A New Paradigm in X-ray Spectral Analysis

Deconvolving X-ray Spectra using Machine Learning

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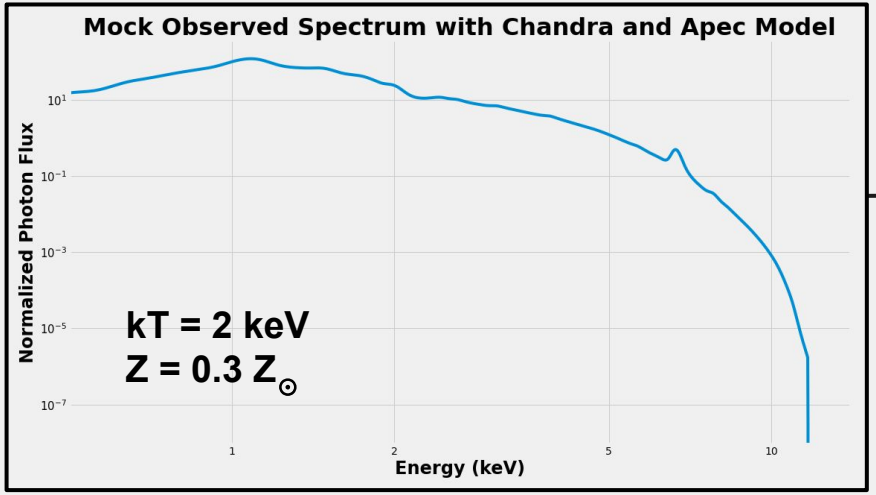
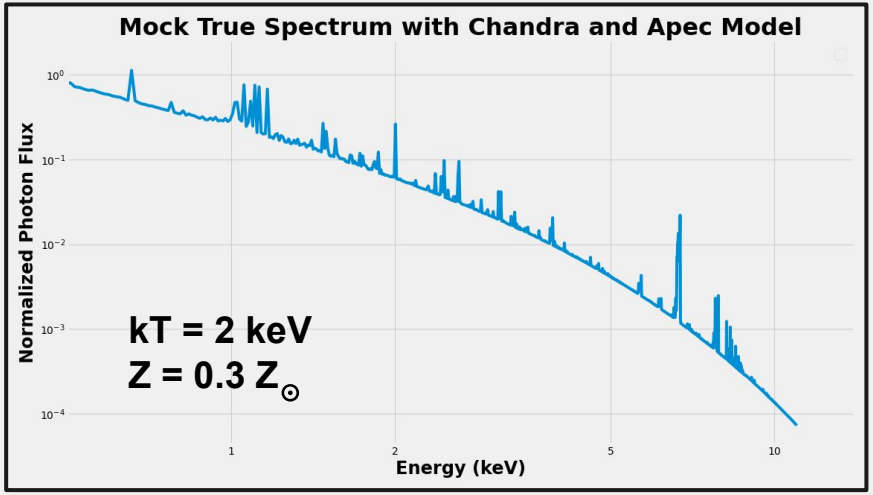
X-TRA

Observations vs Reality

What we observe



The Source's Intrinsic Spectrum

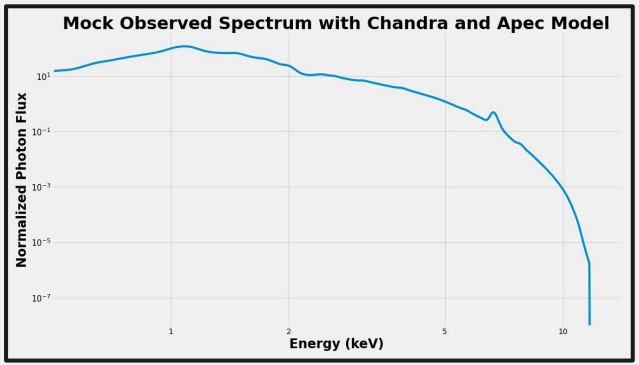


Possible Solutions for the Response Matrix

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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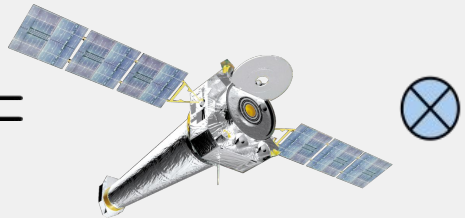

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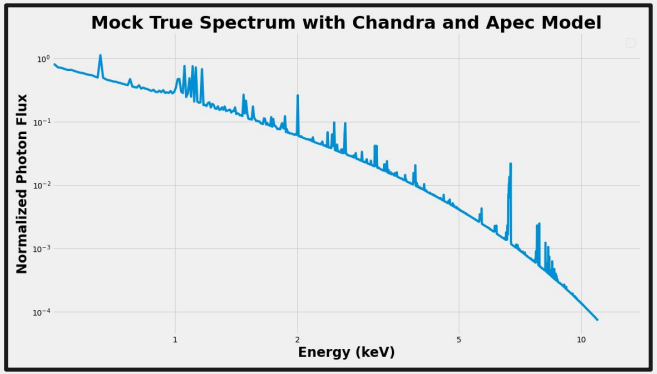


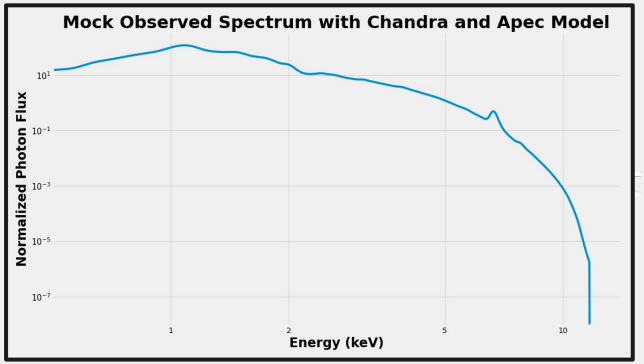
Kaastra & Bleeker 2016 ApJ

Possible 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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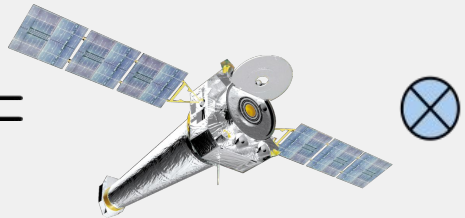

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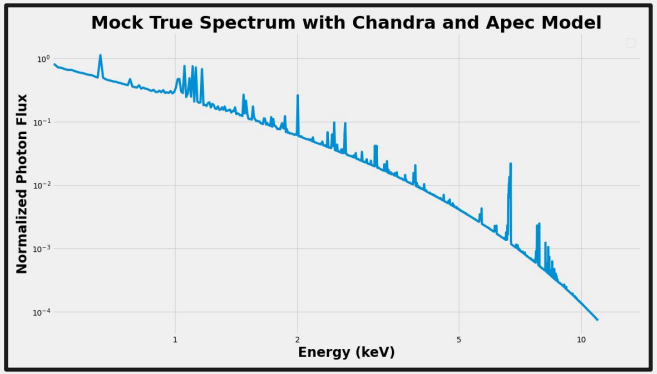
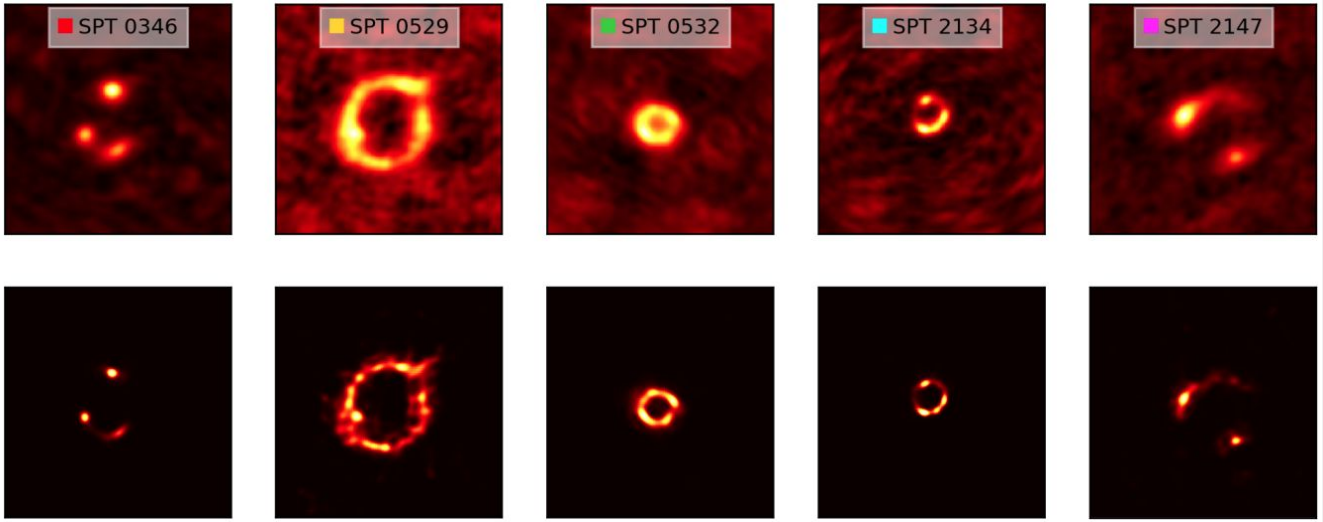


Kaastra & Bleeker 2016 ApJ; see also Rhea et al. 2021 RNAAS

Recurrent Inference Machines

How does a Recurrent Inference Machine work:

Solves the linear equation ***Ax=b*** *iteratively by using an* ***neural network*** *to update a solution.*

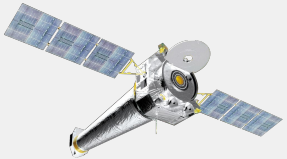


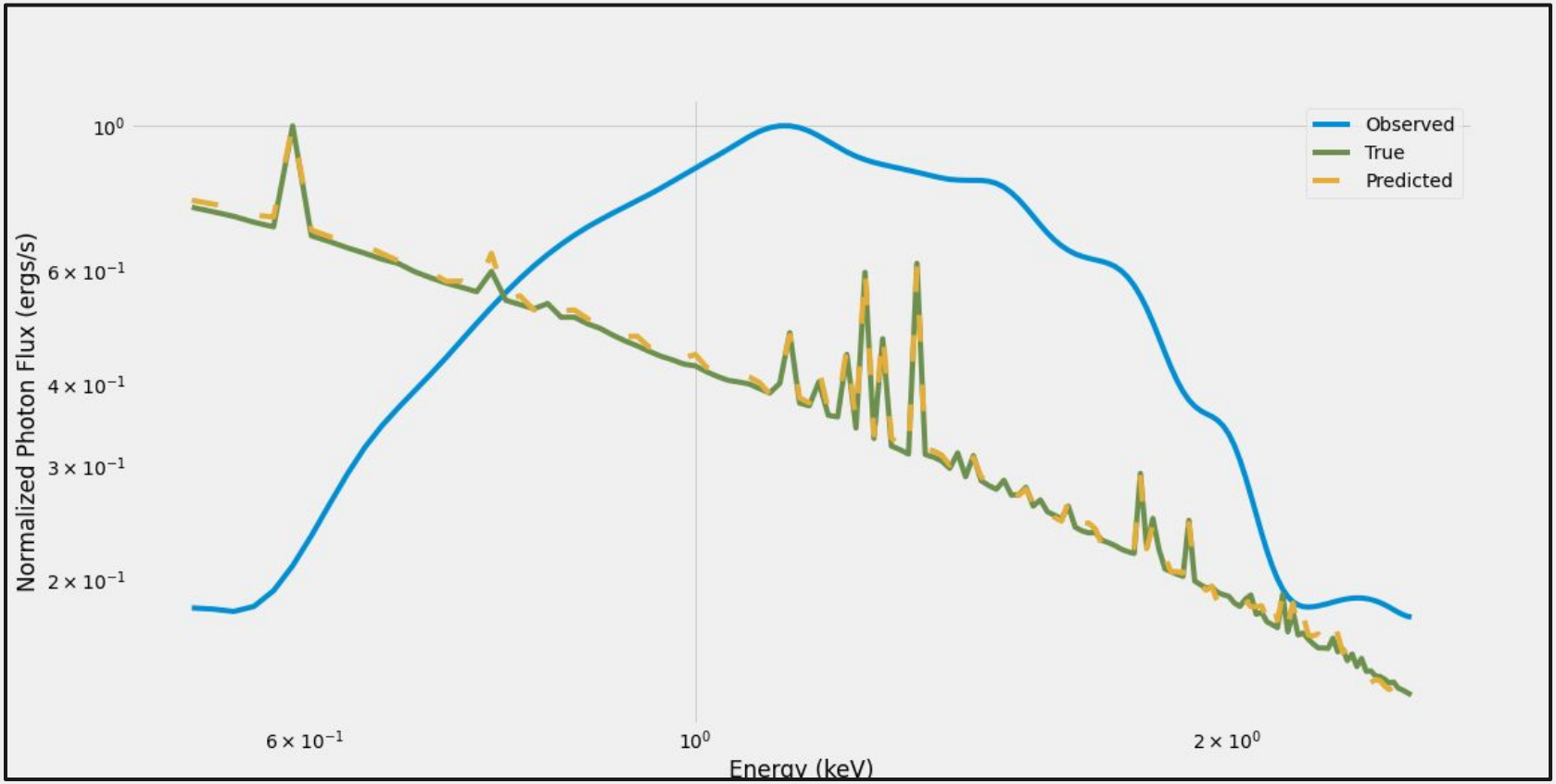
ALMA Dirty Image

RIM Deconvolved Image

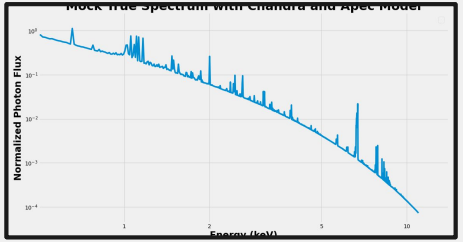
Putzky & Welling 2017; arxiv.org/abs/1706.04008
Morningstar et al. 2018; arxiv.org/abs/1808.00011
Morningstar et al. 2019; arxiv.org/pdf/1901.01359.pdf

Application to X-ray Spectra





What can we do with this?

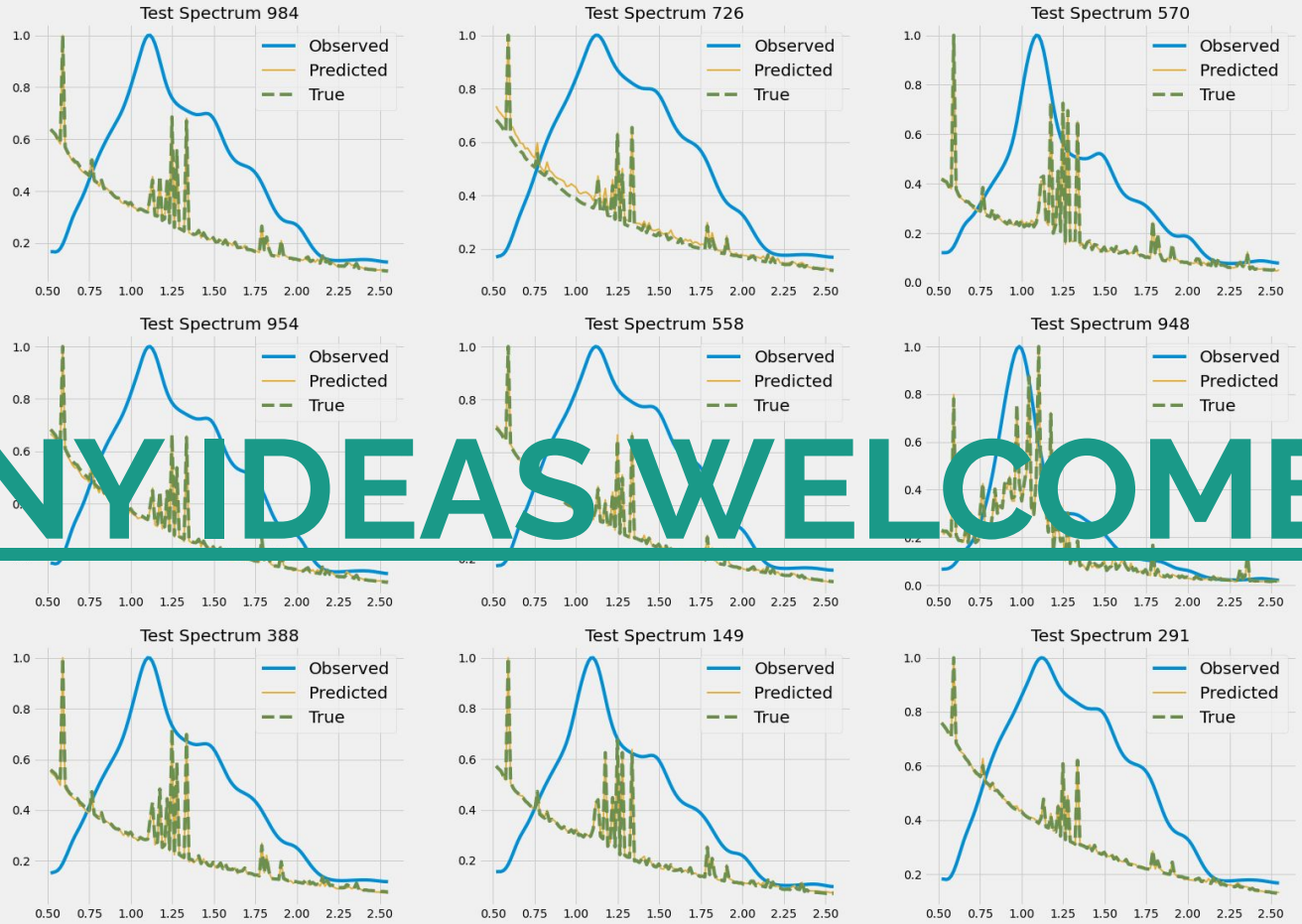


Stack X-ray spectra from all epochs
Rhea et al.

Transient X-ray Sources

By using a calibrator, derive Chandra calibration
Prunier, Rhea, JHL et al.

Parameter Estimation with Neural Networks
Rhea et al.



ANY IDEAS WELCOME!

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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
- Study the calibration of the Chandra X-ray Observatory (Prunier & Rhea et al. in prep.)
- Investigate Metallicity in the outskirts of galaxies

Recurrent Inference Machines

How does a Recurrent Inference Machine work:

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

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$

$$x_{n+1} = x_n - \square$$

$$x_{n+1} = x_n - \nabla_{\mathrm{RIM}} x_n$$

Putzky & Welling 2017
arxiv.org/abs/1706.04008

Morningstar et al. 2018
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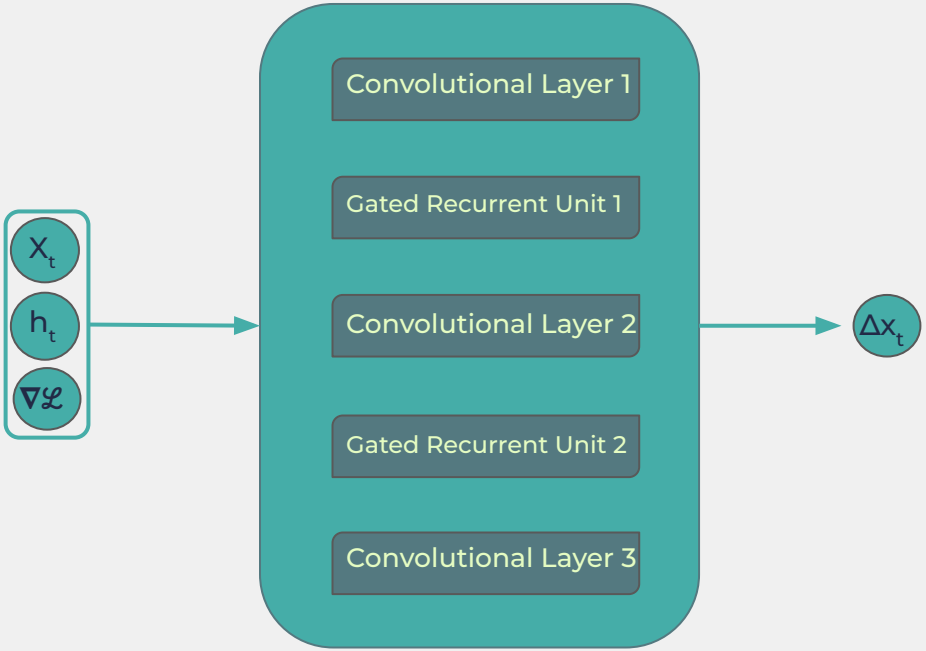

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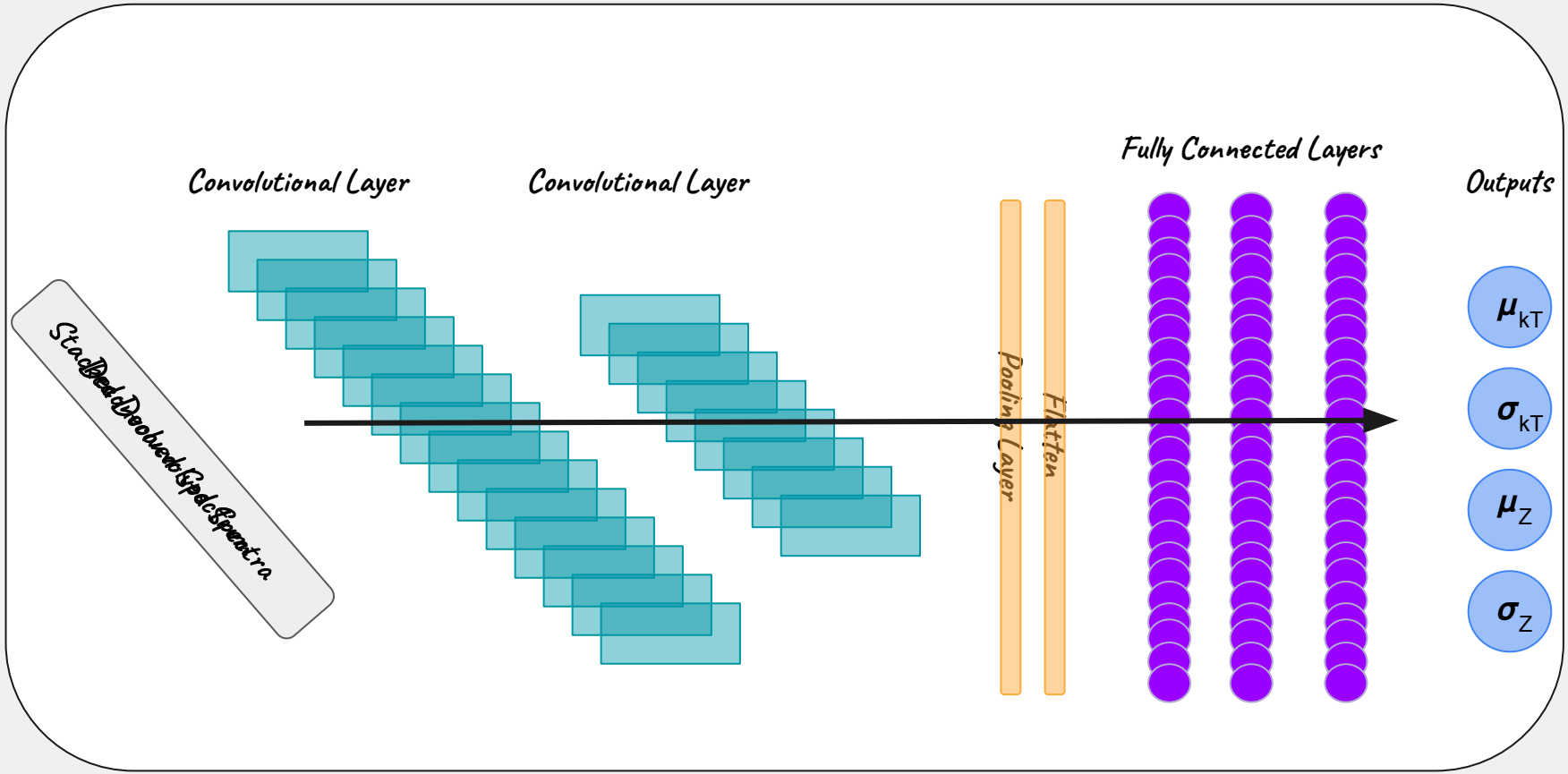
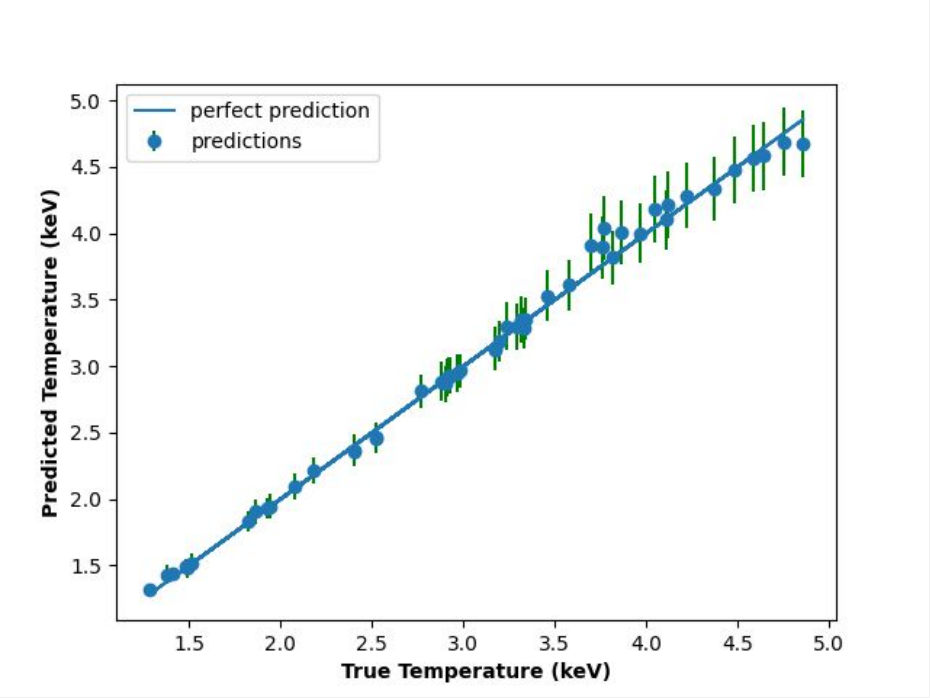
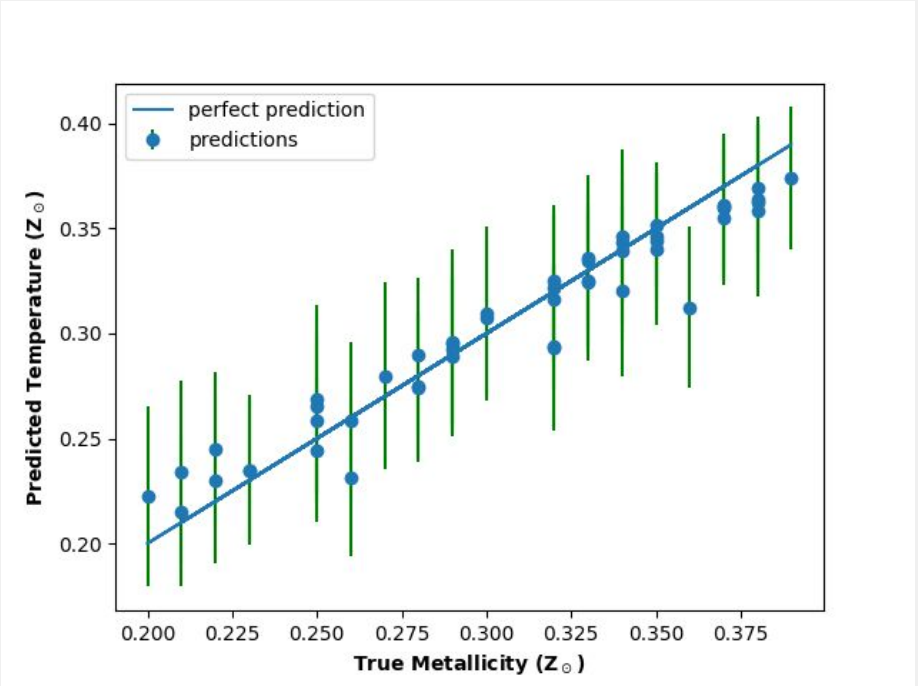
Next Step: Estimate Temperature and Metallicity



Estimate Temperature and Metallicity





Putting it all together!

Preprocessing (RIM)

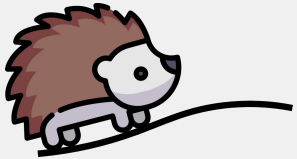
Deconvolve X-ray Spectra s/t we can stack them

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



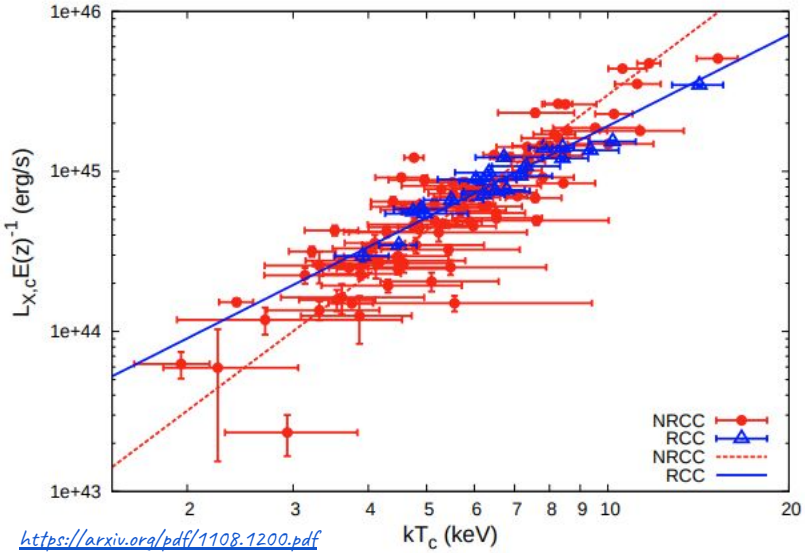
Rhea, C. et al, AJ 160, 5 (2020)

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



https://arxiv.org/pdf/1108.1200.pdf

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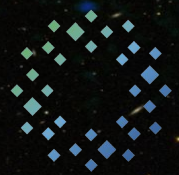
April XX, 2022



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