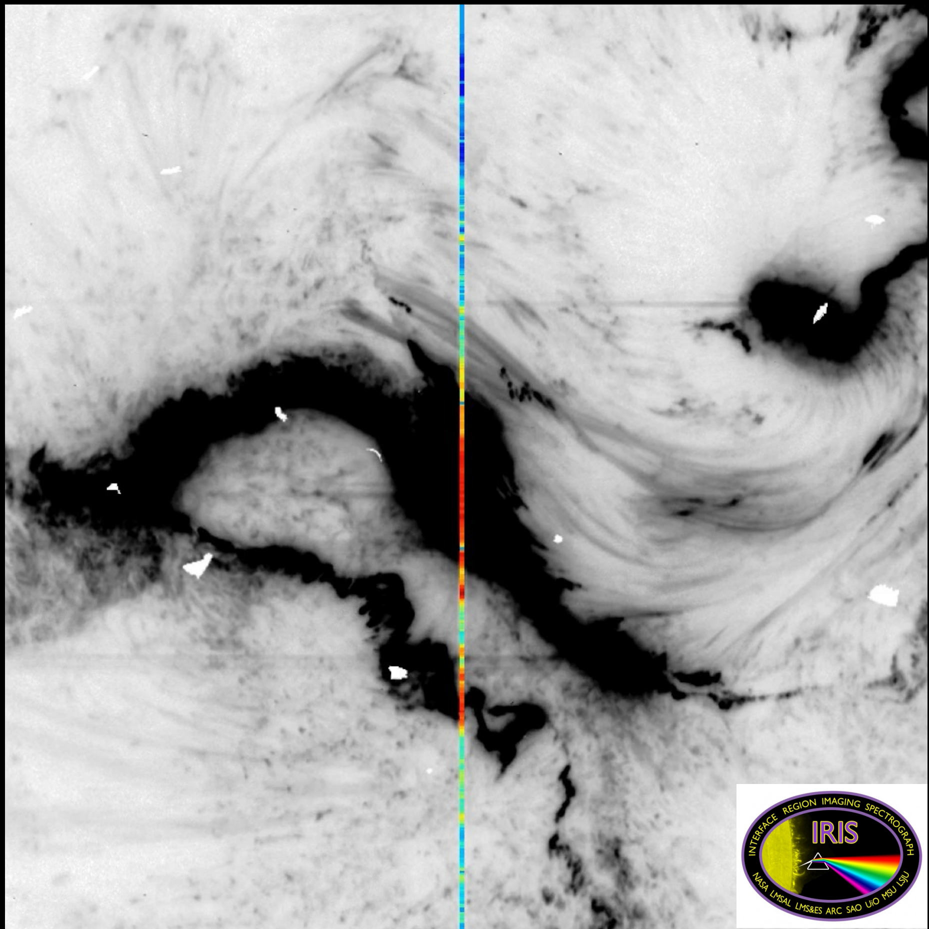

How well can we predict flares based on IRIS Mg II, Si IV, and CII spectra?

by

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University of Bern

Hinode-15/IRIS-12

Joint Science meeting

Prague

19-23 September 2022

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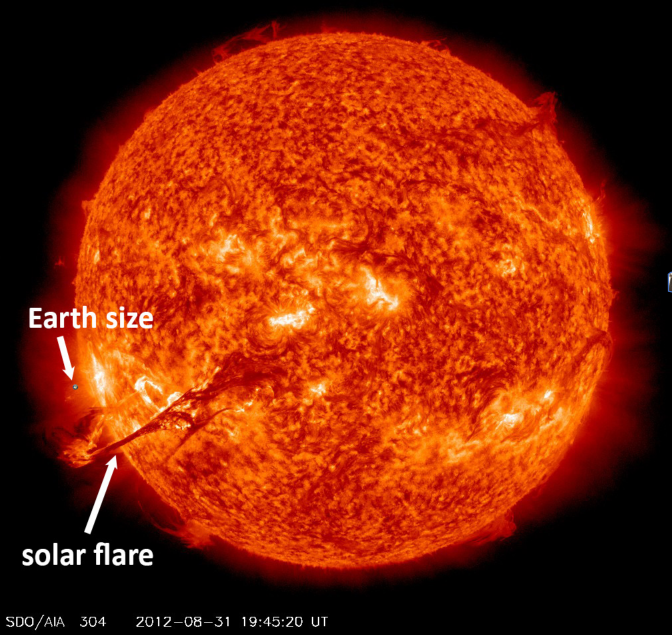
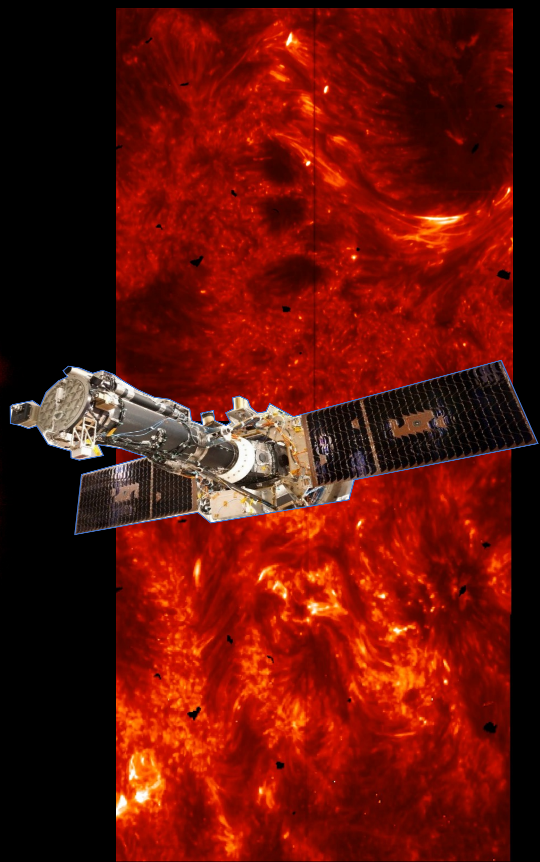
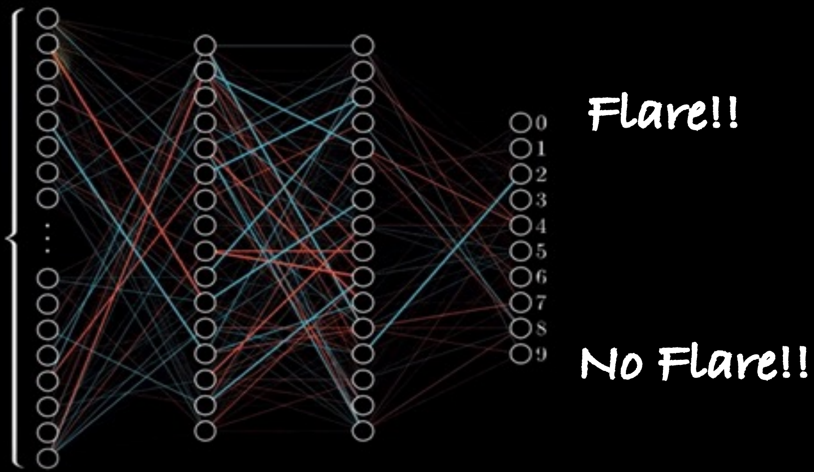
GOAL: Solar flare prediction with IRIS spectra







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State of the art

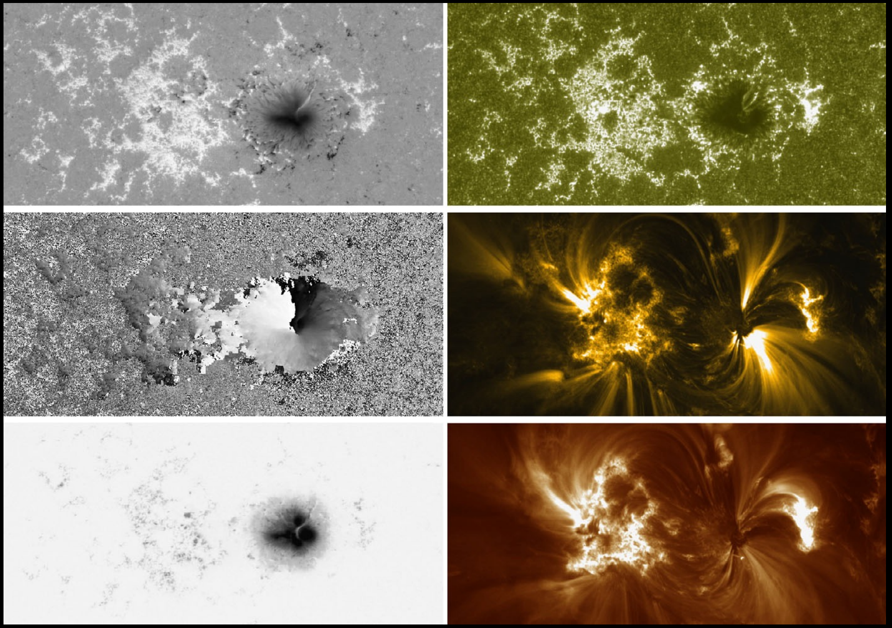
Prediction has previously been investigated with HMI and AIA

See for a summary: G. Barnes et al. 2016 or K. Leka 2019

HMI showed great potential for reliable solar flare prediction but only probing photosphere.

E. Jonas et al. 2018 probed AIA images to add more heights but has not improved predictions in general.

UV brightenings in AIA 1600 Å have been found to be a strong predictor for flares by Nishizuka et al. 2017



Why spectra?

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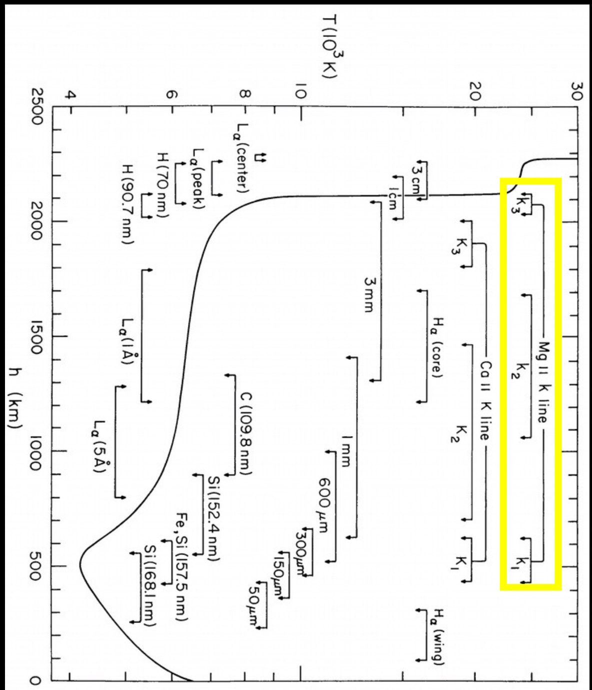
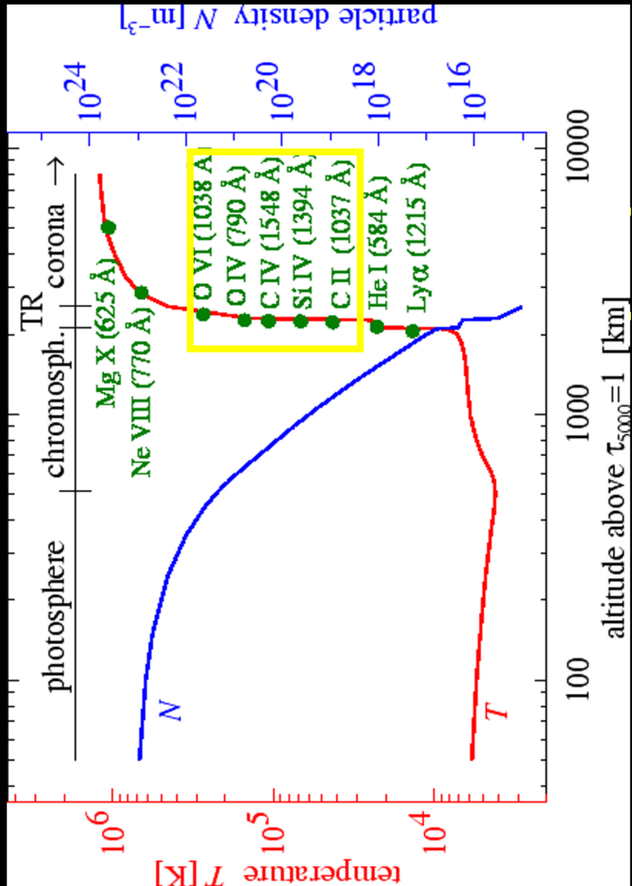
Why spectra?

Formation heights of IRIS spectral lines





Spectral lines contain information about the solar atmosphere at their formation height:

- Flows (Doppler shifts)
- Temperature
- Turbulence
- Density/Electron density

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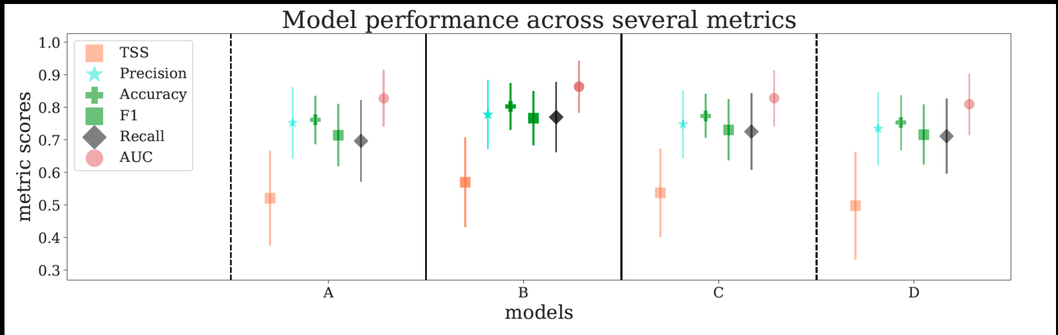
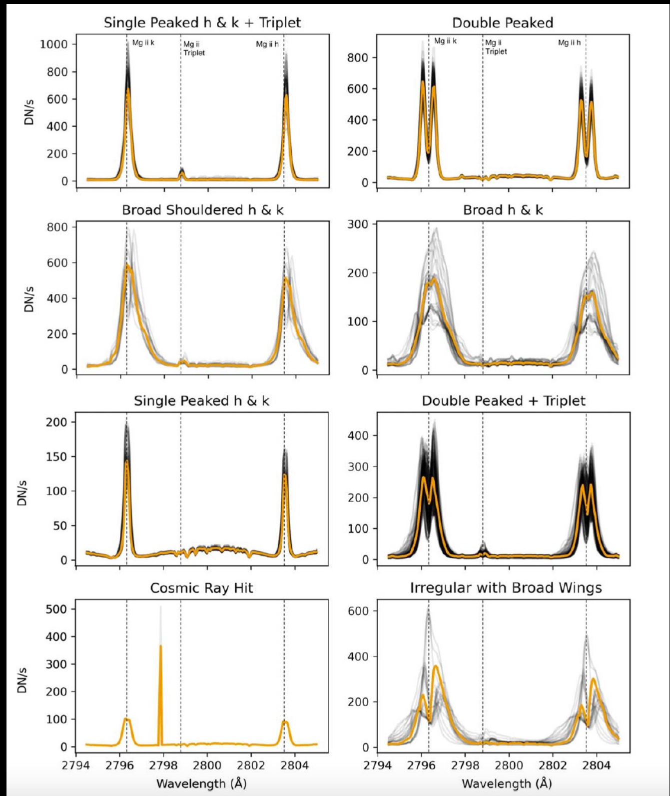
State of the art: Flare prediction with IRIS spectra



Proof of concept: Panos et al. 2020 showed prediction of flares possible on short timescales with Mg II h&k.



Common Preflare signatures: Woods et al. 2021 showed single peak profiles and triplet emission are frequent before flares.

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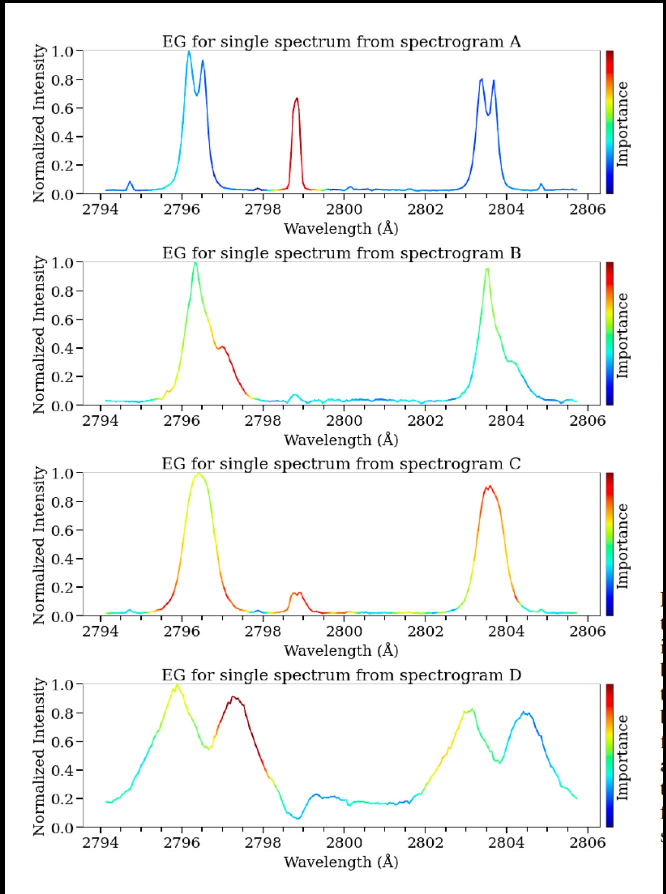
Talk Panos Brandon: Explainable solar flare prediction using IRIS Mg II spectra



- Triplet emission
- Single peaked spectra
- Downflows
- Asymmetric and broad spectra, (complex flows and turbulence)

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NEW:

- Investigate Si IV 1403, C II additionally to Mg II h&k
- More observations, 60 min preflare phase
- All flares reaching GOES-class >C5
- Combination of different spectral lines

Challenges:

- Unique observations, unique observing properties
- The models see spectra, not complete observations

→ Hard to generalize models

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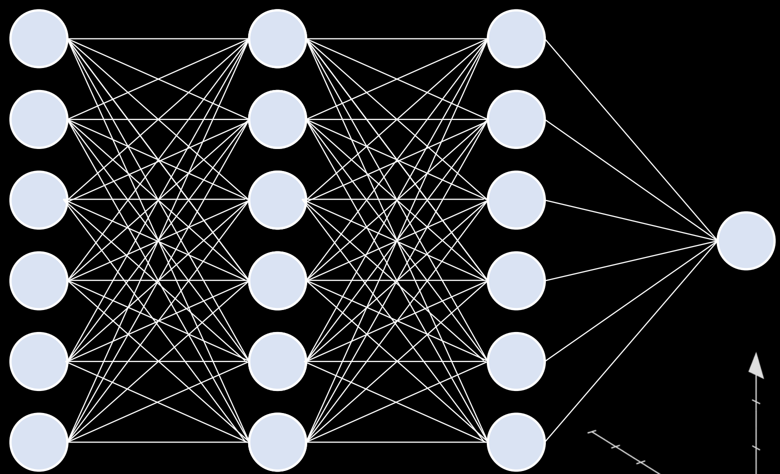
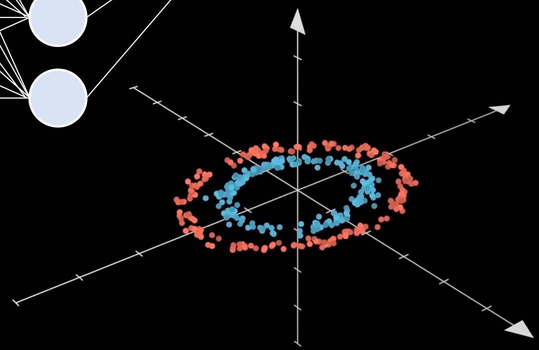
Neural Network (deep, fully connected)





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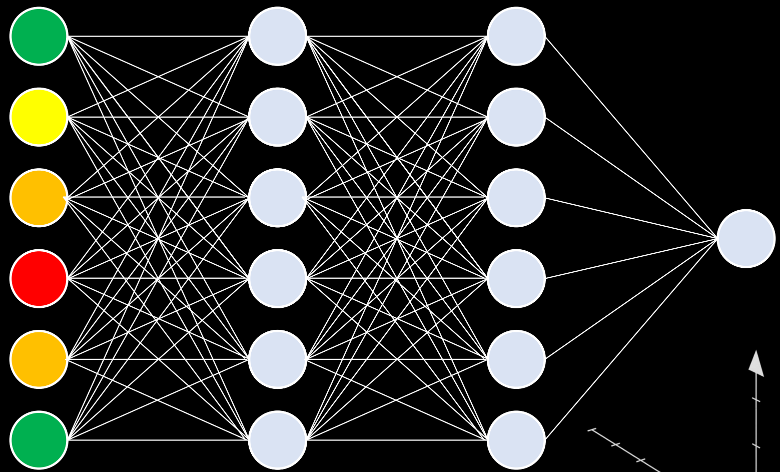
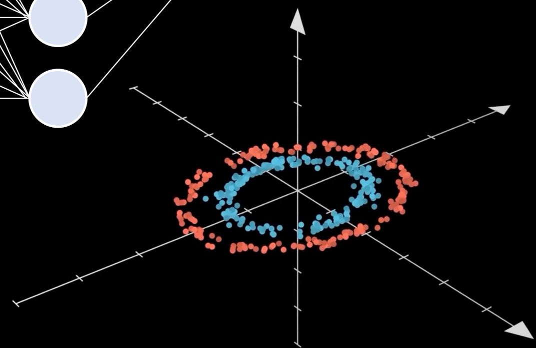
Sam Sartor: youtube.com/watch?v=CfAL_cL3SGQ

Neural Network (deep, fully connected)





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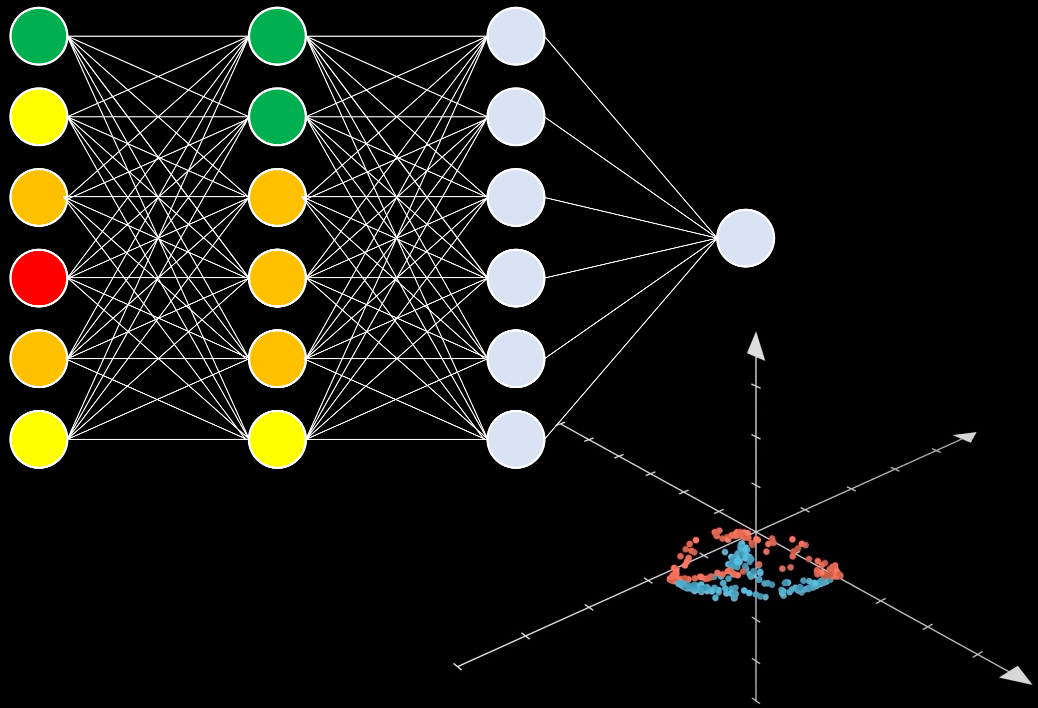
Neural Network (deep, fully connected)



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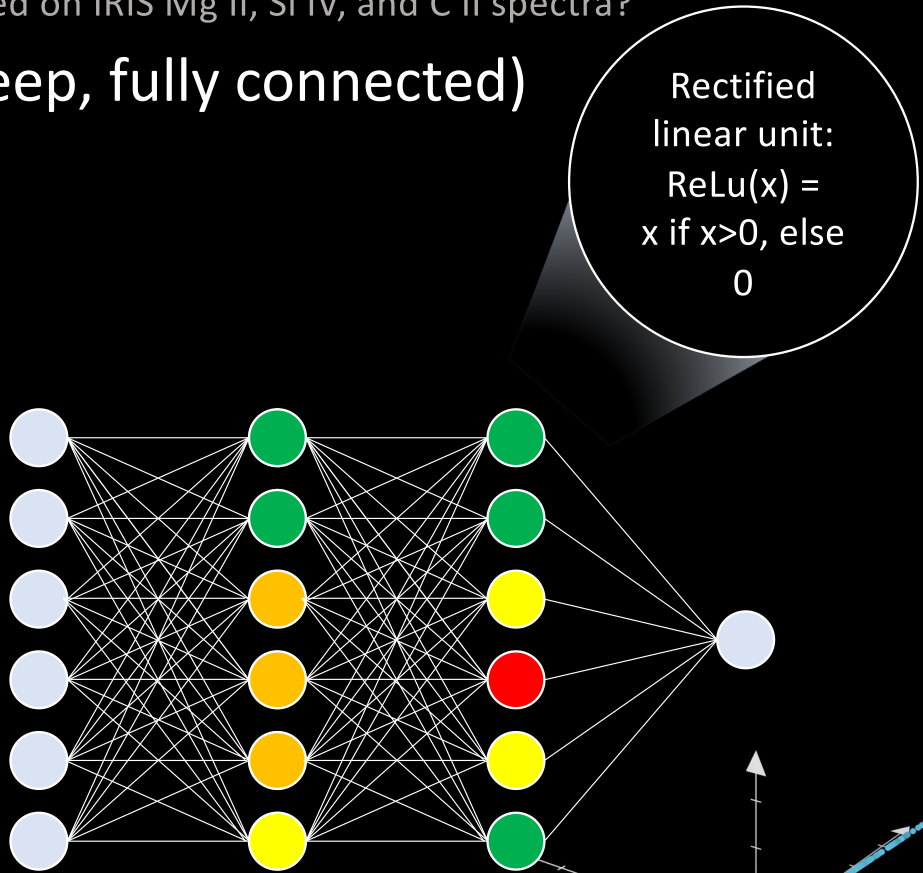
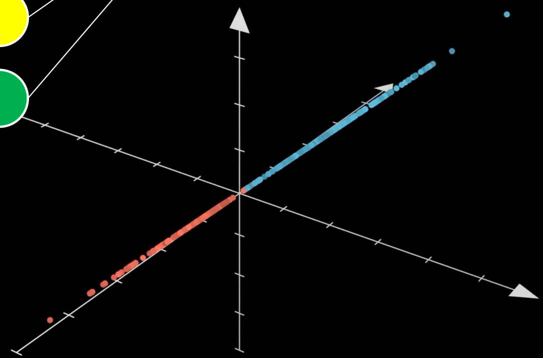
Neural Network (deep, fully connected)





Sam Sartor: youtube.com/watch?v=CfAL_cL3SGQ

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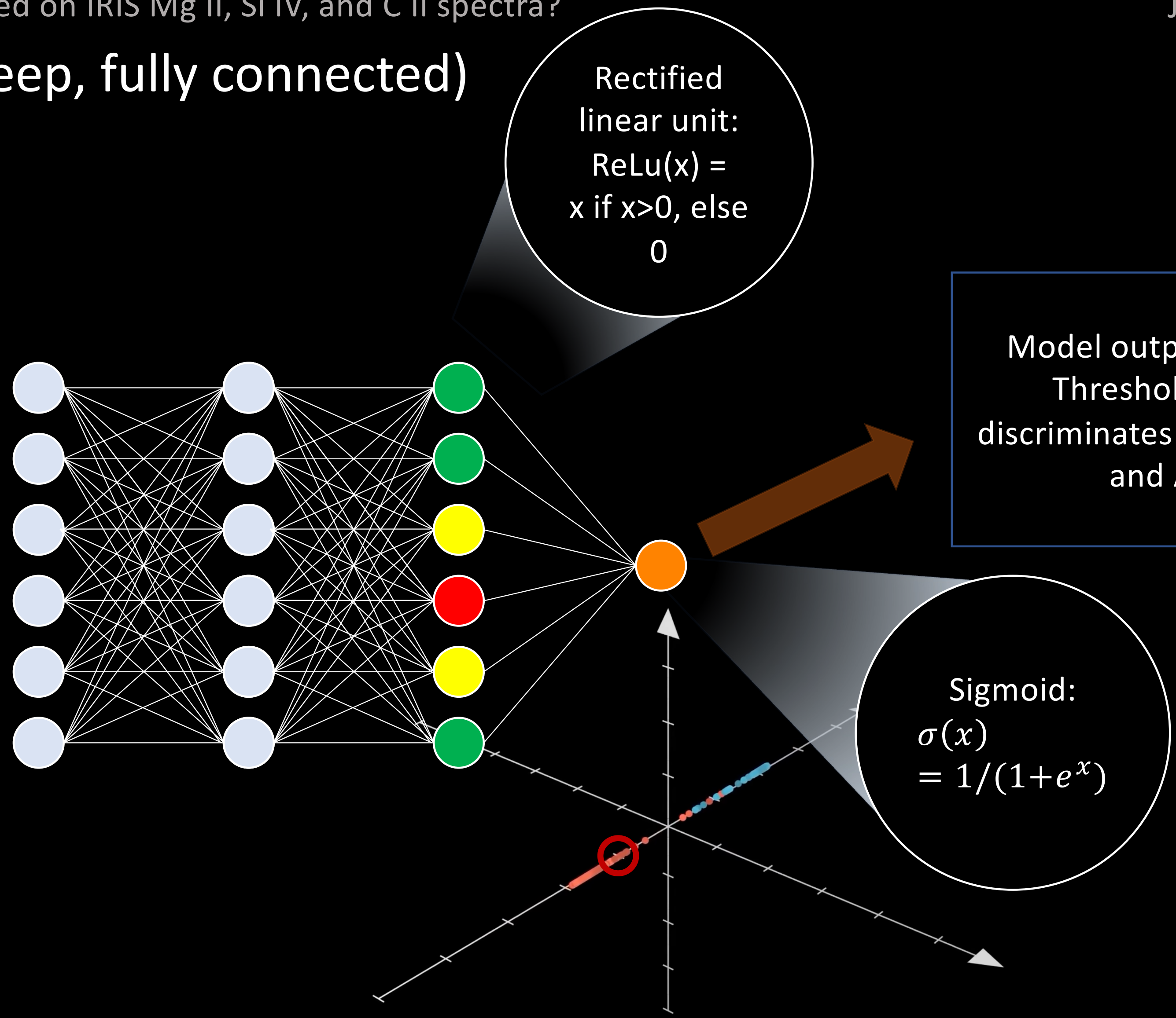
Neural Network (deep, fully connected)



Model output ∈ [0,1]
Threshold = 0.5
discriminates between PF
and AR.

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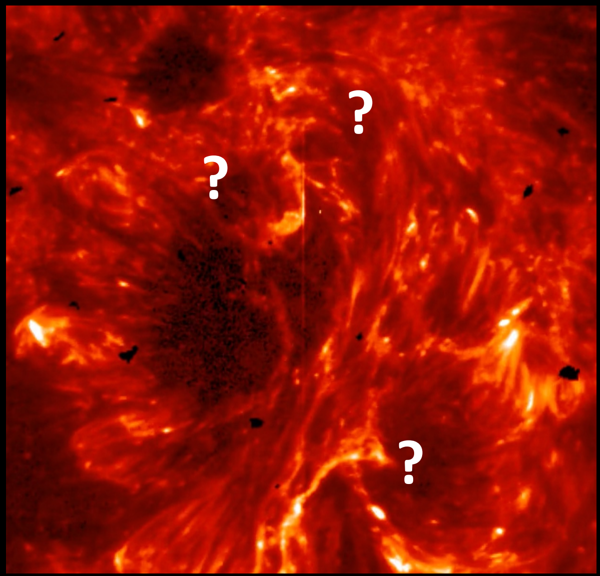
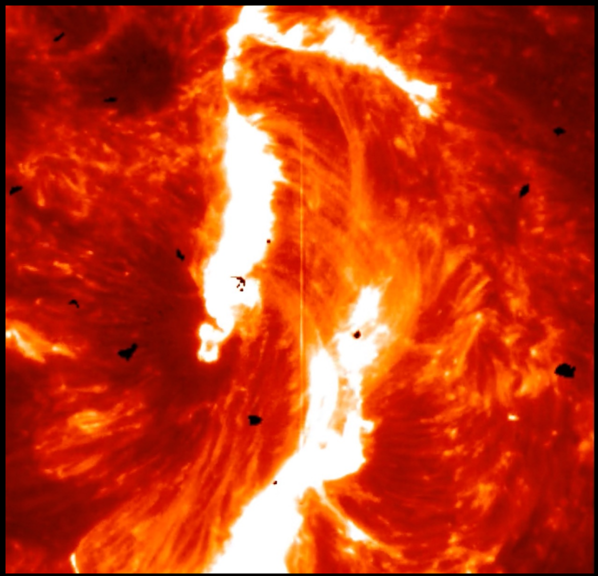
Masking

Problem: Where will the flare happen?





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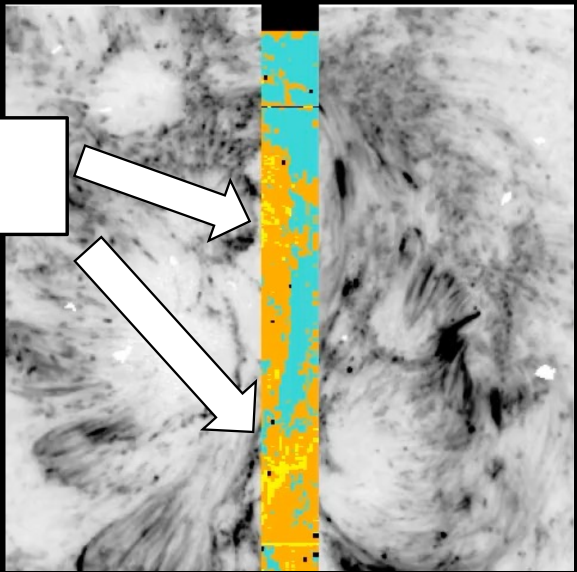
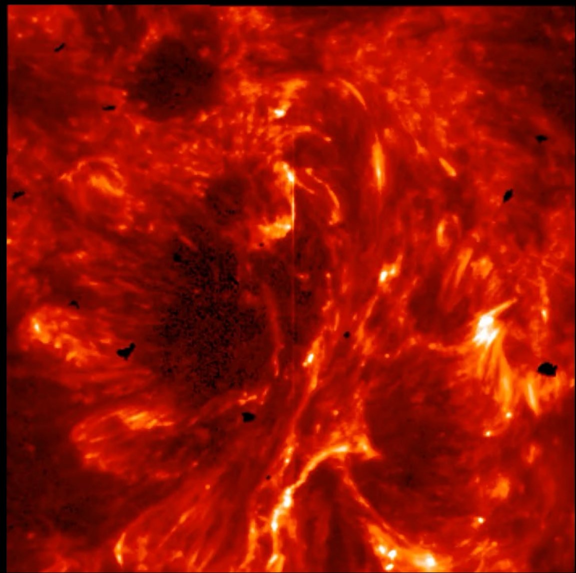
Masking

Find easy way to remove quiet Sun spectra from pre-flare and non-flaring active region observations

Orange and yellow areas are kept





Blue: Quiet Sun
Orange: less quiet sun
Yellow: Definitely not quiet sun

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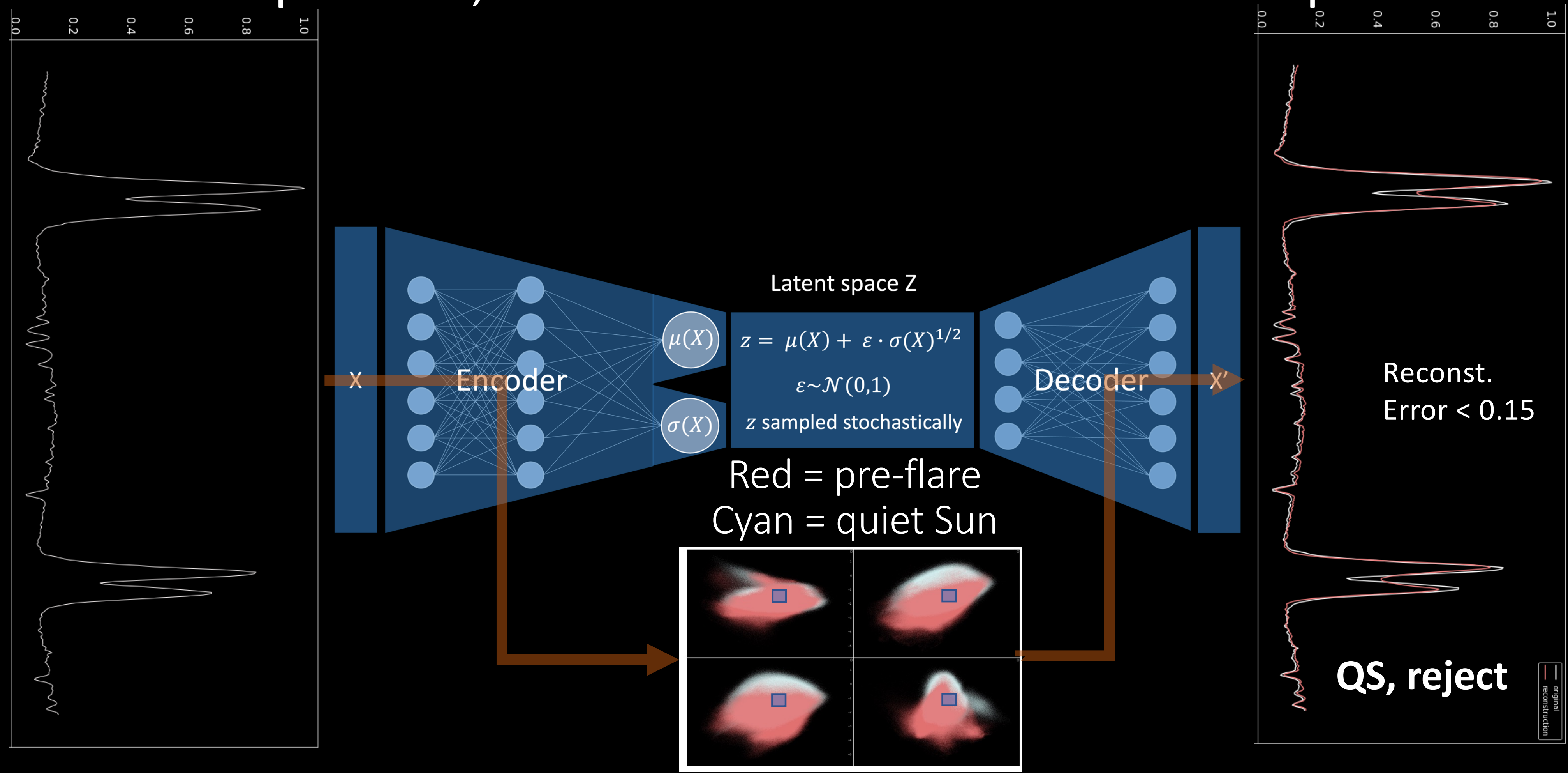
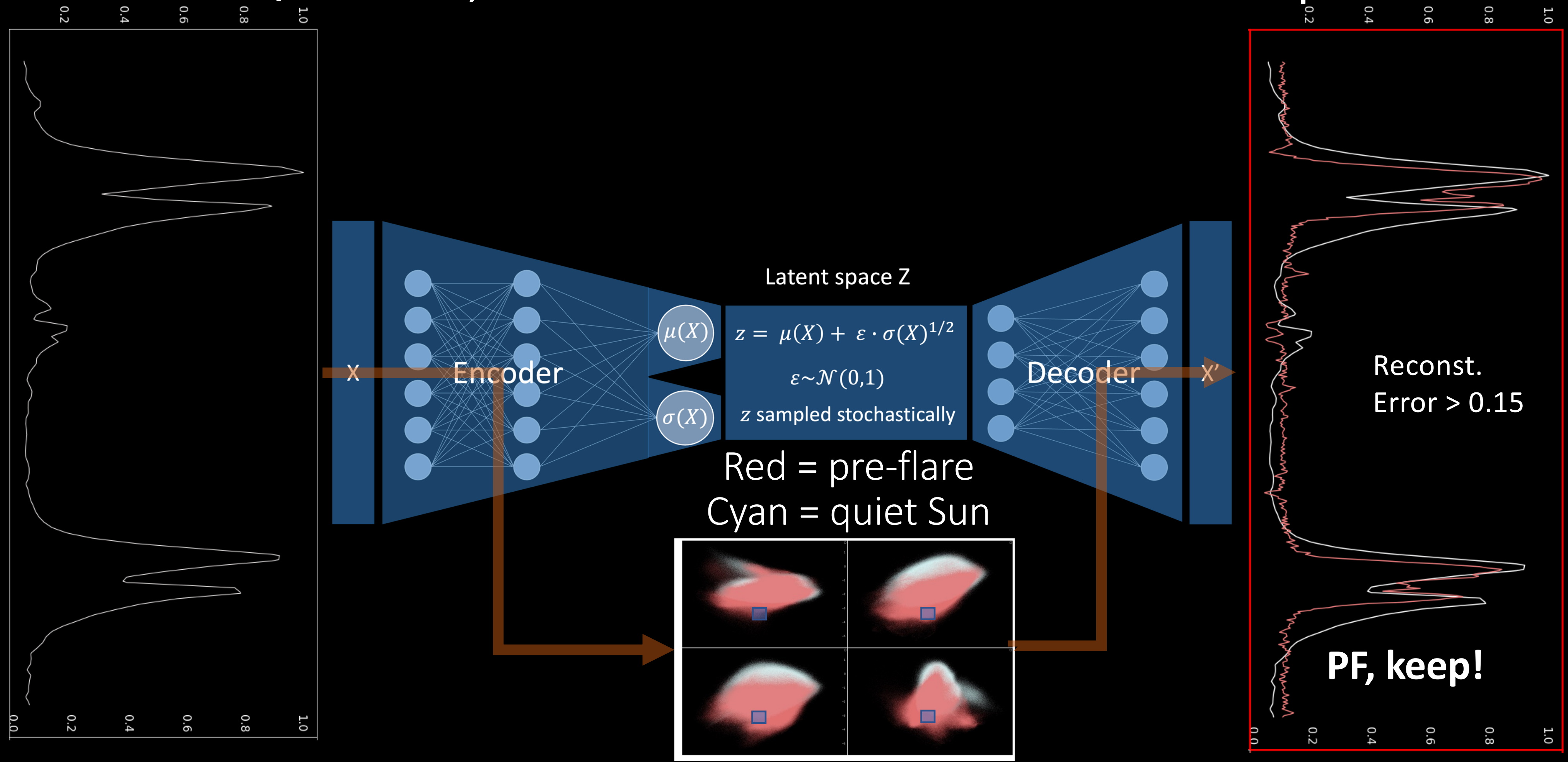
Variational Autoencoder

X = Spectrum, z = vector in 4-dimensional latent space

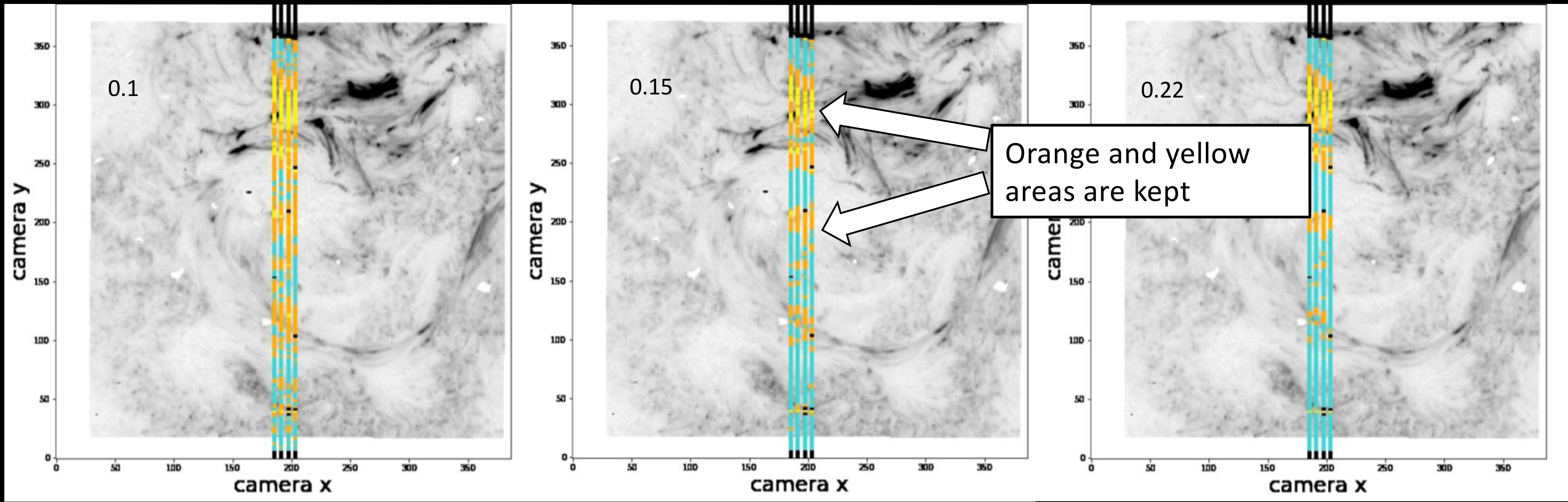


Variational Autoencoder

X = Spectrum, z = vector in 4-dimensional latent space



Choose reconstruction error threshold



Example PF

Experiments were conducted for thresholds = 0.15, = 0.22, and uncleaned datasets

Blue: rec error below threshold
Orange: threshold< rec_error < .4
Yellow: .4 < rec_error

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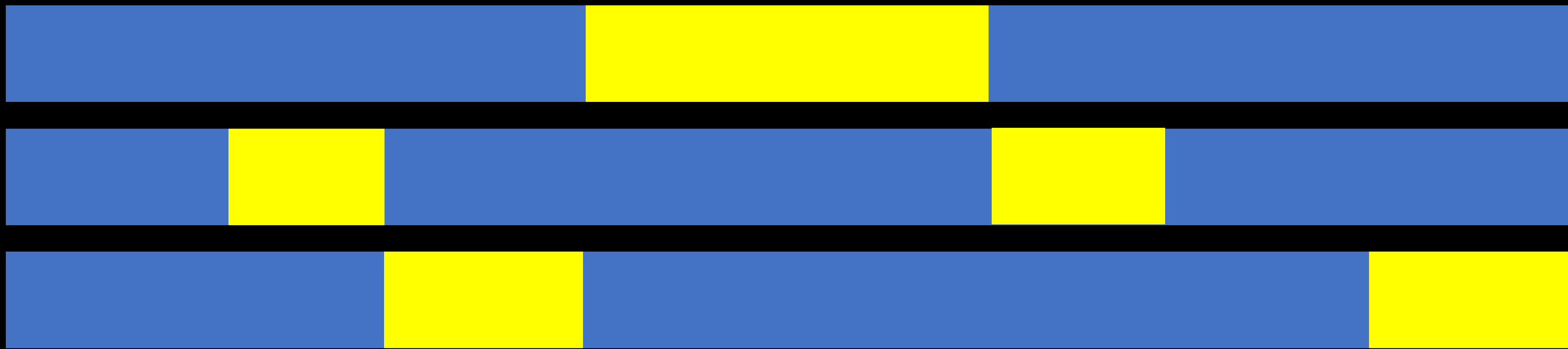
Prediction – Testing models

K- fold crossvalidation, Yellow: Testing set, Blue: Training set



...

Create observationally split sets to estimate true performance:

- 5 folds with disjoint testing sets
- 5 repetitions

→ 25 models

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Prediction – Testing models

Spectra labeled according to the observation class (PF:1 or AR:0)
Model outputs are rounded to 0 and 1.

Comparing labels and outputs we get the **Confusion matrix**:

True negative TN	False positive FP
False negative FN	True positive TP

$$\begin{vmatrix} TN & FP \\ FN & TP \end{vmatrix}$$

Class imbalance invariant score True Skill Statistics TSS:

$$\text{TSS} = \frac{TP}{FN+TP} - \frac{FP}{TN+FP} = \in [-1,1]$$

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Prediction – Testing models

$$\text{TSS} = \frac{TP}{FN+TP} - \frac{FP}{TN+FP} = \in [-1,1]$$

Score between -1 and 1

- 1: perfect predictions
- 0: random guessing
- -1: model is confused (opposite outputs to labels)

- On HMI data scores between roughly 0.5 and 0.75 have been achieved.
- Best score Panos et al. 2020: TSS ~ 0.6

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Data samples for training

Total number of observations:

- Preflare PF : 50, 73 flares, ~25 minutes - 1 hour before flare
- Active region AR : 30, 50+ hours

Experiments: 4 different Architectures

- Reduced set of observations: **Observations from previous studies for proof of concept**
  PF: 19 obs, 32 flares
  AR: 18 obs, ~40+ hours

- Full set of observations:
  PF: 50 obs
  AR: 30 obs

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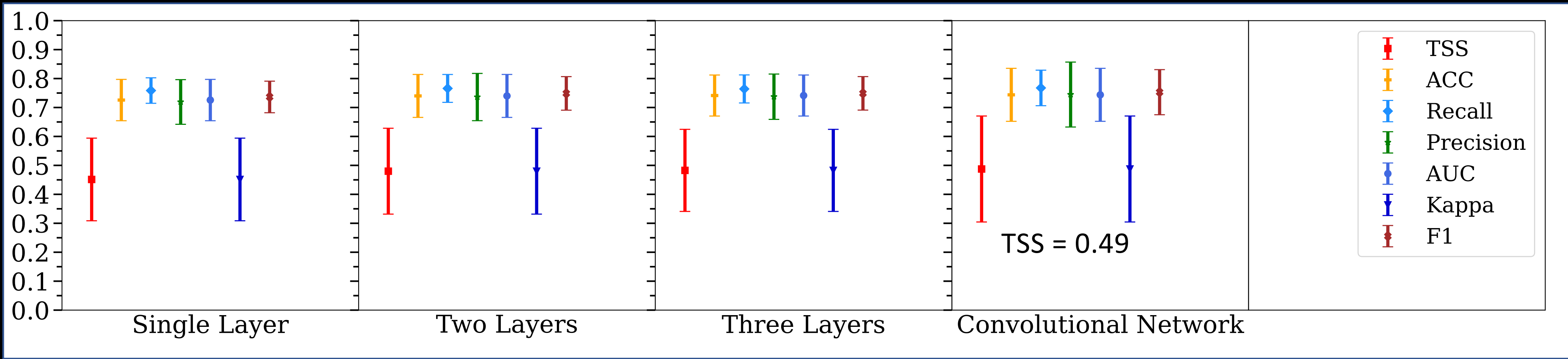
Prediction Scores – Results **Si IV 1403**



- Intensity mask, threshold = 1E+4 erg/(s cm^2 Hz rad)
- Best model Convnet **TSS = 0.49**
- Reduced set of observations

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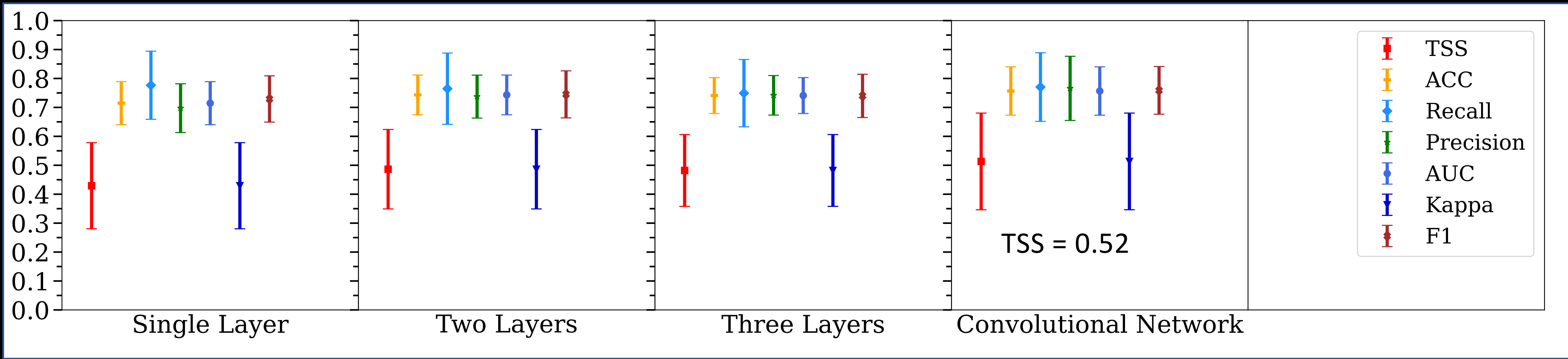
Prediction Scores – Results **C II**



- VAE threshold = 0.15
- Best model Convnet **TSS = 0.52**
- Reduced set of observations

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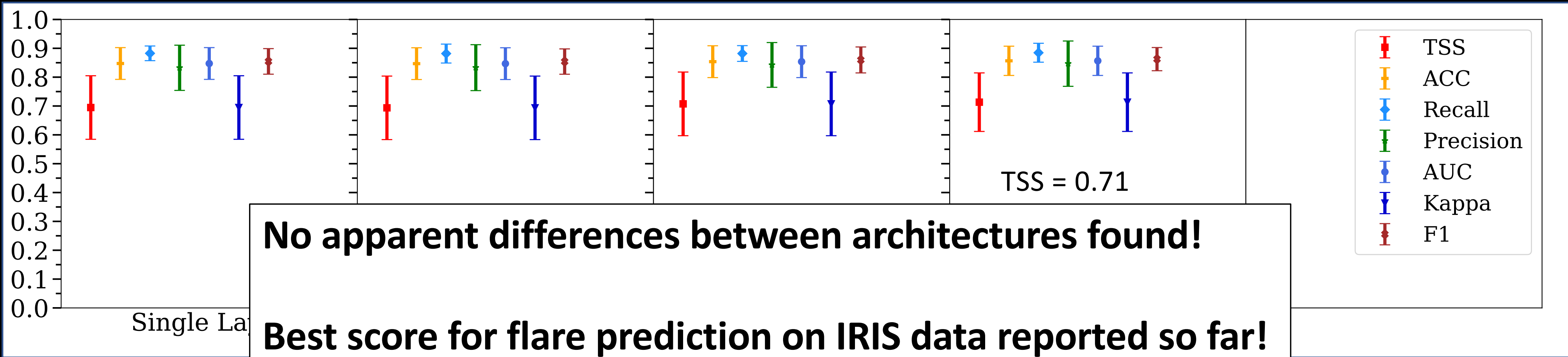
Prediction Scores – Results **Mg II h&k**



No apparent differences between architectures found!

Best score for flare prediction on IRIS data reported so far!

- VAE threshold = 0.15
- Best model Convnet — TSS = 0.71
- Reduced set of observations

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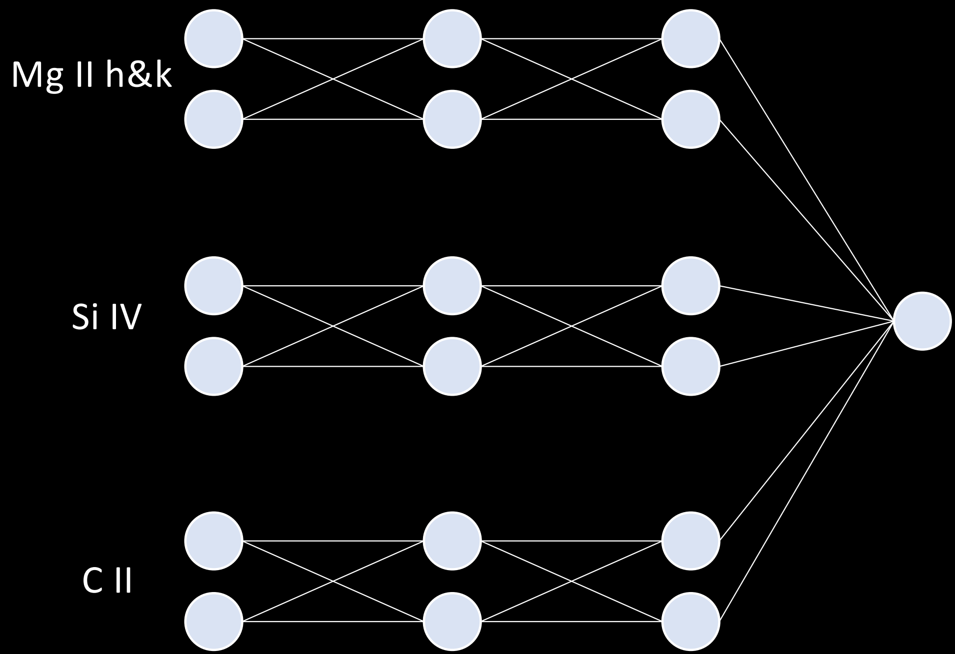
Combined spectral lines

- Unmasked data from **Mg II h&k, Si IV and C II.**
- Only kept pixel with good data in each line

Experiments: **Full set of observations**

- Mg II h&k on this data set
- Mg II h&k + Si IV
- Mg II h&k + C II
- Mg II h&k + Si IV + C II



Conceptual model architecture

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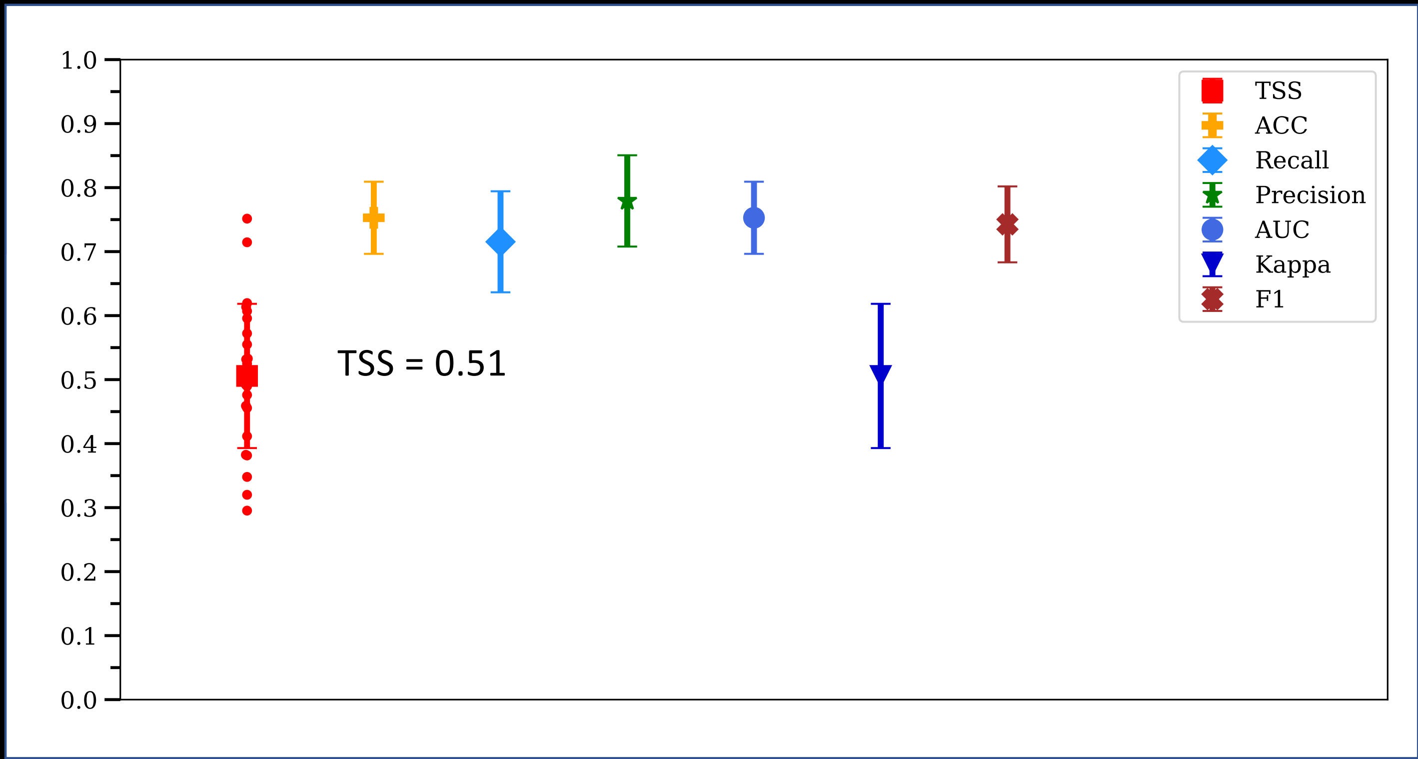
Prediction Scores – Results **Mg II h&k**



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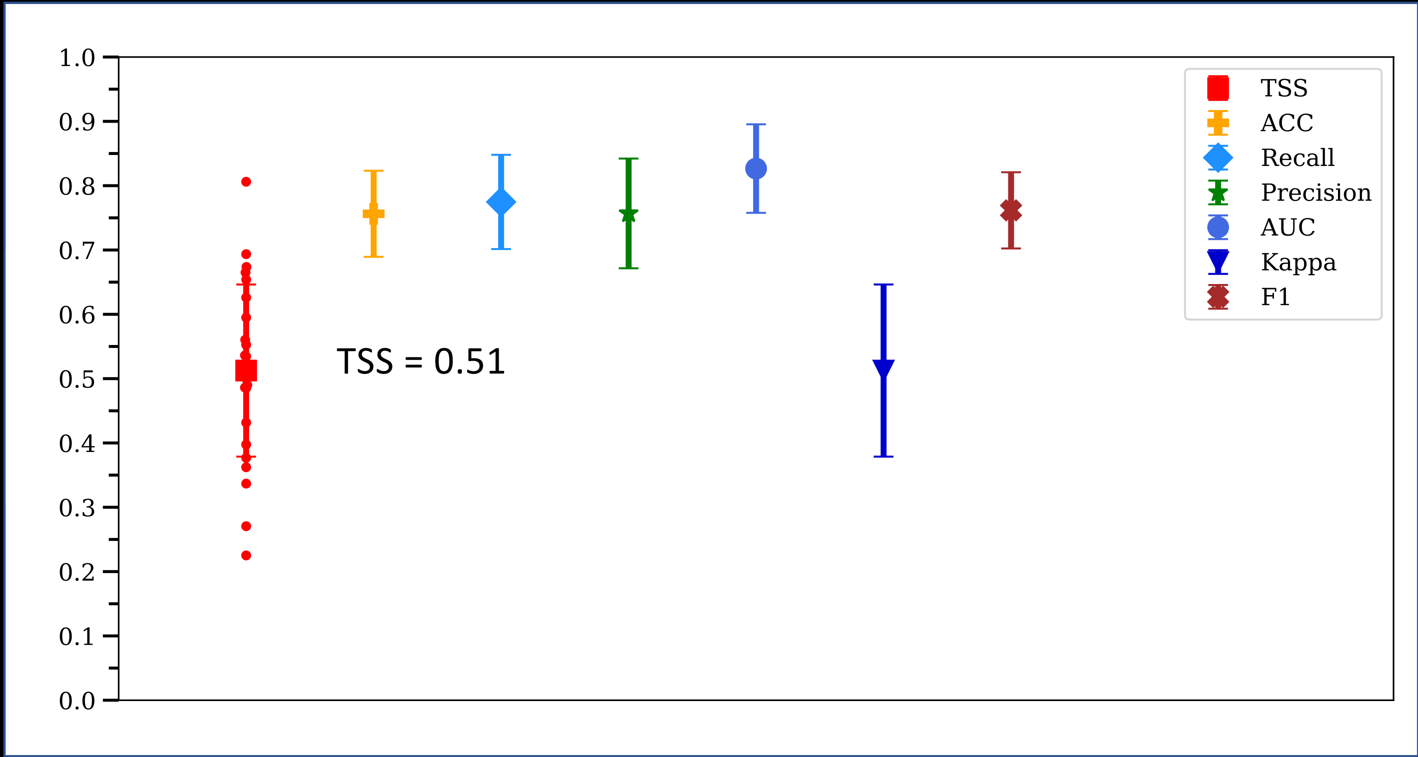
Prediction Scores – Results **Mg II h&k + Si IV**



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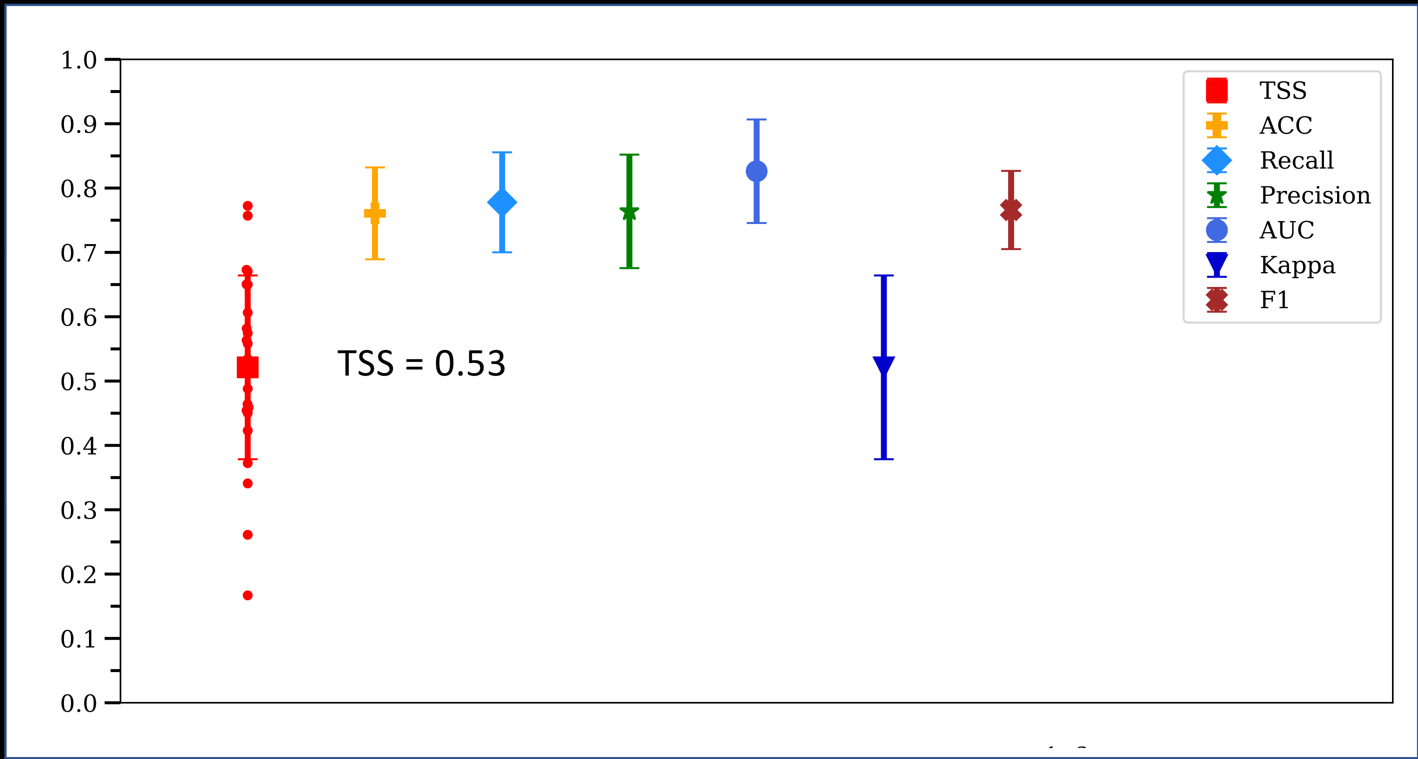
Prediction Scores – Results **Mg II h&k + C II**



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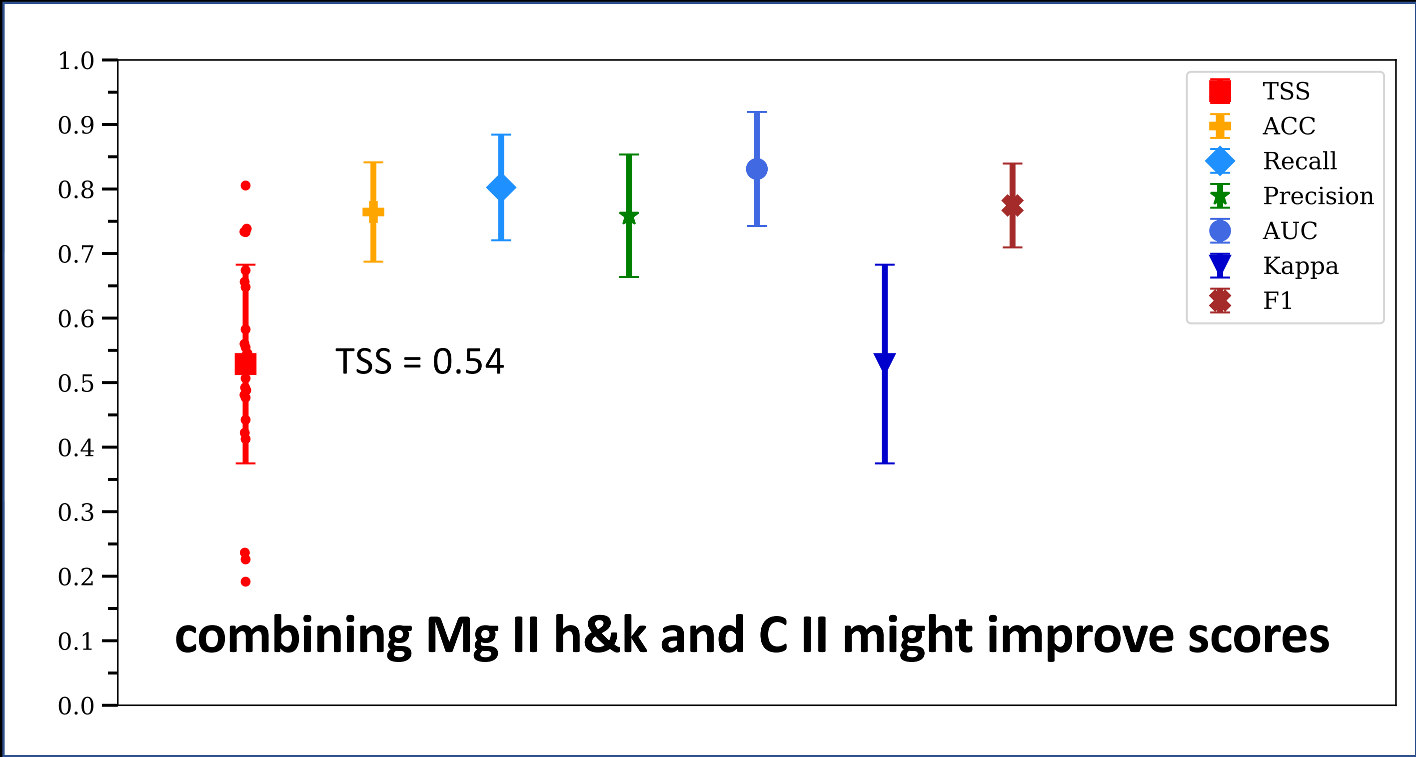
Prediction Scores – Results **All Three lines**



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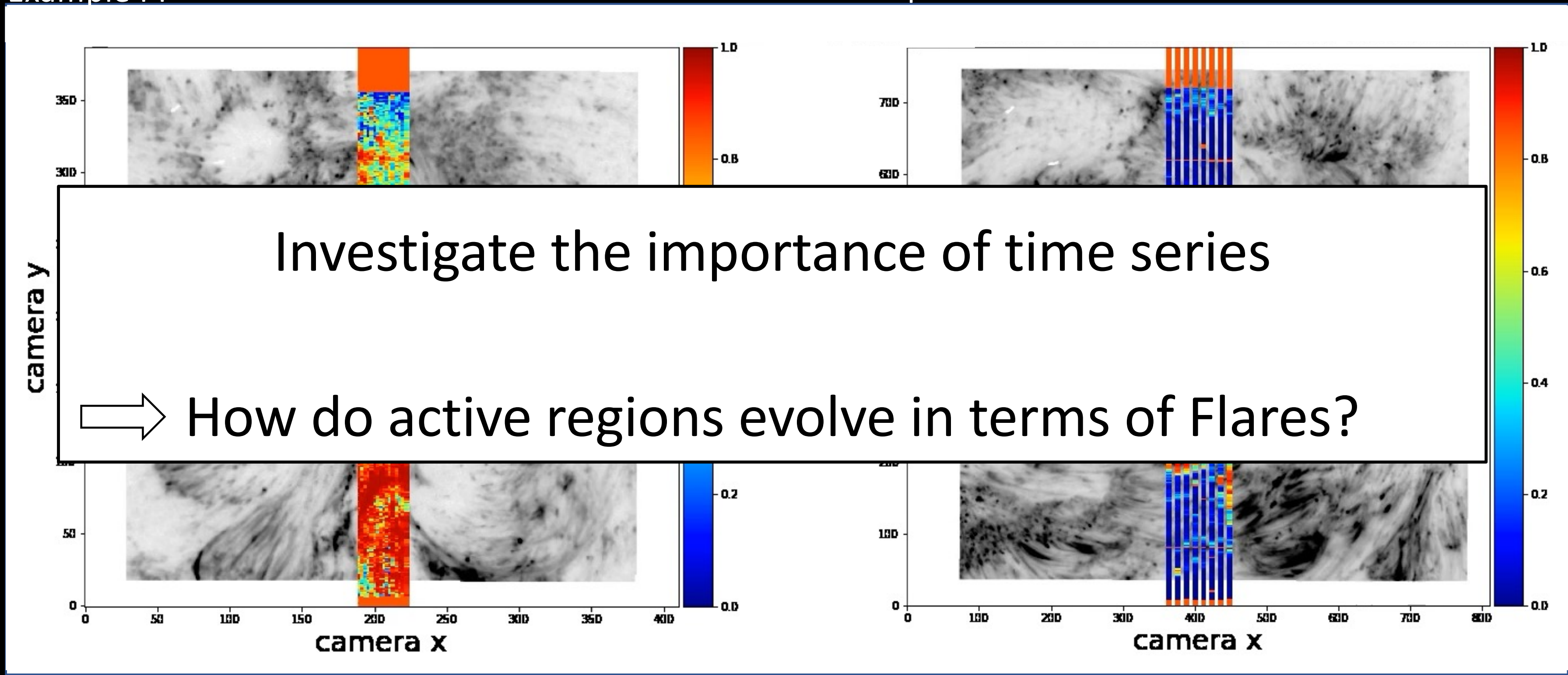
Future Prospects - Outlook

Example PF

Example AR



Investigate the importance of time series

⇨ How do active regions evolve in terms of Flares?

Red: High probability
Blue: Low probability

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Conclusions

- PF observations are **best** distinguishable from AR observations based on spectra from **Mg II h&k** with a **TSS = 0.71 for 1 hour before flare onset**!
- **C II** and **Si IV** have some predictive information but less than **Mg II h&k**
- Each observation has **unique properties** that can affect the training and testing of the models
- **Combining** spectral lines can improve prediction scores but only marginally
- VAE (or other sophisticated masking methods) can lift some of the mixing of PF, AR and QS spectra

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