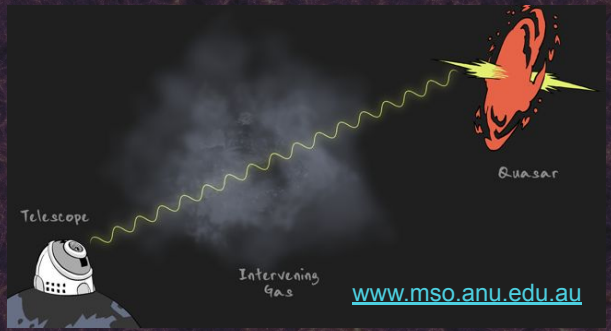
Convolution neural network to characterize the Voigt profile of Lyman-α forest absorbers

Priyanka Jalan (CFT, Poland)
Post Doctorate at Center for Theoretical Physics, Polish Academy of Sciences, Warsaw, Poland

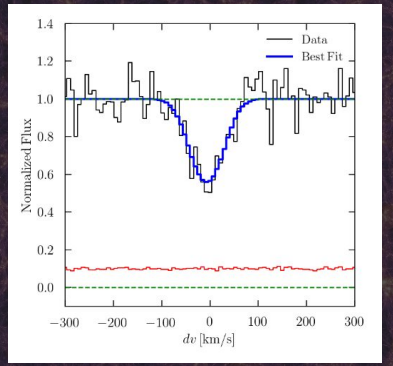
Vikram Khaire (IIST, India), Vivek M (IIA, India), Prakash Gaikwad (MPIA, Germany)

Convolution neural network to characterize the Voigt profile of Lyman-α forest absorbers



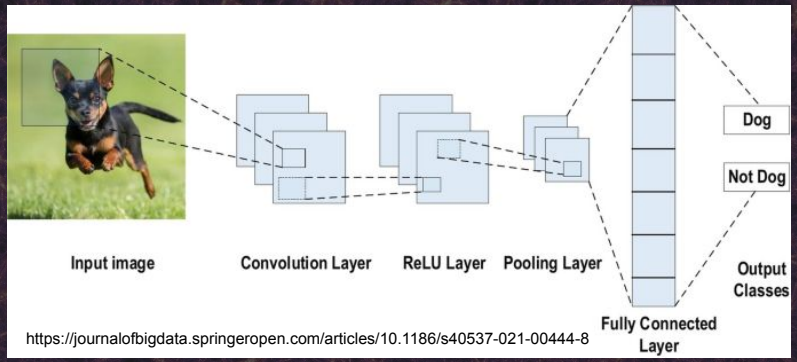
Priyanka Jalan (CFT, Poland)
Vikram Khaire (IIST, India), Vivek M (IIA, India), Prakash Gaikwad (MPIA, Germany)

Convolution neural network to characterize the Voigt profile of Lyman-α forest absorbers



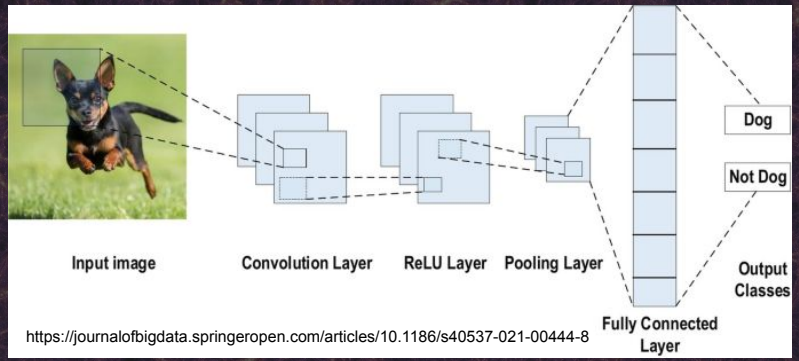
Priyanka Jalan (CFT, Poland)
Vikram Khaire (IIST, India), Vivek M (IIA, India), Prakash Gaikwad (MPIA, Germany)

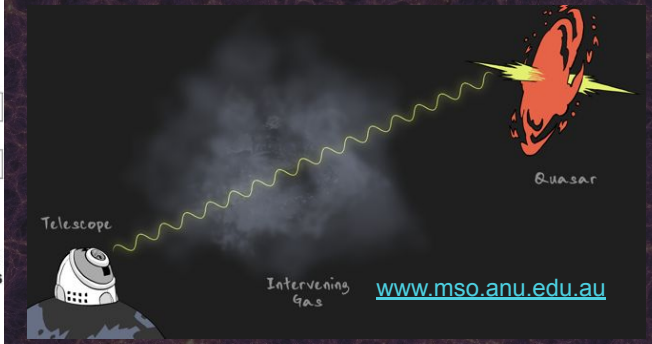
Convolution neural network
to characterize the
Voigt profile of Lyman-α forest absorbers

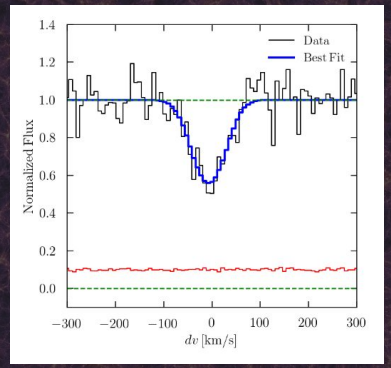


Priyanka Jalan (CFT, Poland)
Vikram Khaire (IIST, India), Vivek M (IIA, India), Prakash Gaikwad (MPIA, Germany)

Convolution neural network to characterize the Voigt profile of Lyman-α forest absorbers



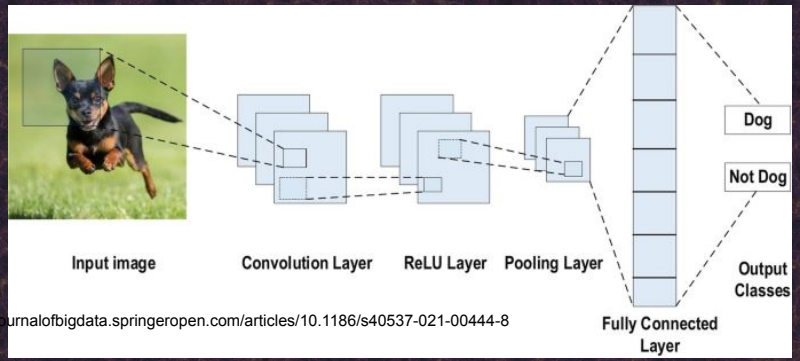




Priyanka Jalan (CFT, Poland)
Vikram Khaire (IIST, India), Vivek M (IIA, India), Prakash Gaikwad (MPIA, Germany)

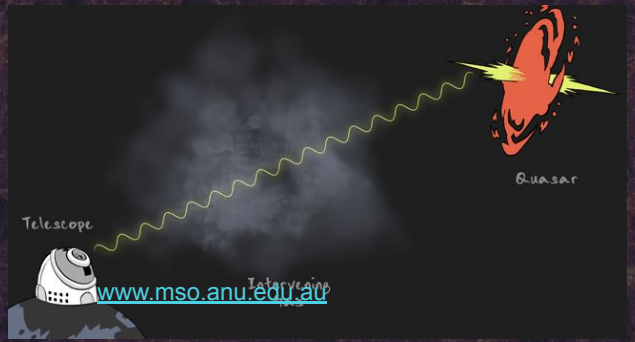
Perks of giving talk at later time in conference!

Machine learning talk by
Mohamed Kubiti



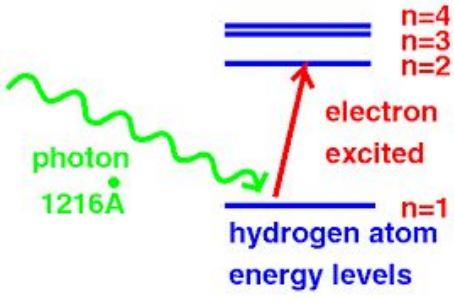
https://journalofbigdata.springeropen.com/articles/10.1186/s40537-021-00444-8

Quasar spectra shown in multiple talks



Quasar spectra

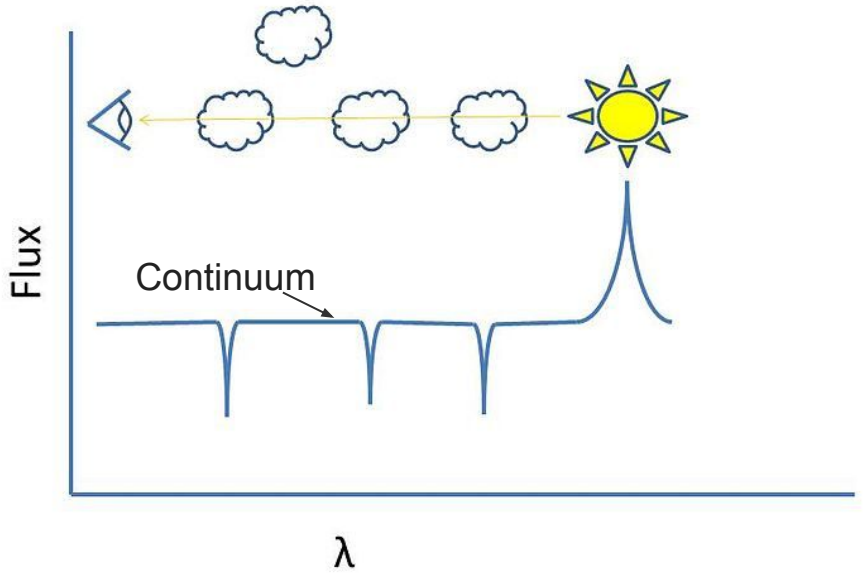
Wavelength < 1216 A (Lyman-α) will be redshifted according to the absorbing cloud.



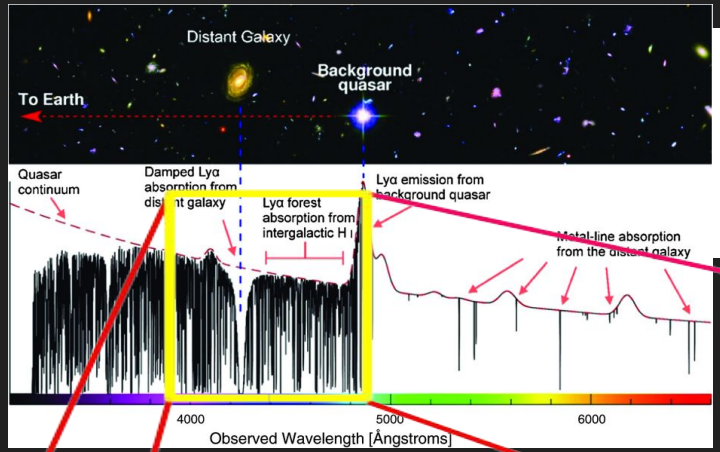
Therefore, depending on the

- absorption redshift, **z**,
- Column density, **NHI**,
- Doppler width, **b**.

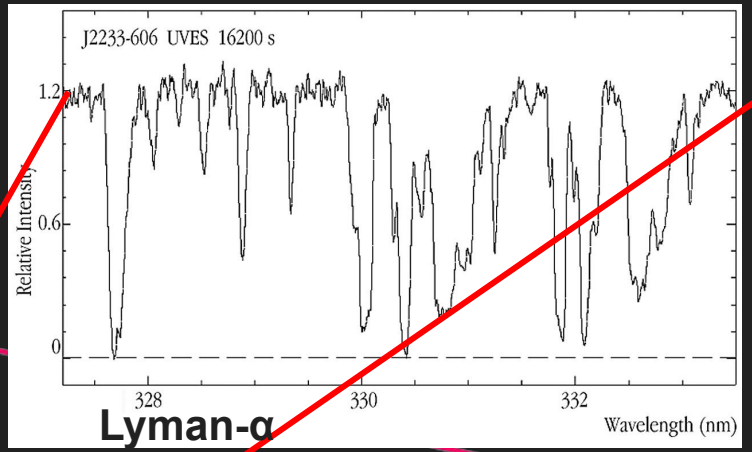
We find absorption line in the spectrum of quasar.

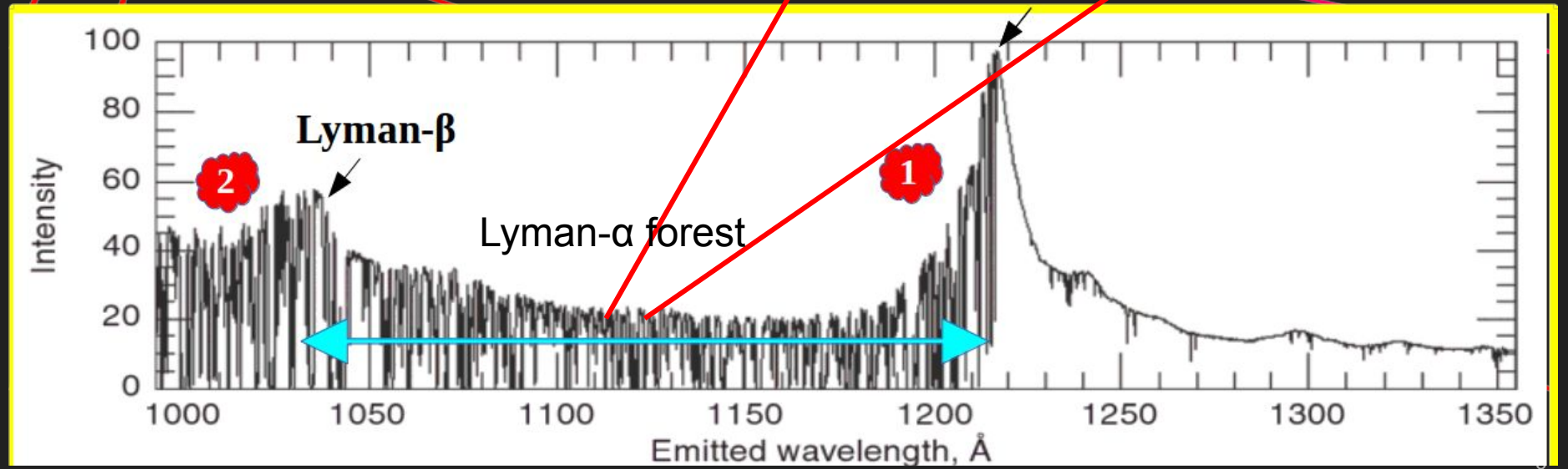


https://socratic.org

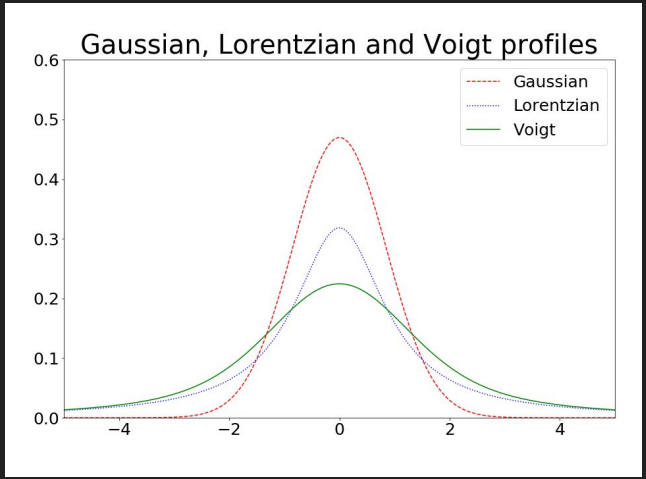


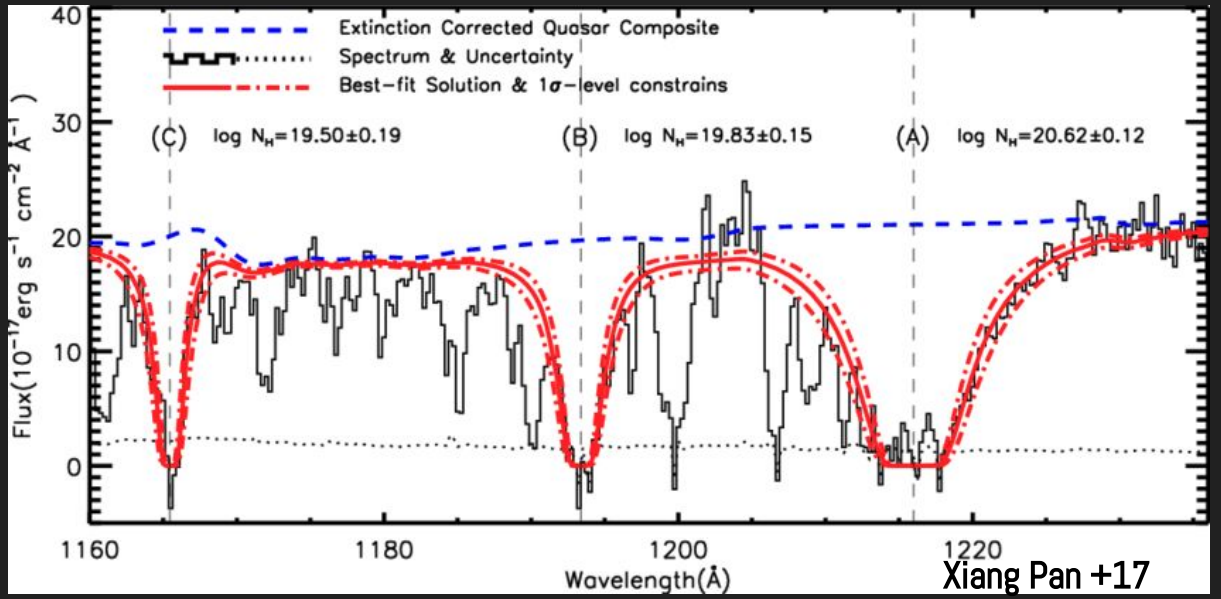
Two parameters **b** and **N** decide the shape of these absorption lines



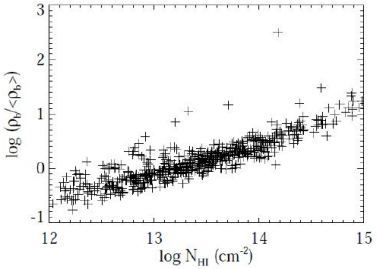


Voigt profile

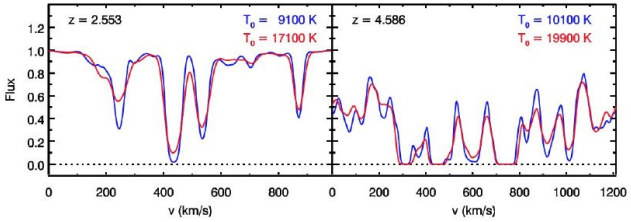




The distribution of the Lyα forest lines in Doppler parameter–column density (b−N) space is a distorted map of the **density–temperature** relation, and can be used to constrain the latter. T(ρ), in turn, contains information on the epoch of reionization and reheating and on the sources of ionizing radiation



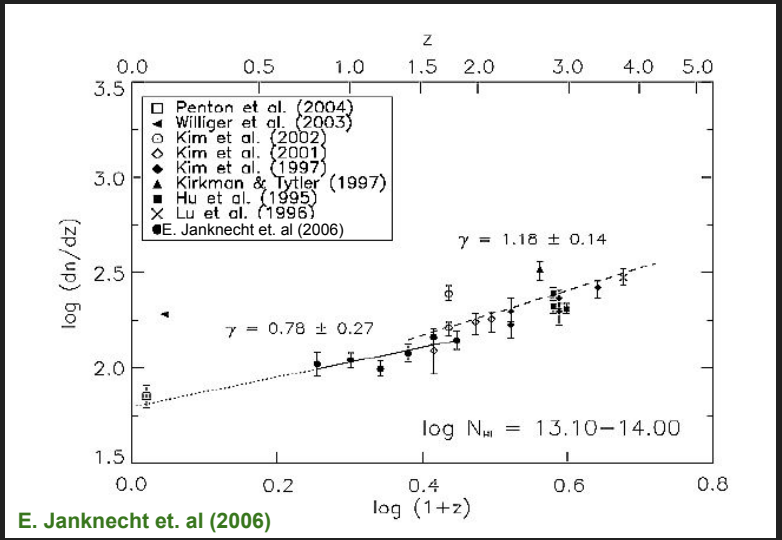
Schaye 2000: The observed column density is a fairly good tracer of the overdensities



Becker et al. 2011: The smoothness of the lines is a fairly good indicator of the temperature

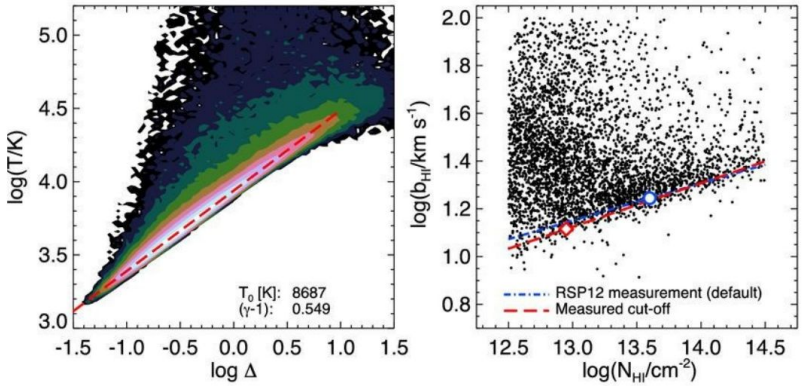
Thermal history of IGM

- The relation between b and N would correspond to a relation between T and density.
- The **temperature will provide thermal history of the IGM.**



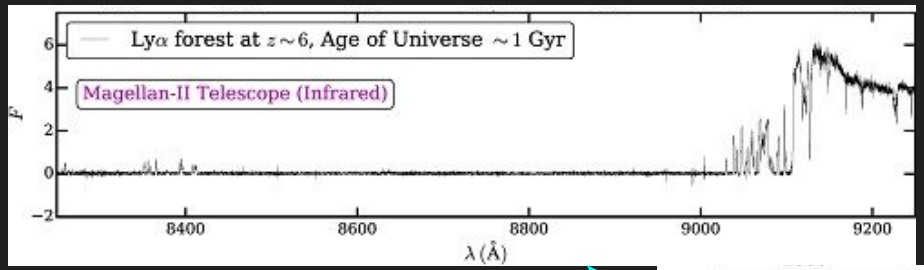
E. Janknecht et. al (2006)

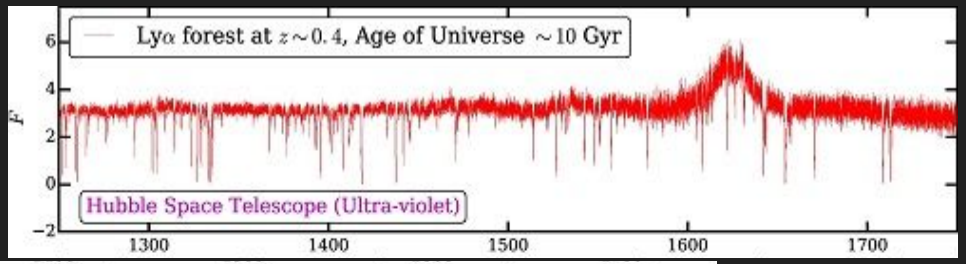
- The temperature – density relation $T = T_0 \Delta^{\gamma}$
  Competition between photoelectric heating and adiabatic cooling



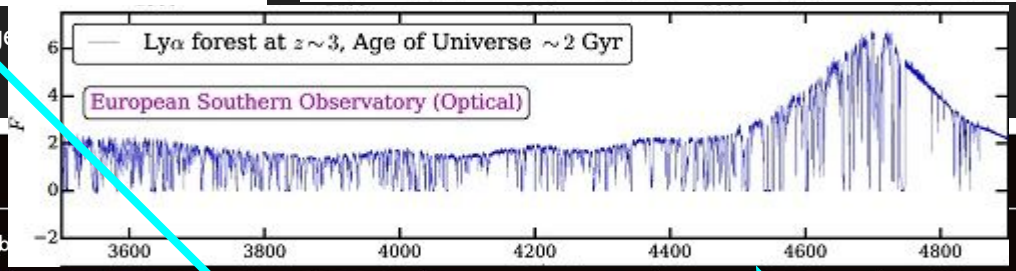
Bolton et al. 2014

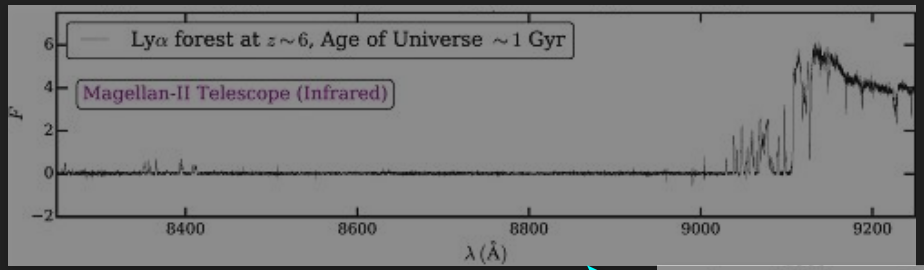
- $dN/dz \propto (1 + z)^{\gamma}$
- dN/dz will decrease towards decreasing redshift. Evolution in the **ionizing background** will also affect the number of absorption systems lying above the column density threshold, and this is a major factor in the evolution of dN/dz. Some evolution is expected as a result of the **expansion of the Universe**.
- Also, calculate effective optical depth and mean free path of IGM.

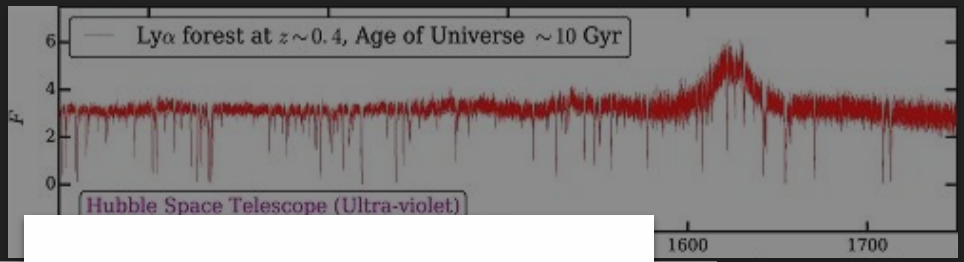




Spectra credit: Kavli Institute for Cosmology, Cambridge

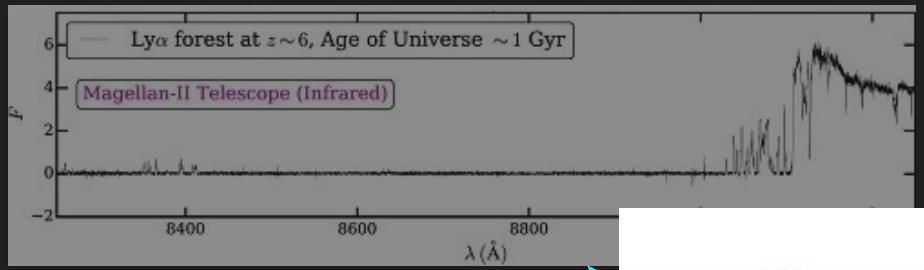


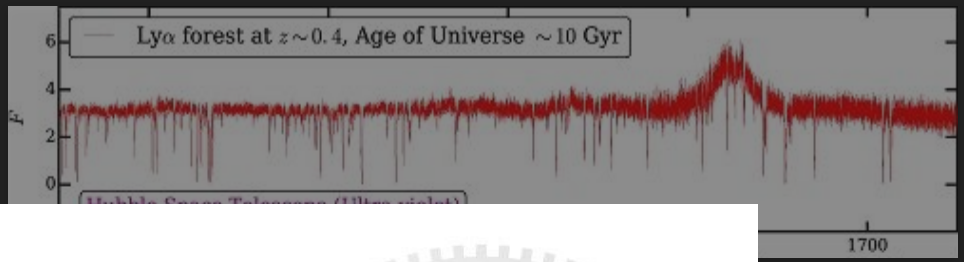




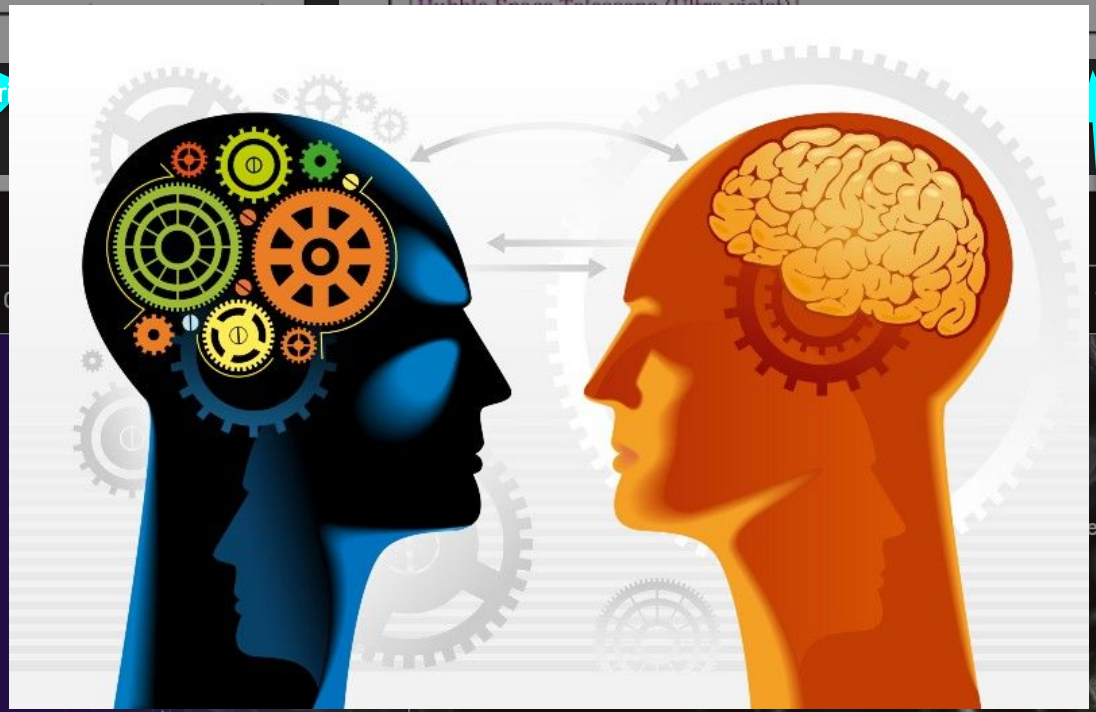
Spectra credit: Kavli Institute for Cosmology, Cambridge

https://www.google.com/url-history-of-big-bang-science



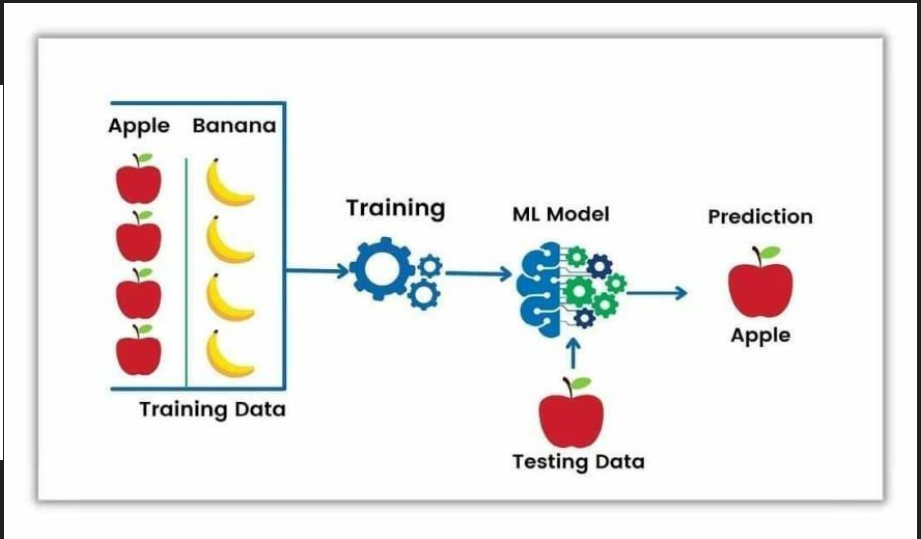


Spectra credit: Kavli Institute for Cosmology, Cambr

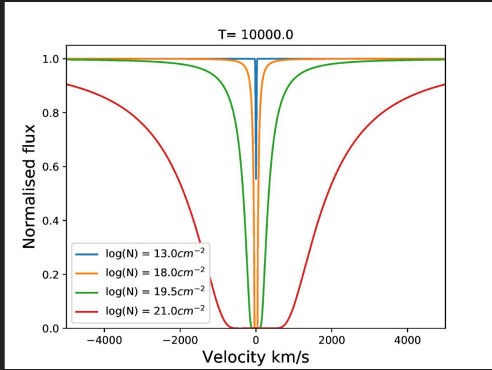


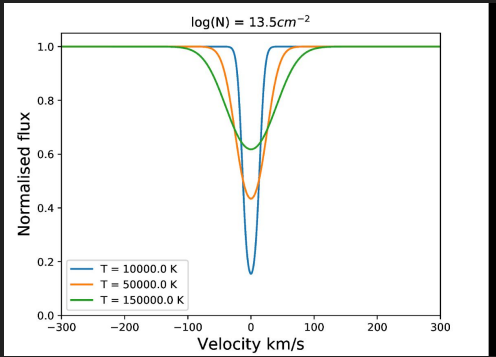
https://www.google.com/url-history-of-big-bang-science

Supervised machine learning



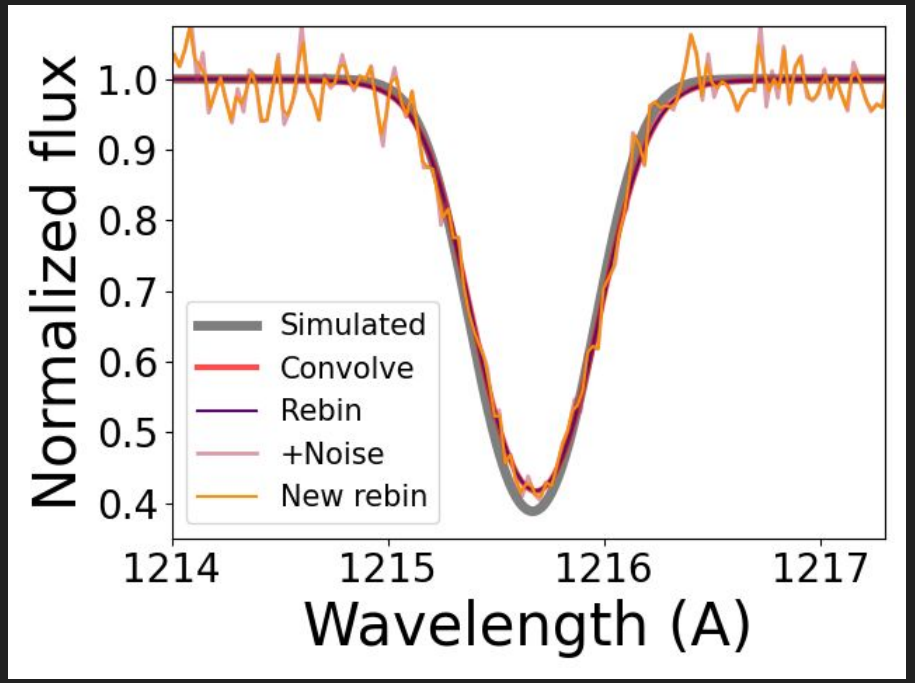
Simulated data

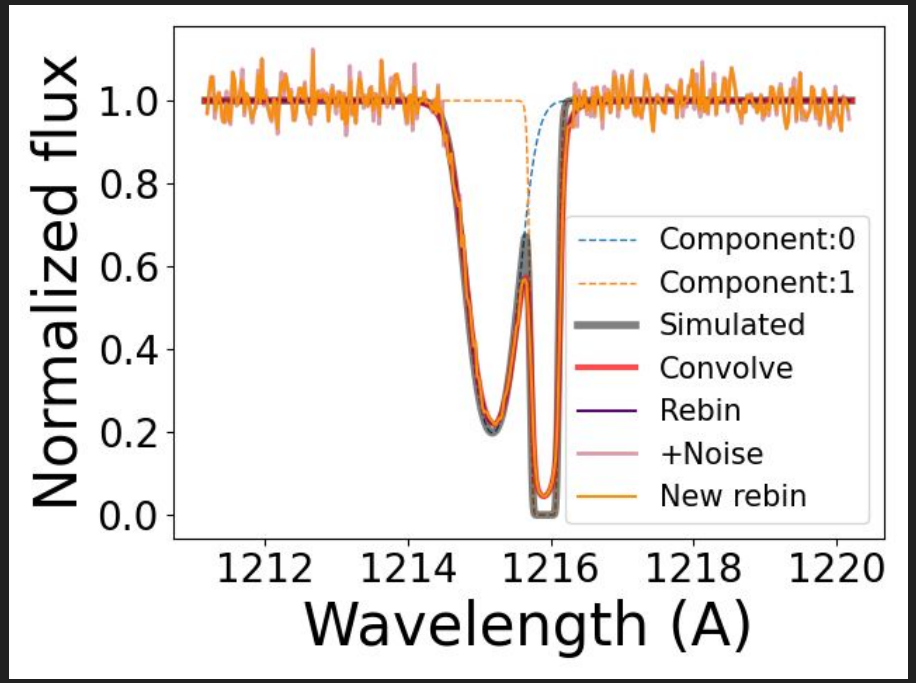




- We have **simulated training and testing datasets** for various column densities and temperature.
- We developed **machine learning algorithm** which will be trained using these training data sets and verified by using the testing data sets.
- We use this trained model to predict the parameters for the absorption lines in the **Lyα forest** for the real data observed from HST.

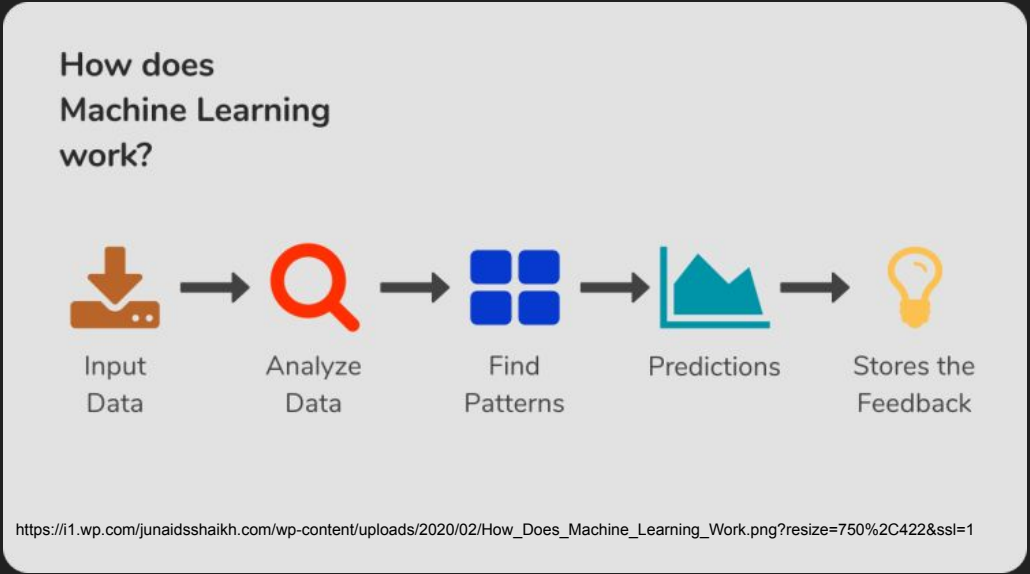
Simulated data as true as real data





Jalan et. al (2023) in prep.

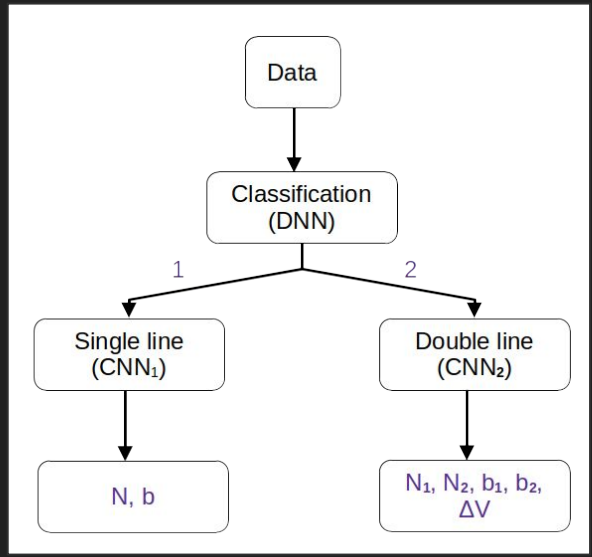
Machine learning



https://i1.wp.com/junaidsshaikh.com/wp-content/uploads/2020/02/How_Does_Machine_Learning_Work.png?resize=750%2C422&ssl=1

- We are going to use machine learning to **predict the b and N** parameters without actually fitting the voigt profile!!!
- What takes hours will be done in seconds!!!

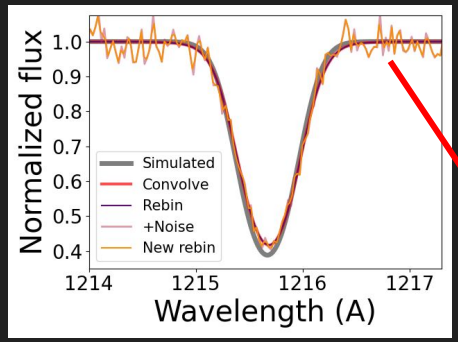
- How well the model is working depends how good it is predicted the true labels.
- Here we use two algorithms:
  - Classification: DNN
  - Regression: CNN



Jalan et. al (2023) in prep.

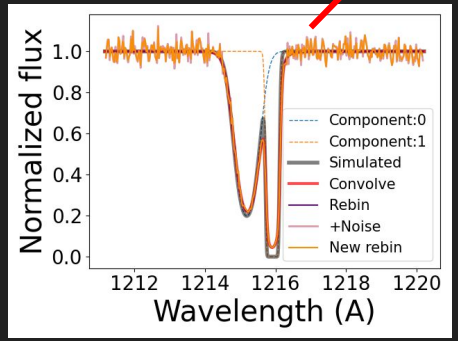
Classification algorithm

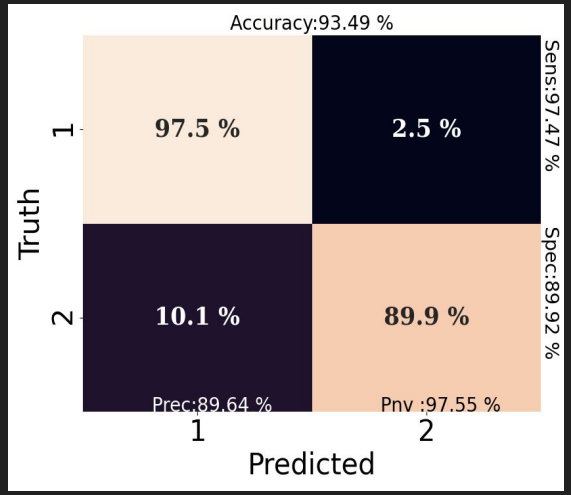
N_{true}=1



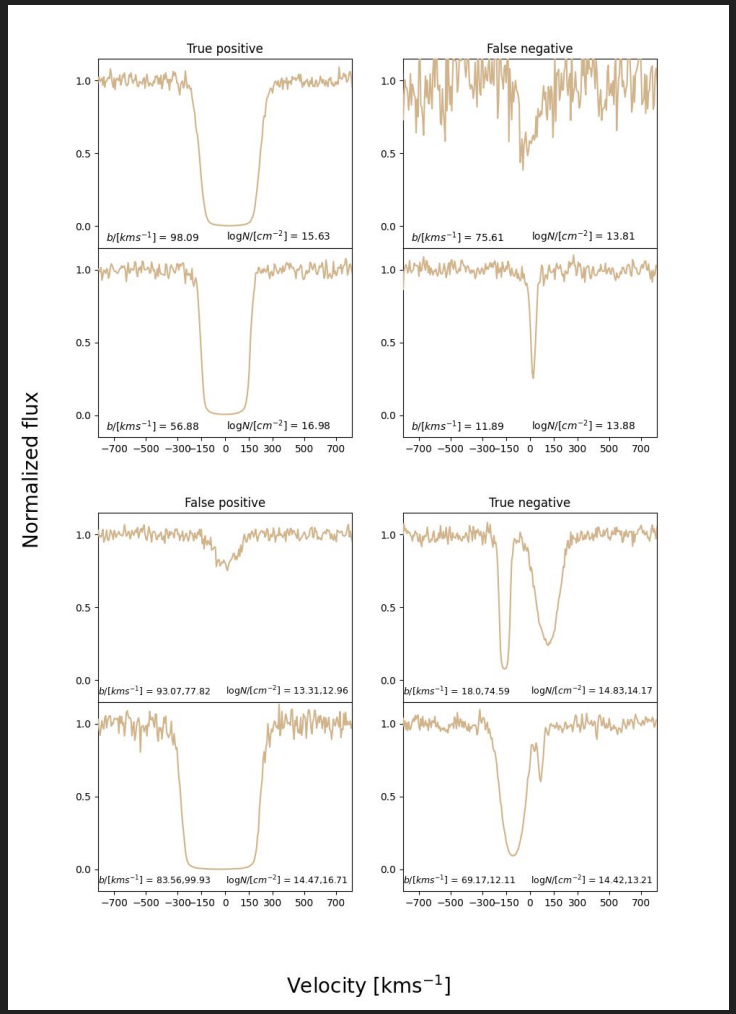
Normalised fluxes

N_{true} =2



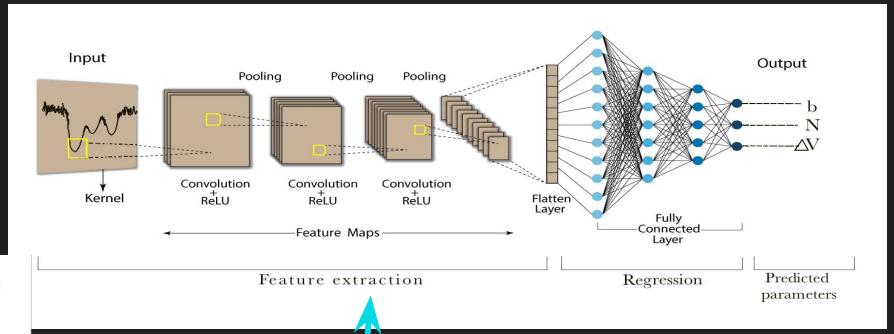


N_{pred} = 1 or 2



Jalan et. al (2023) in prep.

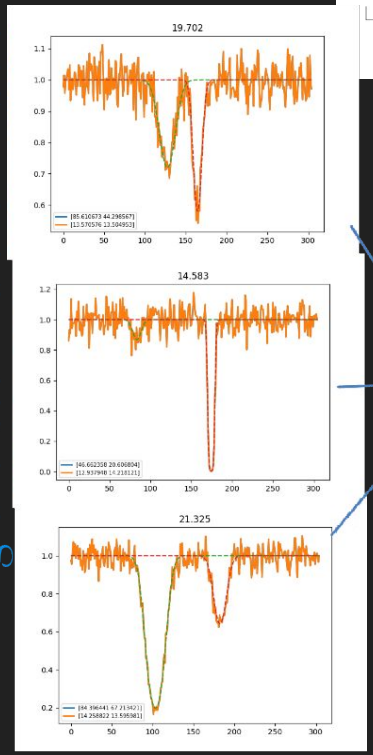
2.5 M dataset
80% training
20% testing



Column density
Doppler width
Velocity separation

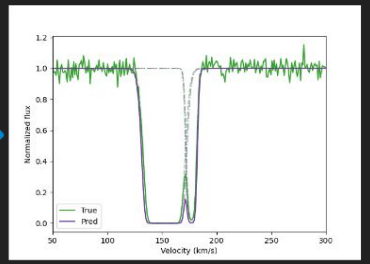
Prediction

Training dataset and their labels

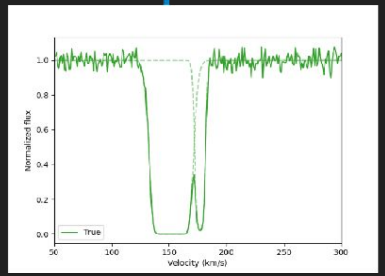


Model

Trained model



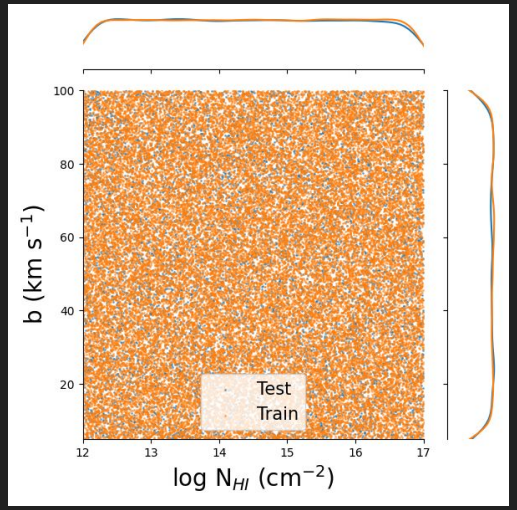
Optimizer: Adam
Activation fn: Leaky ReLU
Loss fn: MSE

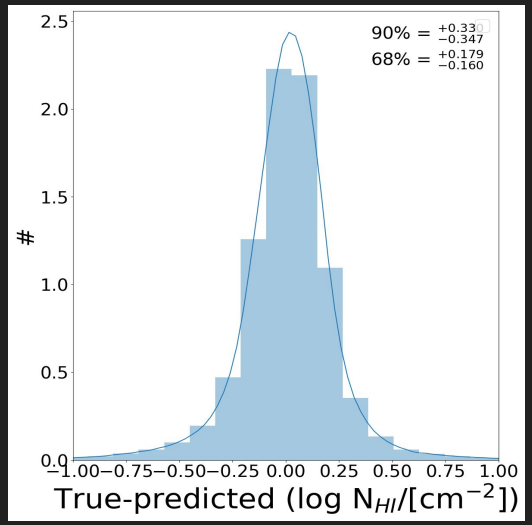


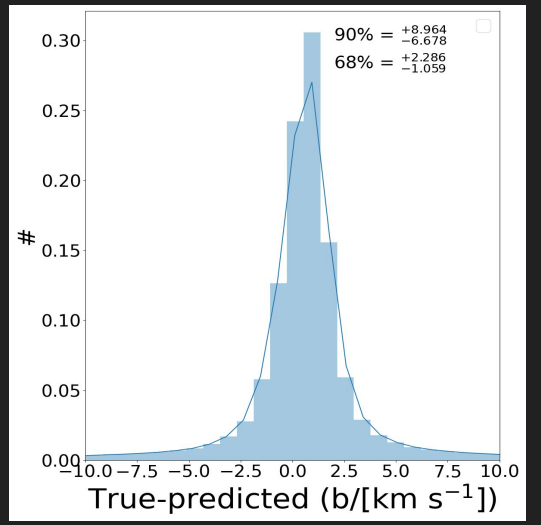
Testing data

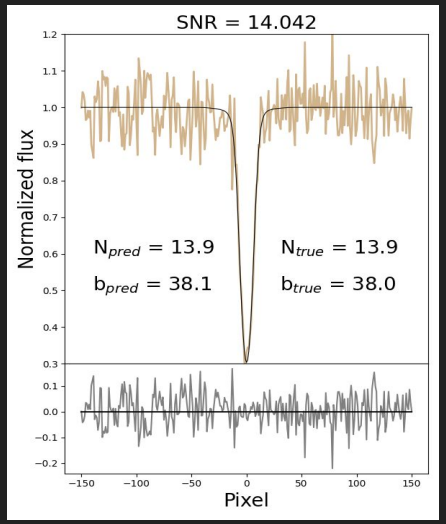
N=1 line

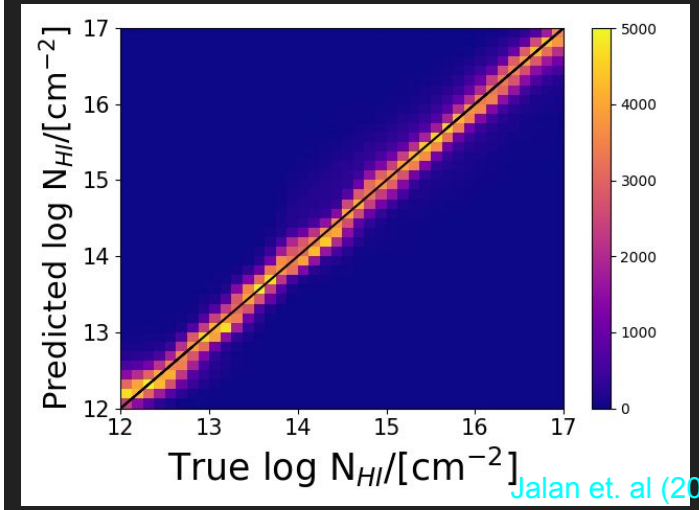
Training and testing dataset

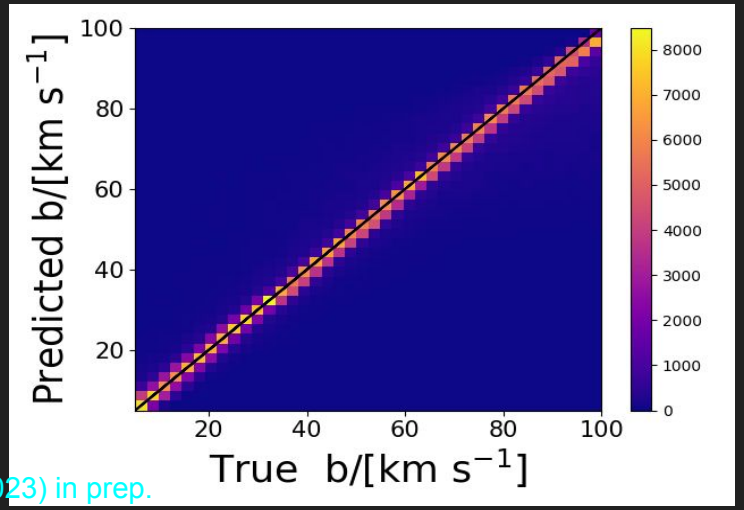




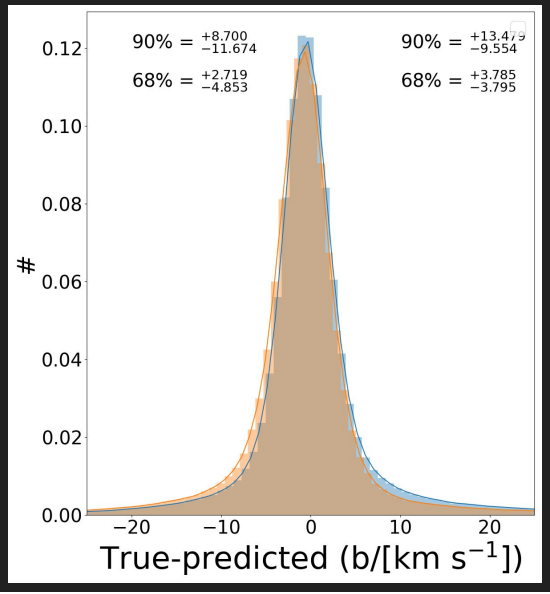


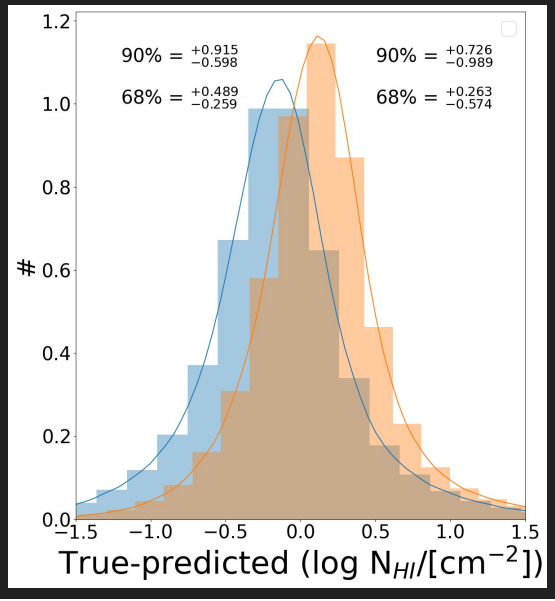


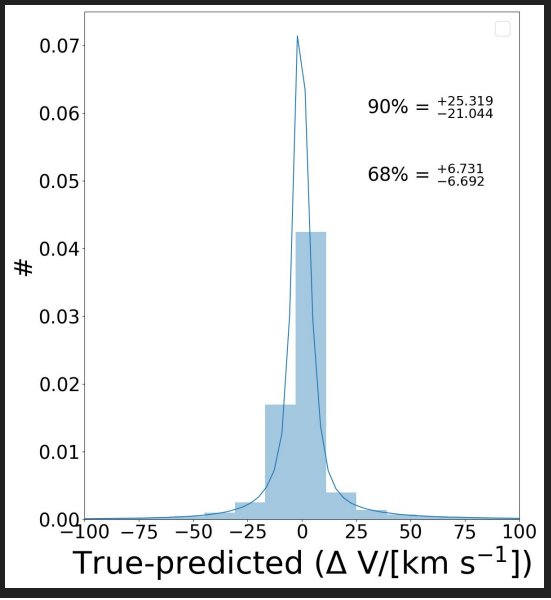


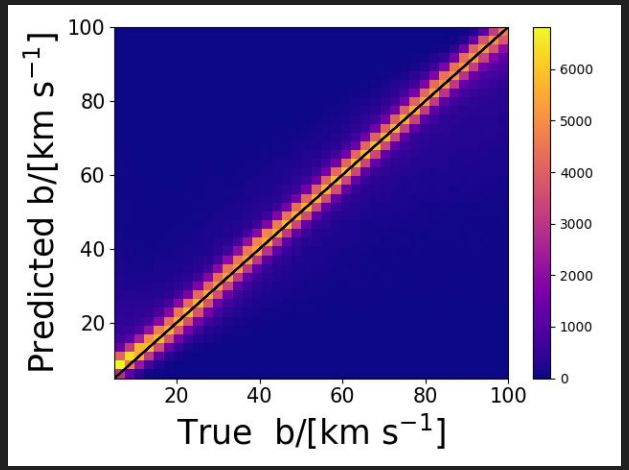


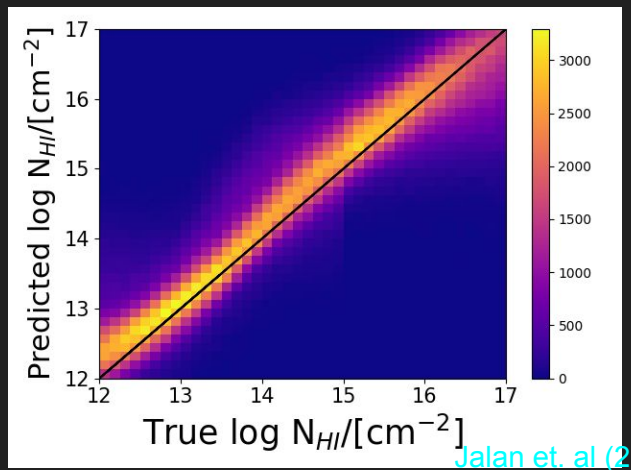
Jalan et. al (2023) in prep.

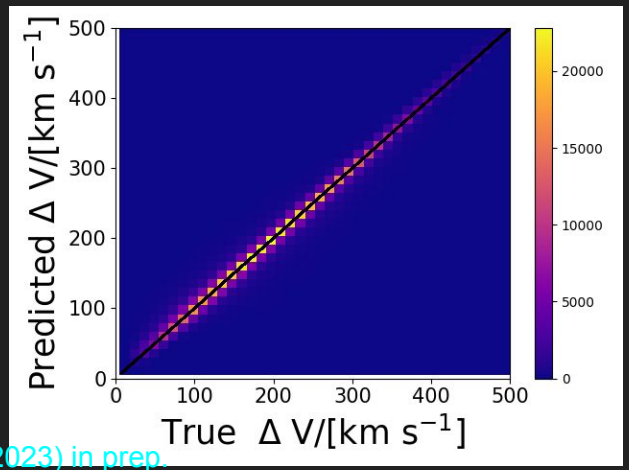








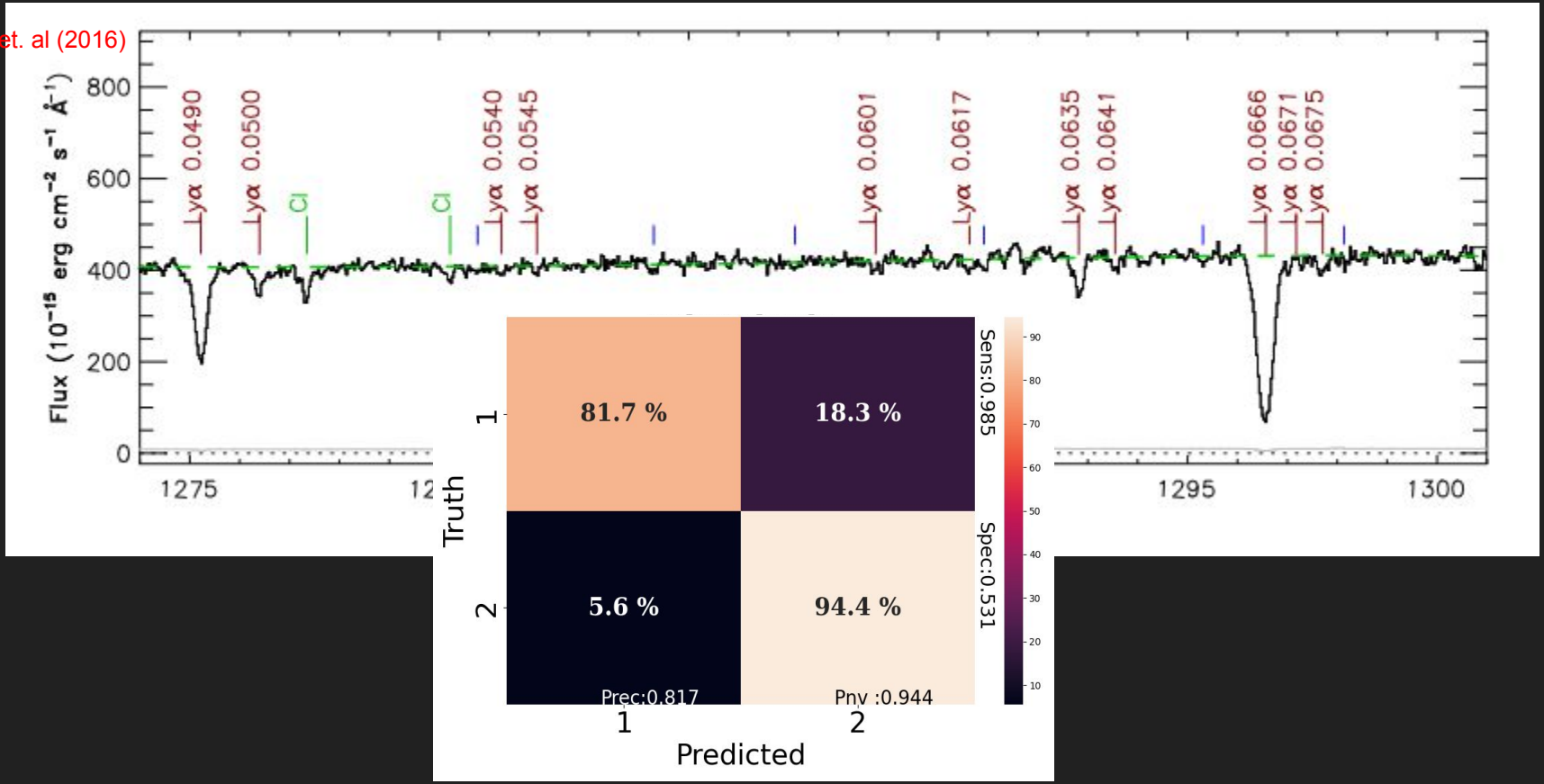




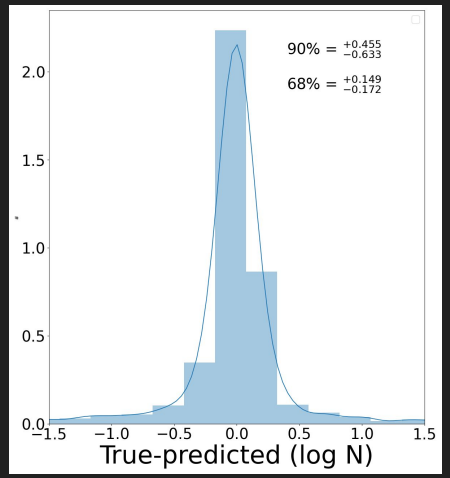
Jalan et. al (2023) in prep.

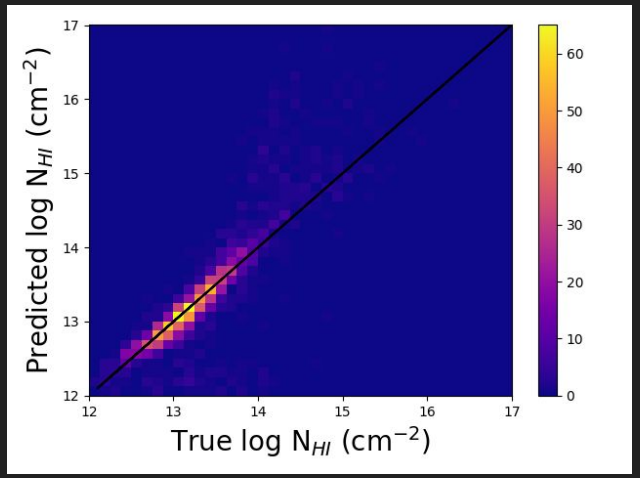
A trained model used to predict the parameters for real data

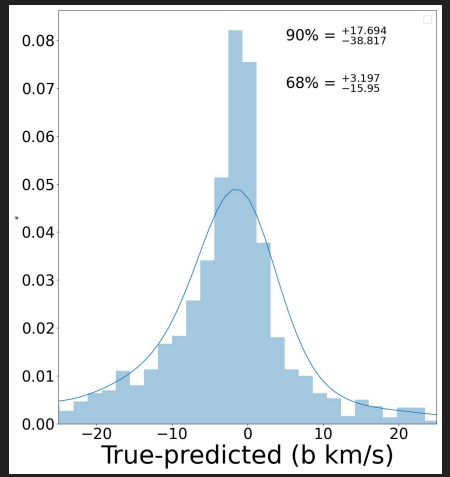
Danforth et. al (2016)

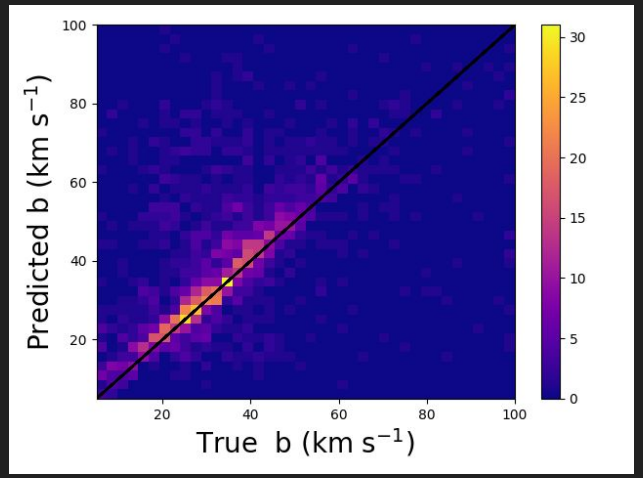


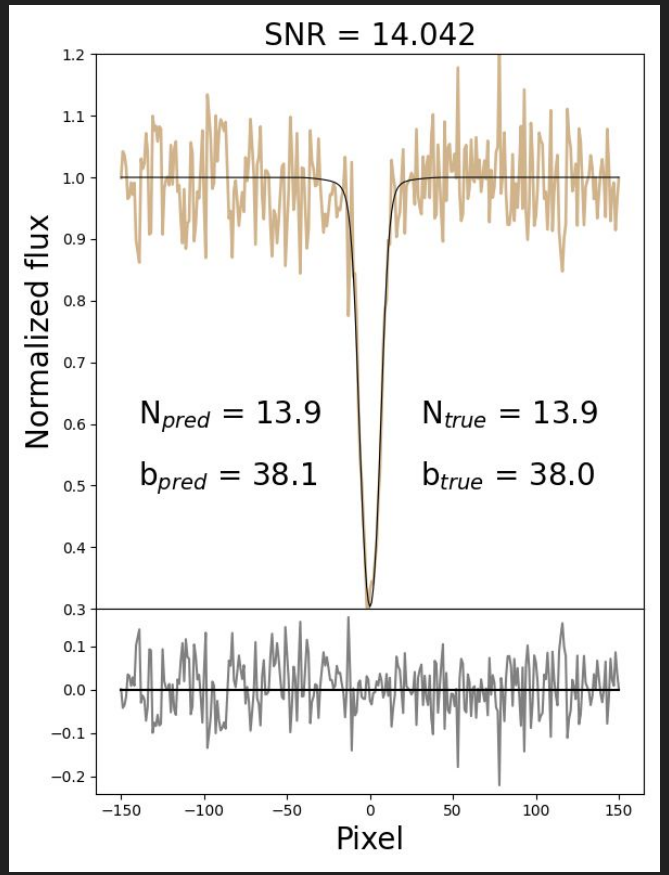
Real data N=1


90% = +0.455 −0.633
68% = +0.149 −0.172
True-predicted (log N)


Predicted log N_HI (cm^−2)
True log N_HI (cm^−2)


90% = +17.694 −38.817
68% = +3.197 −15.95
True-predicted (b km/s)


Predicted b (km s^−1)
True b (km s^−1)


SNR = 14.042
Normalized flux
N_pred = 13.9
b_pred = 38.1
N_true = 13.9
b_true = 38.0
Pixel

Summary

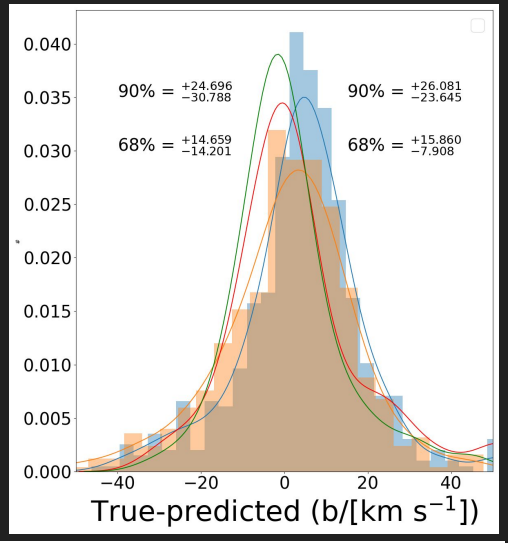
1. We have developed a **deep neural network** to classify the number of absorption lines and found accuracy of 94%.
2. We have developed a **convolutional neural network** to estimate the parameters of the absorption lines for simulated data and find the predicted values consistent with true values
3. We tested these algorithms on quasar spectra observed by HST (Danforth et. al 2016).
4. We find that the classification algorithm for real observed data has accuracy of 90%.
5. The **caveat** is presence of two absorption lines with same absorption redshift are identified as one.
6. The parameters estimated for correctly identified absorption lines are consistent with true values estimated by manual fitting and semi-automated codes from **Danforth et. al (2016)** and **Prakash et. al (2018)**.

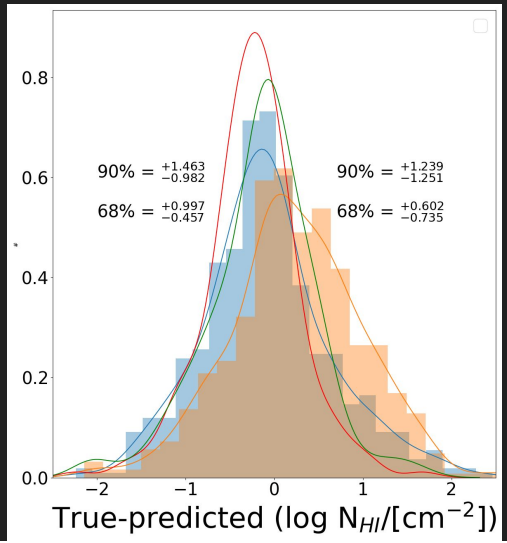
For more detail contact me on pjalan@cft.edu.pl

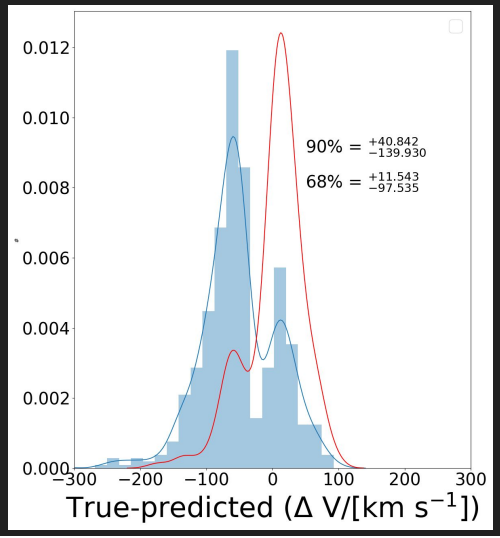
Why did the machine learning model go to the therapist?

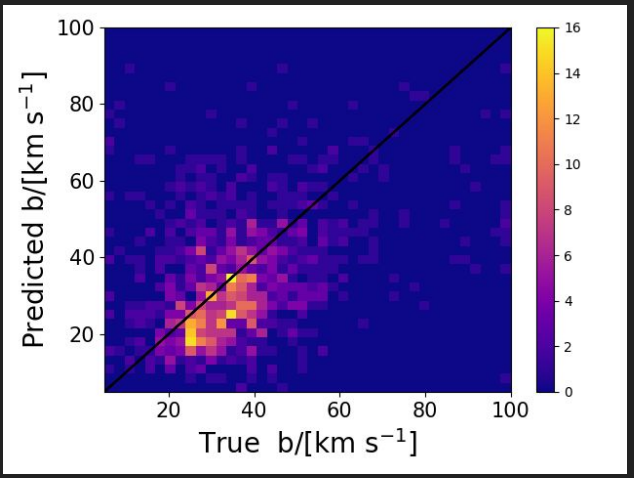
Because it had too many hidden layers and couldn't express its emotions properly!

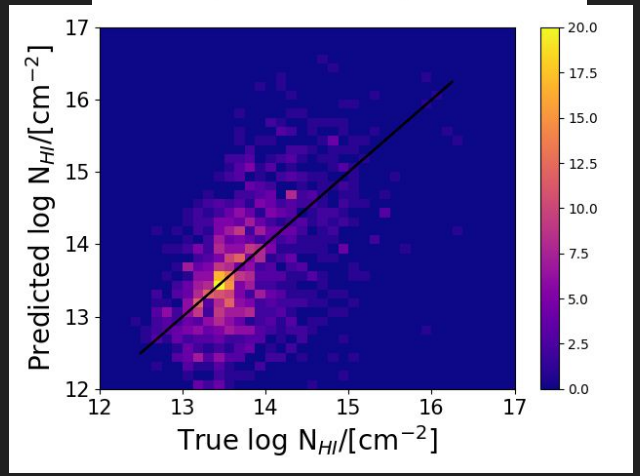
Real data N=2

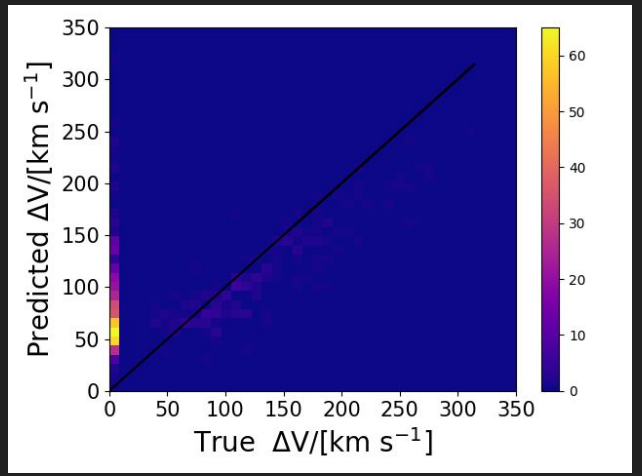

90% = +24.696 −30.788
68% = +14.659 −14.201
90% = +26.081 −23.645
68% = +15.860 −7.908
True-predicted (b/[km s^{-1}])


90% = +1.463 −0.982
68% = +0.997 −0.457
90% = +1.239 −1.251
68% = +0.602 −0.735
True-predicted (log N$_{HI}$/[cm^{-2}])


90% = +40.842 −139.930
68% = +11.543 −97.535
True-predicted (Δ V/[km s^{-1}])


Predicted b/[km s^{-1}]
True b/[km s^{-1}]

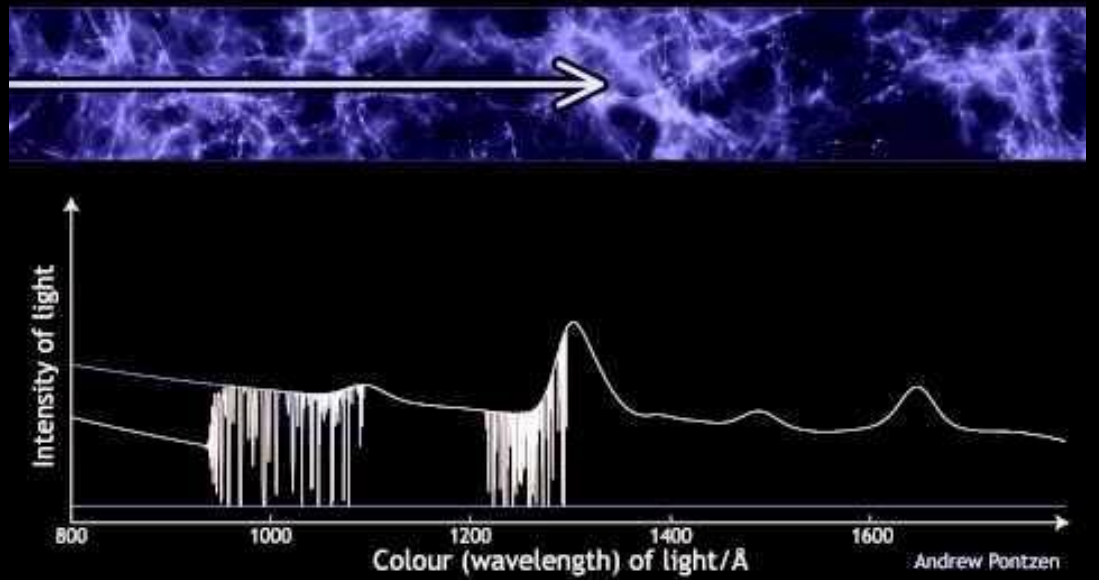

Predicted log N$_{HI}$/[cm^{-2}]
True log N$_{HI}$/[cm^{-2}]


Predicted ΔV/[km s^{-1}]
True ΔV/[km s^{-1}]

Quasar Spectra

As the radiation passes from quasar through the intergalactic medium towards the observer the imprint of the material is available in the quasar spectra.

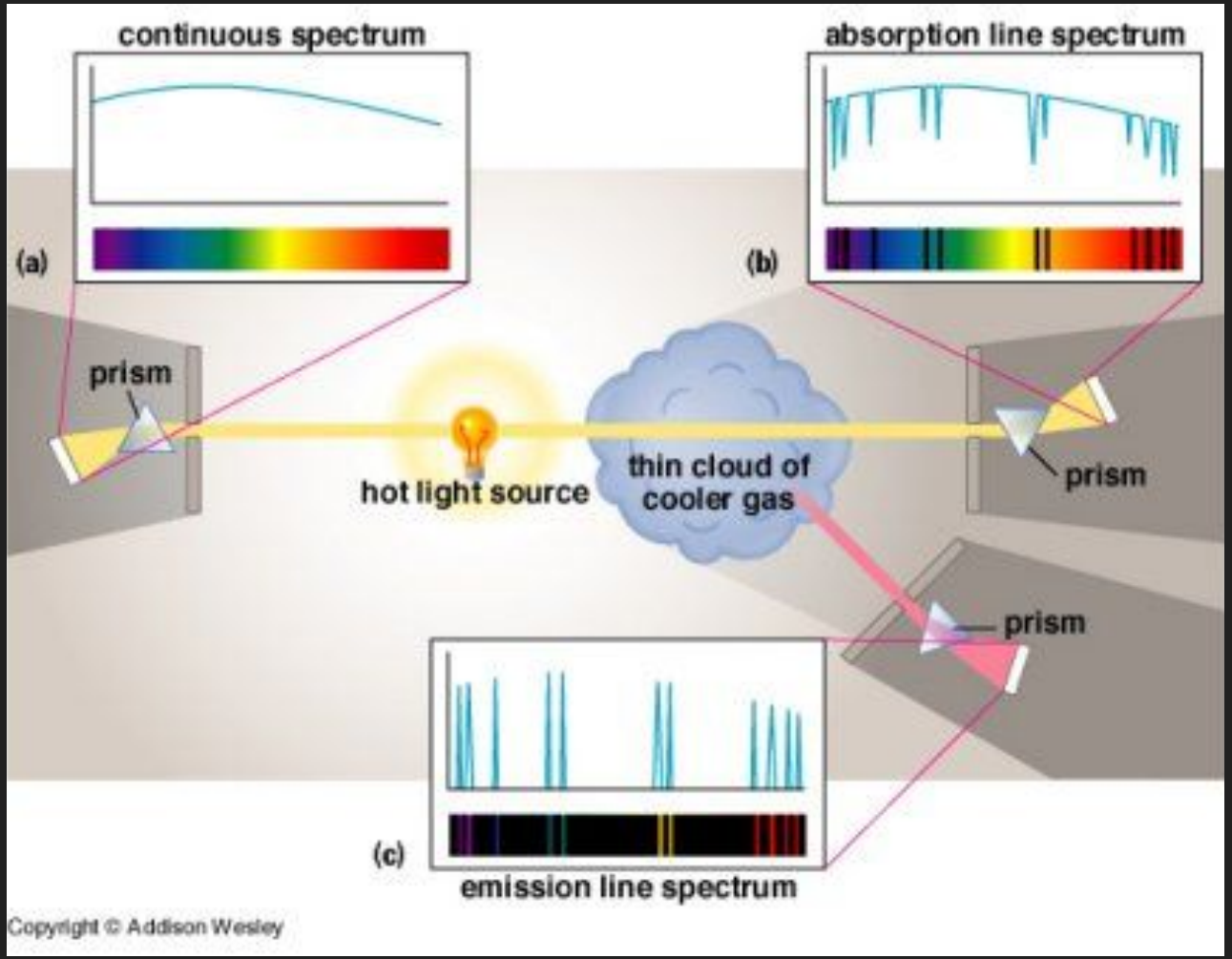
- Absorption: as long as emission source is there we will see absorption
- Can be traced to very high redshifts
  - Redshift = $\lambda_{obs}/\lambda_{rest}$ -1
- IGM is ionized by the **UVB radiation** (1 particle in 1 cubic meter and 1 particle in 10^4 is neutral).

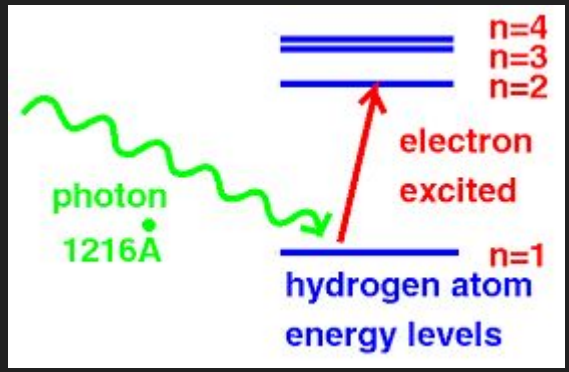


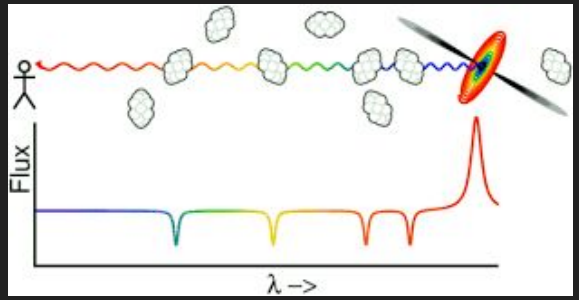
Extra slides

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}(y_i - \tilde{y}_i)^2$$

- AI is the overarching term for algorithms that examine data to find patterns and solutions. Artificial intelligence resembles the human ability to problem solve. Most AI projects use either machine learning or deep learning.
- Machine learning is a type of artificial intelligence that uses data and an algorithm to solve one or more problems.
- Deep learning is an advanced type of machine learning that uses neural networks to learn and make predictions using unstructured data.


continuous spectrum
absorption line spectrum
(a)
(b)
prism
hot light source
thin cloud of cooler gas
prism
prism
(c)
emission line spectrum
Copyright © Addison Wesley


n=4
n=3
n=2
electron excited
photon
1216Å
n=1
hydrogen atom
energy levels


Flux
λ –>