A New Paradigm in X-ray Spectral Analysis

Deconvolving Spectra using Machine Learning

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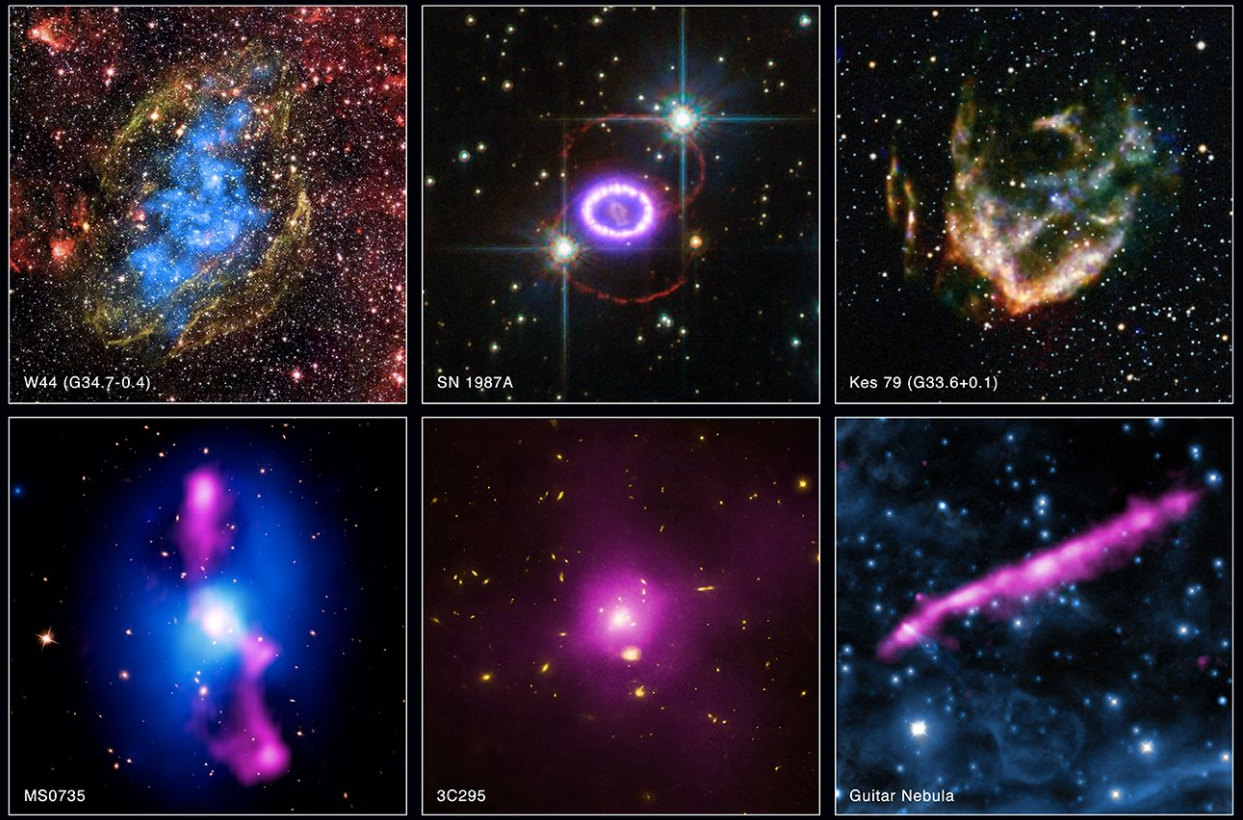
CRAQ Comprendre l'Univers Understanding the Universe

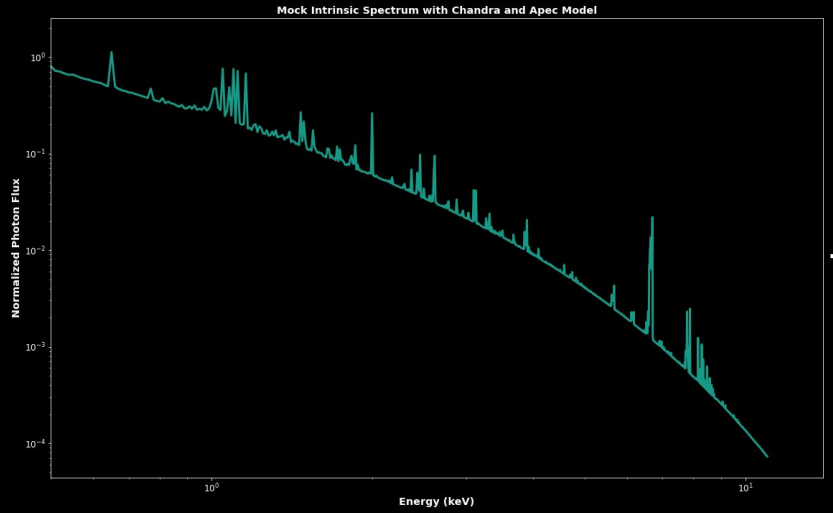
X-TRA

X-ray Astronomy

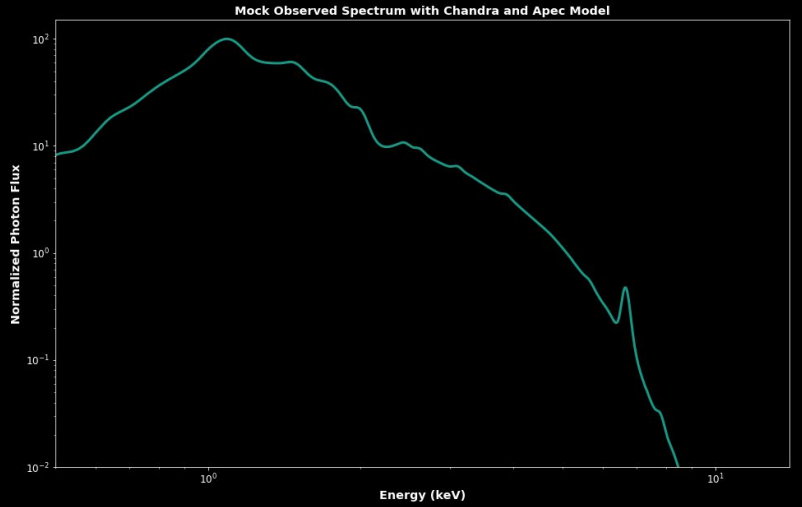


Observations vs Reality

The Source's Intrinsic Spectrum



What we observe

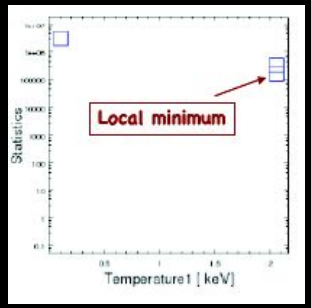


Why do we need this?

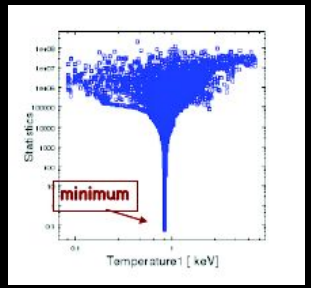
1. Initial Parameter Estimation for Traditional Fitting Methods

Fit Space

LevMar



Monte Carlo

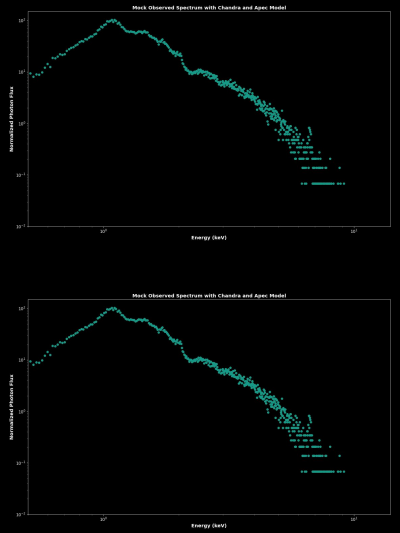


Images adopted from Sherpa

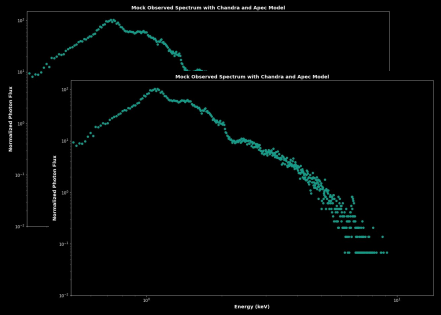
Why do we need this?

1. Initial Parameter Estimation for Traditional Fitting Methods
2. Stacking of X-ray Data

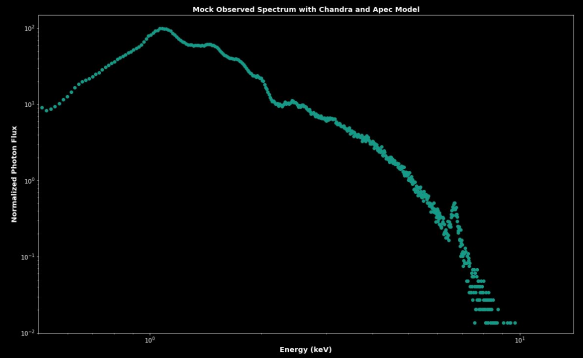
Individual Spectra



Combine Spectra



Stacked Spectra



Outline of Presentation

- Introduction
  - Formulation of observed spectrum
  - Effect of Response Matrix in Observations
  - Previously Attempted Solutions
- Recurrent Inference Machine
  - Introduction
  - Basic Example
  - In the Context of X-ray Spectra
- Next Steps

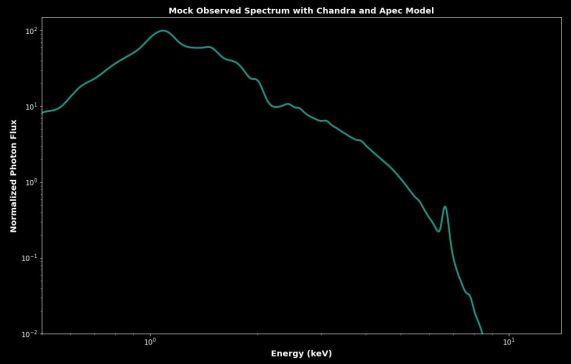
Introduction

Potential Solutions for the Response Matrix

E = Photon Energy Space

E' = Detector Energy Space

$$S_{obs}(E) = \int_0^{\infty} R(E', E)\, S_{true}(E)\, dE$$



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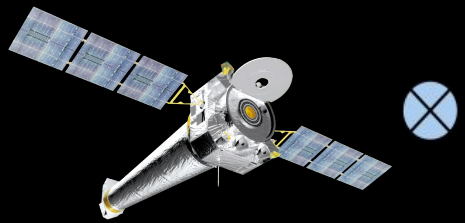
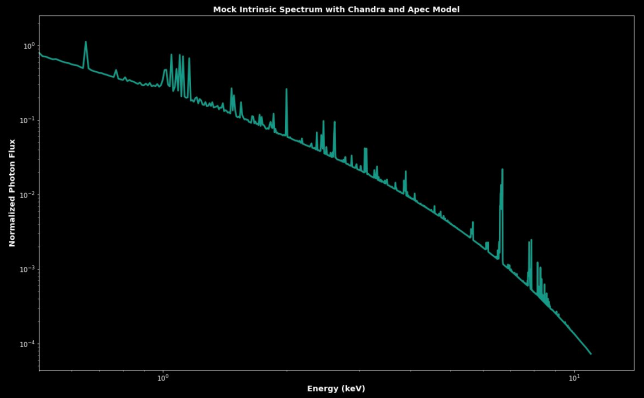




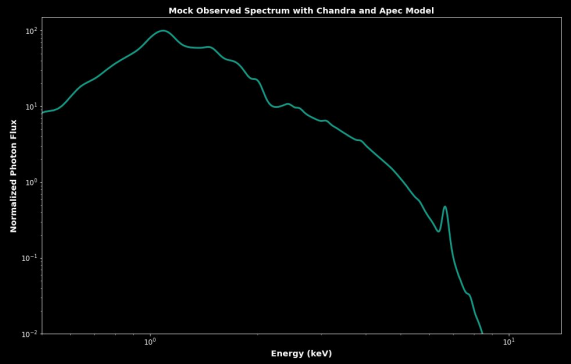
Kaastra & Bleeker 2016 ApJ

Potential Solutions for the Response Matrix

i = Photon Energy Space

j = Detector Energy Space

$$S_{obs_i} = \sum_{ij} R_{ij} S_{true_j}$$



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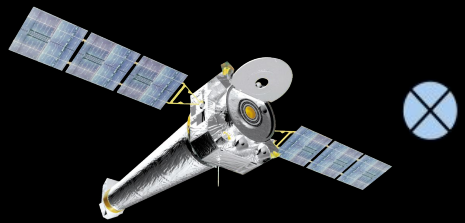
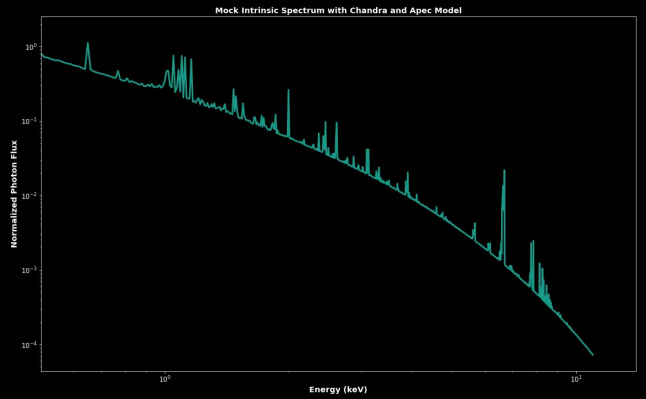
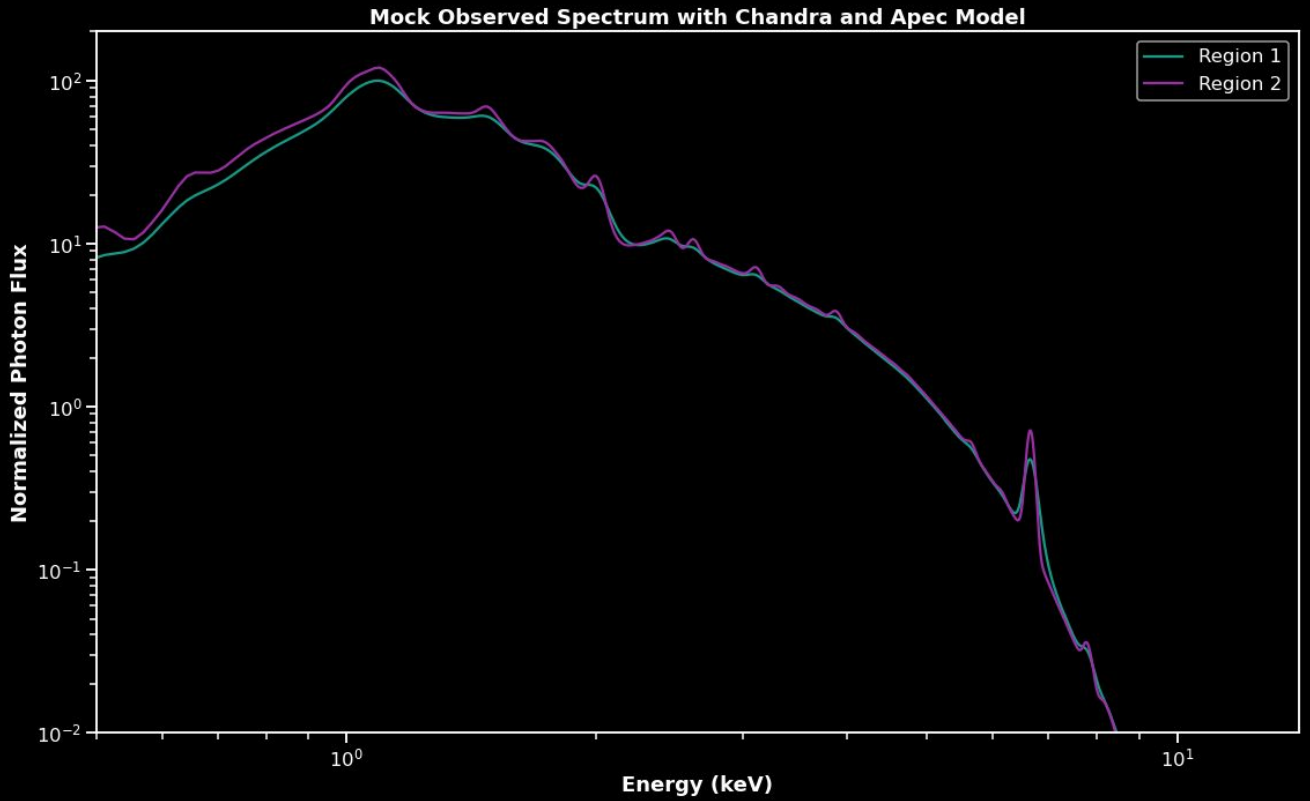




Kaastra & Bleeker 2016 ApJ

Effects of Response Files



Solving the Matrix Equation

$$R\, S_{true} = S_{obs}$$

Pseudo-Inverse

$$S_{true} = R^{\dagger} S_{obs}$$

DOES NOT WORK

Tikhonov Regularization

$$\left| R S_{true} - S_{obs} \right|_{L_2} - \mu \left| D \right|_{L_2}$$

$$S_{true} = [R R^T + \mu I]^{\dagger} [R^T S_{obs}]$$

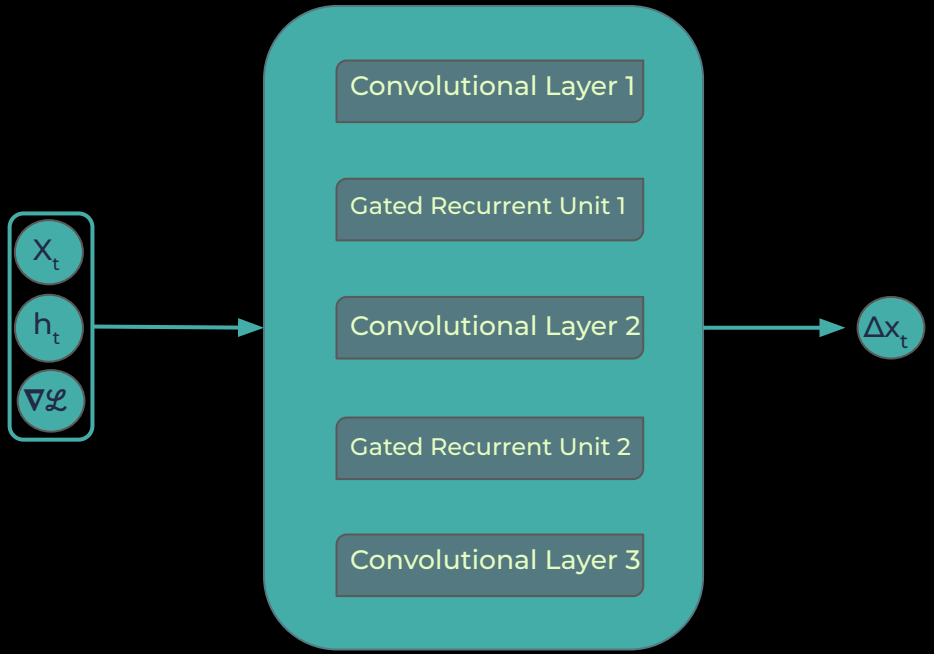
Rhea et al., RNAAS, 2021, 5, 5; 2105.09470

Recurrent Inference Machine

Recurrent Inference Machines

How does a Recurrent Inference Machine work:

*Solve the linear equation **Ax=b** iteratively by using an RNN to update solution*



Putzky & Welling 2017
arxiv.org/abs/1706.04008

Morningstar et al. 2018
arxiv.org/abs/1808.00011

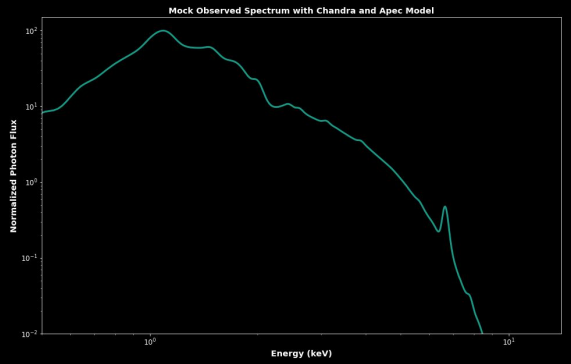
Morningstar et al. 2019
arxiv.org/pdf/1901.01359.pdf

A quick reminder about our problem

i = Photon Energy Space

j = Detector Energy Space

$$S_{obs_i} = \sum_{ij} R_{ij} S_{true_j}$$



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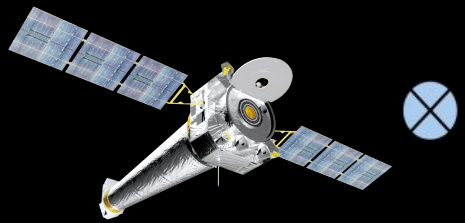
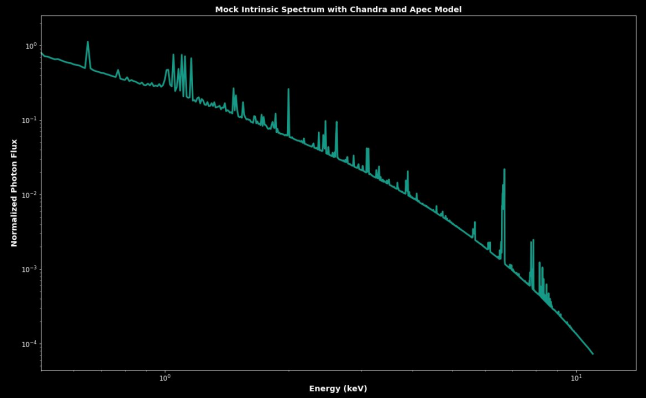
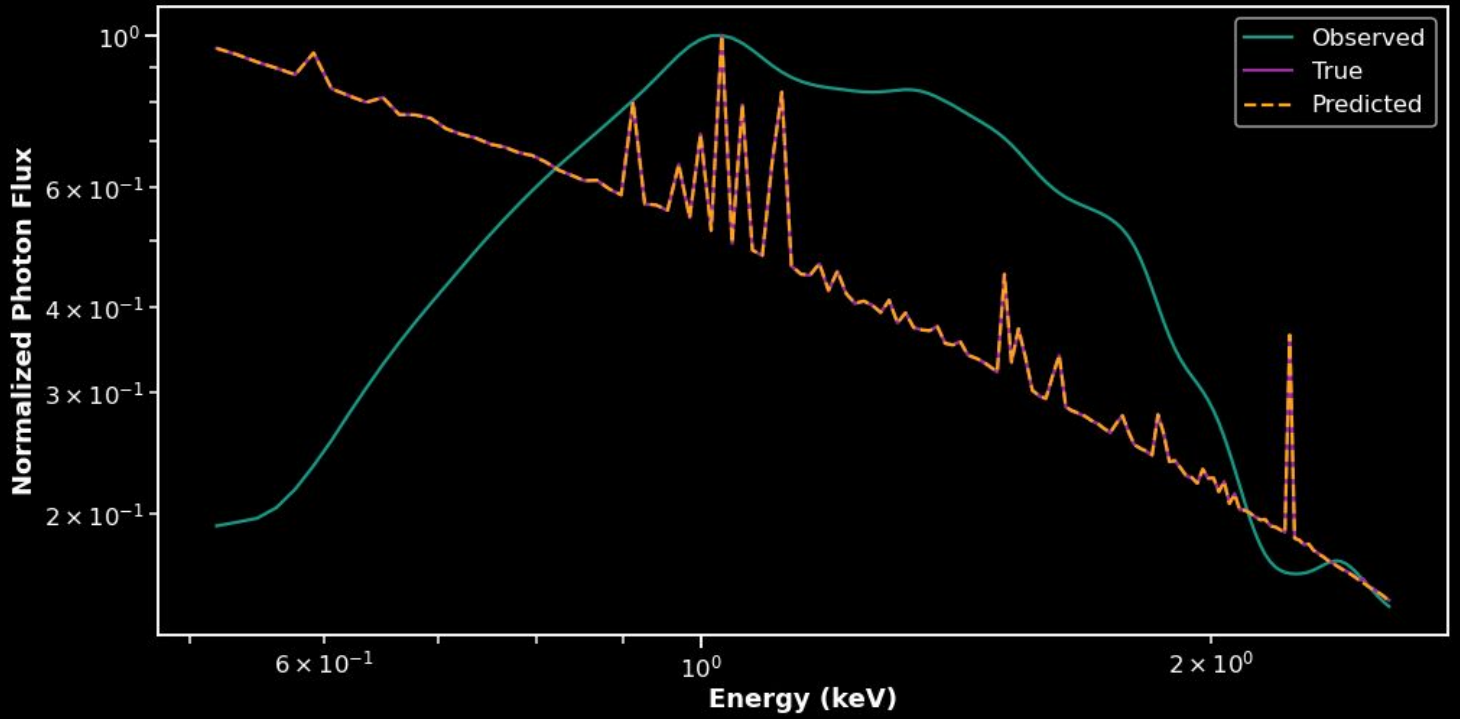




Kaastra & Bleeker 2016 ApJ

Application to X-ray Spectra



What can we do with this?

- Train a convolutional neural network to estimate the underlying parameters (Rhea et al. in prep.)
- Explore the transiency of X-ray sources (Rhea et al. in prep.)
- Study the calibration of the Chandra X-ray Observatory (Prunier & Rhea et al. in prep.)
- Investigate Metallicity in the outskirts of galaxies

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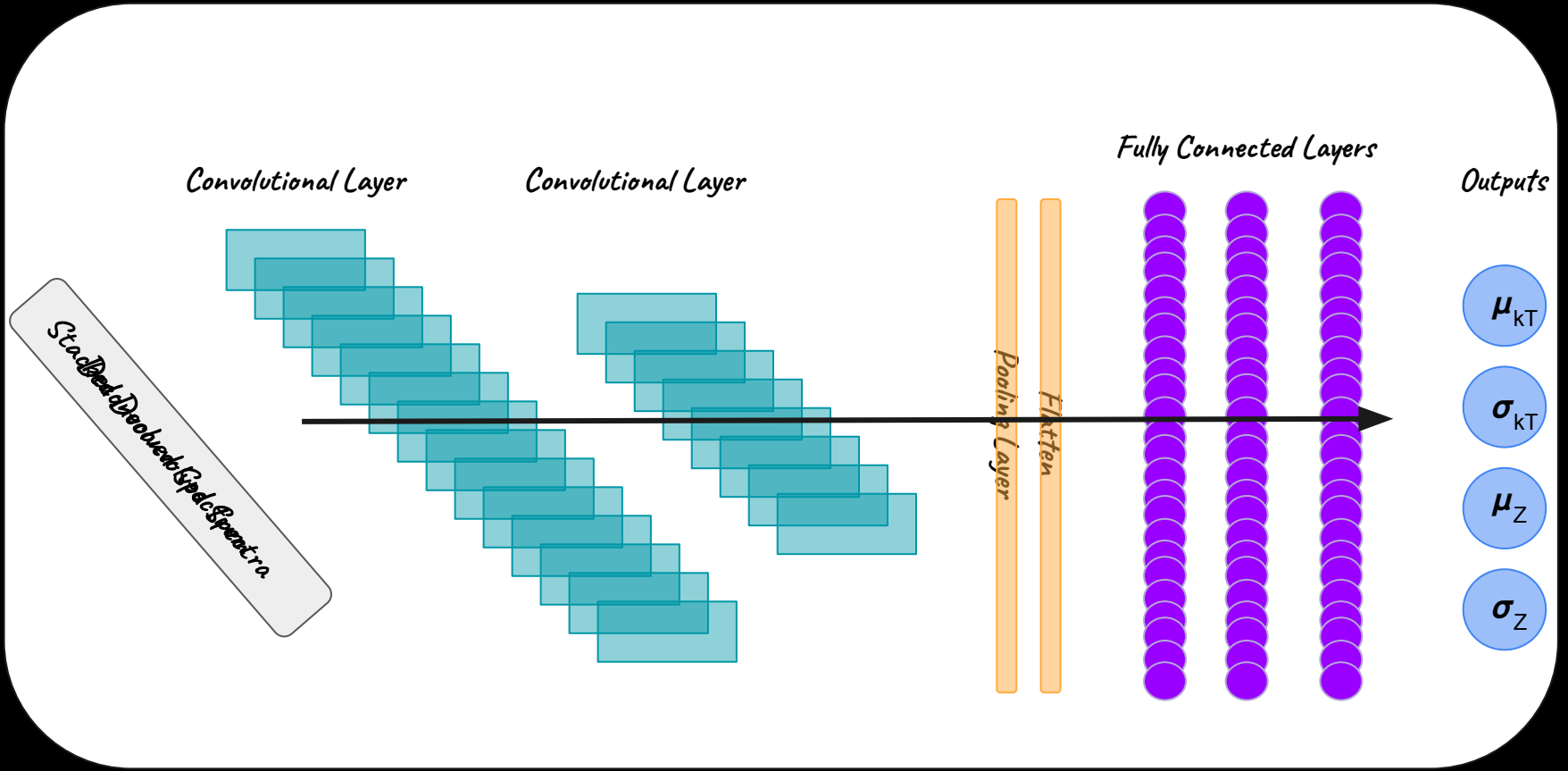
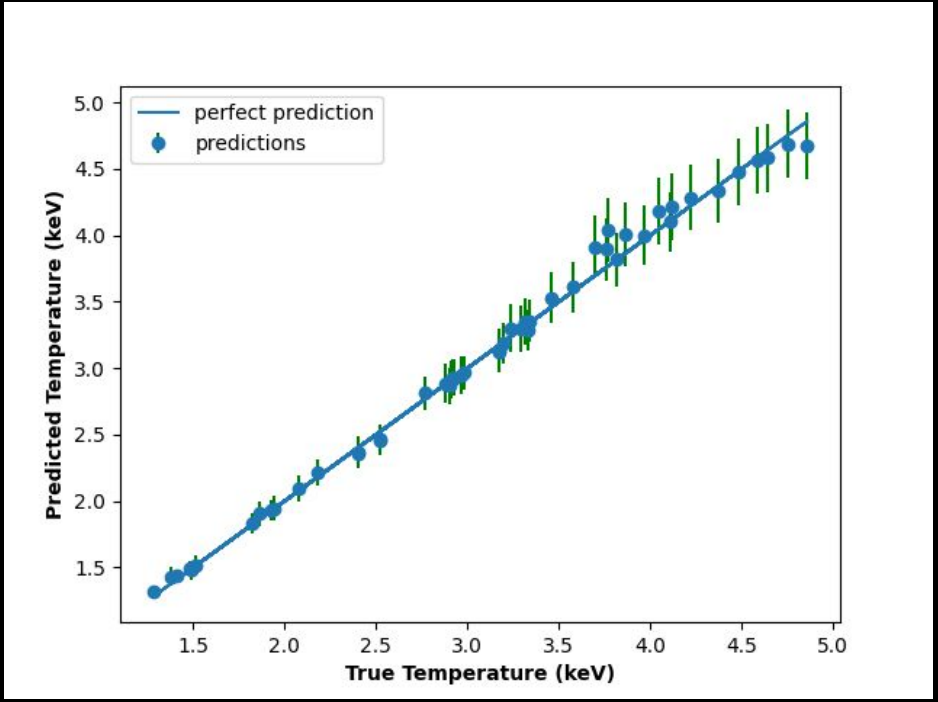
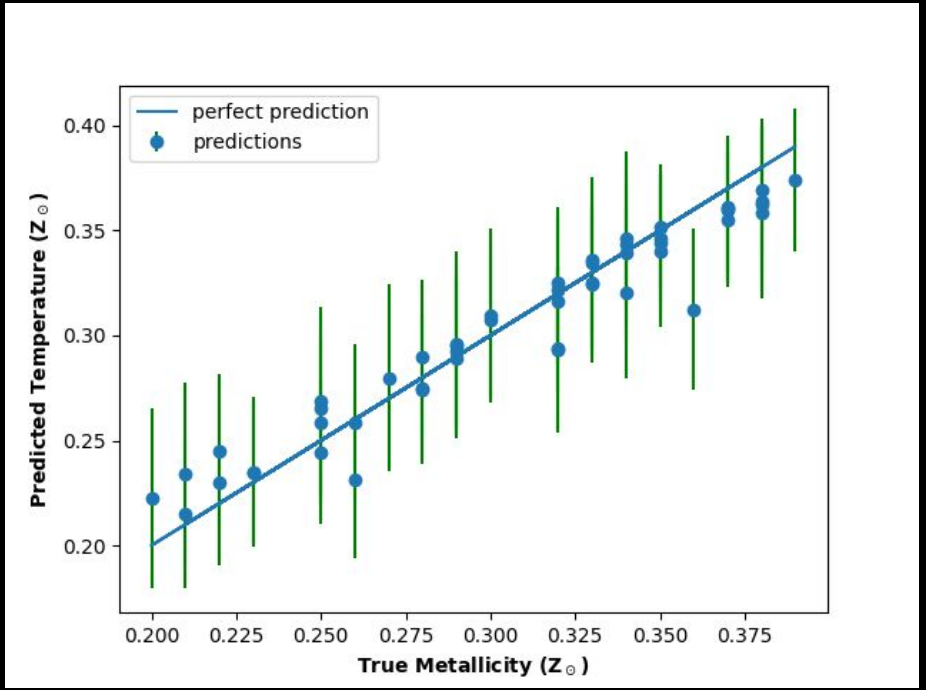
Next Step: Estimate Temperature and Metallicity



Estimate Temperature and Metallicity





Putting it all together!

Preprocessing (RIM)

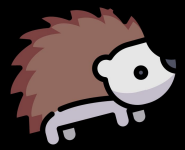
Deconvolve X-ray Spectra s/t we can stack them

Mixture Density Network

Train MDN on deconvolved spectra to obtain posterior distributions of temperature and metallicity

Bayesian Inference (BXA)

Use MDN results as priors to do a full Bayesian inference approach to X-ray Spectral Fitting



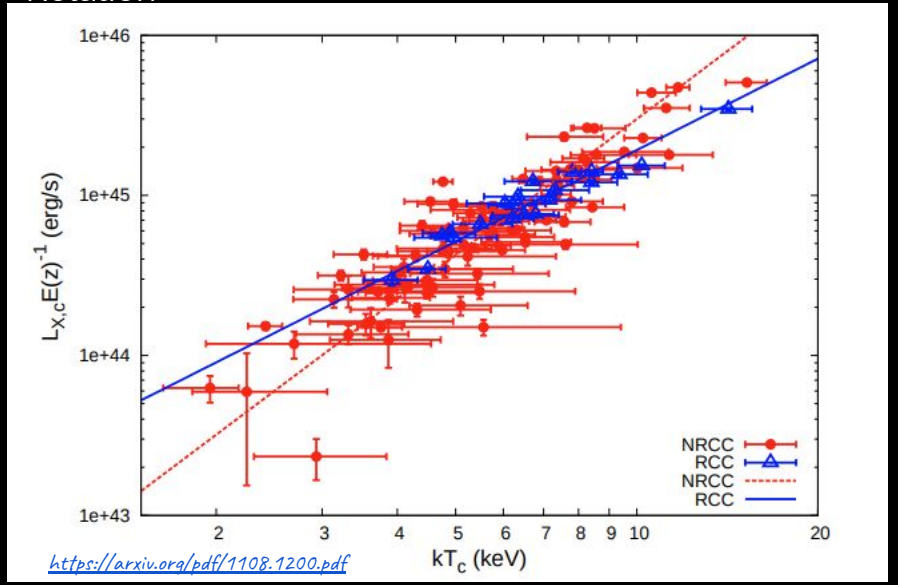
Rhea, C. et al, AJ 160, 5 (2020)

Buchner, J. et al, A&A 564, A125 (2014)

Next Steps

1. Converge RIM on larger dataset
   a. Redo CNN analysis on larger dataset
2. Apply to real data (Self-Similarity)
   a. Reduce Chandra Data
   b. Use RIM to deconvolve
   c. Apply CNN to estimate parameters
3. Potential other ideas?

Galaxy Cluster X-ray Luminosity-Temperature Relation



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