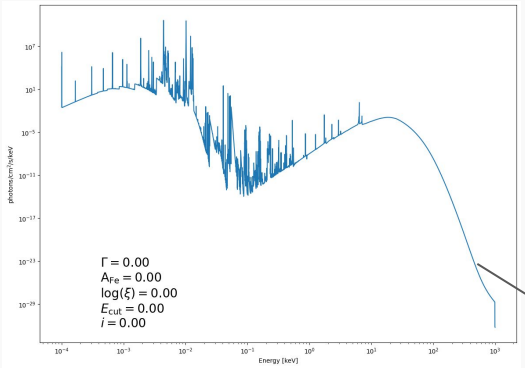
- Various components of the black hole system contribute to the X-Ray spectra shown
- Features on the X-Ray spectra correspond to certain characteristics of the black hole system

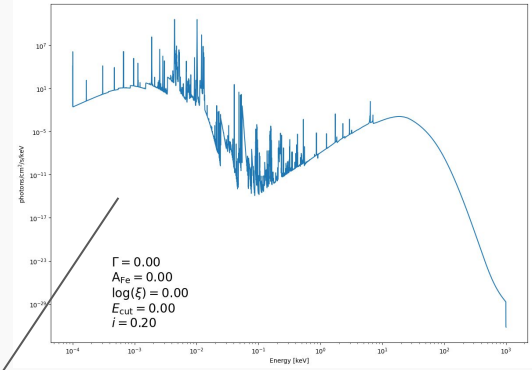
XILLVER: X-ray reflection model

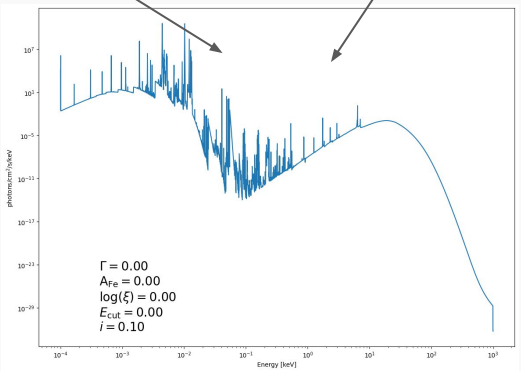


- Astrophysicists utilize X-ray reflection models to generate tables of X-ray spectra used to fit observed X-ray spectra

Linear Interpolation



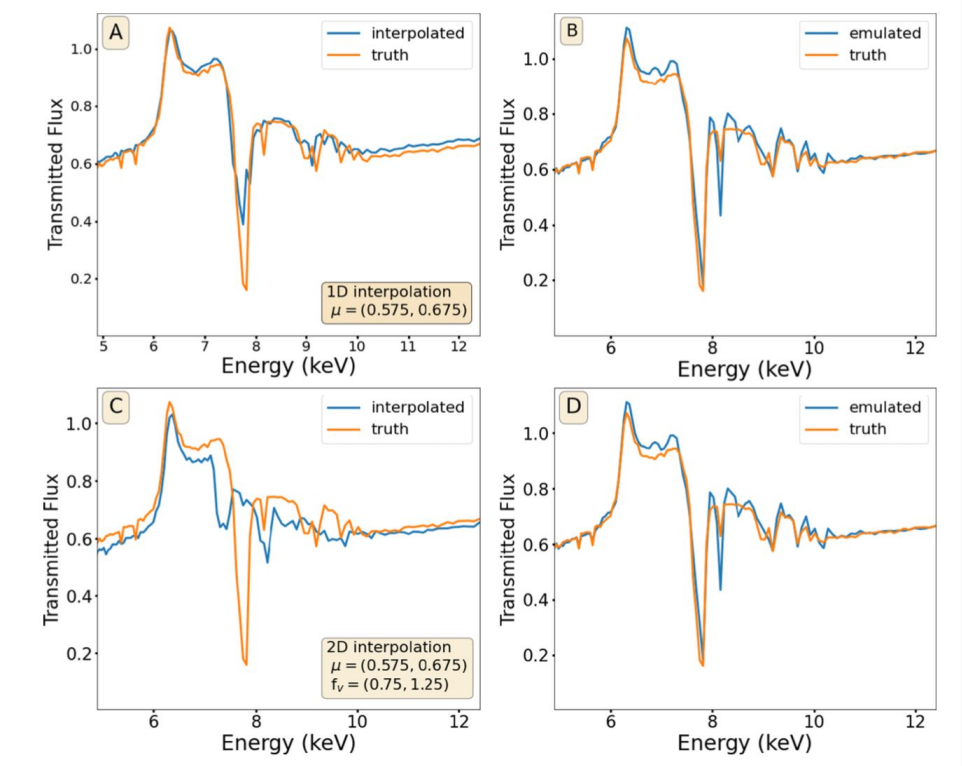




- Linear interpolation is used to fit the observed X-Ray spectra; otherwise we will not get a matching X-Ray spectra.

- Here, interpolation is performed solely on the inclination parameter, but in practice can also be done along the iron absorption, ionization, and other parameters

Matzeu et al, X-Ray Accretion Disk-wind Emulator, 2022

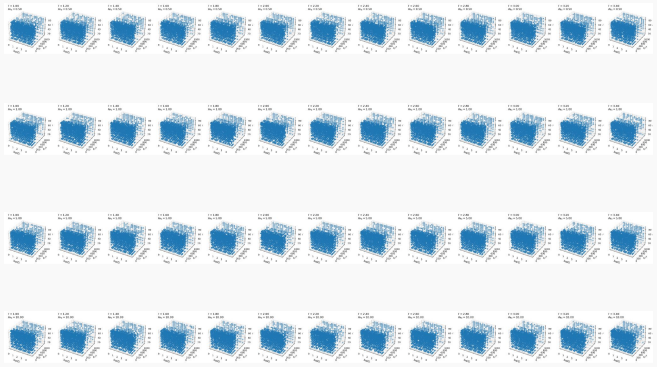


- Comparison between linear interpolation and interpolation performed by a neural network

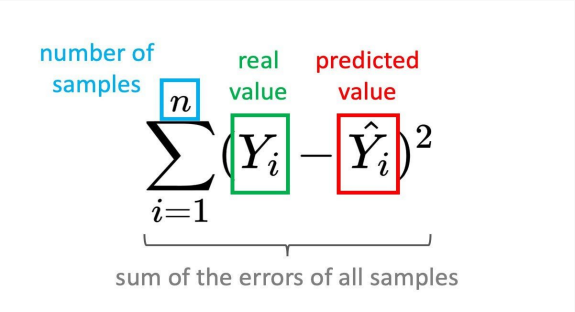
Advantages of X-Ray Emulation with Machine Learning

- Astrophysicists, who use large tables of computed spectra, rely on linear interpolation to fit their observed spectra and approximate their system's parameters.

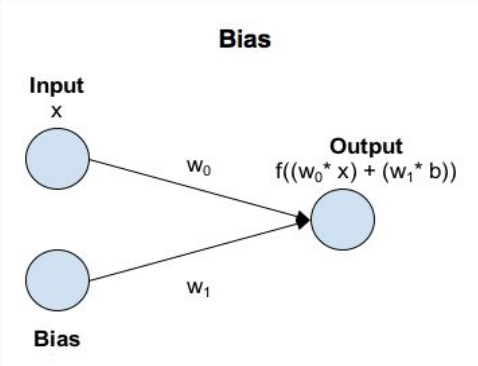
- Larger tables of higher resolution X-Ray spectra may require even more storage/memory



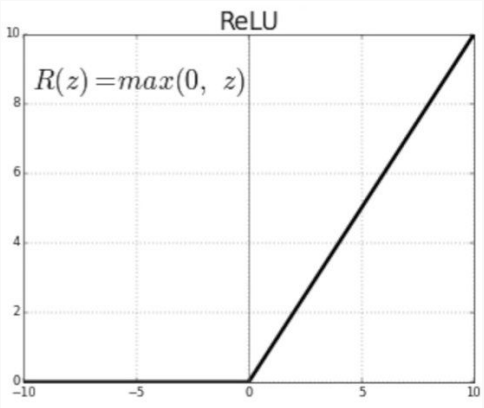
Neural Network Background



- Mean square error Loss function

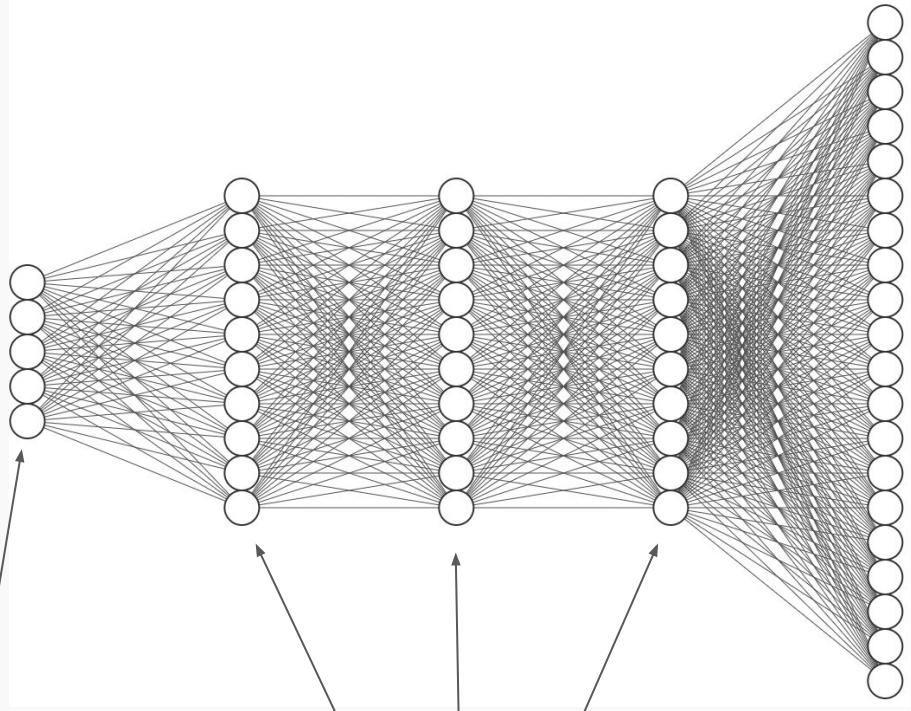


- Weights & Biases

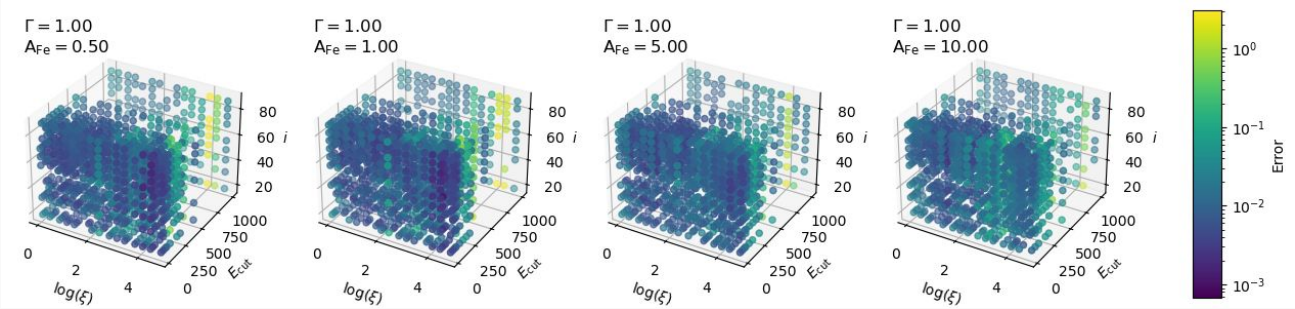


- Activation function that allows neural network to capture nonlinearity

Matzeu et al Model Architecture

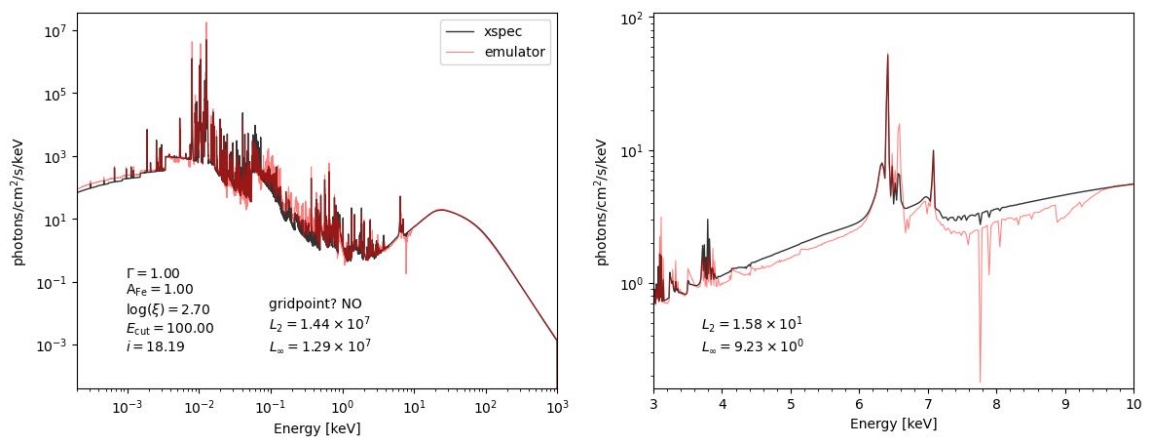


Matzeu et al Emulator's Errors



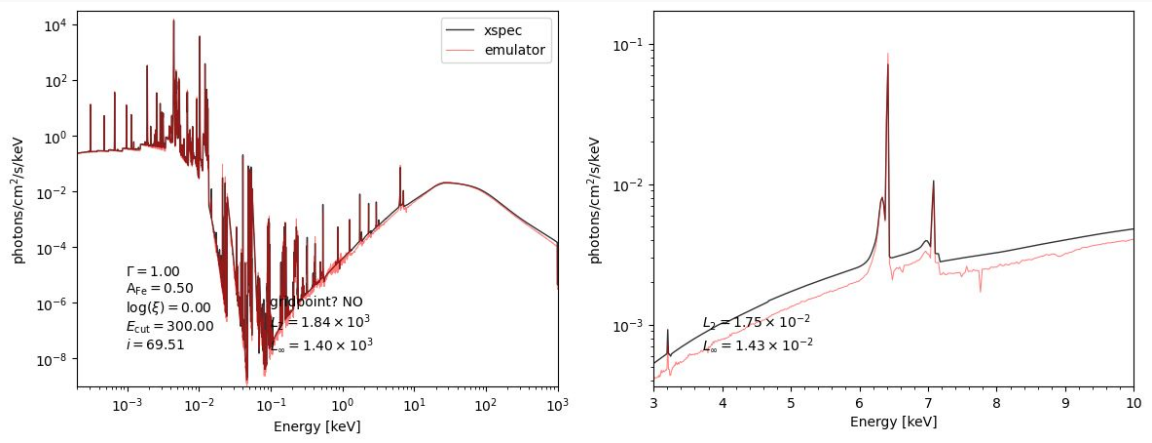
- Visualization of Matzeu Emulator's errors in the parameter space
- Mainly occur in regions of low gamma, high epsilon, and high energy cutoff

Matzeu et al Emulator's Predictions



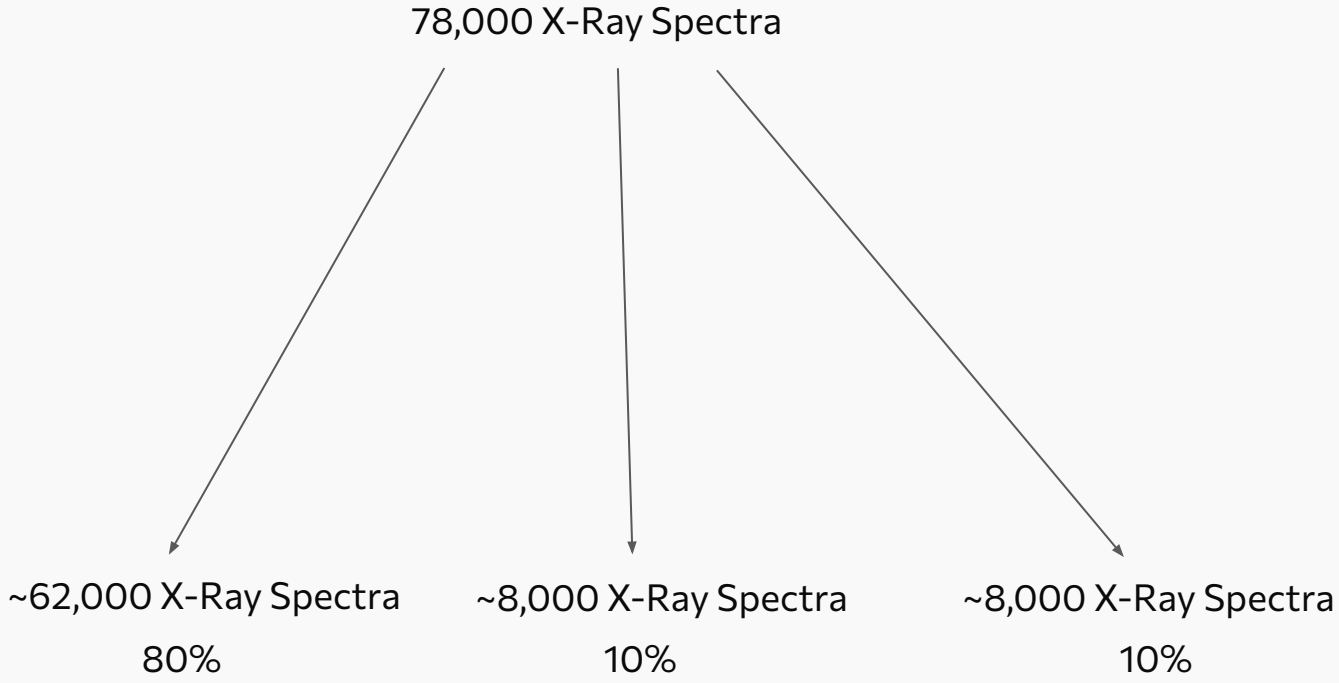
- High error X-ray spectra

Matzeu et al Emulator's Predictions

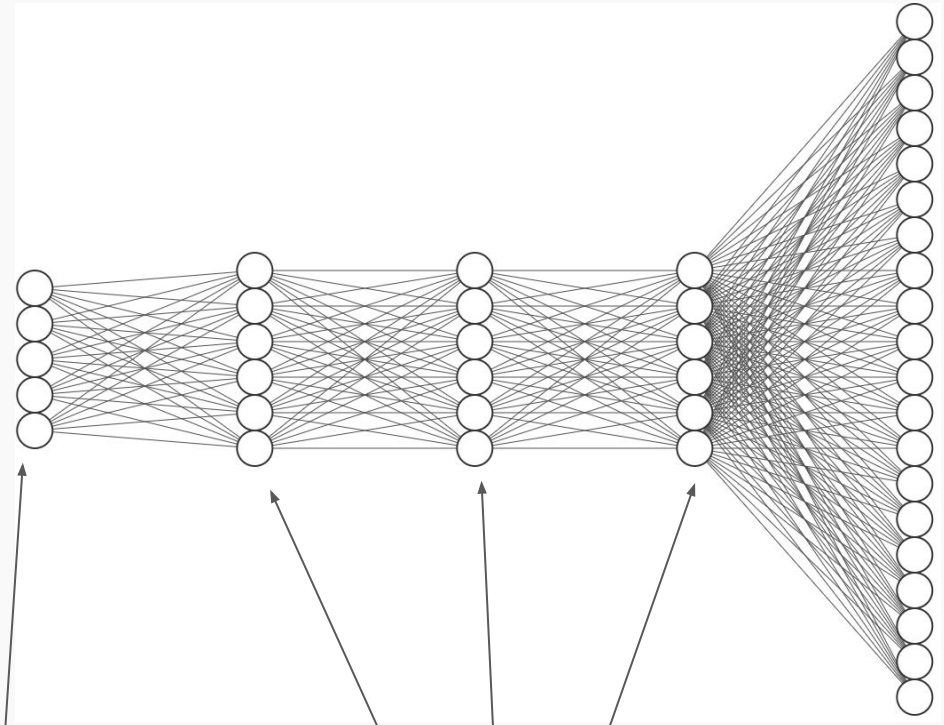


- Low error X-ray spectra

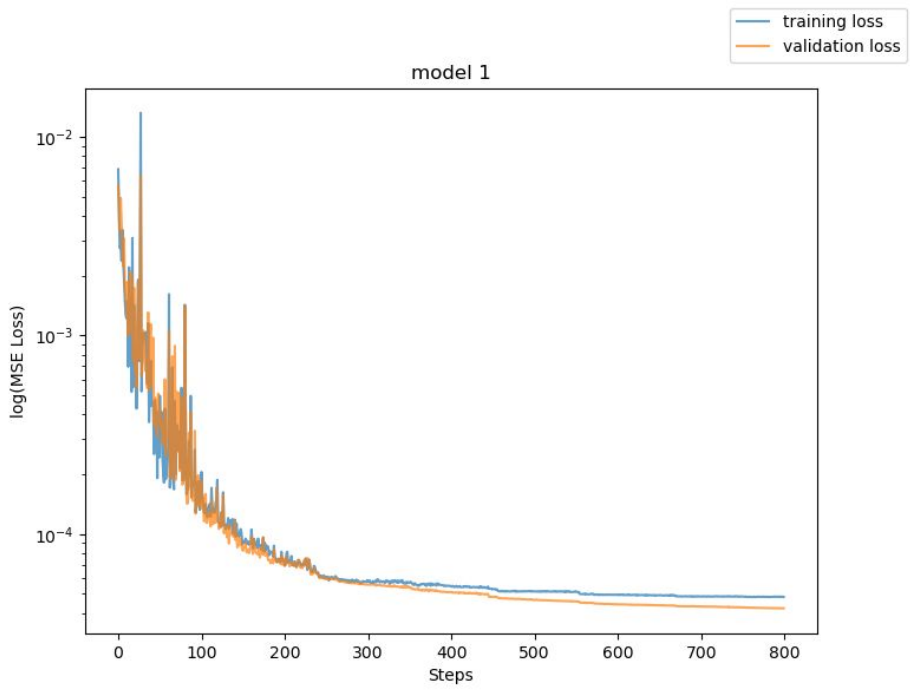
Data Splitting



Our Model Architecture

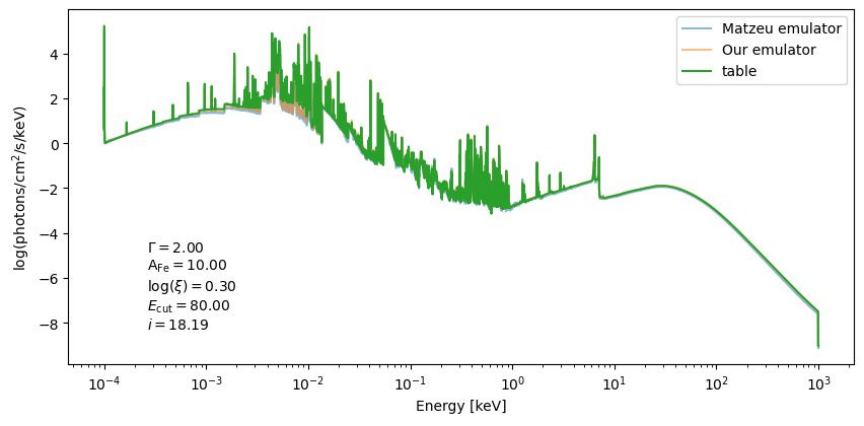


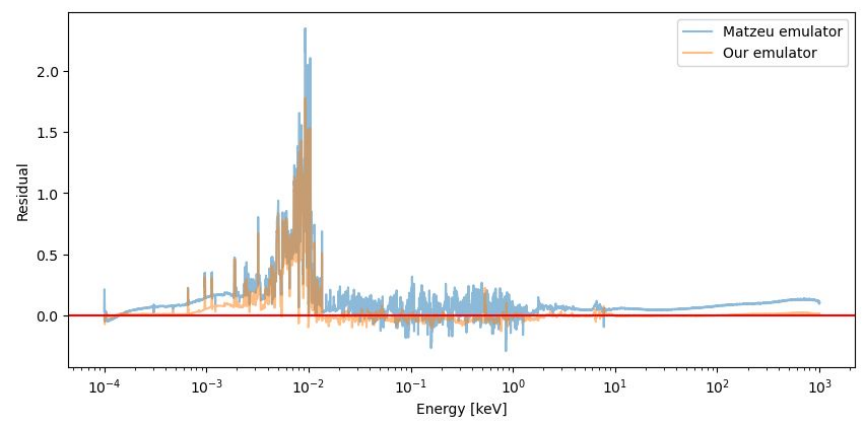
Model Training



- Saved the model at its global minima validation loss
- Adaptive learning rate that decreases when the change in the loss slows down

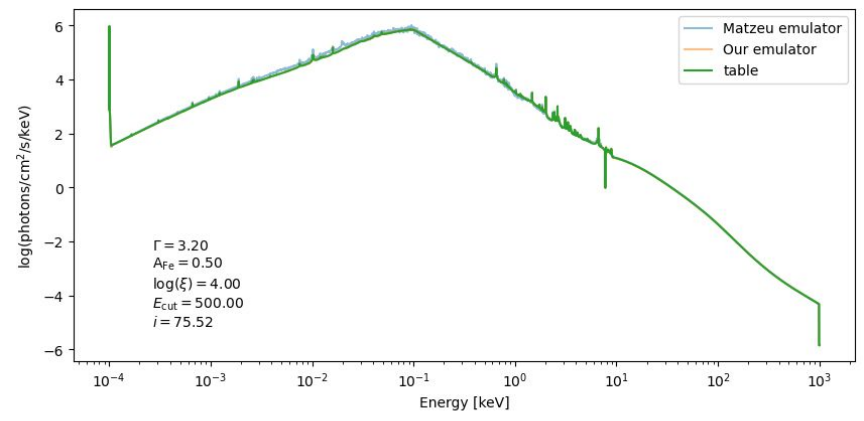
Matzeu et al Emulator vs Our Model: Training Data

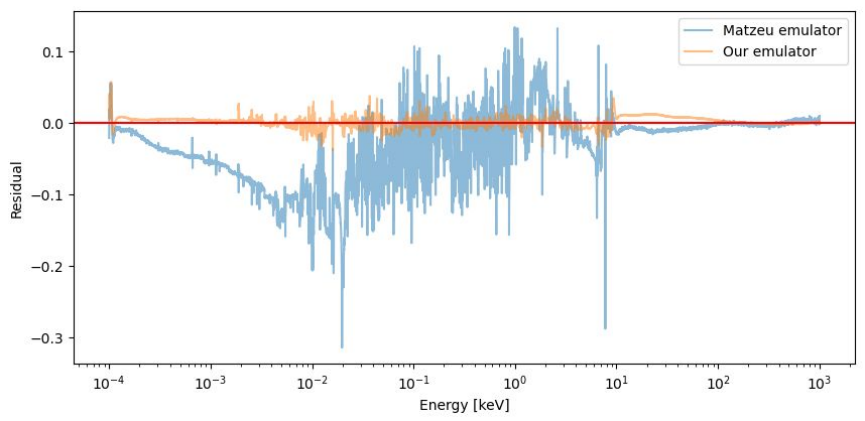




- High error X-Ray spectra

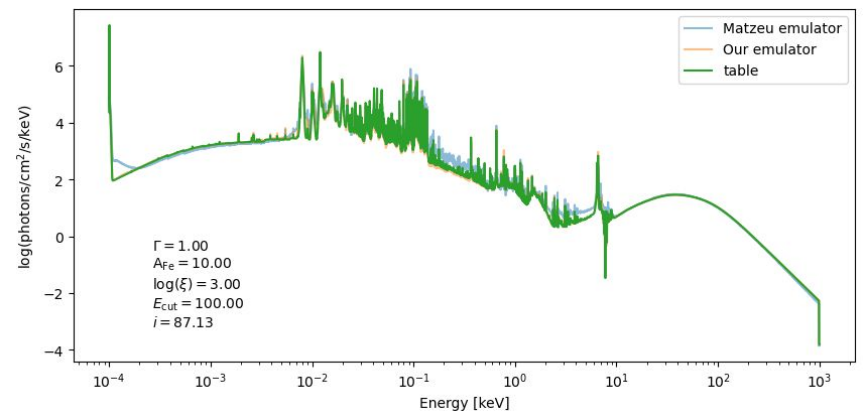
Matzeu et al Emulator vs Our Model: Training Data

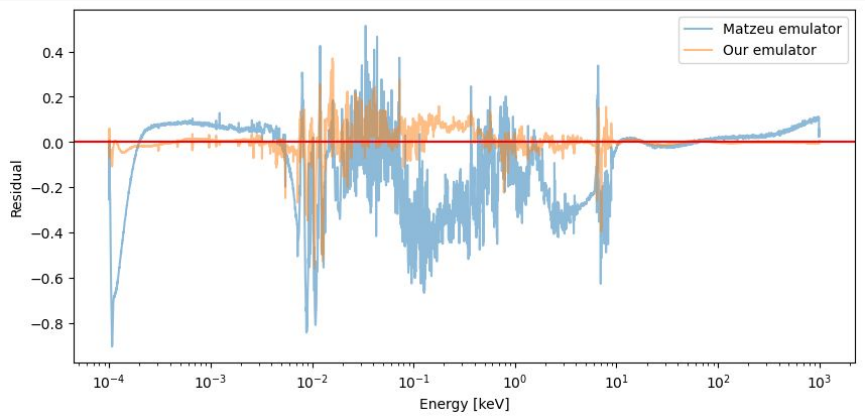




- Low error X-Ray spectra

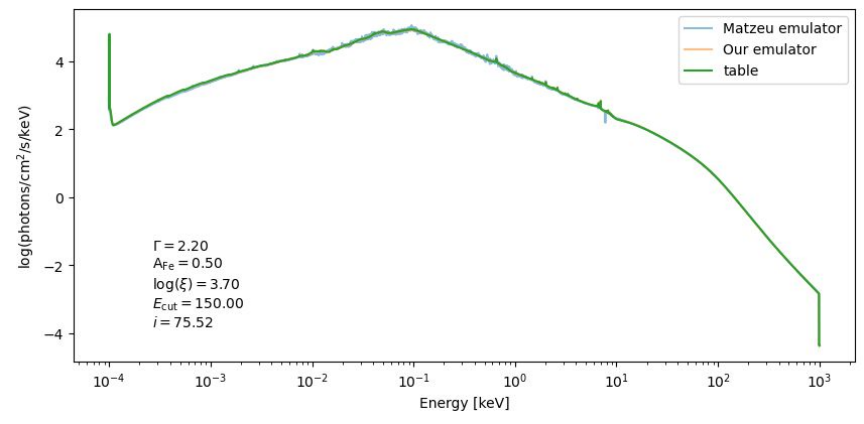
Matzeu et al Emulator vs Our Model: Testing Data

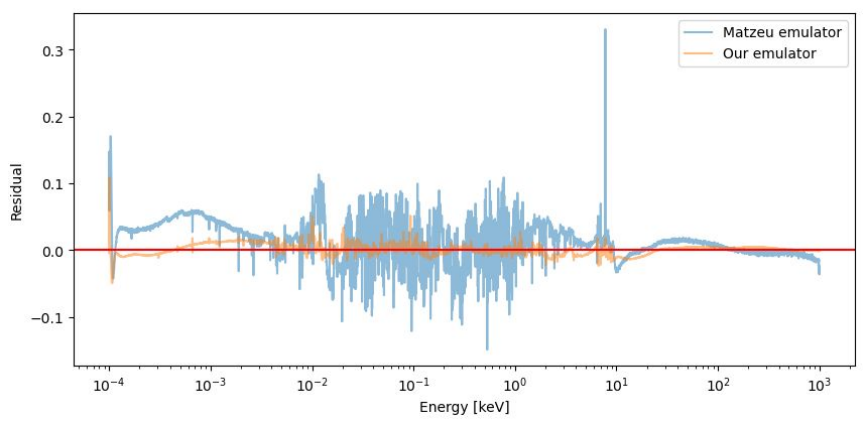




- High error X-Ray spectra

Matzeu et al Emulator vs Our Model: Testing Data





- Low error X-Ray spectra

Future Work

- Generate more data in regions of higher error for more training data
- Generating off gridpoint x-ray spectra to compare linear interpolation to emulation
- Alternative ways of representing X-ray spectra data

Summary

- Neural networks can emulate X-ray spectra as an alternative to linear interpolation
- Benefits include more accurate interpolation and less storage/memory required
- Additional network architectures were tested
- More data should be created for training and testing purposes

Acknowledgements

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Feedback Form