Combining neural networks and galaxy light subtraction for discovering strong lenses with HSC

Yuichiro Ishida (Kyushu University B4),

Kenneth Wong (University of Tokyo), Anton Jaelani (ITB),

Anupreeta More (IUCAA)

What is strong lensing?

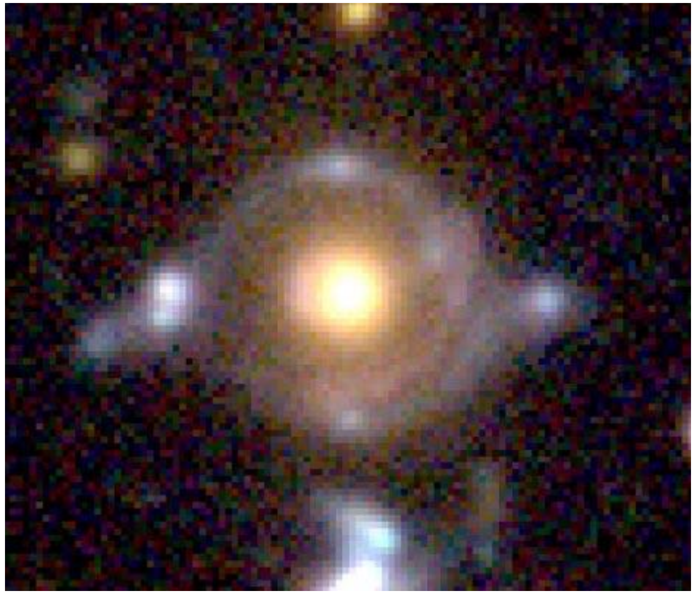
What is strong lensing?

The phenomenon that we can see the multiple images of background galaxy when a foreground galaxy and bright background galaxy are aligned.

Usage of strong lenses

- The mass structure of galaxies
- The properties of dark matter
- High-resolution studies of distant sources
- The measurement of cosmological parameters

(e.g., Refsdal 1964; Wong et al. 2020)



Tanaka et al. (2016)

Searching for Strong Lenses

- Strong lenses are very rare：source galaxy, lensing galaxy, and earth should be in line

→deep, wide-field, multiband imaging surveys that cover a large area of the sky
(e.g., Sloan Digital Sky Survey (SDSS), Kilo-Degree Survey (KiDS),
Hyper Suprime-Cam Subaru Strategic Program (HSC SSP))

→We have to search for strong lenses from millions of galaxies

→efficient searching method is needed

Citizen science (e.g., Space Warps; More et al. (2023))

Arc-finding algorithms (e.g., YATTALENS; Sonnenfeld et al. 2018)

Machine learning (e.g., Canameras et al. 2021; Shu et al. 2022)

Searching for Strong Lenses

- Strong lenses are very rare：source galaxy, lensing galaxy, and earth should be in line

→deep, wide-field, multiband imaging surveys that cover a large area of the sky
(e.g., Sloan Digital Sky Survey (SDSS), Kilo-Degree Survey (KiDS),
Hyper Suprime-Cam Subaru Strategic Program (HSC SSP))

→We have to search for strong lenses from millions of galaxies

→efficient searching method is needed

Citizen science (e.g., Space Warps; More et al. (2023))

Arc-finding algorithms (e.g., YATTALENS; Sonnenfeld et al. 2018)

Machine learning (e.g., Canameras et al. 2021; Shu et al. 2022)

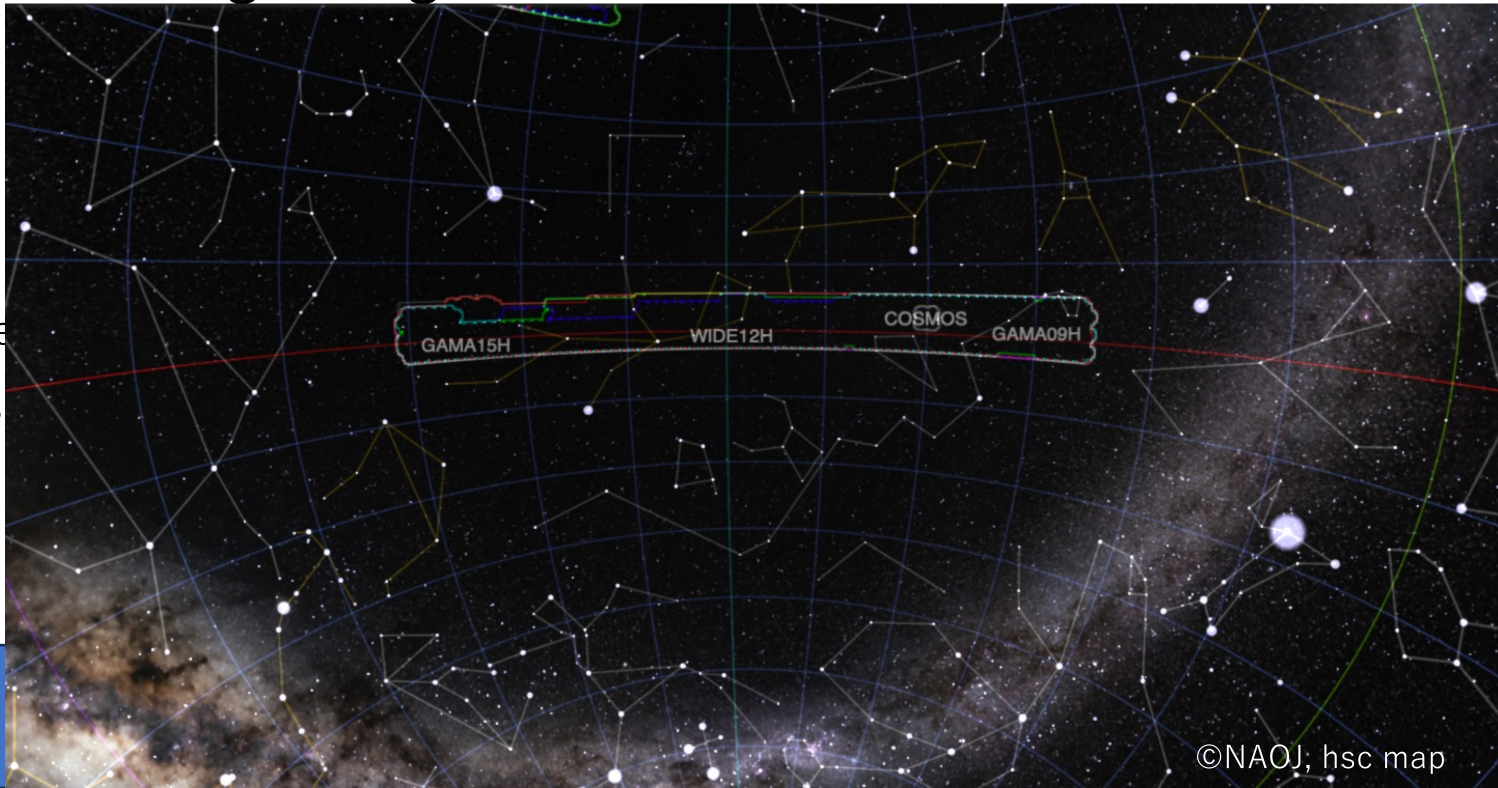
Searching for Strong Lenses

- Strong lenses are very rare：source galaxy, lensing galaxy, and earth should be in line

  →deep, wide-field, multiband imaging surveys that cover a large area of the sky
  (e.g., Sloan Digital Sky Survey (SDSS), Kilo-Degree Survey (KiDS),
  Hyper Suprime-Cam Subaru Strategic Program (HSC SSP))

  →We have to search for strong

  →efficient searching metho
  Citizen science (e.g., Space
  Arc-finding algorithms (e
  Machine learning (e.g., Ca



Searching for Strong Lenses

- Strong lenses are very rare：source galaxy, lensing galaxy, and earth should be in line

→deep, wide-field, multiband imaging surveys that cover a large area of the sky
(e.g., Sloan Digital Sky Survey (SDSS), Kilo-Degree Survey (KiDS),
Hyper Suprime-Cam Subaru Strategic Program (HSC SSP))

→We have to search for strong lenses from millions of galaxies

→efficient searching method is needed

Citizen science (e.g., Space Warps; More et al. (2023))

Arc-finding algorithms (e.g., YATTALENS; Sonnenfeld et al. 2018)

Machine learning (e.g., Canameras et al. 2021; Shu et al. 2022)

Seaching for Strong Lenses

- Strong lenses are very rare：source galaxy, lensing galaxy, and earth should be in line

→deep, wide-field, multiband imaging surveys that cover a large area of the sky
(e.g., Sloan Digital Sky Survey (SDSS), Kilo-Degree Survey (KiDS),
Hyper Suprime-Cam Subaru Strategic Program (HSC SSP))

→We have to search for strong lenses from millions of galaxies

→efficient searching method is needed

Citizen science (e.g., Space Warps; More et al. (2023))

Arc-finding algorithms (e.g., YATTALENS; Sonnenfeld et al. 2018)

Machine learning (e.g., Canameras et al. 2021; Shu et al. 2022)

⇨**Combining**

Features of our Neural Networks

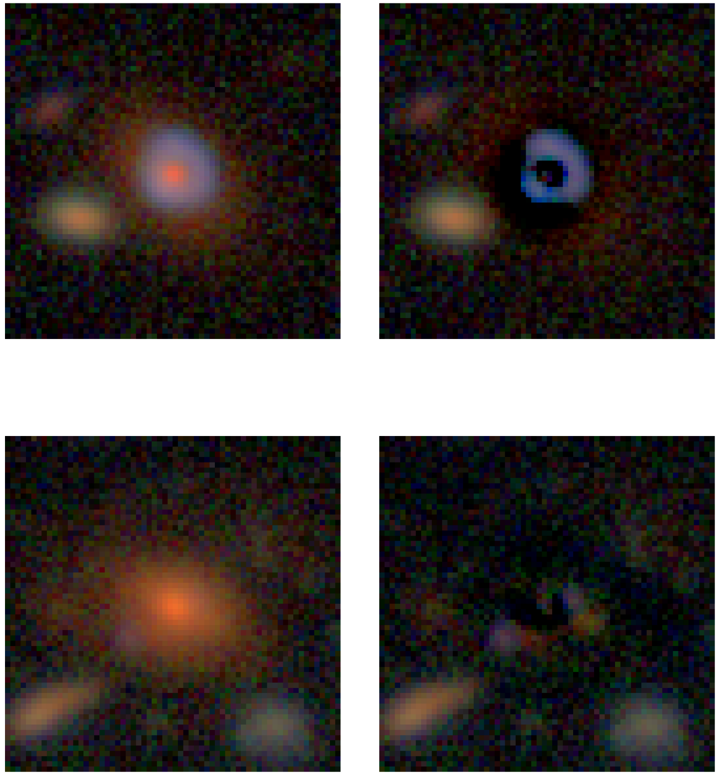
- Architectures
  - CNNs (Convolutional Neural Networks)
    →CNNs can process imaging data efficiently and identify characteristic patterns.
  - Auto tuning of hyperparameters with Keras Tuner
- Data
  - We used g, r, i-band images from HSC SSP wide (Aihara et al. 2019)
  - We used mock lenses as training dataset (Jaelani et al. 2023)
  - Subtraction of central (i.e., lens) galaxy with modified version of YATTALENS software (Sonnefeld et al. 2018)
    →highlight the characteristics of source galaxy light

Features of our Neural Networks

- Architectures
  - **CNNs (Convolutional Neural Networks)**
    → CNNs can process imaging data efficiently and identify characteristic patterns.
    - Auto tuning of hyperparameters with Keras Tuner
- Data
  - We used g, r, i-band images from HSC SSP wide (Aihara et al. 2019)
  - We used mock lenses as training dataset (Jaelani et al. 2023)
  - **Subtraction of central (i.e., lens) galaxy with modified version of YATTALENS software (Sonnefeld et al. 2018)**
    →highlight the characteristics of source galaxy light

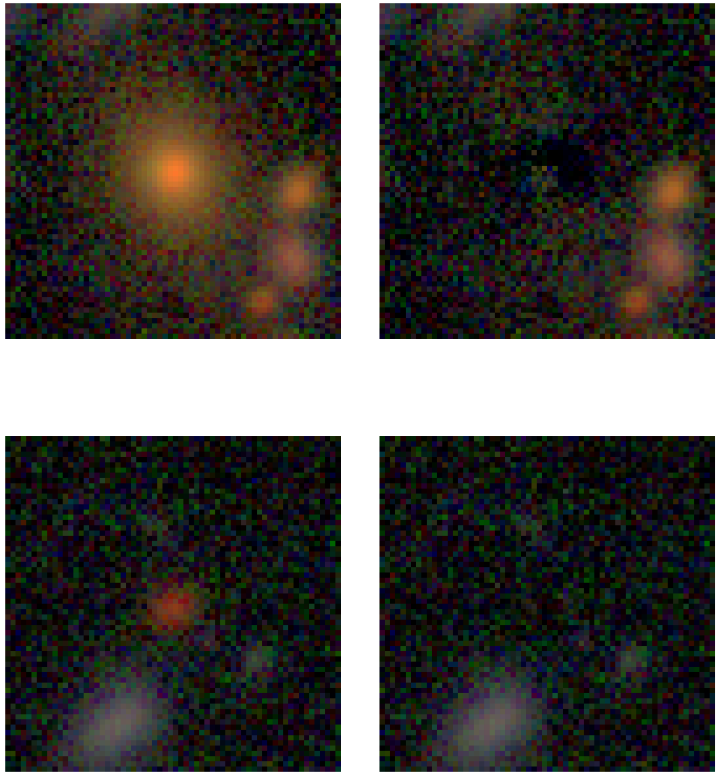
Training Dataset

Mock Lens



Normal image　Subtracted image

Non-Lens

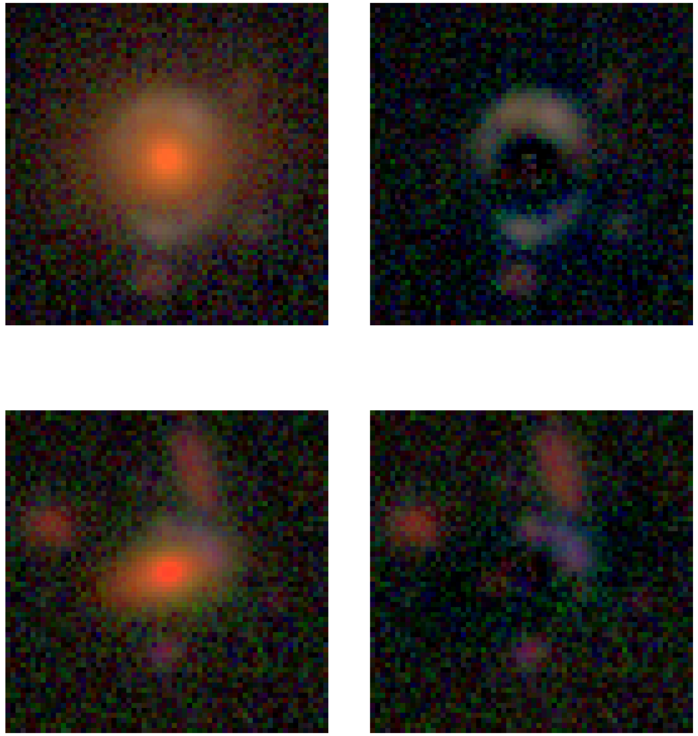


Normal image　Subtracted image

(Jaelani et al. 2023)

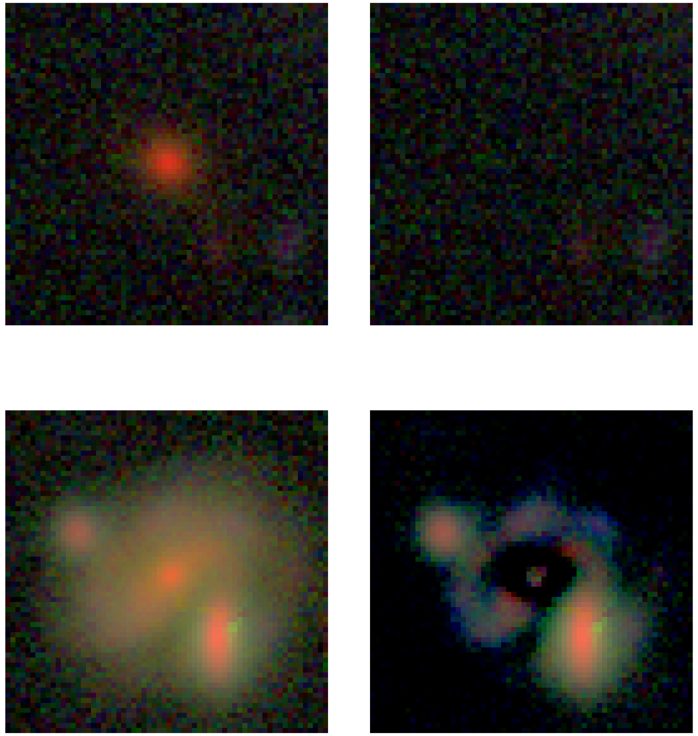
Test Dataset

Real Lens



Nomal image   Subtracted image

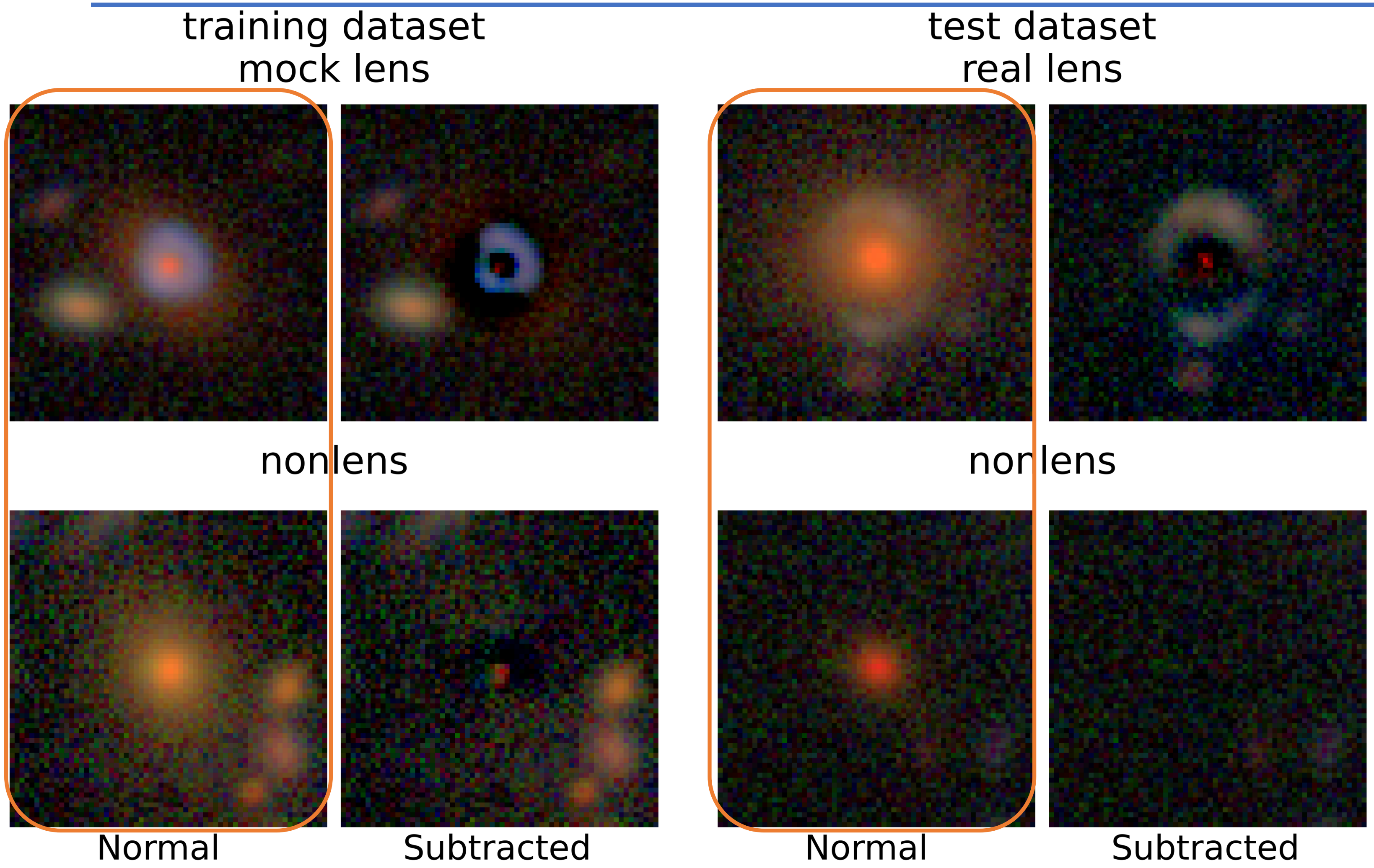
Non-Lens



Nomal image   Subtracted image

(Sonnenfeld et al. 2018, 2020; Wong et al. 2018)

Dataset



fid_dataset: The fiducial HSC gri-band imaging data

sub_dataset: The HSC imaging data with light subtraction

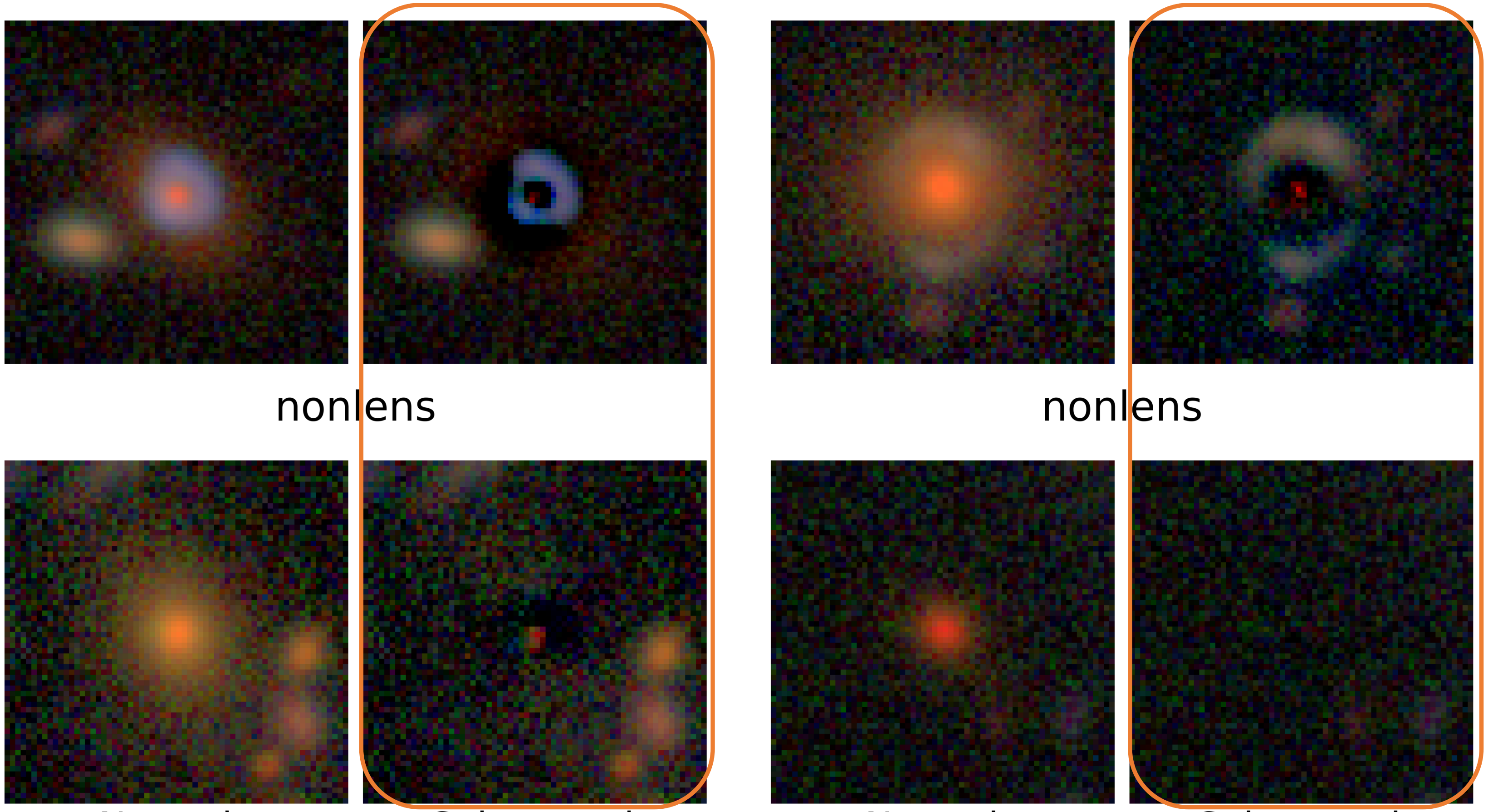
stack_dataset: The combination of “fid” and “”sub”

(Jaelani et al. 2023, Sonnenfeld et al. 2018, 2020; Wong et al. 2018)

Dataset

training dataset
mock lens

test dataset
real lens



Normal Subtracted Normal Subtracted

fid_dataset: The fiducial HSC gri-band imaging data

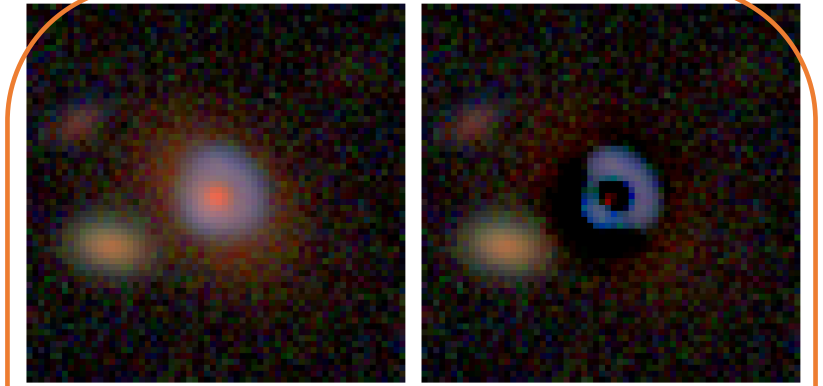
sub_dataset: The HSC imaging data with light subtraction

stack_dataset: The combination of “fid” and “”sub”

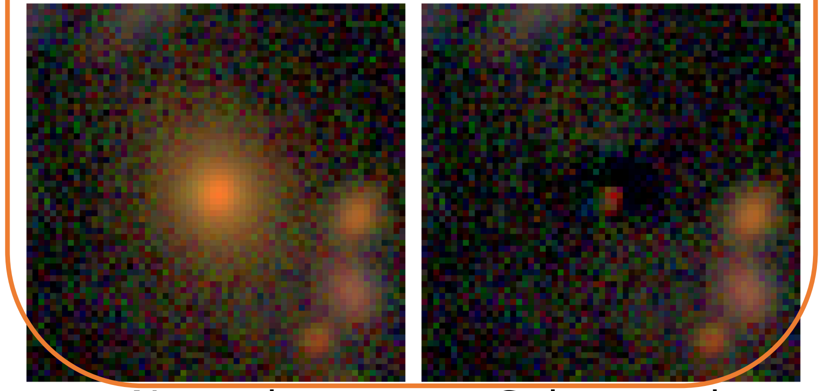
(Jaelani et al. 2023, Sonnenfeld et al. 2018, 2020; Wong et al. 2018)

Dataset

training dataset
mock lens

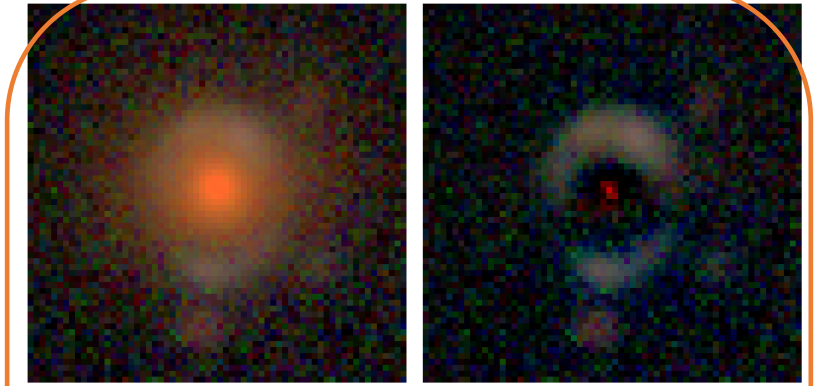


nonlens

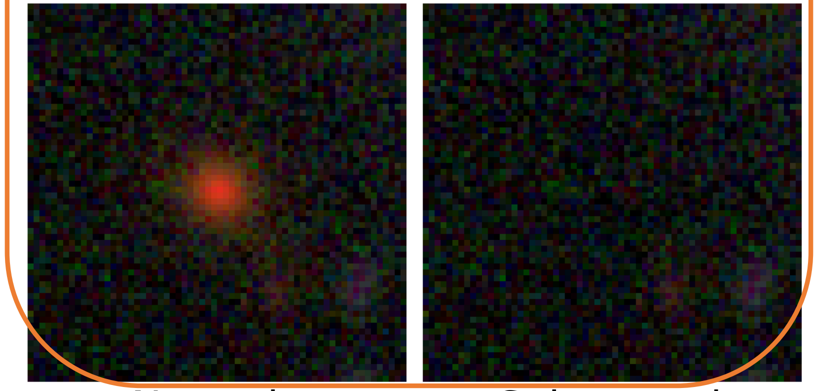


Normal Subtracted

test dataset
real lens



nonlens



Normal Subtracted

fid_dataset: The fiducial HSC gri-band imaging data

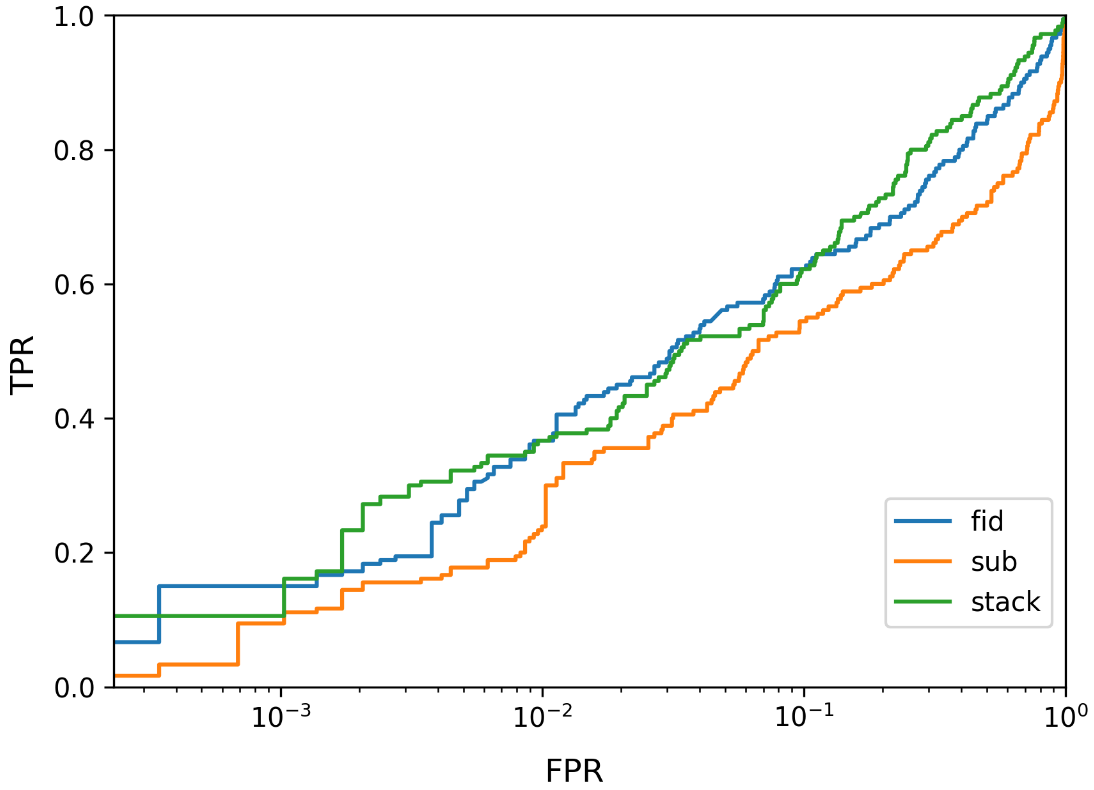
sub_dataset: The HSC imaging data with light subtraction

stack_dataset: The combination of “fid” and “sub”

(Jaelani et al. 2023, Sonnenfeld et al. 2018, 2020; Wong et al. 2018)

Comparison of neural networks optimized for each dataset

better



ROC curve of models optimized for each_dataset

Higher is better. Maximum is 1.

	AUROC
model_fid	0.808
model_sub	0.712
◎ model_stack	0.837

Vertical axis: TPR (True Positive Rate)

$$\mathrm{TPR} = \frac{\mathrm{TP}}{\mathrm{TP} + \mathrm{FN}}$$

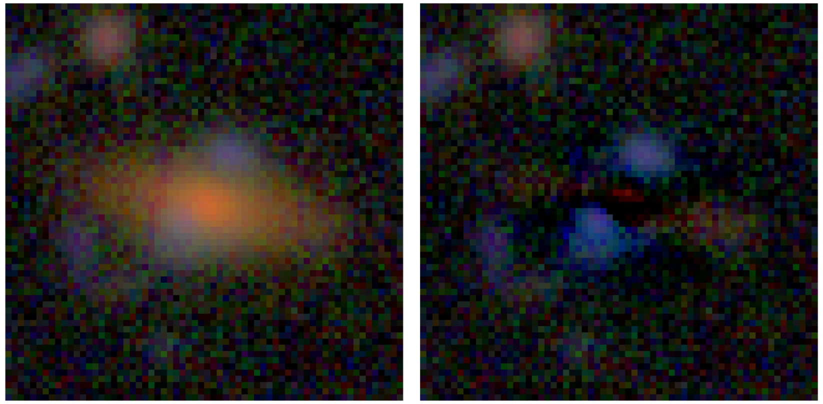
Horizontal axis: FPR (False Positive Rate)

$$\mathrm{FPR} = \frac{\mathrm{FP}}{\mathrm{FP} + \mathrm{TN}}$$

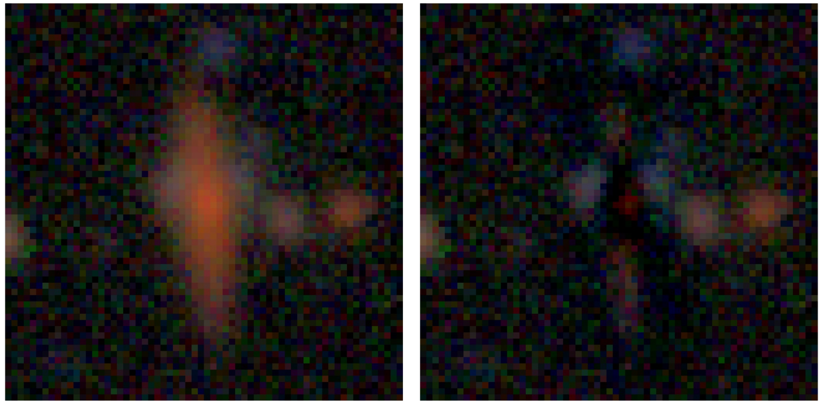
Fid vs. Sub vs. Stack (lens)

lens samples from test dataset (fid vs. sub vs. stack)

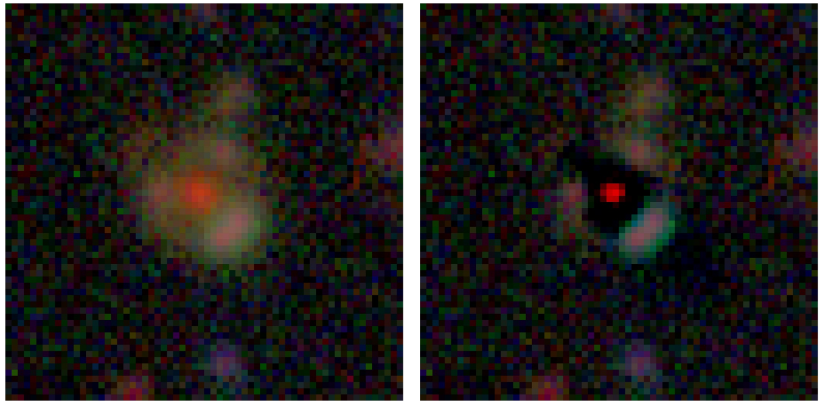
O (fid) – O (sub) – O (stack)



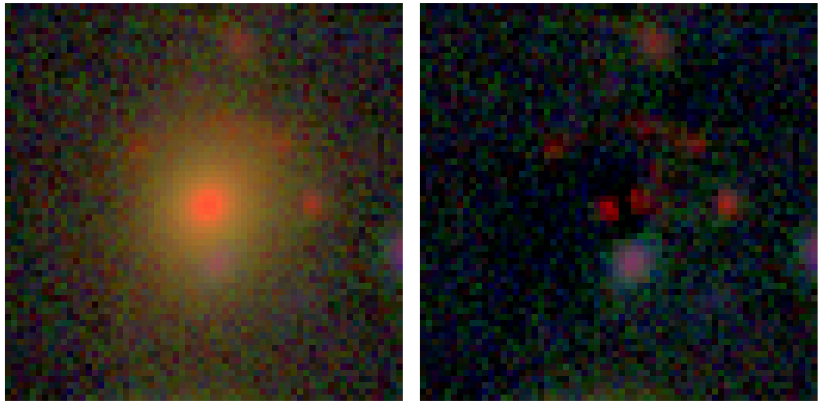
X (fid) – O (sub) – O (stack)



O (fid) – X (sub) – O (stack)



O (fid) – X (sub) – X (stack)

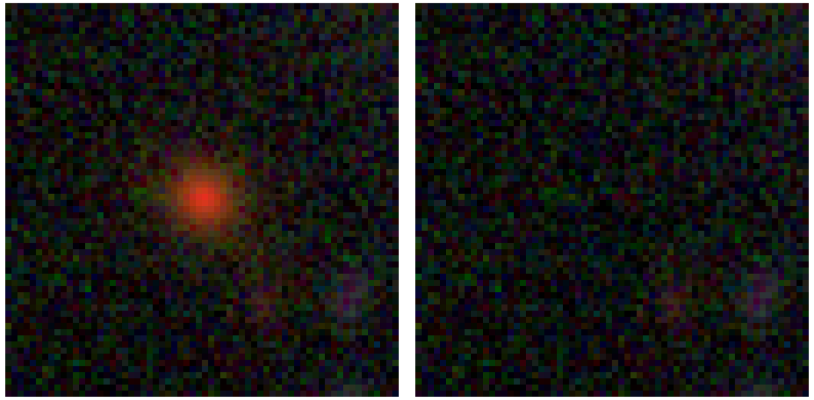


o = correct
x = incorrect

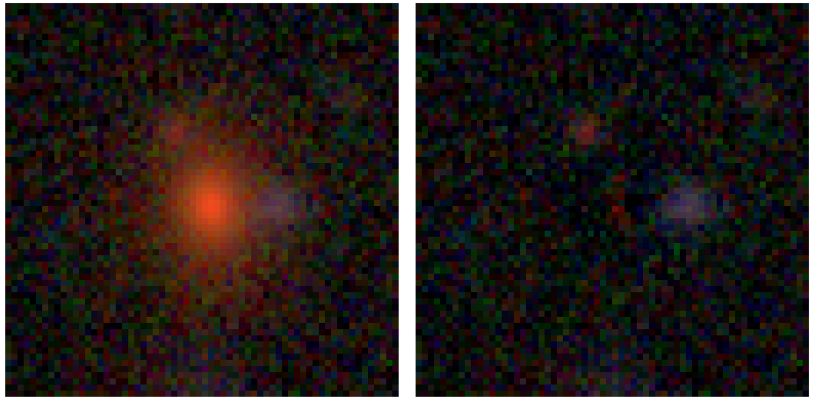
Fid vs. Sub vs. Stack (Non-lens)

Fid vs. Sub vs. Stack in nonlens

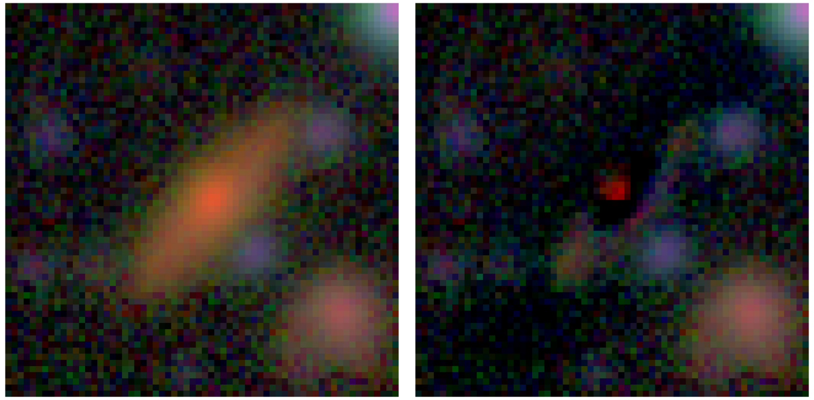
O (fid) – O (sub) – O (stack)



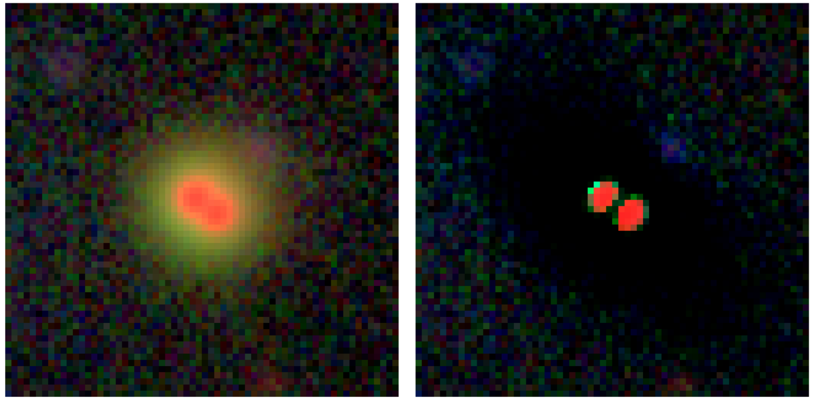
X (fid) – O (sub) – O (stack)



O (fid) – X (sub) – O (stack)



O (fid) – X (sub) – X (stack)



o = correct
x = incorrect

Collaboration Work

- Ensemble method (Holloway et al. 2023)
  - Our prediction is used for Ensemble method

Combined Classifier：Citizen Science (Sonnenfeld et al. 2020)
CNNs (Canameras et al. (2021), Shu et al. (2022), Jaelani et al. (2023), Ishida et al. (in prep))

- Comparison of different neural network with common test dataset (More et al. in prep)
  - compare our network with other CNNs (Canameras et al. (2021), Shu et al. (2022), Jaelani et al. (2023)) to evaluate performance

Summary and Future Work

- Summary
  - We subtract the lens galaxy light to improve the performance of CNNs for discovering strong lenses in the HSC SSP
  - combining subtracted images and fiducial images gives better performance (Ishida et at. in prep)

	AUROC
model_fid (using fiducial imaging data)	0.808
model_sub (using imaging data with light subtraction)	0.712
model_stack (the combination of “fid” and “sub”)	0.837

- Future Work
  - We will reduce residuals in the center of subtracted images to improve the performance
  - We will explore the specific examples more to investigate characteristics of misclassified objects.
  - investigate other methods of light subtraction