Development of a Machine Learning-Based Transient Alert System for Tomo-e Gozen

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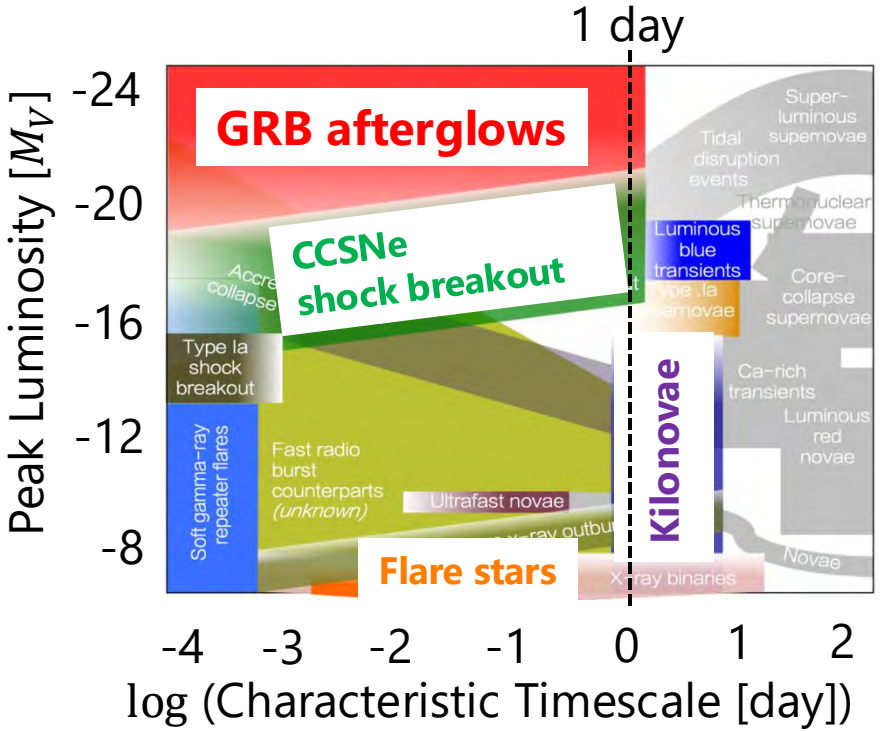
Nozomu Tominaga (NAOJ), Ichiro Takahashi (Science Tokyo),

Kenta Taguchi (Kyoto Univ.), Masaomi Tanaka (Tohoku Univ.) and Tomo-e Gozen collaboration

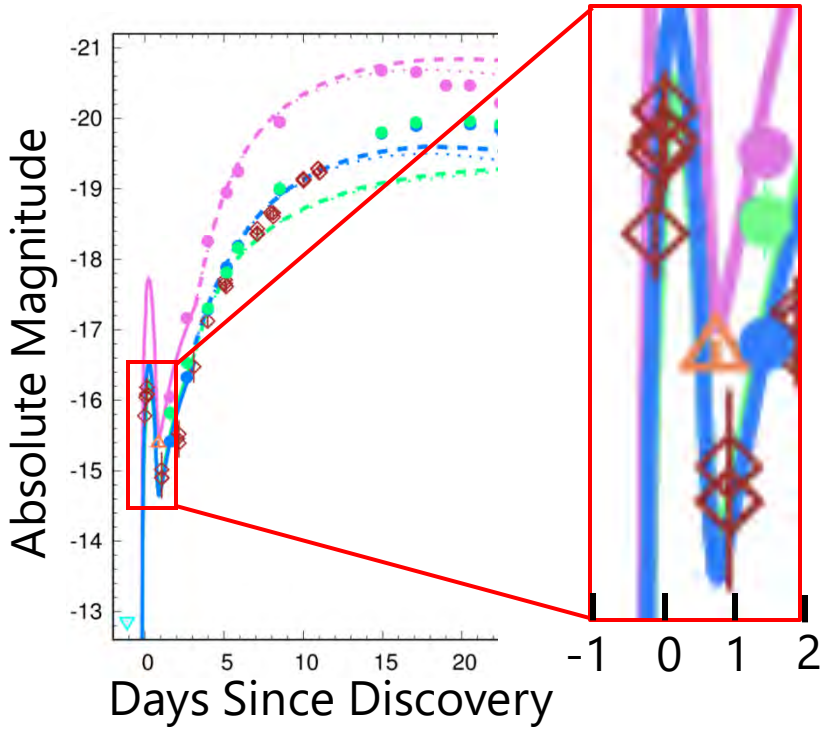
EAMA11@Toki Messe, Niigata, December 12th , 2025 MM-4C

Introduction: Time-domain astronomy

- Time-domain astronomy: Studying time-varying objects.
- **Rapid follow-up observations are necessary** especially for transients (Short-timescale variabilities $\lesssim$ 1 day).
  - ➢ Kilonovae, Flare stars, Supernova shock breakout, etc.



Based on Buckley et al., 2020, Fig. 1.



Early flux excess of a peculiar SN Ia SN 2020hvf

~ 1day

Based on Jiang et al., 2021, Fig. 6.

Introduction: Tomo-e Gozen transient survey

Tomo-e Gozen transient survey

- **All-Sky Survey:** ~5000 deg^2/night, ~2 visit/night
- **High-Cadence Survey:** ~2500 deg^2/night, 2-3 visit/night

+

- **Neutrino alert follow-up observations**

→ MM-12P by Toshikage-san

- **GW alert follow-up observations**
- **X-ray alert follow-up observations**





1.05m
Schmidt telescope
(Kiso observatory)

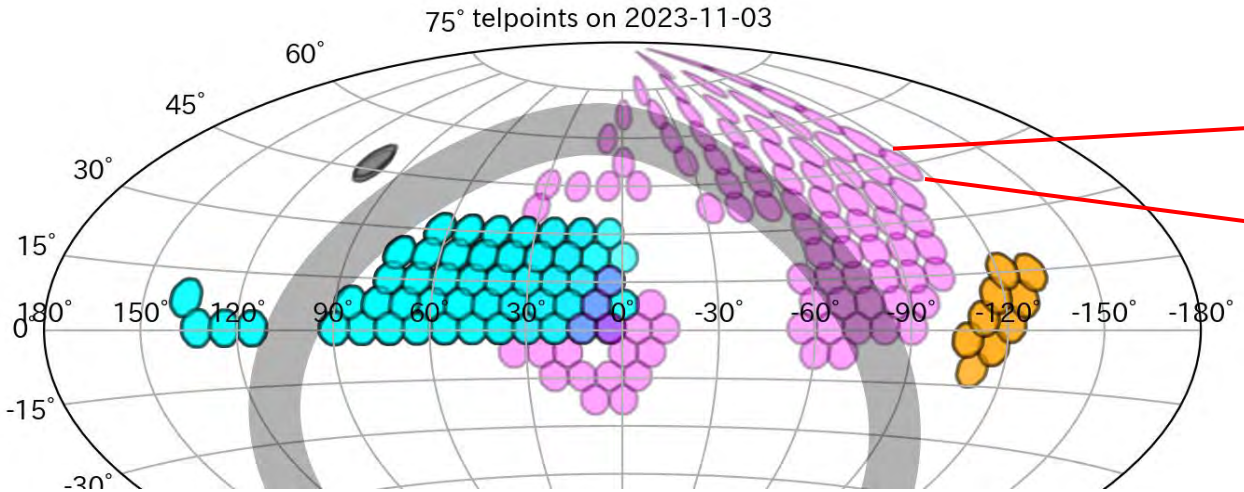
Introduction: Tomo-e Gozen transient survey

Tomo-e Gozen transient survey

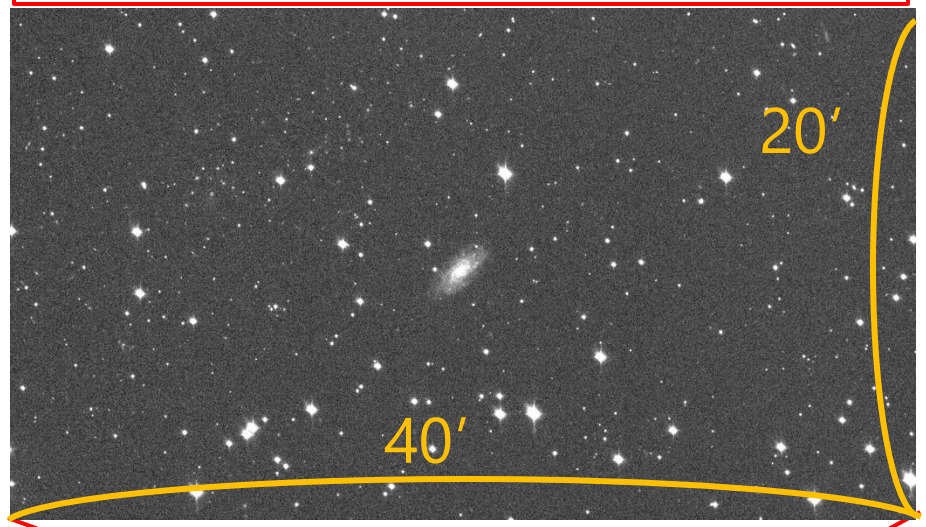
- **All-Sky Survey:** ~5000 deg^2/night, ~2 visit/night
- **High-Cadence Survey:** ~2500 deg^2/night, 2-3 visit/night
- 2 fps video data

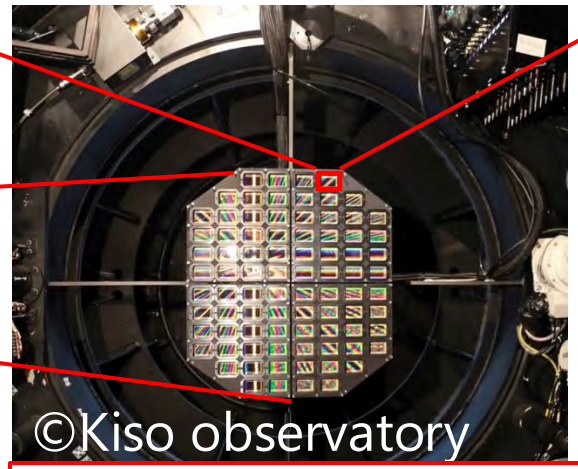
→ Stacked image of a video data (6 seconds)

→ Limiting magnitude ≲ 19 mag



Tomo-e Gozen image with one sensor





Tomo-e Gozen camera with 84 CMOS sensors

Sako et al. 2018

Introduction: Aim of this research

- Develop feature-based ML models (a discriminator & a classifier).
- Develop a transient event alert system.

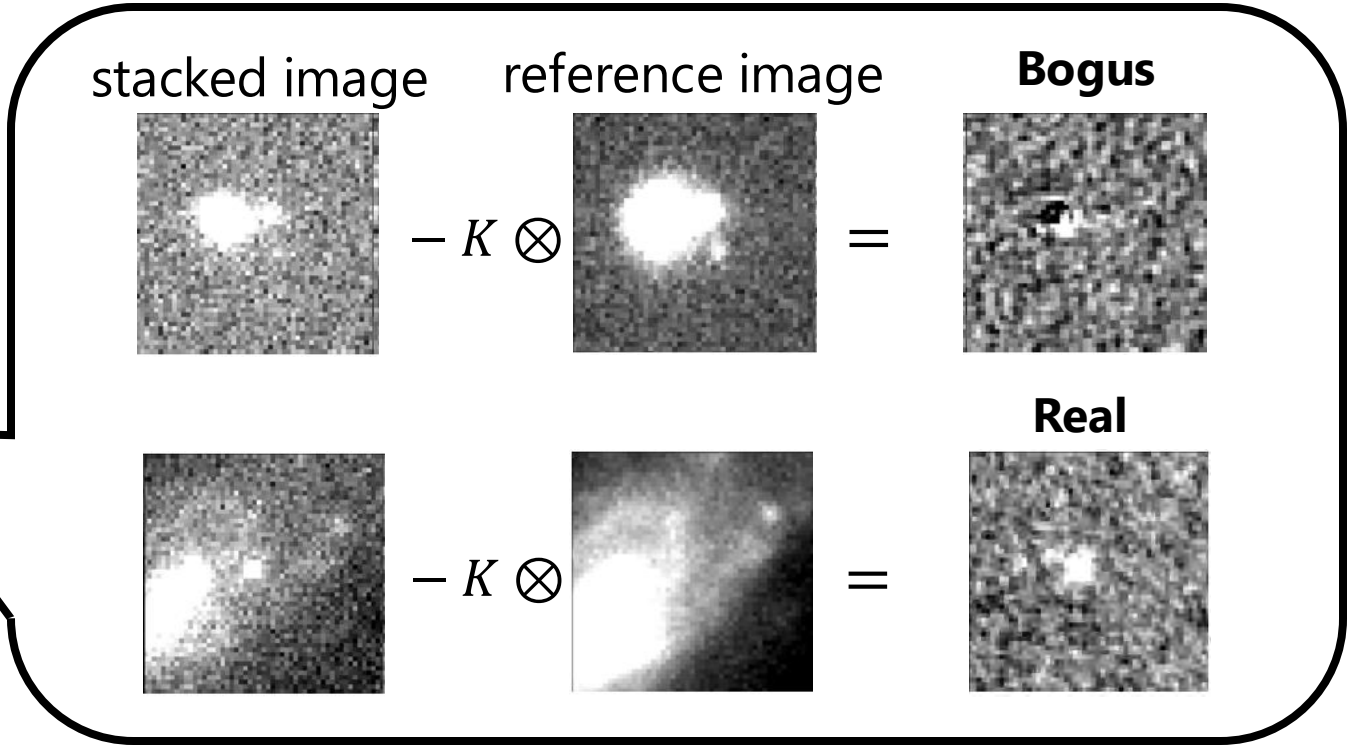
Image-based ML model
(Takahashi et al., 2022)

High-count pixel region $\sim 10^7$/night

"CNN-Real" detections $\sim 10^4$/night

If already recorded once

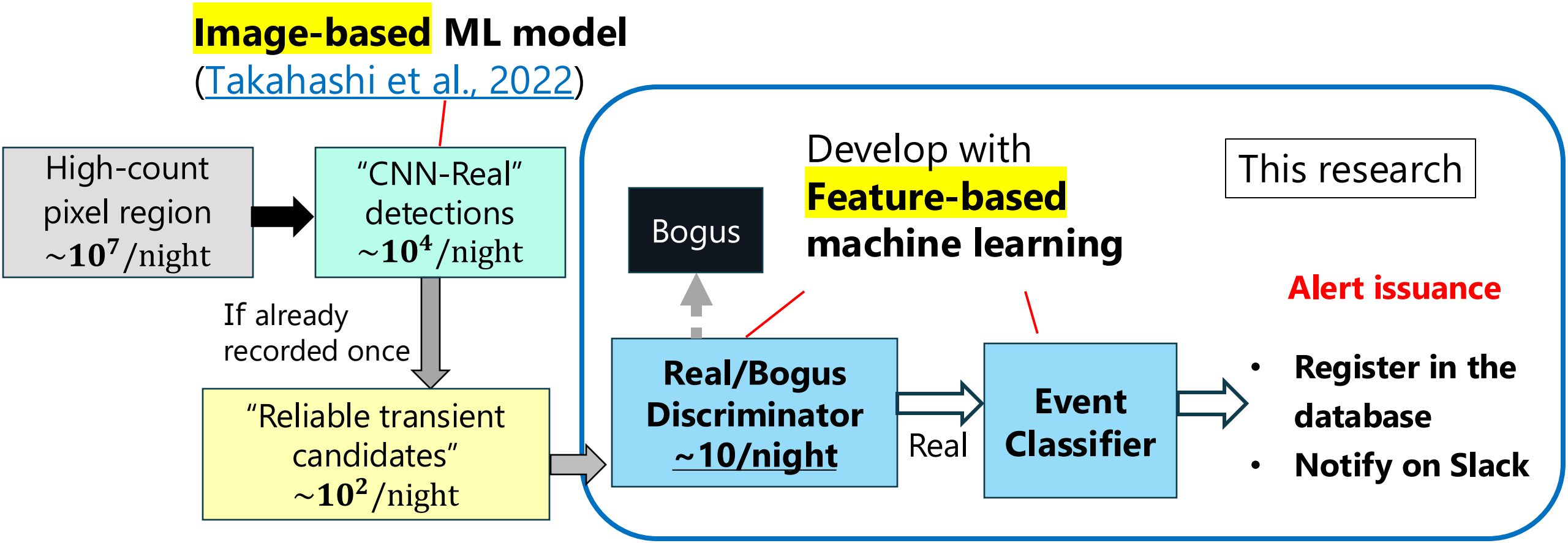
"Reliable transient candidates" $\sim 10^2$/night



still contained ~90% false detections.
Real-time alerts had not been achieved.

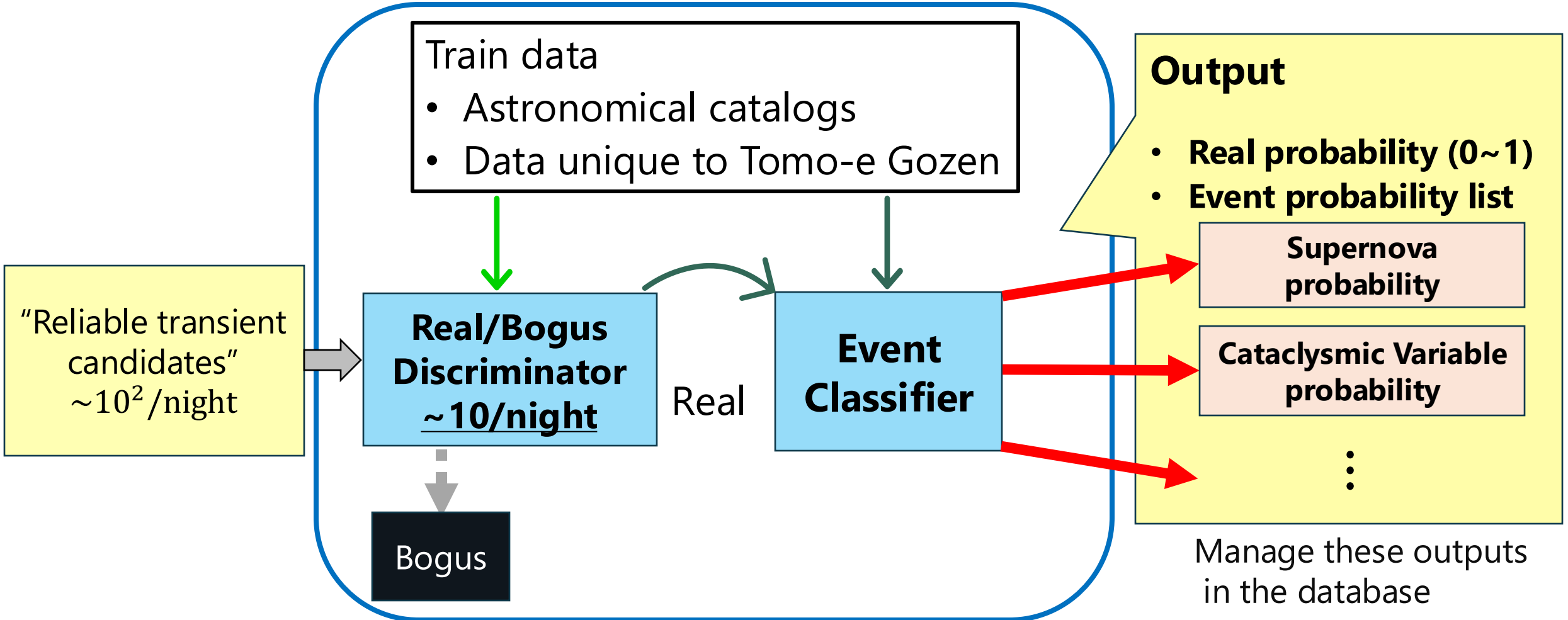
Introduction: Aim of this research

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Developing machine-learning (ML) models

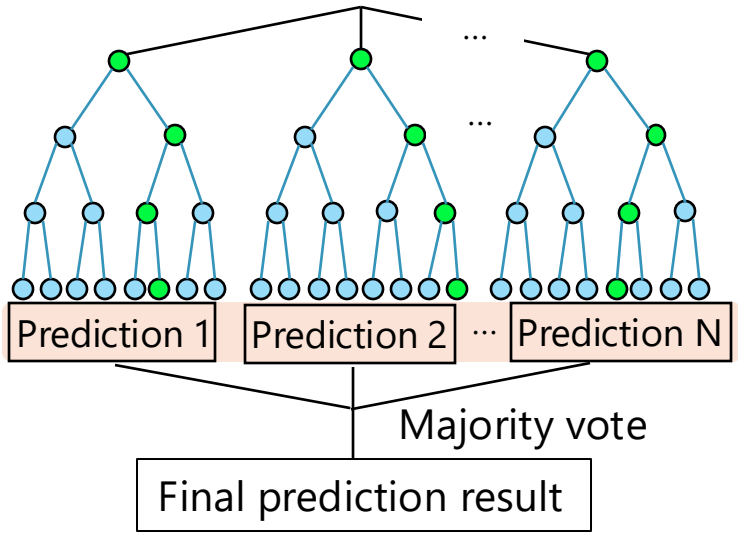
- CNN in the Tomo-e Gozen pipeline does not use astronomical information.
- Develop two machine-learning models with random forest (RF) algorithm.



Developing machine-learning (ML) models

Why Random Forest (RF) algorithm?

- This is **feature-based**.
- It is possible to create a **high-precision and interpretable model** relatively easily.



We aim to develop the discriminator that satisfies

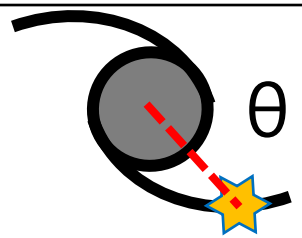
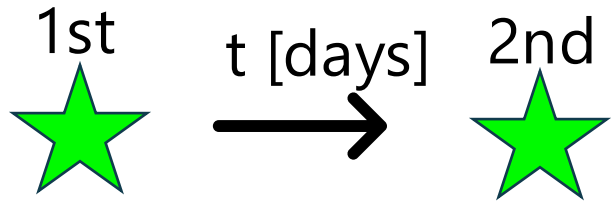
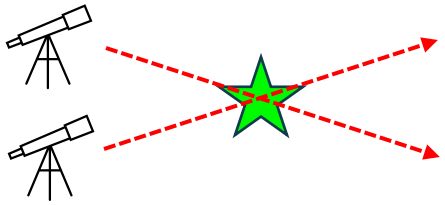
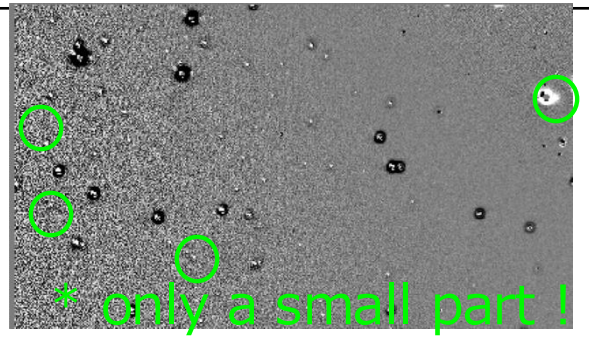
$\boldsymbol{TPR \geq 0.8}$ **and** $\boldsymbol{FPR \leq 0.05.}$

(True Positive Rate) (False Positive Rate)

Assuming 10 true and 90 false "reliable candidates" daily, **8 correct and 4.5 false alerts would be issued** each day.

Confusion matrix		**Predicted**	
		Negative	Positive
Actual	Negative	TN (True Negative)	FP (False Positive)
	Positive	FN (False Negative)	TP (True Positive)

Developing ML models: Features

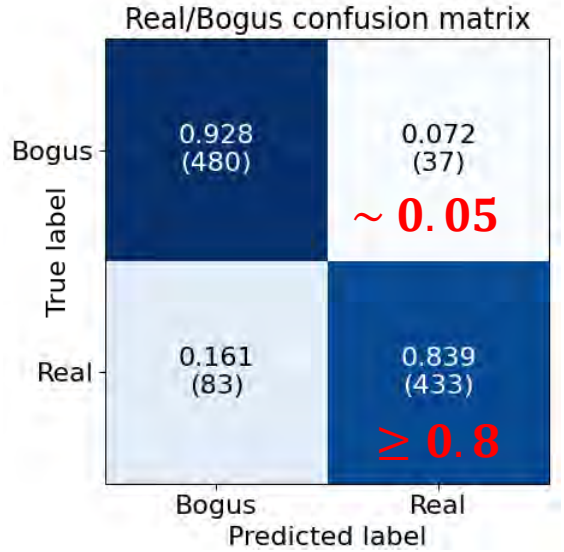
	Astronomical catalogs	Observation data of Tomo-e Gozen
Examples of features ①	The angular separation to the visually nearest galaxy	The The time interval between Tomo-e Gozen 1st and 2nd records
Aim	Galactic vs. extragalactic discrimination	Burst vs. non-burst discrimination
Figure		
Examples of features ②	Annual parallax of the visually nearest object	Number of detections per difference image
Aim	Association with a galactic star	Subtraction failure check
Figure		

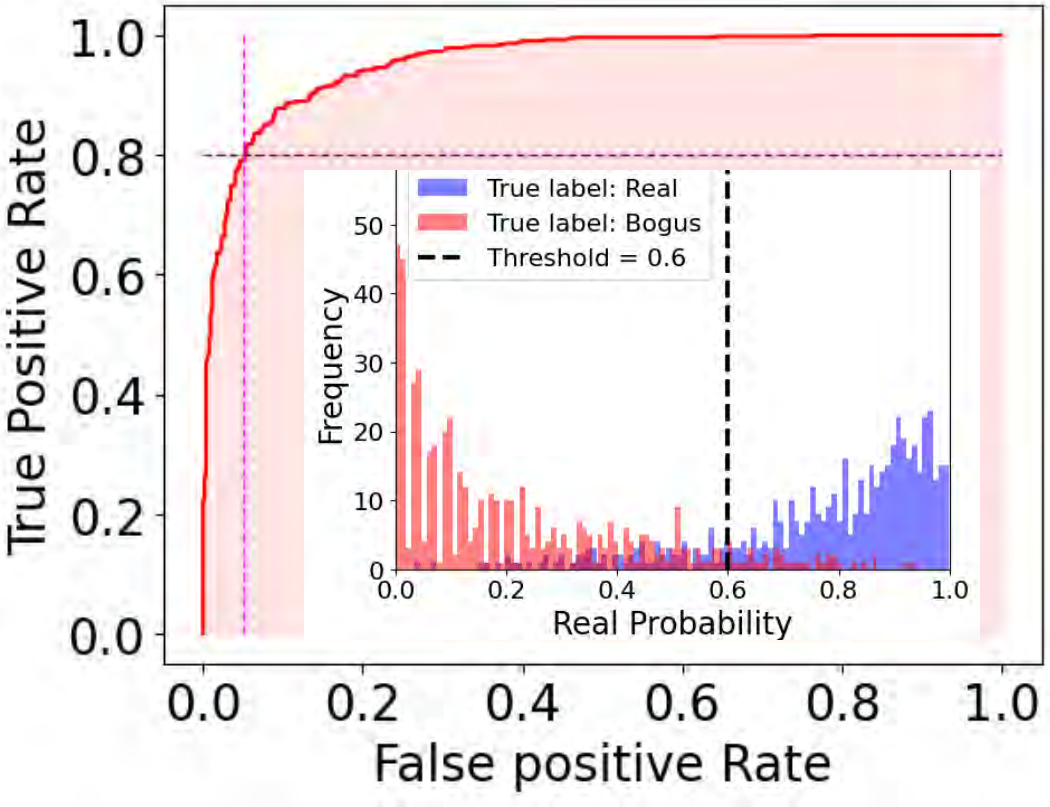
Results of Real/Bogus discriminator

The Real/Bogus discriminator model **almost achieved** $\boldsymbol{TPR \geq 0.8}$ **&** $\boldsymbol{FPR \leq 0.05}$ with the test dataset.

AUC (Area Under the ROC Curve) = 0.957

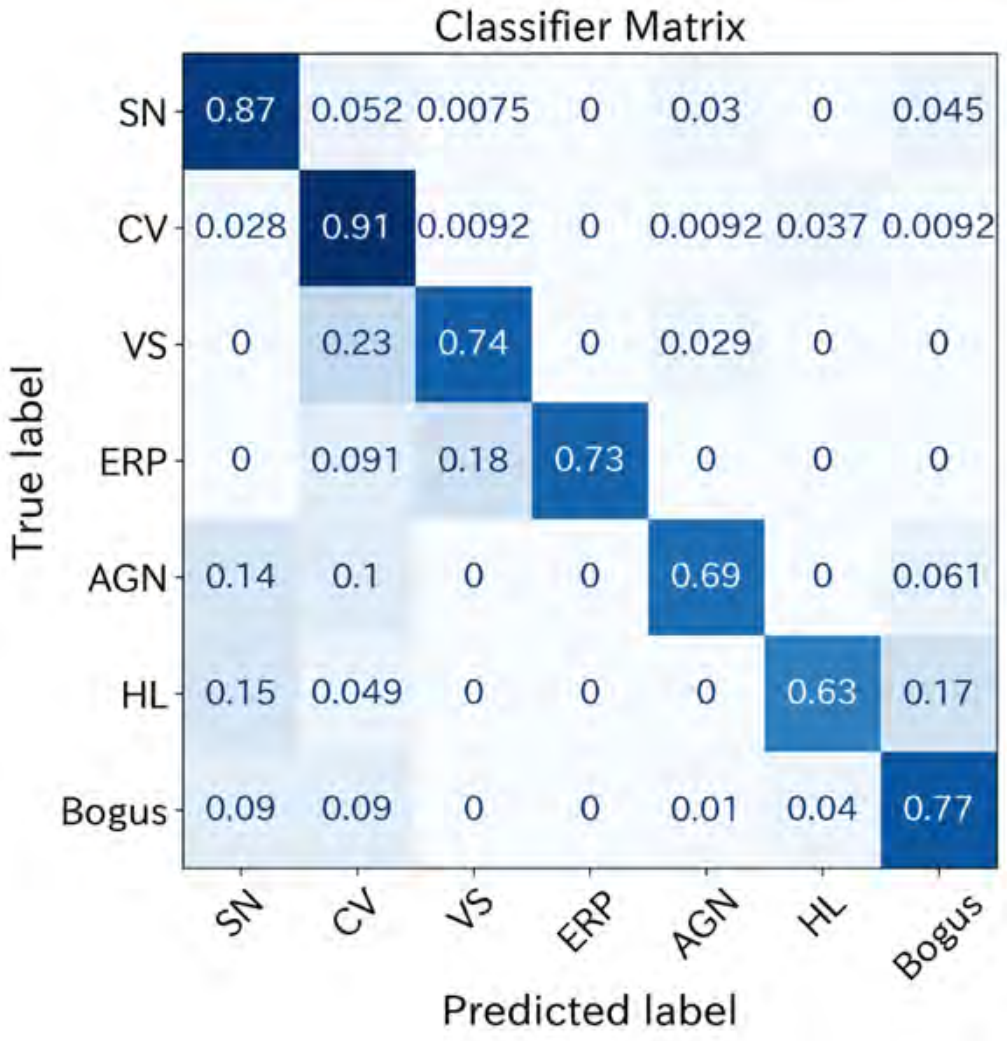
Threshold: Real Prob ≥ 0.6 is labeled as "Real".





	Features	Importance
1	CNN Real Probability	0.0919
2	Pan-STARRS separation	0.0691
3	Gaia mean G mag	0.0445
4	Gaia separation	0.0442
5	Time interval between two records	0.0441

Results of event classifier



A 7×7 matrix illustrating the correspondence between predicted labels and true labels in a classifier model. Each cell displays the row-normalized proportion.

- Classification of the probability list output by the classifier:

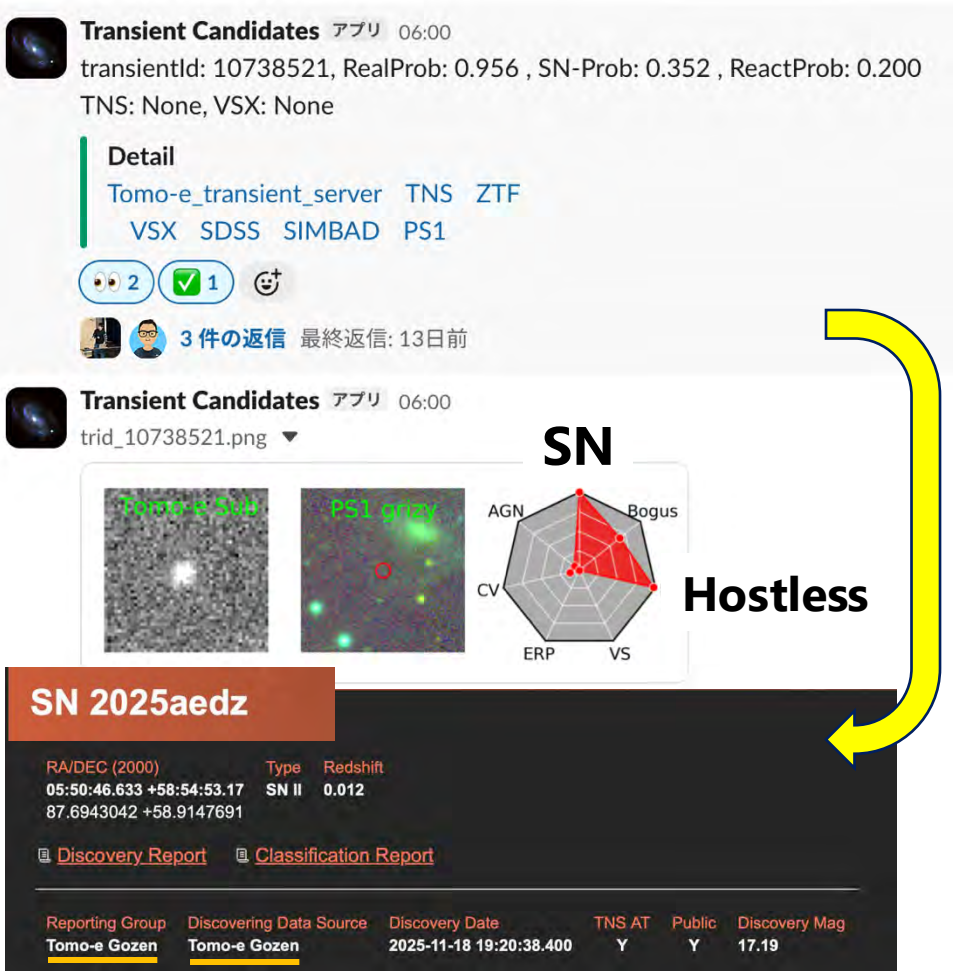
[SN, CV, long-term Variable Star, Eruptive Star, AGN, Hostless object, Bogus]

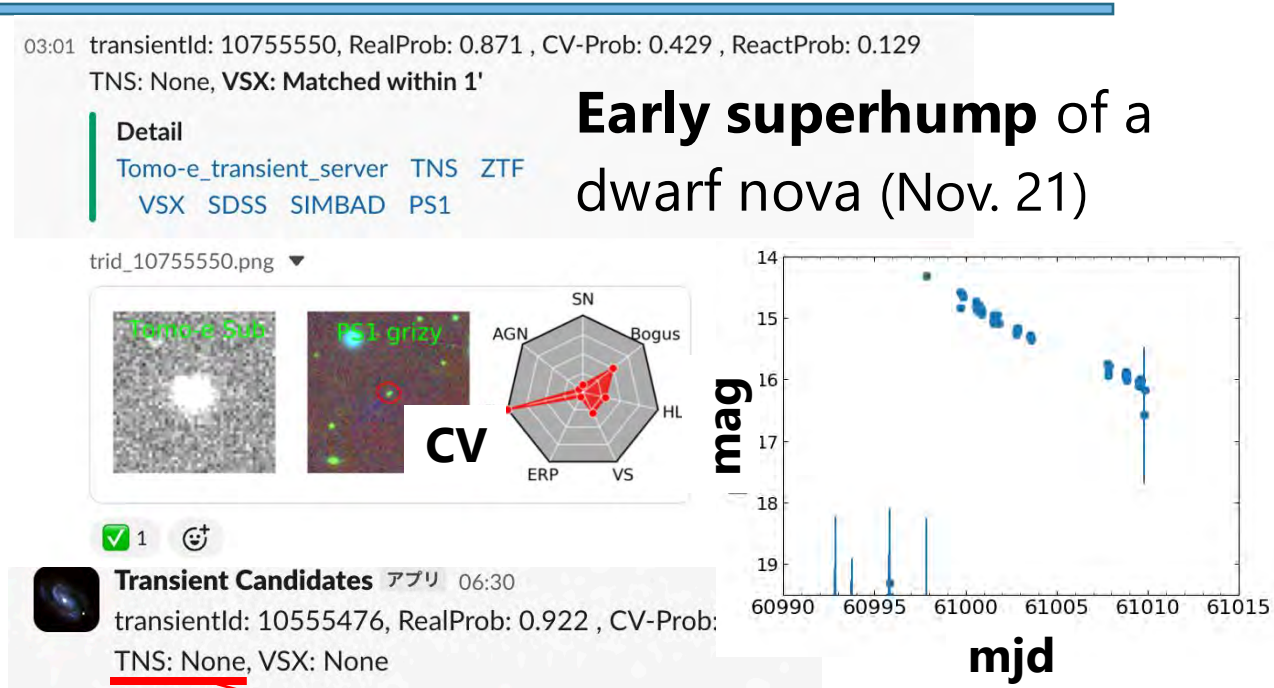
	Features	Importance
1	RF Real Probability	0.0805
2	GLADE+ galaxy separation	0.0480
3	Gaia separation	0.0434
4	Pan-STARRS separation	0.0442
5	GLADE galaxy separation	0.0351

Recent alert examples

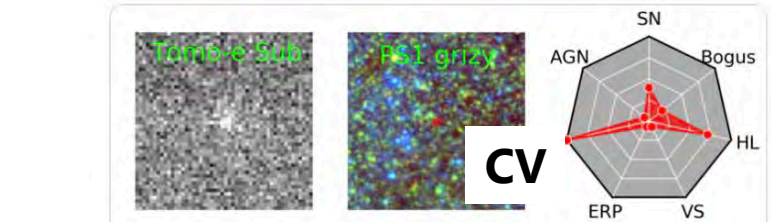
- Recent alert examples

Discovery of SN 2025aedz! (Nov. 19)





Early superhump of a dwarf nova (Nov. 21)



Early detection of a nova in M33 (Sep. 23)

Transients discovered by Tomo-e Gozen

- Discovery reports to Transient Name Server (2024-): 5 reports (SN 2024acn, SN 2024ahe, SN 2024iez, AT 2024aexk, SN 2025aedz)

+ multiple early detections

ID	Name	Reps	Class	RA	DEC	Obj. Type	Redshift	Host Name	Host Redshift	Reporting Group/s	Discovery Data Source/s	Classifying Group/s	Disc. Internal Name	Public	Object Spectra	Discovery Mag/Flux	Discovery Filter	Discovery Date (UT)
193143	SN 2025aedz	4	1	05:50:46.633	+58:54:53.17	SN II	0.012			Tomo-e Gozen, ZTF, ATLAS, GOTO	Tomo-e Gozen, ZTF, ATLAS, GOTO	None		Y	1	17.19	Clear-	2025-11-18 19:20:38.400
168967	AT 2024aexk	2		20:47:03.957	+10:20:57.55					Tomo-e Gozen, ZTF	Tomo-e Gozen, ZTF		Tomo-e 202412aaaasgbxl	Y		18.66	Clear-	2024-12-25 09:21:36.000
151055	SN 2024iez	3	1	14:48:19.684	+20:49:43.43	SN Ia	0.075			Tomo-e Gozen, GOTO, Pan-STARRS	Tomo-e Gozen, GOTO, Pan-STARRS	TCD	Tomo-e 202405aaafx	Y	1	19.24	Clear-	2024-05-03 16:22:04.800
144583	SN 2024ahe	5	2	23:02:37.838	+41:13:57.58	SN Ia-91T-like	0.014			Tomo-e Gozen, ATLAS, ZTF, GOTO, Pan-STARRS	Tomo-e Gozen, ATLAS, ZTF, GOTO, Pan-STARRS	None, LiONS		Y	2	18.94	Other-	2024-01-12 09:49:23.000
144460	SN 2024acn	5	2	11:10:40.441	+21:06:26.87	SN II	0.031			Tomo-e Gozen, ATLAS, ZTF, Pan-STARRS, BlackGEM	Tomo-e Gozen, ATLAS, ZTF, Pan-STARRS, BlackGEM	LiONS, None	Tomo-e 202401aaayb	Y	2	17.57	Other-	2024-01-13 19:30:26.000

Future work

- We conducted follow-up through the **OISTER** framework
  → PO-21P by Nogami-san

➢ We will implement **automated follow-ups**.

- Tomo-e Gozen (N 35°47′50.0″, E 137°37′31.5″) alert system has a **potential to become a good information source for the time-domain astronomy community in East Asia.**

➢ We will expand the collaboration network.

"Time zone in Asia is unique"
in Tanaka-san's talk

- Image processing is limiting the immediacy of alerts.

➢ Introducing MDX (**data platform**), we will solve this problem soon.

Summary

1. **Tomo-e Gozen** conducts an optical transient survey every night.
2. **ML–based discriminator and classifier** enable the issuance of transient alerts.
3. **Follow-up observations** triggered by these alerts have been conducted with OISTER, a Japanese collaboration framework .
4. In the future, **we aim to expand both the observing network and the scientific targets**.