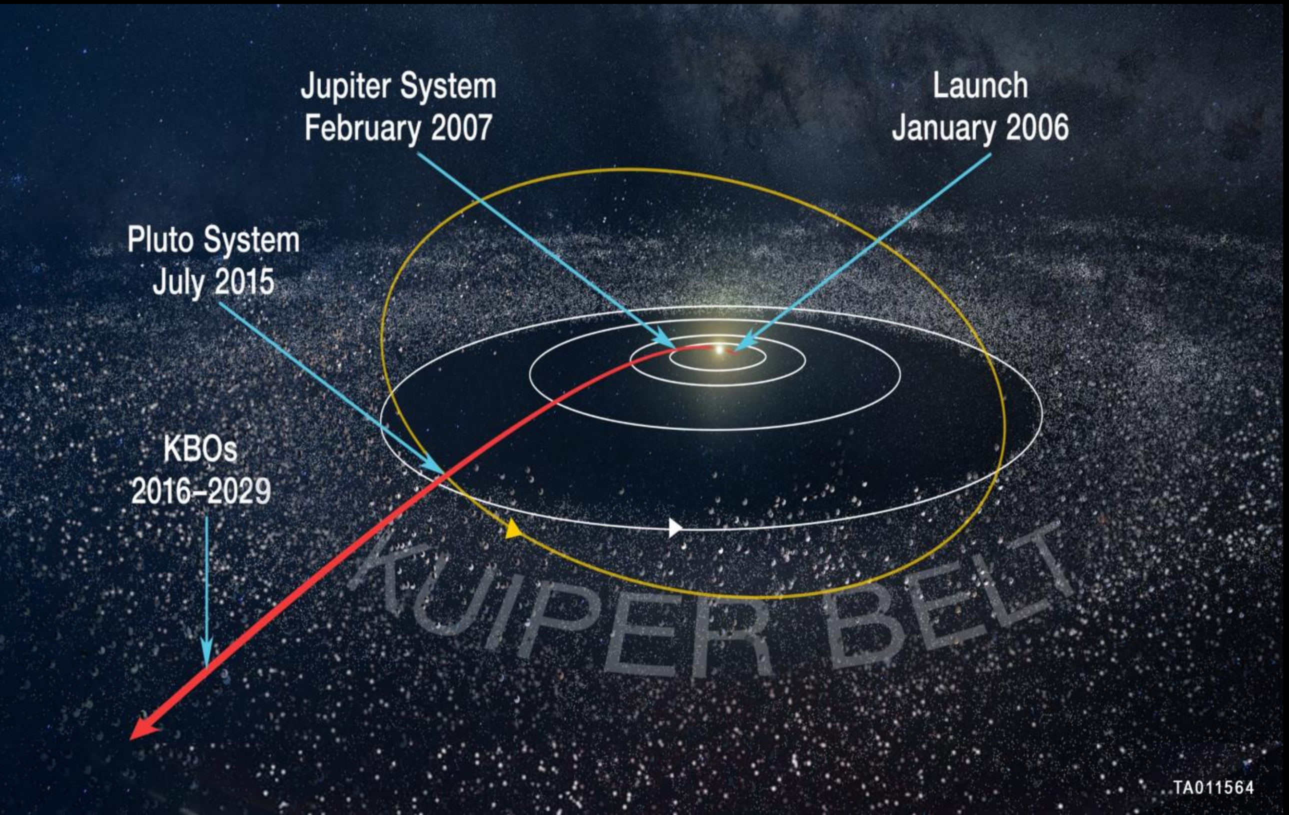
Subaru User's Meeting 2025

A CNN-based AI for Object Detection in KBO search Images collected by Subaru telescope



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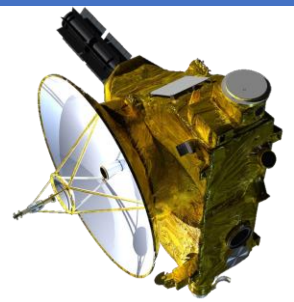
[1]University of Occupational and Environmental Health, Japan, [2]Chiba Institute of Technology, [3]Japan Aerospace Exploration Agency, [4]National Astronomical Observatory of Japan, [5]University of Science and Technology of China, [6]Southwest Research Institute Boulder, [7]National Research Council Canada Herzberg Astronomy and Astrophysics Research Centre, [8]University of Victoria, [9]Planetary Science Institute, [10]University of Virginia, [11]Sokendai, [12]University of Tokyo

Team Introduction

Team Objectives



◆What is the KBO search team

The extended missions were started in 2016. After the Arrokoth flyby, the KBO search team has focused on the two objectives:

(1) **find another KBO for flyby**

(2) **observe as many KBOs as possible from the spacecraft.**

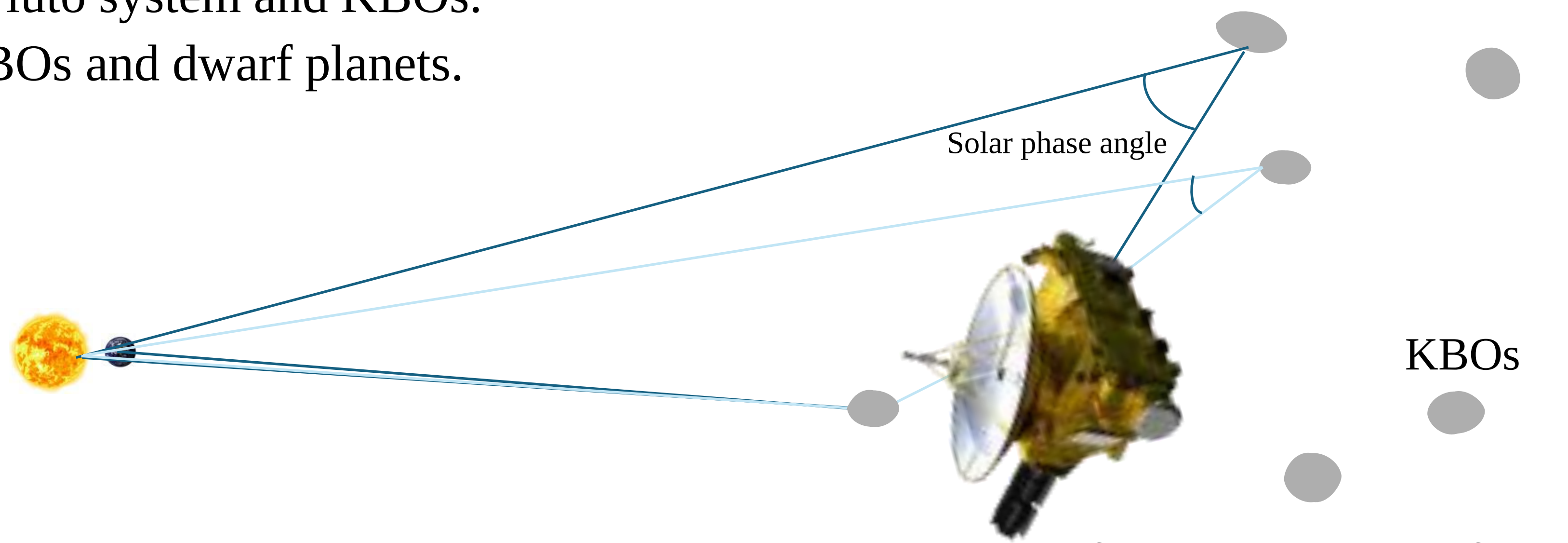
◆What is NASA's New Horizons (NH)

- NH is a flyby mission to study the Pluto system and KBOs.
- NH has now observed almost 40 KBOs and dwarf planets.

The NH has observed the surface layers of outer solar system bodies in detail for the first time. Great success!

KEM1 2016-2019

KEM2 2022-2029



From Earth we can only observe KBOs at solar phase angles of 0 to 2 degrees, but from a spacecraft in the Kuiper belt we can observe KBOs at much larger solar phase angles.

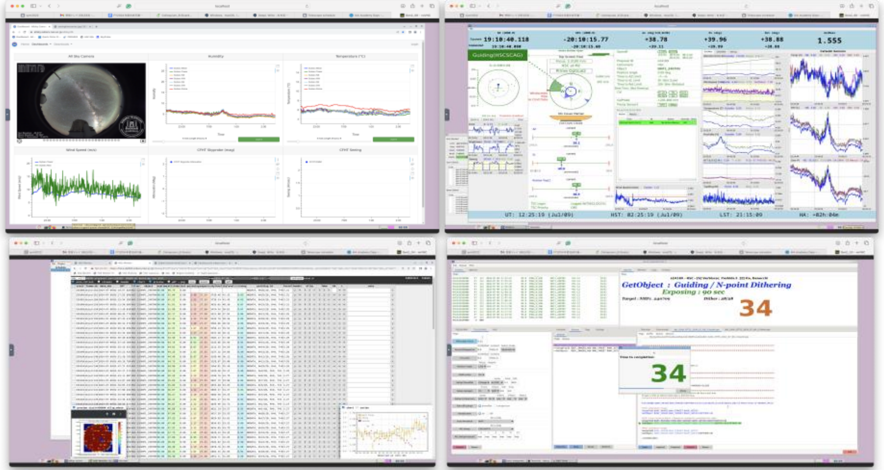
Data Set

Year	Observation Time (MJD)	Pipeline Night	R.A. (°)	Dec. (°)	Number Exposures	Sequence Duration (hrs)
2020	58995.4	03068	287.37585	-20.22724	81	2.7
	58997.5	03070	288.74057	-20.57457	76	2.7
	58998.5	03071	287.33743	-20.12725	123	4.1
	58999.5	03072	288.71466	-20.37960	127	4.3
	59000.5	03073	287.31192	-20.12834	126	4.2
	59001.5	03074	288.68802	-20.38238	58	4.1
	59019.5	03092	287.14477	-20.04175	129	4.4
	59020.5	03093	288.66147	-20.05024	117	4.0
	59021.5	03094	287.11257	-20.05892	113	3.8
	59022.5	03095	288.62929	-20.05384	101	3.4
	59024.5	03097	287.06207	-20.06483	129	4.3
	59025.5	03098	288.57787	-20.06015	119	4.0
	59073.3	03145	286.25079	-20.16488	116	3.9
	59074.3	03146	287.67551	-20.12296	128	4.3
	59075.3	03147	286.22292	-20.16881	127	4.3
	59076.3	03148	287.74292	-20.16470	121	4.3
2021	59374.5	03447	288.54961	-21.09995	115	4.2
	59382.5	03455	288.44956	-21.10000	94	3.4
	59400.4	03473	288.00157	-20.28053	117	4.1
	59462.2	03535	288.35953	-21.35001	119	4.0
	59463.2	03536	286.58291	-21.34999	116	3.9
2022	59732.5	03805	288.50000	-21.66665	111	3.9
	59733.5	03806	288.49996	-21.66668	119	4.1
	59759.5	03832	288.25939	-21.42730		
	59760.5	03833	288.25943	-21.42732		
	59872.2	03945	288.42499	-21.40842		
	59873.2	03946	288.42503	-21.40844		
	59875.2	03948	288.37854	-21.41377		
2023	60196.3	04269	288.25001	-21.44998		
	60197.3	04270	288.25002	-21.44998		

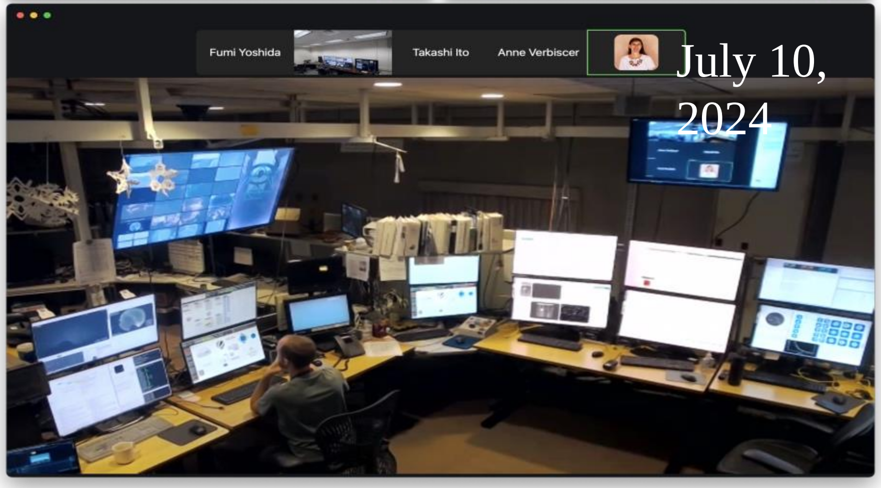
Total data size of raw images is about **6.4 TB**

◆Major Config of observation

- ~ 100 images are taken per night (~200GB raw data)
- An exposure time of 90 seconds per image.
- r2 or special wide filter.



The analysis screen of observation.



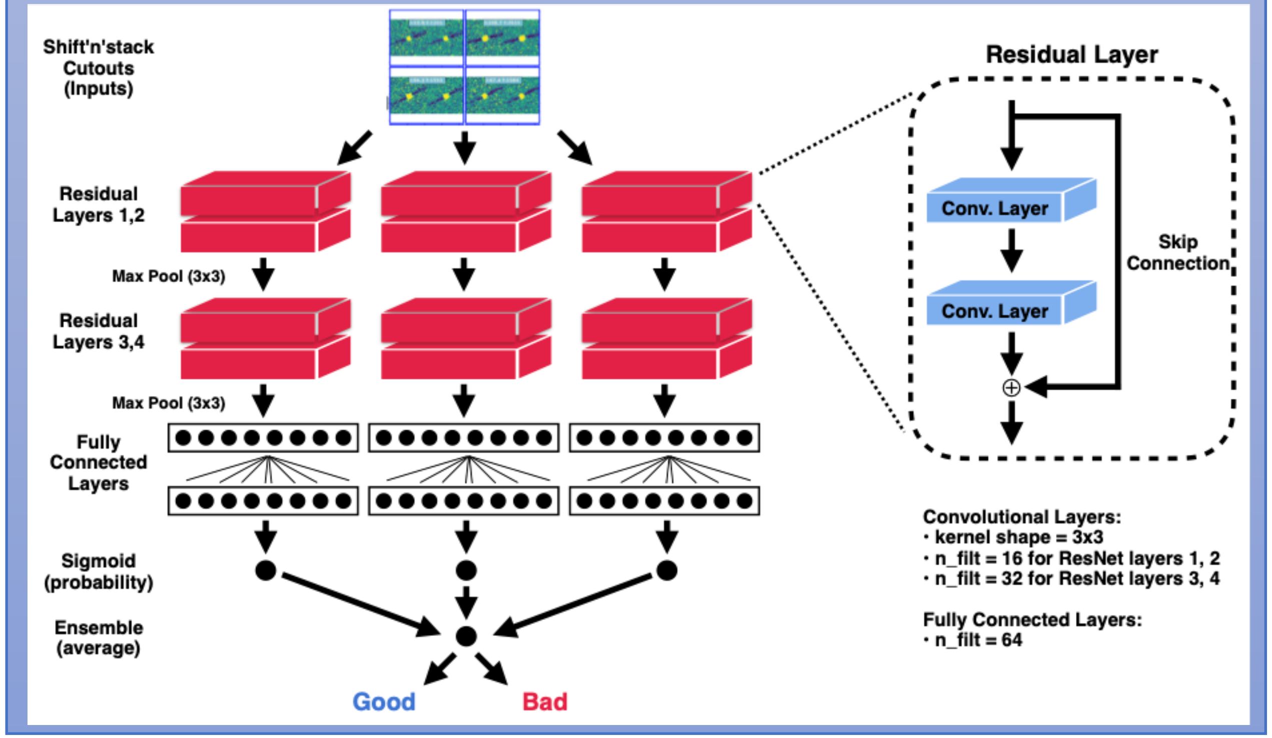
View of the observation room at Subaru Telescope

Data analysis method

Canada & US team

Method 1 Fraser et al. (2024)

LSST pipeline + GPU + machine learning



Principle:

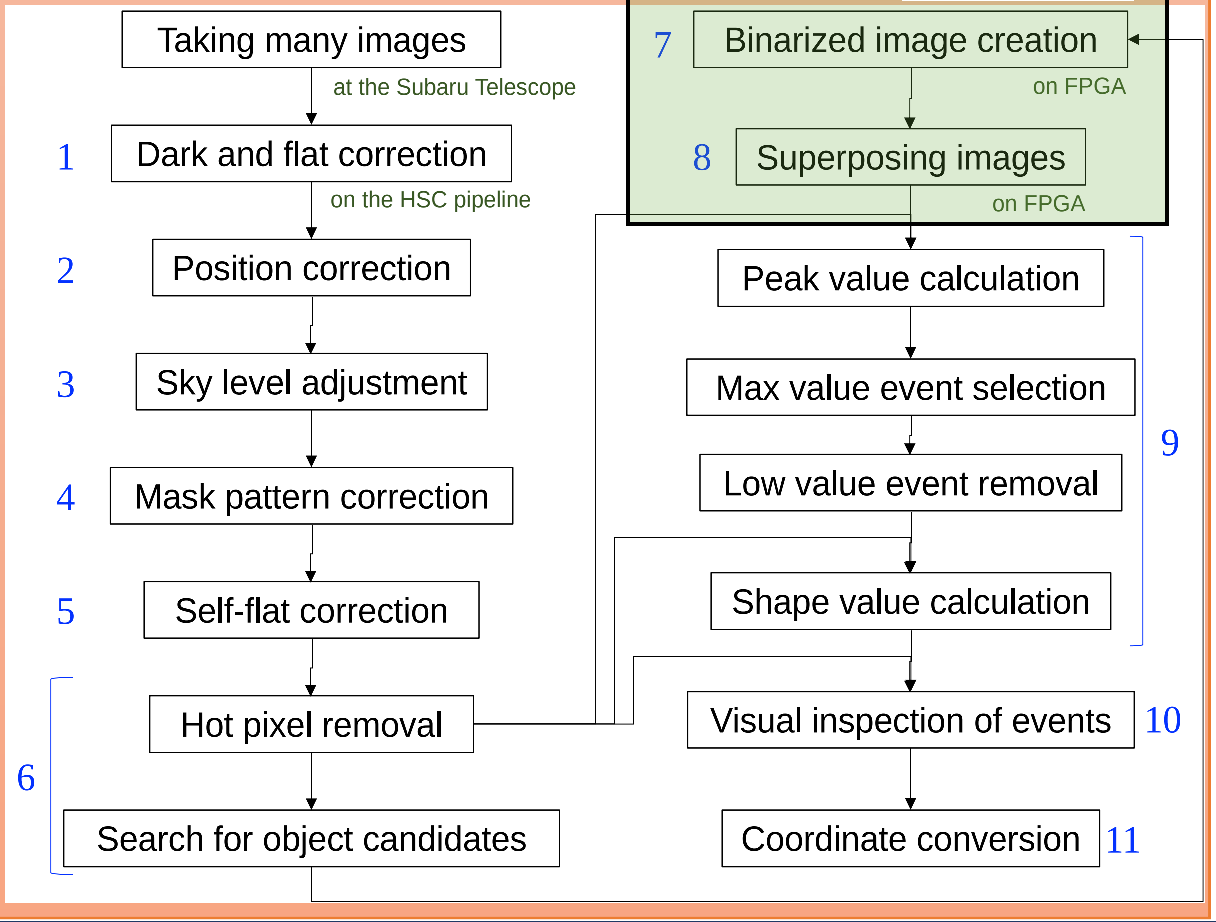
- **<u>Assume the typical velocity range of KBOs</u>** and find objects moving at that velocity.
- Since KBOs are faint, the images are **<u>superposed</u>** to amplify the signal.

Japan team

Method 2 Yoshida et al. (2024)

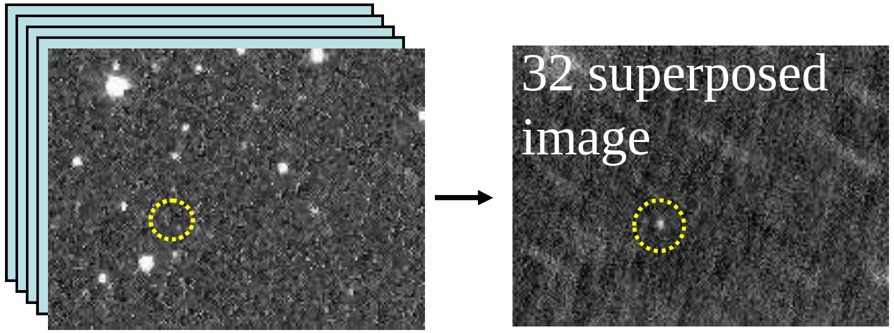
HSC pipeline + JAXA moving object detection system

FPGA

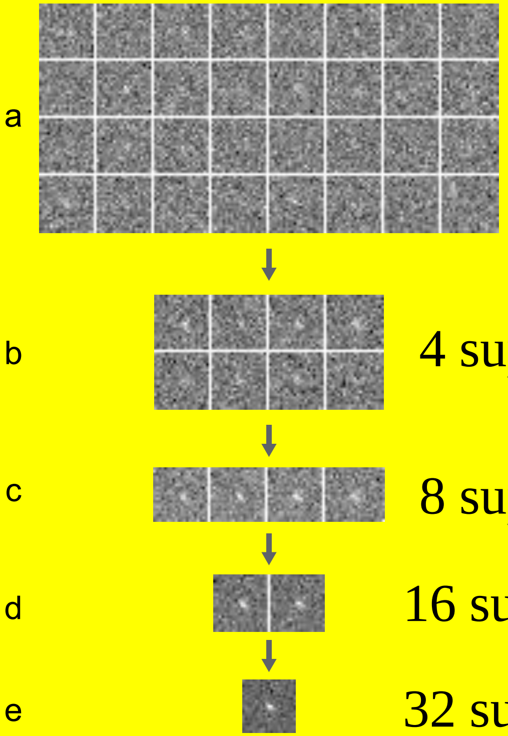


Independent Data analysis by JAXA's system.

◆Summary of the procedures performed in the JAXA system



Faint objects can be seen by superposeing images.



An object candidate detected in each of the images.

4 superposed images

8 superposed images

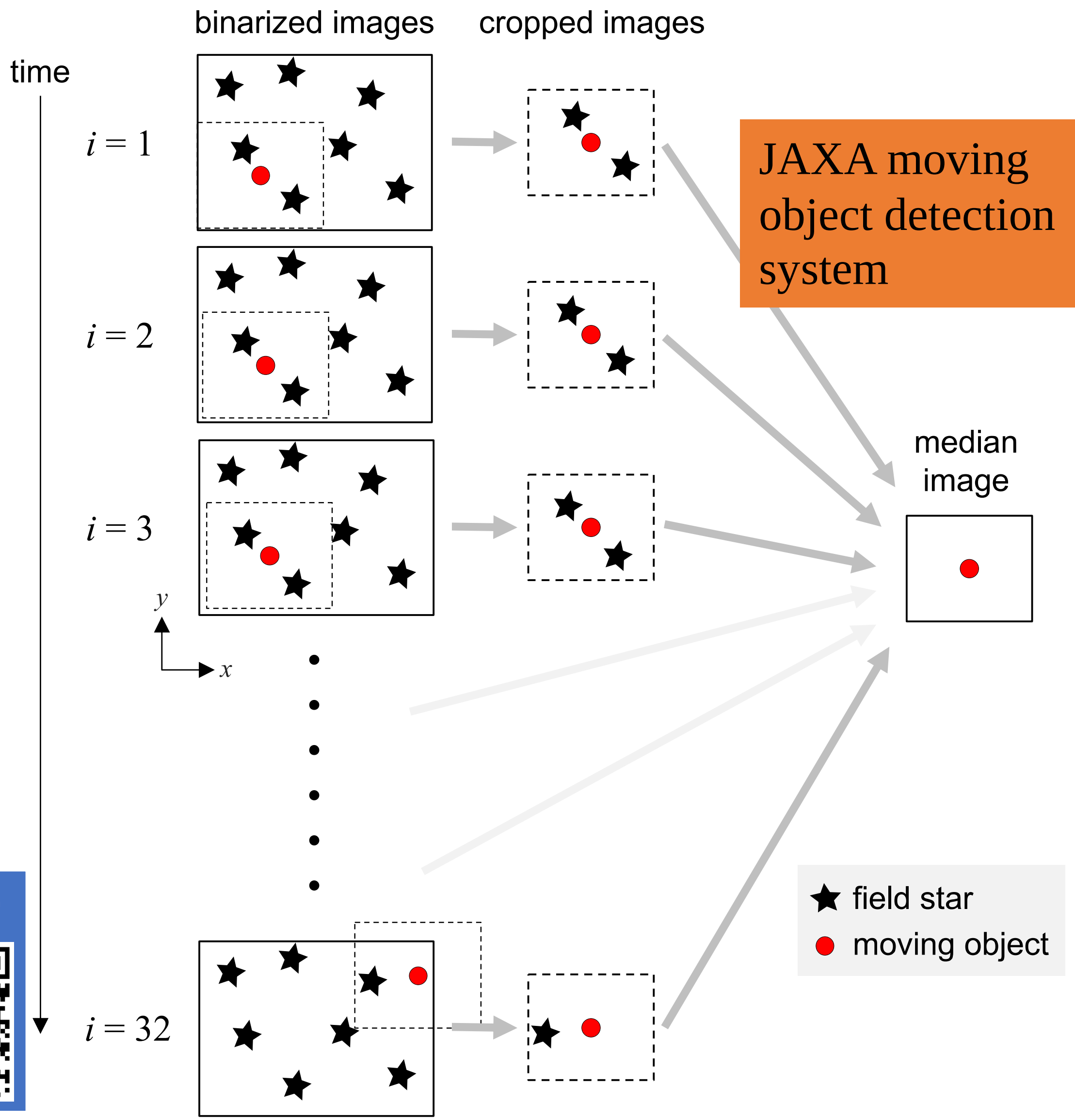
16 superposed images

32 superposed images

Crop and superpose portions of the image at an assumed speed.

If the candidate is real object, we can see a light source in the center of each image.

Please refer our paper for details.
Yoshida et al. 2024 PASJ



Yoshida et al. 2024 PASJ, 76, 720–732, https://doi.org/10.1093/pasj/psae043

Subaru Telescope		CfCA		Chiba Institute of Technology PERC	ISAS	
Japanese	English	Japanese	English	Japanese・English	Japanese	English

Buie et al. Accepted for publication in The Planetary Science Journal （https://arxiv.org/abs/2403.04927）
Fraser et al. Accepted for publication in The Planetary Science Journal （https://arxiv.org/abs/2407.21142）

NAOJ		Subaru Telescope		CfCA		Chiba Institute of Technology PERC	NASA New Horizons
Japanese	English	Japanese	English	Japanese	English	Japanese・English	English

Machine Learning Methods

Introduction：Research topic and objective

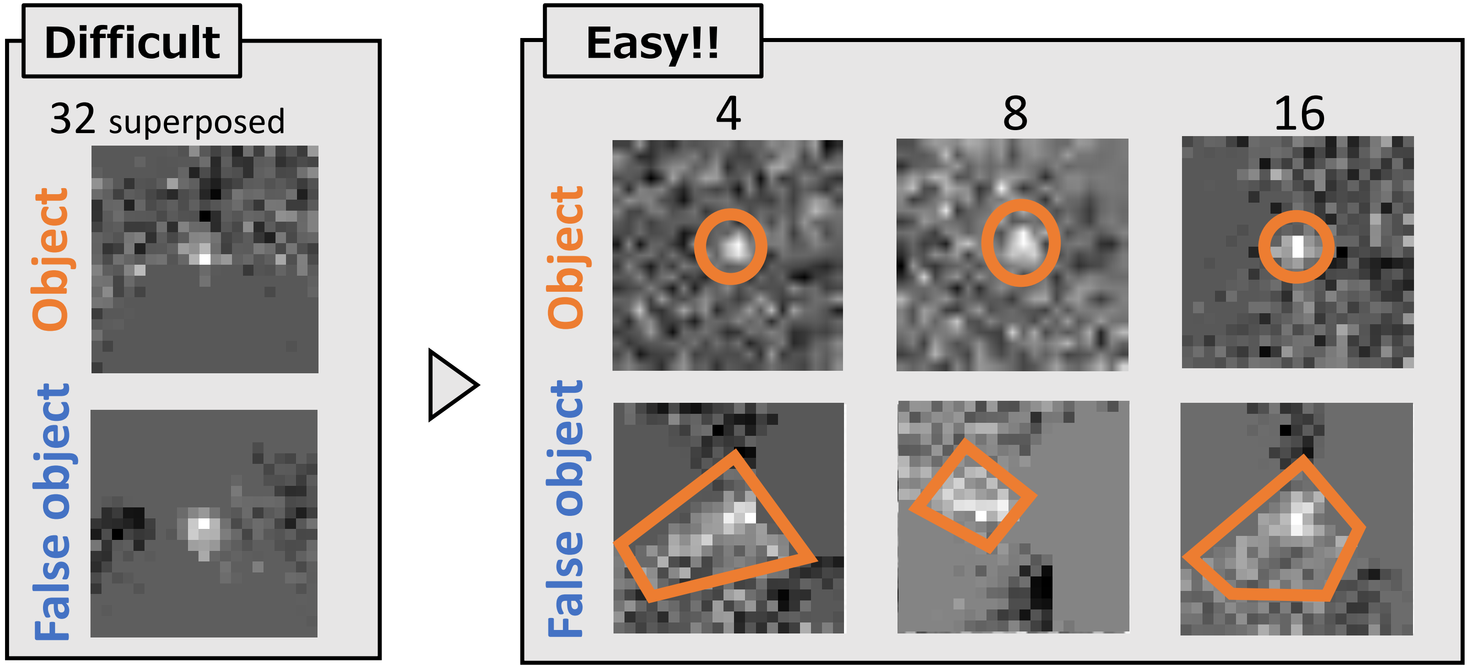
◆Classification **by a 32 superposed image**

- The highest accuracy achieved was **92%**.
- The main cause was images, which were difficult to classify **even for the human eye.**

◆Classification **by multi superposed images**

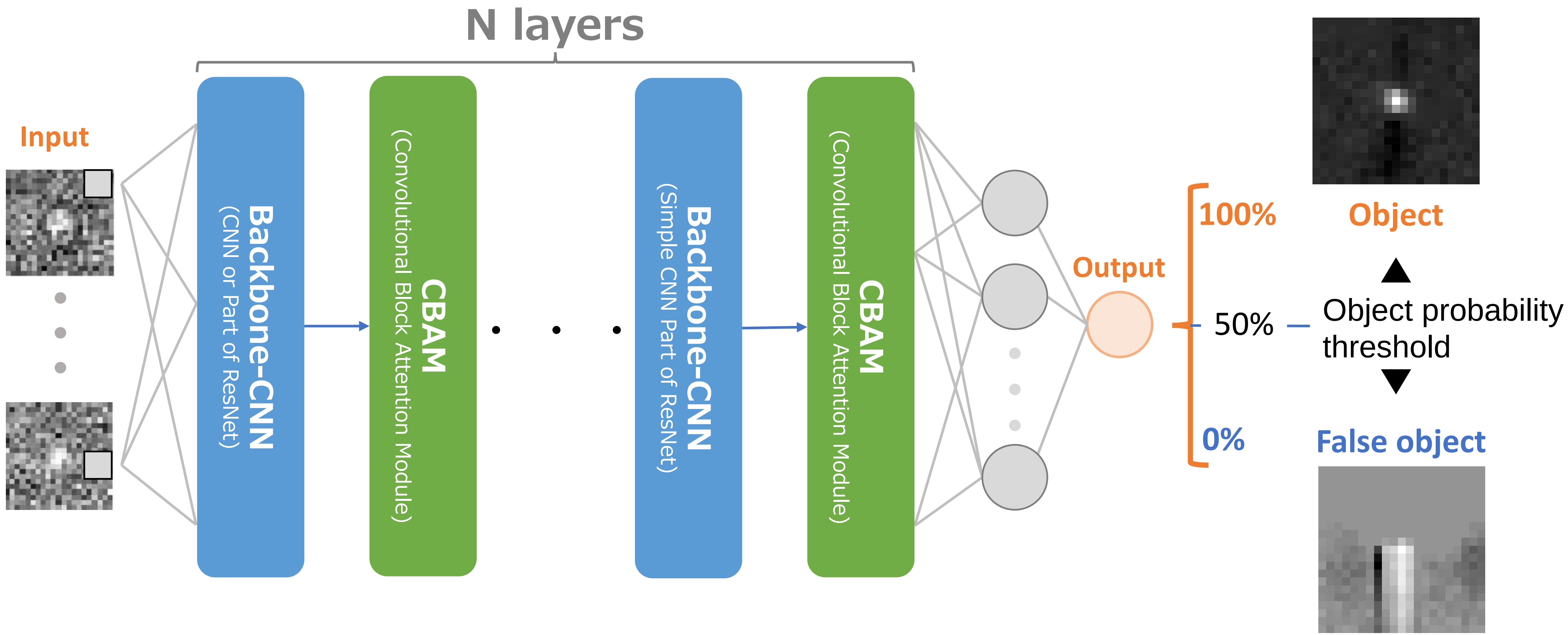
- For human classification, images with **4, 8, 16, 32 superposed** were used

Image for visual inspection for real KBOs



Realization of **a** highly accurate **detection method**
by **a machine learning** using multiple superposed images as input

Methodology：Model Architecture

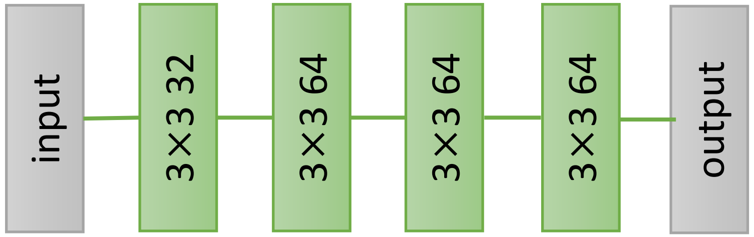


Methodology：Concept of Models

Backbone-CNN

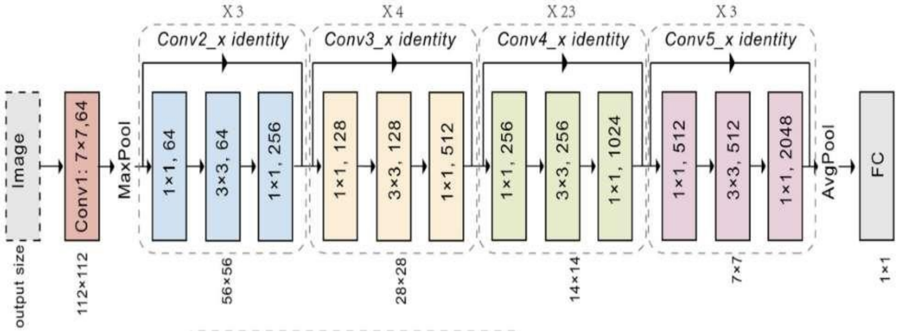
■ **Simple CNN**

- 2 or 4 layers
- 6 different types of channel



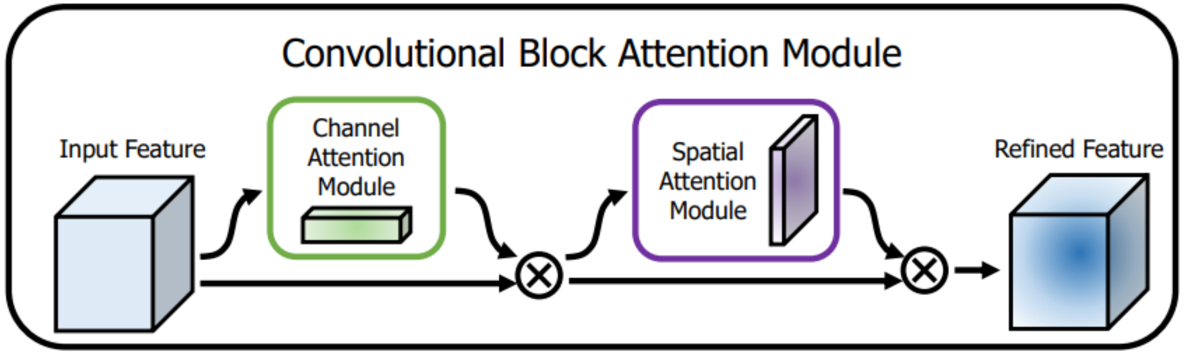
■ **Complex CNN**

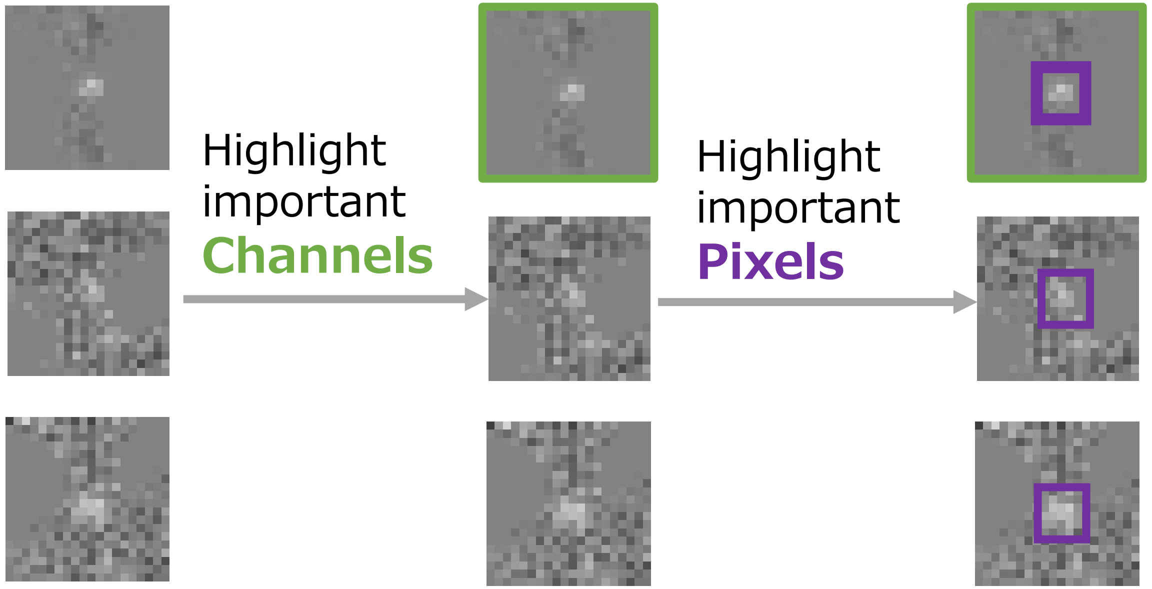
- Based on ResNet[1]
- 5 different types of layers :
  18, 34, 50, 101, 152 layers



CBAM

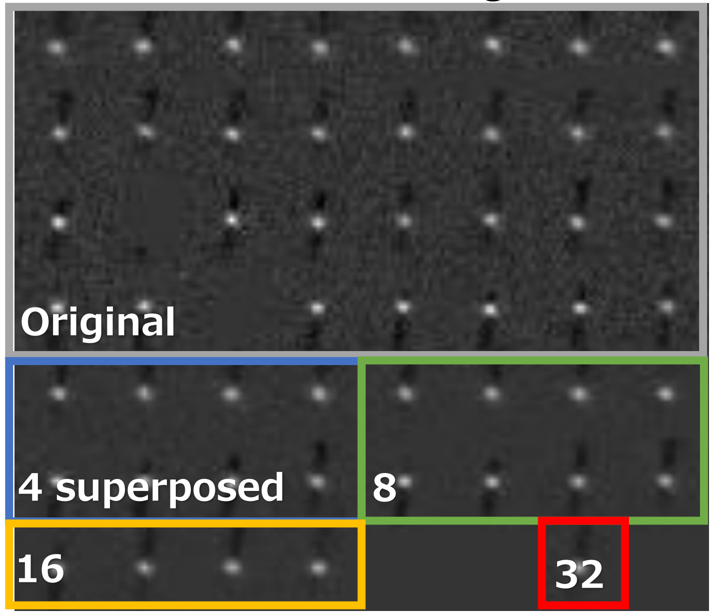
■ It learns which channels and which positions are important with attention, improving performance.





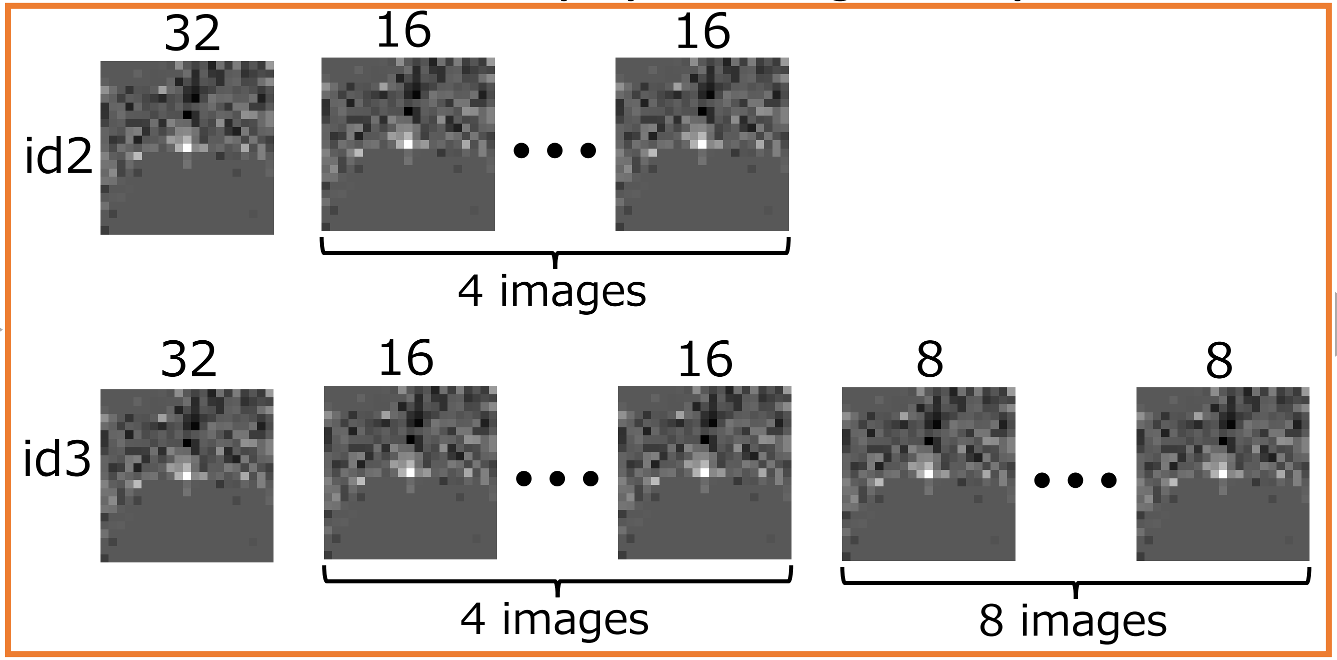
Methodology：How to create Multi Input Data

One of the teaching data

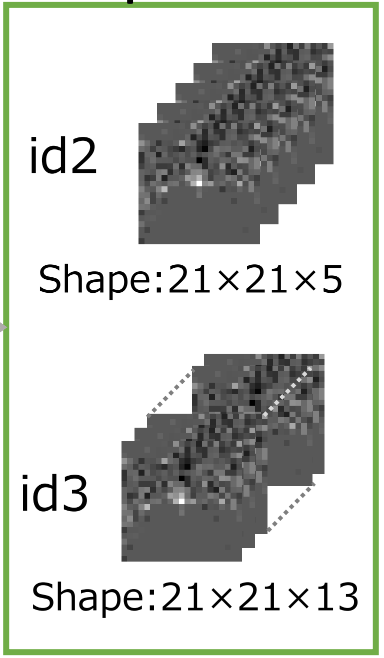


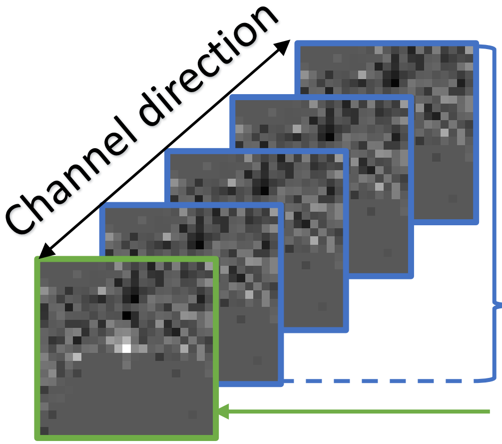
32-superposed image :1
16-superposed image :4
8-superposed image :8
4-superposed image :8

Selection of superposed images for input



Input Data





Input data is created by concatenating the images along the channel direction.

Four 16-superposed images

One 32-superposed images

Data Shape
21×21×5

21×21 : Image Size
5 : Channel Size

Experiment：Experimental Setup of Simple CNN

Table1

Name	Item					
Id	No1	No2	No3	No4	No5	No6
channel set	32-64	64-128	32-32-64-64	64-64-128-128	32-64-128-256	64-128-256-512
Layer	2	2	4	4	4	4
Parameters (1ch input data)	47.0K (K : kilo)	130K (K : kilo)	93.2K (K : kilo)	315K (K : kilo)	500K (K : kilo)	1.77M (M : million)
Epoch	30					
Batch size	32					
Learning ratio*	0.01					
Change raito*	0.1					
Change step*	5, 10, 15, 20, 25					
Optimizer	SGD : Stochastic Gradient Descent					
Loss function	BCE : Binary Closs Entropy					
momentum	0.9					
weight decay	0.0001					

*To reduce loss, the learning rate was decreased by a factor of 10 (change ratio) at specified epochs(change step) as the training progressed.

Experiment：Experimental Setup of Complex CNN

Table2

Name	Item				
Id	**res18**	**res34**	**res50**	**res101**	**res152**
Base Model	**ResNet 18**	**ResNet 34**	**ResNet 50**	**ResNet 101**	**ResNet 152**
Layer	**18**	**34**	**50**	**101**	**152**
Parameters (1ch input data)	**3.18M (M : million)**	**11.4M (M : million)**	**13.2M (M : million)**	**24.9M (M : million)**	**34.6M (M : million)**
Epoch	**30**				
Batch size	**32**				
Learning ratio*	**0.01**				
Change raito*	**0.1**				
Change step*	**5, 10, 15, 20, 25**				
Optimizer	**SGD : Stochastic Gradient Descent**				
Loss function	**BCE : Binary Closs Entropy**				
momentum	**0.9**				
weight decay	**0.0001**				

*To reduce the loss, the learning rate was decreased by a factor of 10 (change ratio) at specified epochs(change step) as the training progressed.

Exp 1 : Train & Test by one supervised dataset

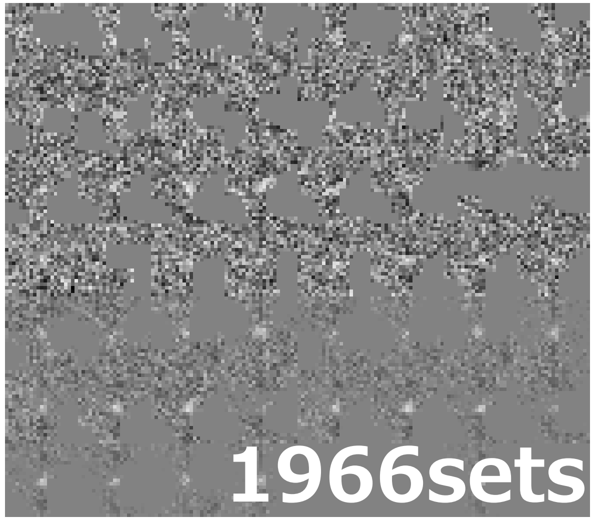
Concept

- The model was trained and its classification performance evaluated using a dataset from a single day's observations.

Objective

- To verify the absolute performance of the model on the training data.

All superposed images



An output image of the JAXA's system

The split data

Training Data
1415sets

Valid Data
157sets

Test Data
394sets

Data Processing

1. Augmentation
We use **rotating** and **flipping** to augment the images by **6 times.**

2. Scaling
To improve learning efficiency, we scaled the images by **standardization**

Data post-processing

Training Data
8490sets

Valid Data
942sets

Test Data
2364sets

Exp 2 : Test by another supervised dataset

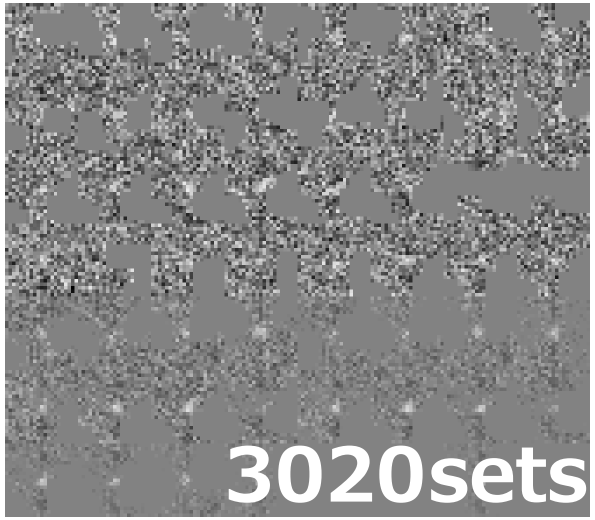
Concept

- The model's performance was evaluated using a dataset from another day's observations.

Objective

- To evaluate the performance on untrained observation data from different days.

All superposed images



An output image of the JAXA's system

Models are pretrained with the teacher dataset

All data used as test data.

Data Processing

~~**1. Augmentation**~~

~~We use **rotating** and **flipping** to augment the images by **6 times**.~~

2. Scaling

To improve learning efficiency, we scaled the images by **standardization**

Data post-processing

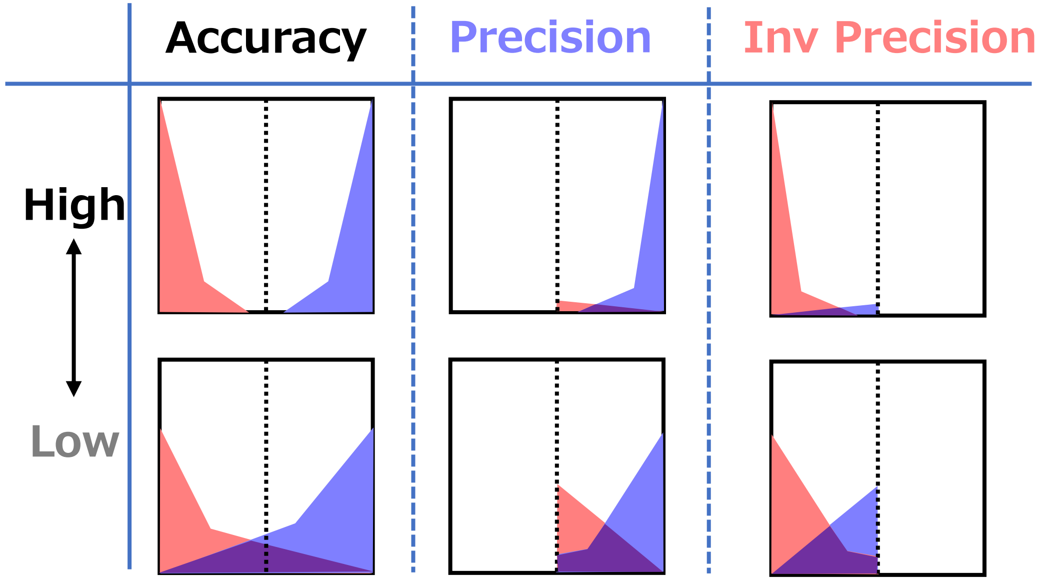
Test Data

3020sets

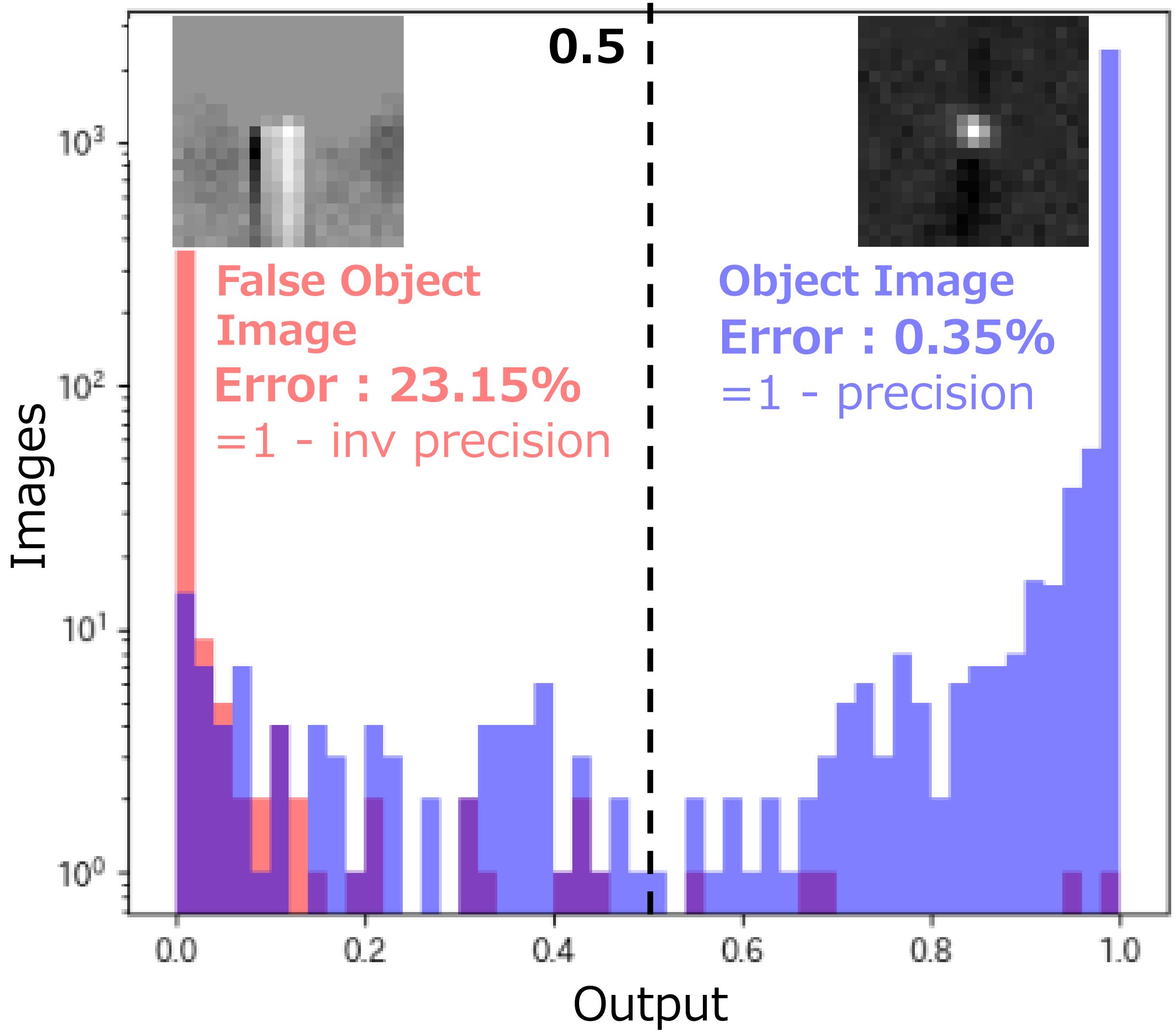
Result of Exp1, 2

◆Performance

Metrics	Teacher Dataset	Test Dataset	diff
Accuracy	**96.82**	**96.26**	**-0.56**
Recall	97.25	96.07	-1.18
Precision	**98.52**	**99.65**	**+1.13**
Inv Precision	**91.81**	**77.85**	**-13.06**
F1-Score	97.88	97.83	-0.05



◆Histogram of Test observation dataset



Result of Exp 3 : Human cost reduction rate

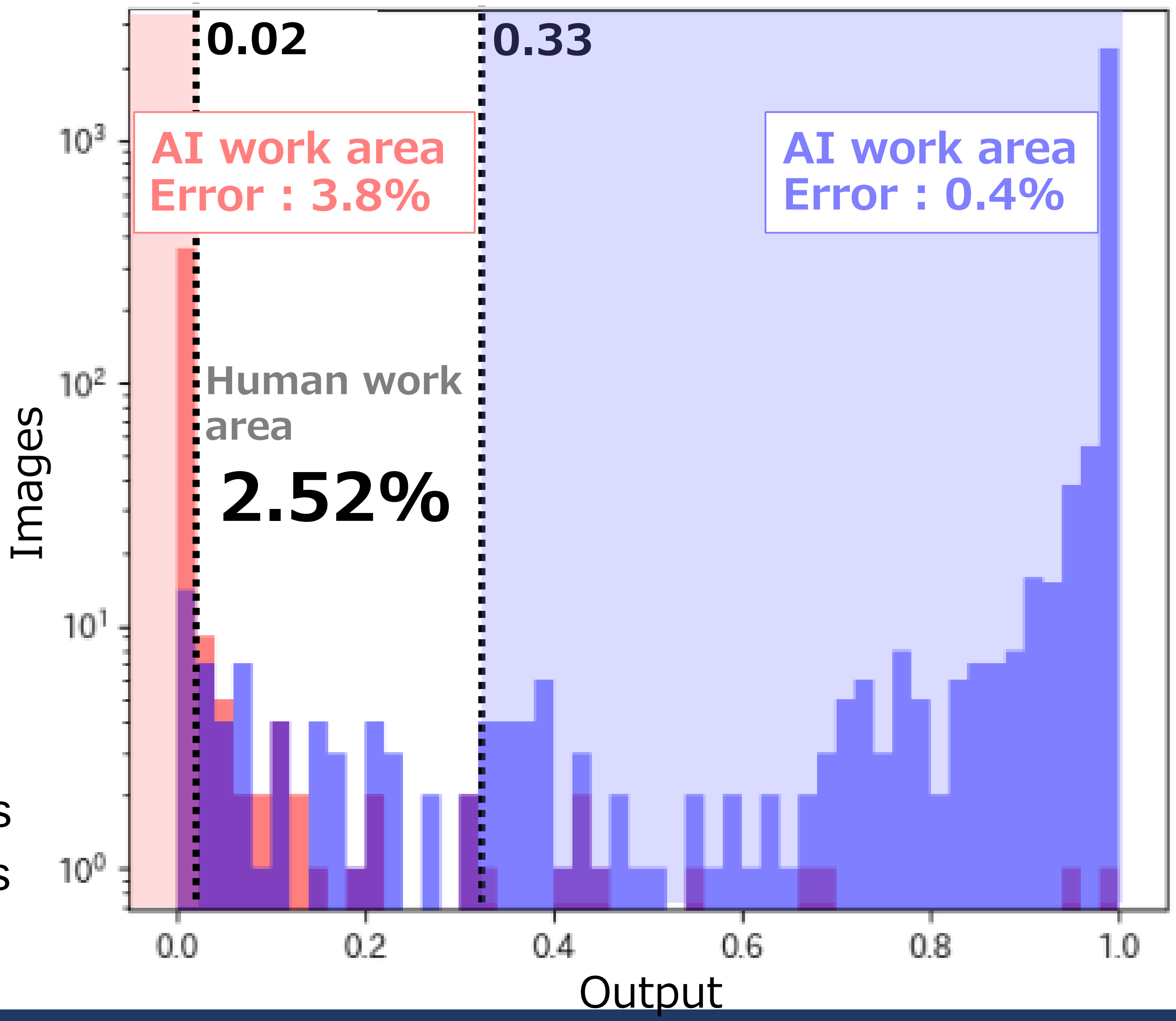
◆Performance

Metrics	Before adj Th0.5	After adj Th0.02, 0.33
Accuracy	96.26	96.72
Recall	99.65	99.46
Precision	**96.07**	**99.65(+3.68)**
Inv Precision	**77.85**	**96.23(+18.4)**
F1-Score	97.83	99.56

◆Human cost reduction rate

- **97.38% reduction possible!**
- Error
  - Object Images : 0.35%≒10 images
  - False Object Images : 3.77%≒15 images

◆Histogram of Test observation dataset



Conclusion

◆We are conducting observations using Subaru to support the search for the **second flyby object of New Horizons**.

◆**JAXA's Moving Object Detection System** enables the detection of faint moving objects through its unique superposition method.

◆To improve the efficiency of object detection in superposed images, we developed **a model that takes multiple images as input**.

◆Through threshold adjustments, the model achieved **a 97.38% reduction in human tasks.**