E.A. Milne Centre

for Astrophysics

Predicting the Ages of Galaxies with an Artificial Neural Network

Laura. J. Hunt [1, 2]

Kevin. A. Pimbblet [1, 2] and David. M. Benoit [1]

[1] E.A. Milne Centre, University of Hull

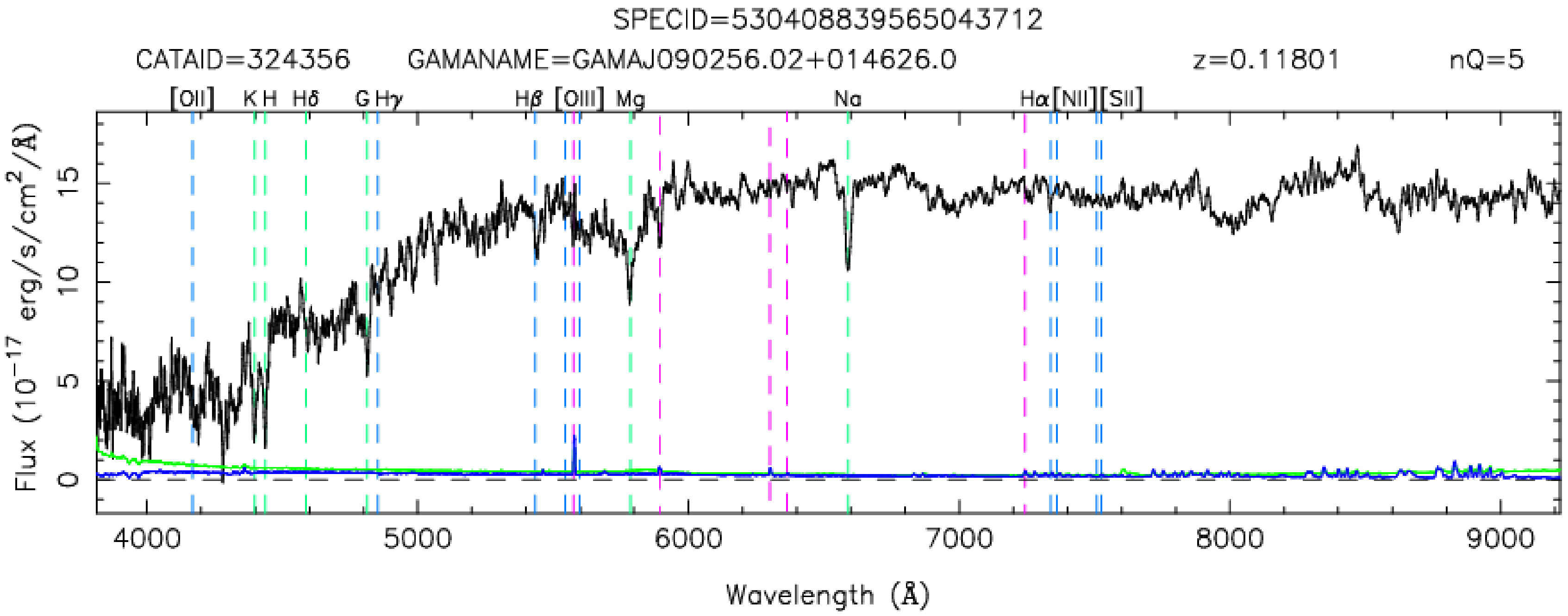
[2] Centre of Excellence for Data Science, AI and Modelling (DAIM), University of Hull

Galaxy Spectra

Composite of their stars, gas and dust

Key components:

- The continuum
- Emission lines
- Absorption lines



Equivalent Widths (EWs)

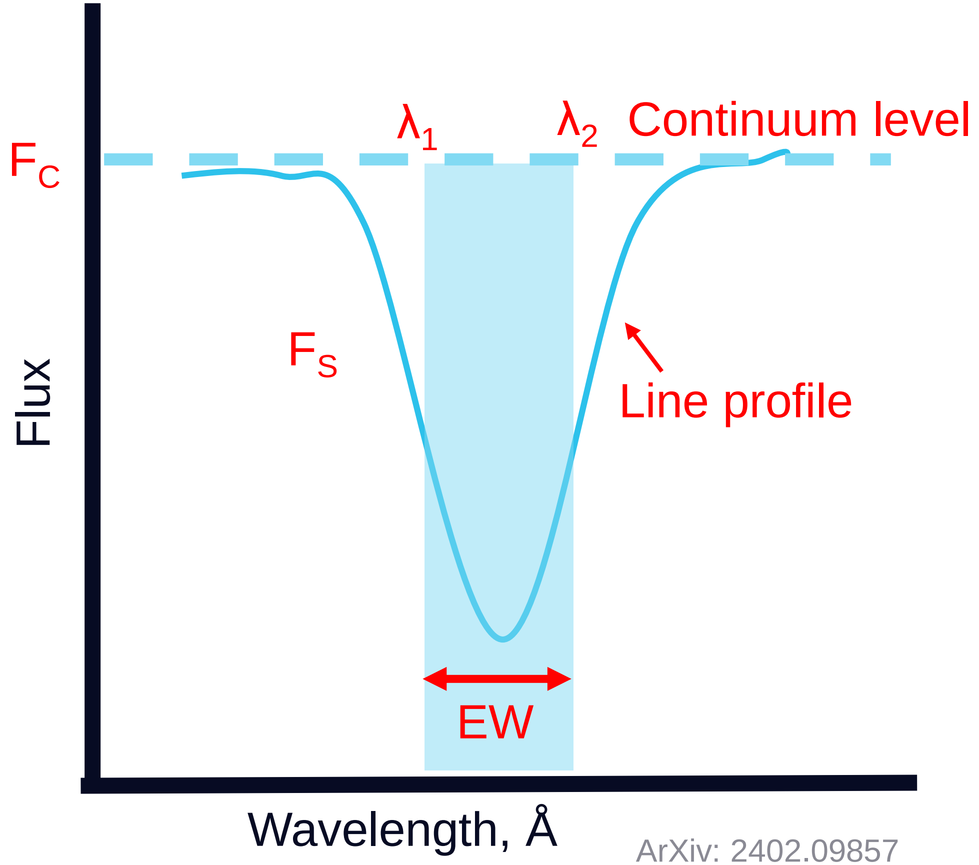
- The strength of a spectral line
- **EWs** (Gordon et al. 2017) from Galaxy And Mass Assembly (GAMA) survey (Drive et al. 2009; Liske et al. 2015) DR3 (Baldry et al. 2018)

$$W_\lambda = \int \left(1 - \frac{F_s}{F_c}\right) d\lambda$$

EW

Flux of observed spectrum

Flux of local continuum



Spectral Lines - Equivalent Widths (EWs)

Spectral Line	Description	Spectral Line	Description
D4000*	Balmer break	MH	Mgb + MgH
Hα	Hydrogen alpha	FC	Fe I + Ca I
Hβ	Hydrogen beta	CNB	CN UV cyanogen band
HγA	Hydrogen gamma A	G	CH G band
[OIII] R	Doubly ionized oxygen R	MgG	Magnesium b triplet
[OIII] B	Doubly ionized oxygen B	NaD	Sodium D doublet
[SII] R	Singly ionized silicon R		
[SII] B	Singly ionized silicon B		

EWs from GAMA survey DR3 (Gordon et al. 2017)

*D4000 (Balmer break) is a ratio rather than a spectral line

GAMA Ages

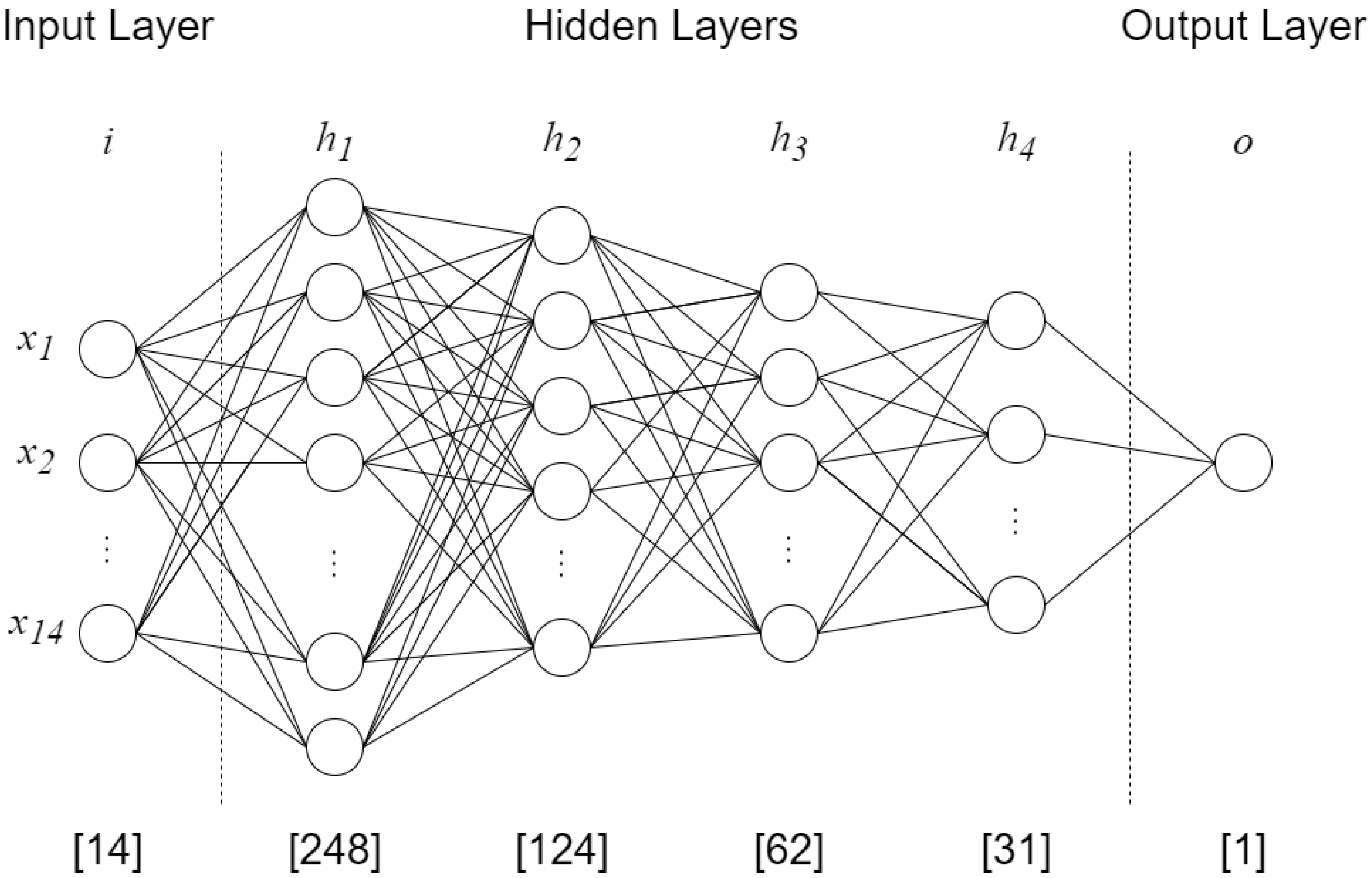
- **Median mass-weighted ages** from DR3 (Baldry et al. 2018) of the Galaxy And Mass Assembly (GAMA) survey (Drive et al. 2009; Liske et al. 2015)
- Generated by the **MAGPHYS SED fitting model** (da Cunha, Charlot & Elbaz 2008) e.g.
  - 9.405 dex(yr) -> median 50^{th} percentile
  - ± 0.326 (1σ) -> $16\text{-}84^{th}$ percentile range
  - ± 0.618 (2σ) -> $2.5\text{-}97.5^{th}$ percentile range

Artificial Neural Network (ANN)

- Supervised learning
  - Labelled training data -> ages
- 14 input features -> EWs
- 1 output feature -> age

Hyperparameters

- Activation function (softsign)
- Loss function (mean squared error)
- Optimiser (Adam)
- Number of hidden nodes (465)
- Number of layers = 6 (4 hidden)
- Test-train split (80-20)
- Batch size (32)
- Epochs (40)



Artificial Neural Network (ANN)

- Supervised learning
  - Labelled training data -> ages
- 14 input features -> EWs
- 1 output feature -> age

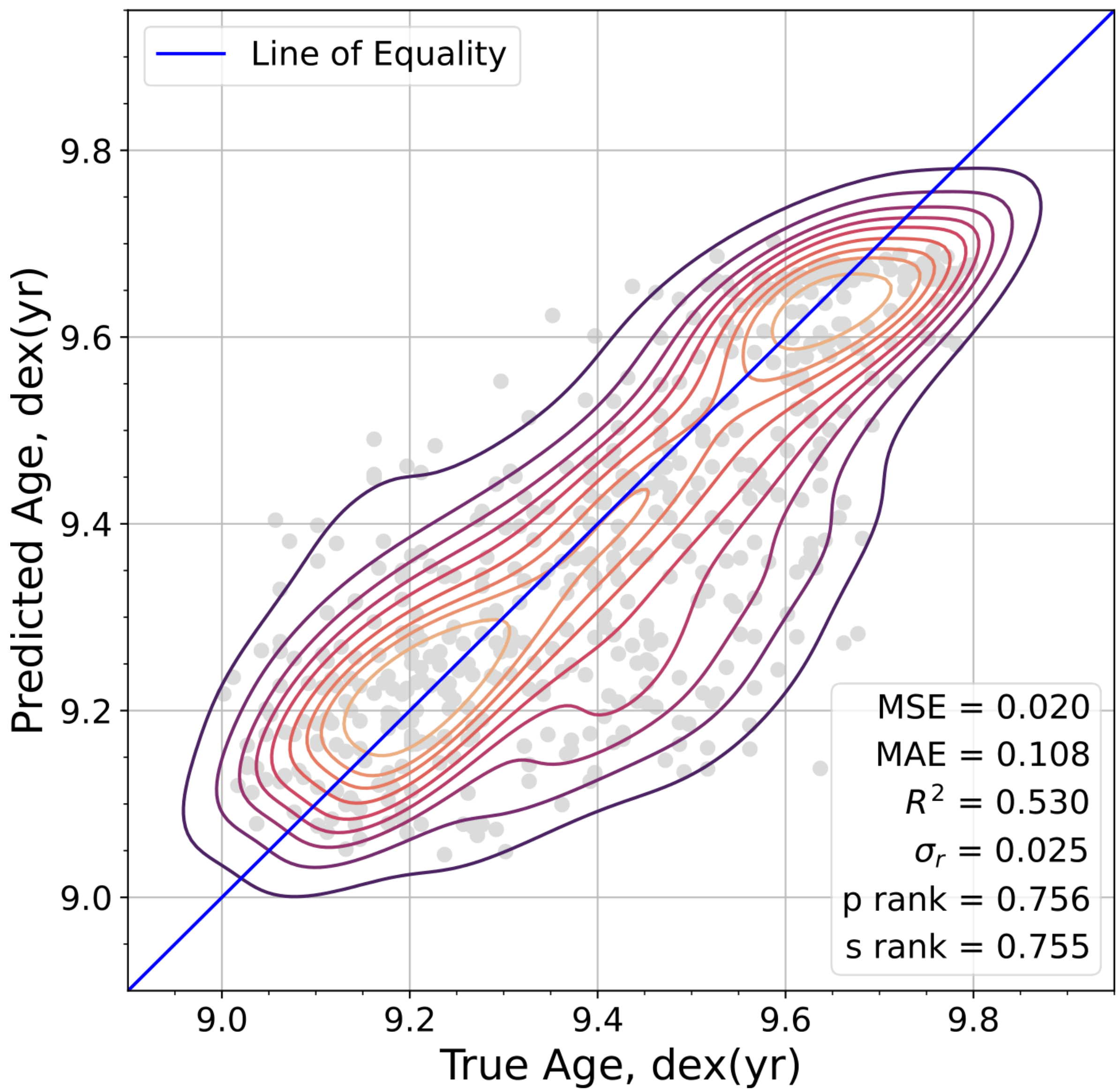
Hyperparameters

- Activation function (softsign)
- Loss function (mean squared error)
- Optimiser (Adam)
- Number of hidden nodes (465)
- Number of layers = 6 (4 hidden)
- Test-train split (80-20)
- Batch size (32)
- Epochs (40)

$$y = \frac{x}{1 + |x|}$$

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

$$N_h = \frac{N_s}{a(N_i + N_o)}$$



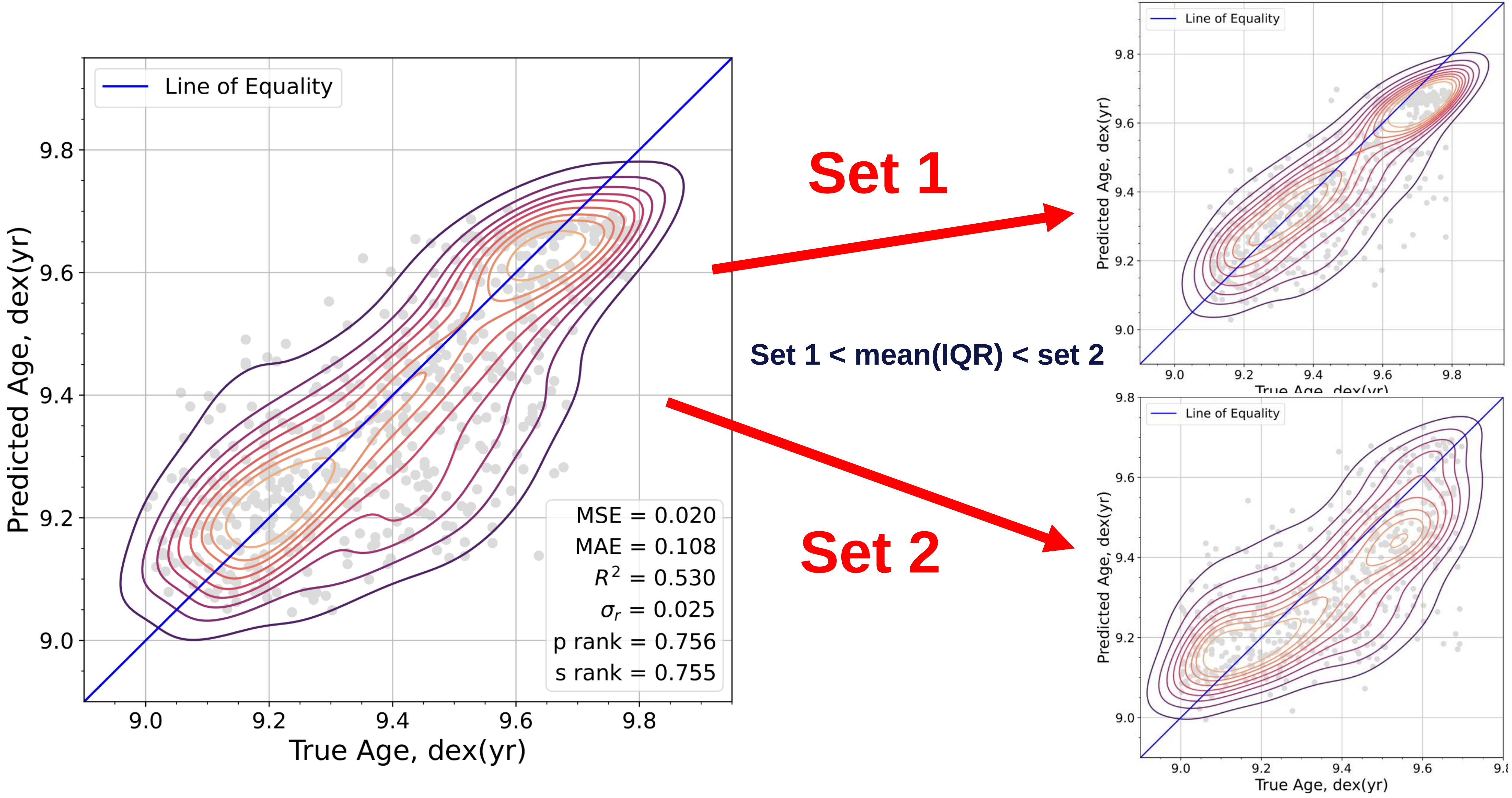
p Rank	s Rank
0.756	0.755

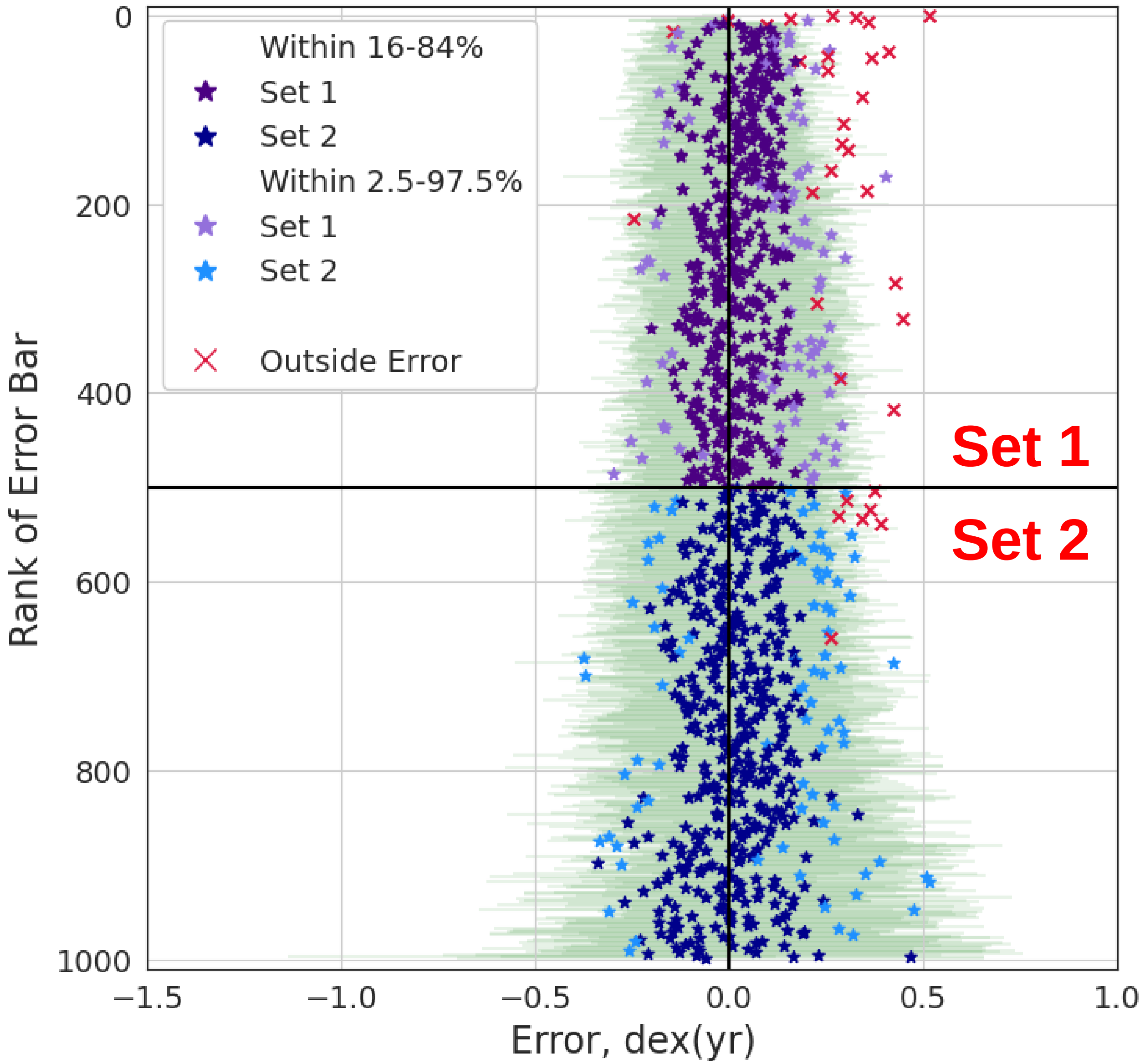
MSE	MAE	R^2 Score
0.020	0.108	0.530

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

$$MAE = \frac{\sum_{i=1}^{n}|y_i - \hat{y}_i|}{n}$$

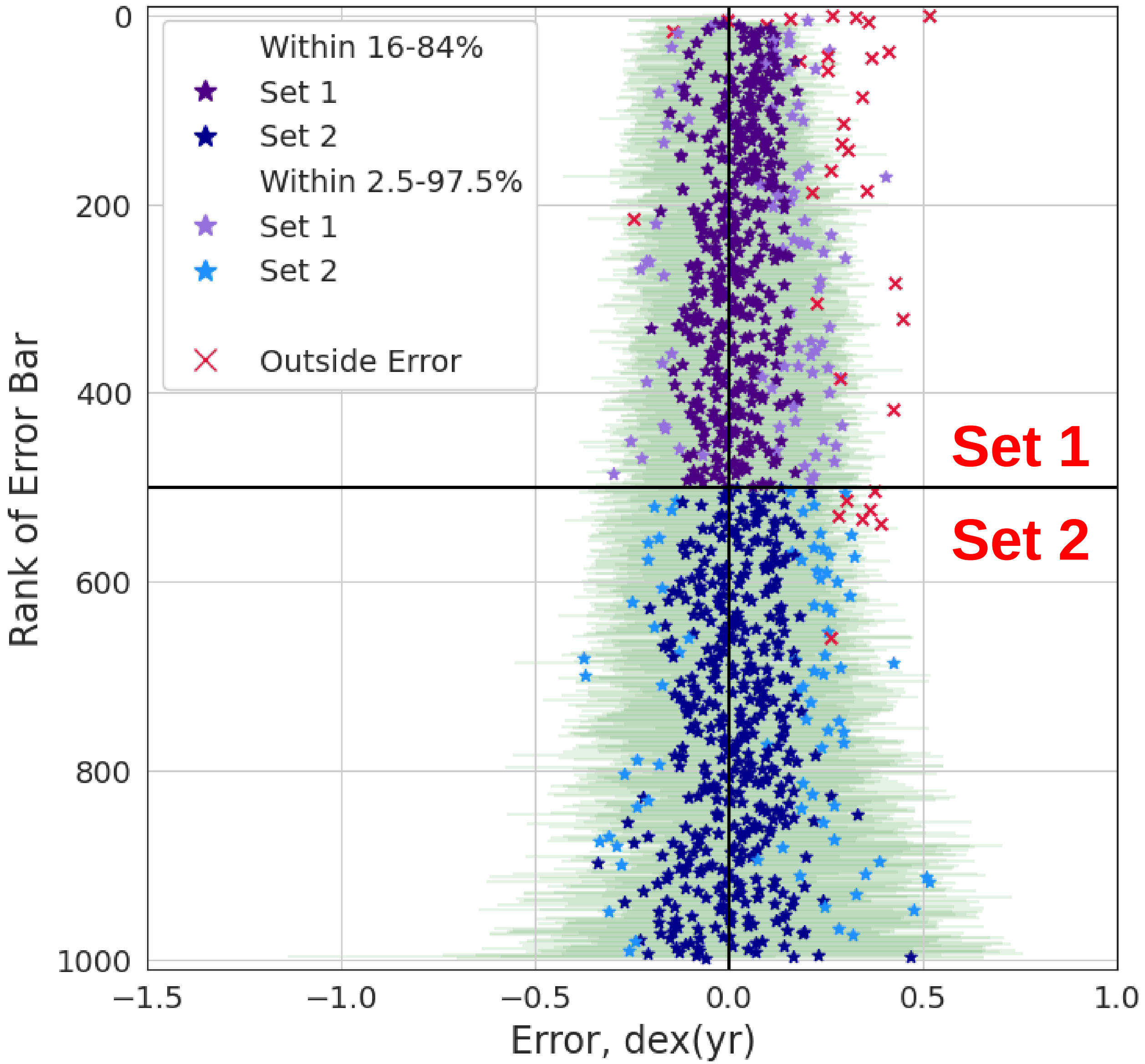
$$R^2(y, \hat{y}) = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$


Line of Equality
Predicted Age, dex(yr)
True Age, dex(yr)
9.0
9.2
9.4
9.6
9.8
MSE = 0.020
MAE = 0.108
R^2 = 0.530
σ_r = 0.025
p rank = 0.756
s rank = 0.755
Set 1
Set 1 < mean(IQR) < set 2
Set 2



MSE	Total In	In 16-84	In 2.5-97.5	Outside
Combined	96.7%	80.3%	16.4%	3.3%
Set 1	94.8%	78.2%	16.6%	5.2%
Set 2	98.6%	82.4%	16.2%	1.4%

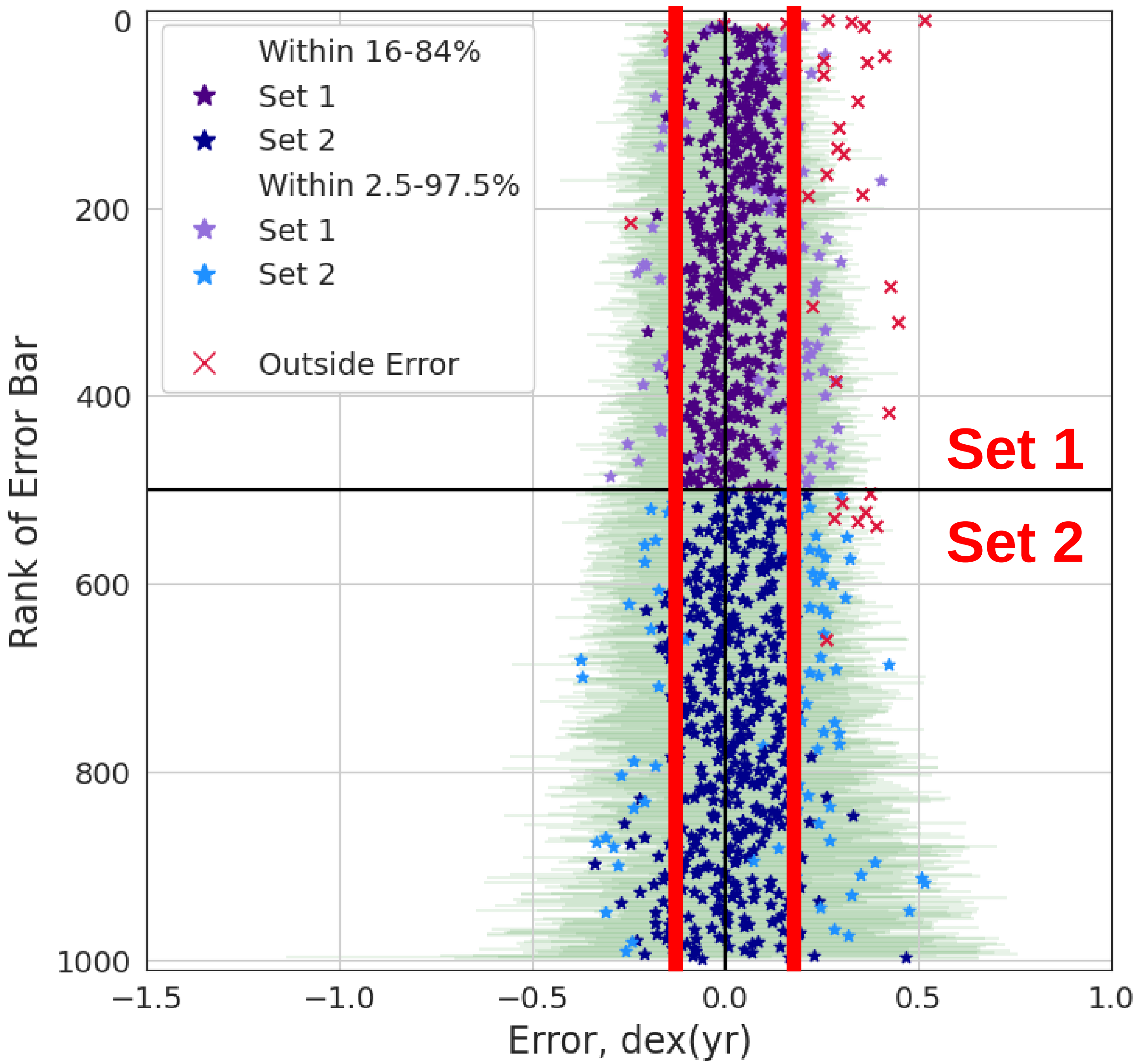
- **Set 1 < mean(IQR) < set 2**
- **96.7% of galaxies are correctly predicted within the true age errors**
- More mispredictions in set 1 but correct predictions are more accurate
- Ages tend to be underpredicted (more predictions on right)



2σ

MSE	Total In	In 16-84	In 2.5-97.5	Outside
Combined	96.7%	80.3%	16.4%	3.3%
Set 1	94.8%	78.2%	16.6%	5.2%
Set 2	98.6%	82.4%	16.2%	1.4%

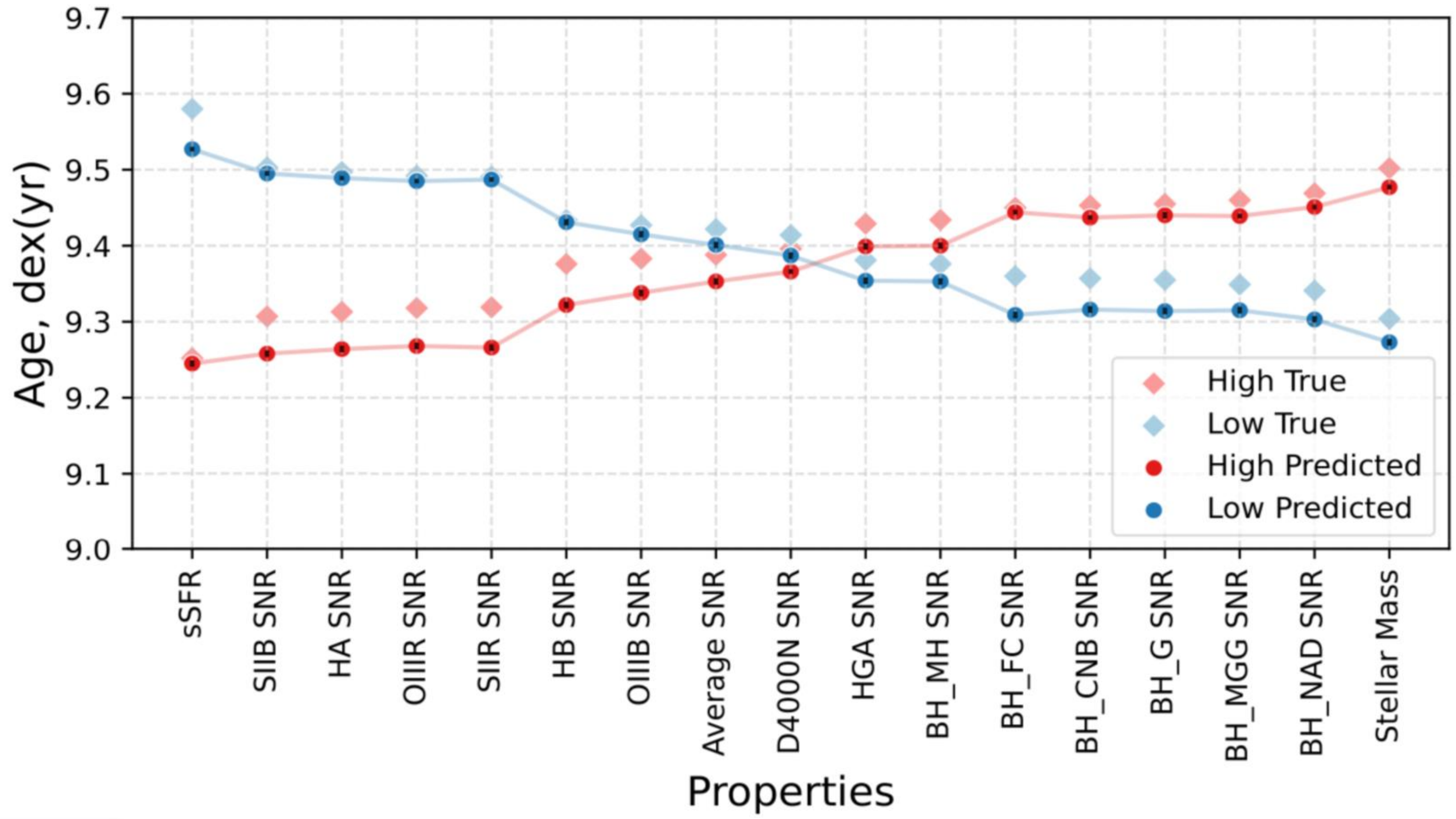
- **Set 1 < mean(IQR) < set 2**
- **96.7% of galaxies are correctly predicted within the true age errors**
- More mispredictions in set 1 but correct predictions are more accurate
- Ages tend to be underpredicted (more predictions on right)



1σ

MSE	Total In	In 16-84	In 2.5-97.5	Outside
Combined	96.7%	80.3%	16.4%	3.3%
Set 1	94.8%	78.2%	16.6%	5.2%
Set 2	98.6%	82.4%	16.2%	1.4%

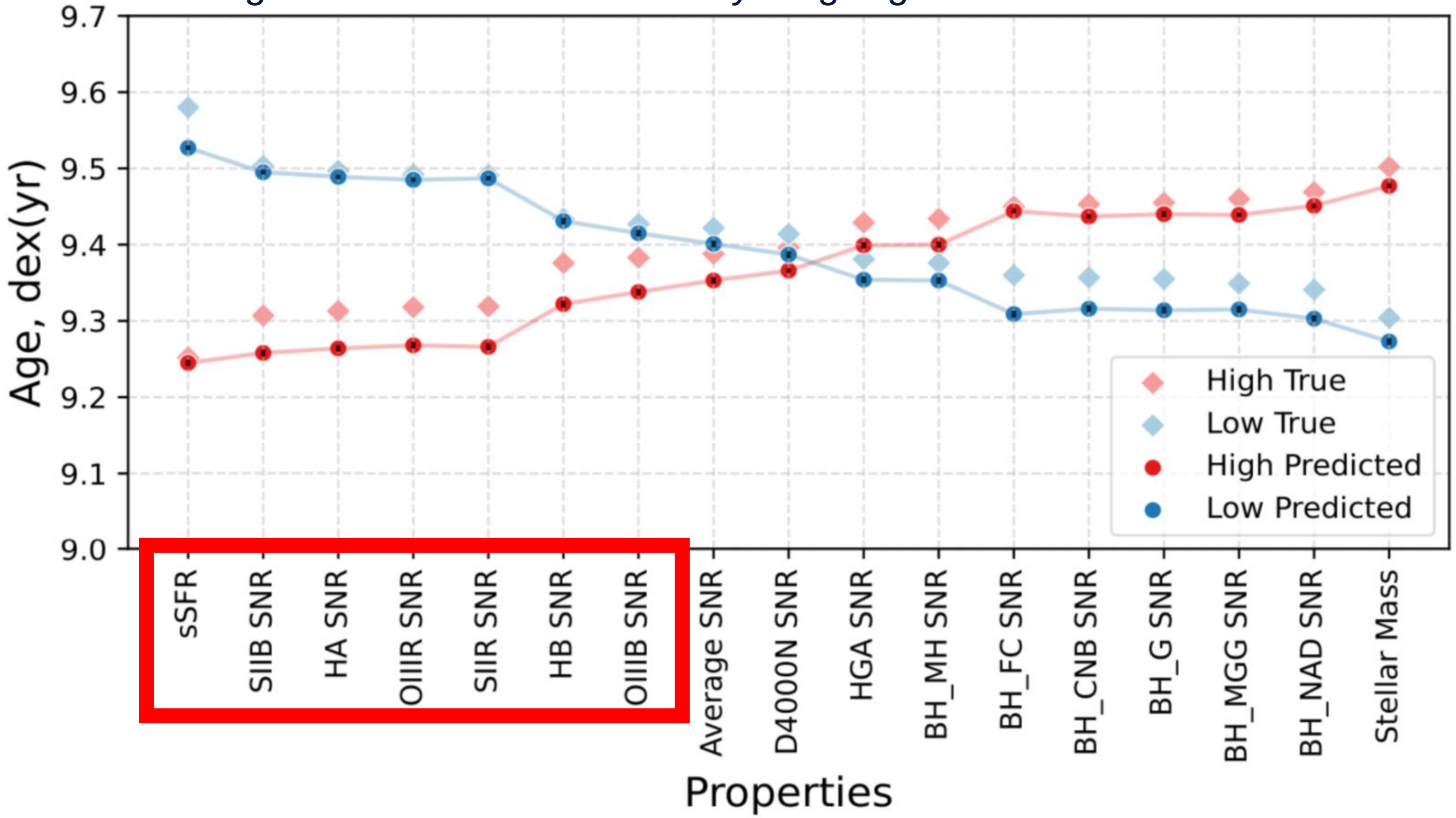
- **Set 1 < mean(IQR) < set 2**
- **96.7% of galaxies are correctly predicted within the true age errors**
- More mispredictions in set 1 but correct predictions are more accurate
- Ages tend to be underpredicted (more predictions on right)



- Split 500 validation set by average property value
  - High set -> red
  - Blue set -> low

Specific star formation rate (sSFR)

- Measures star formation per unit mass
- We expect sSFR to decrease with mass
- Higher sSFR associated with younger galaxies

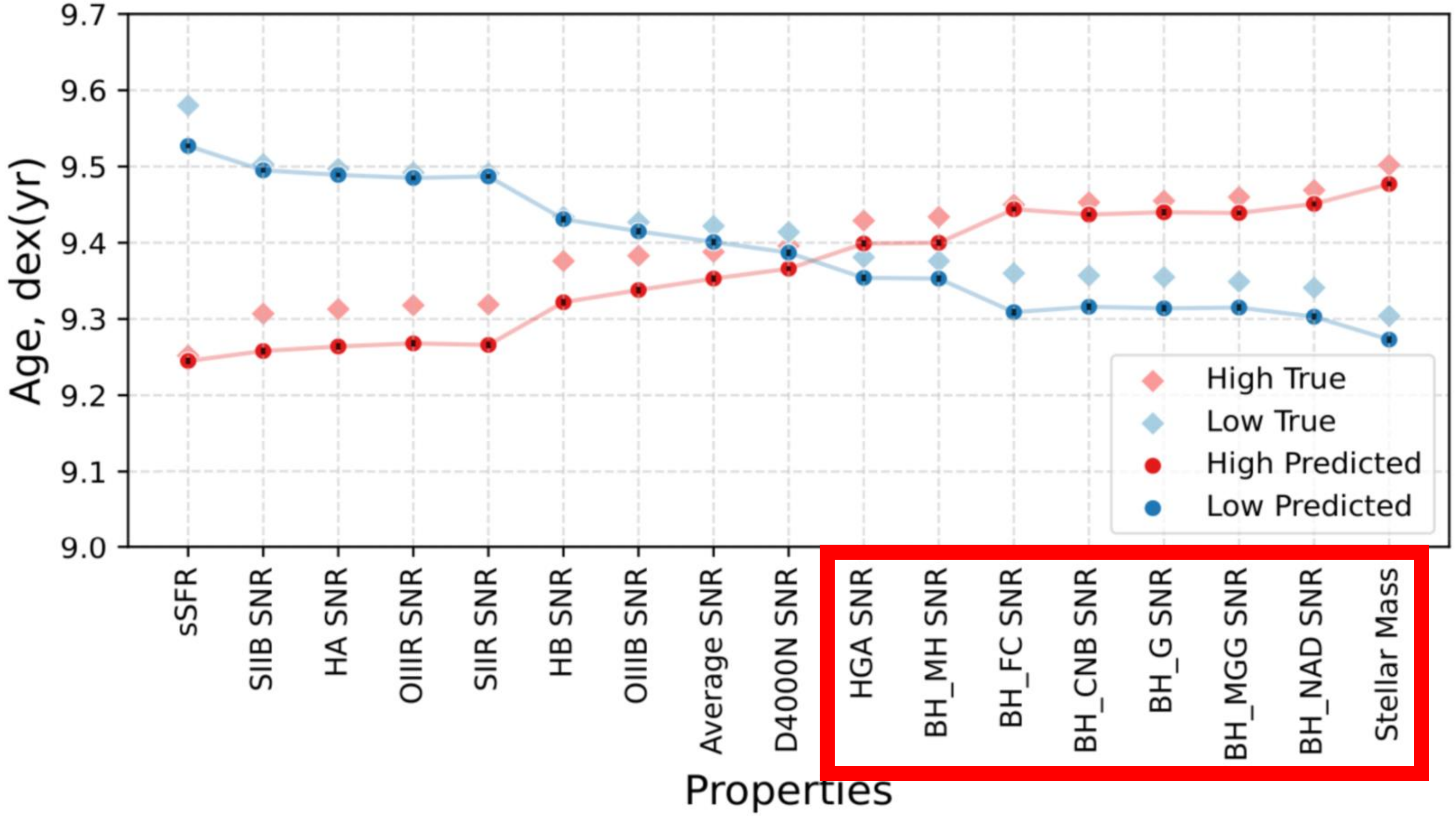


- Split 500 validation set by average property value
  - High set -> red
  - Blue set -> low
- Left hand side:
  - Younger galaxies = higher values
  - Older galaxies = lower values

EWs: [SII] B, Hα, [OIII] R, [SII] R, Hβ, [OIII] B + sSFR

Stellar Mass

- Mass of the galaxy attributed to stars
- Higher mass associated with older galaxies



EWs: HλA, MH, FC, CNB, G, MgG, NaD + Stellar mass

- Split 500 validation set by average property value
  - High set -> red
  - Blue set -> low
- Left hand side:
  - Younger galaxies = higher values
  - Older galaxies = lower values
- Right hand side:
  - Younger galaxies = lower values
  - Old galaxies = high values

Summary

1. The ratios between different spectral lines can be used to infer the ages of galaxies

2. Our ANN is able to predict the ages of galaxies based on their EWs from their spectra
   - ~80% precision within ~1σ
   - ~97% precision within ~2σ

3. Predictions are more precise when true age is more precise

4. Predictions are physically motivated (e.g. sSFR, stellar mass and tracers for star formation)