

Optical and infrared observations for GW/neutrino sources

Masaomi Tanaka (Tohoku University)

on behalf of the A03 team

Nozomu Tominaga (NAOJ), Kazuya Matsubayashi (U. Tokyo),

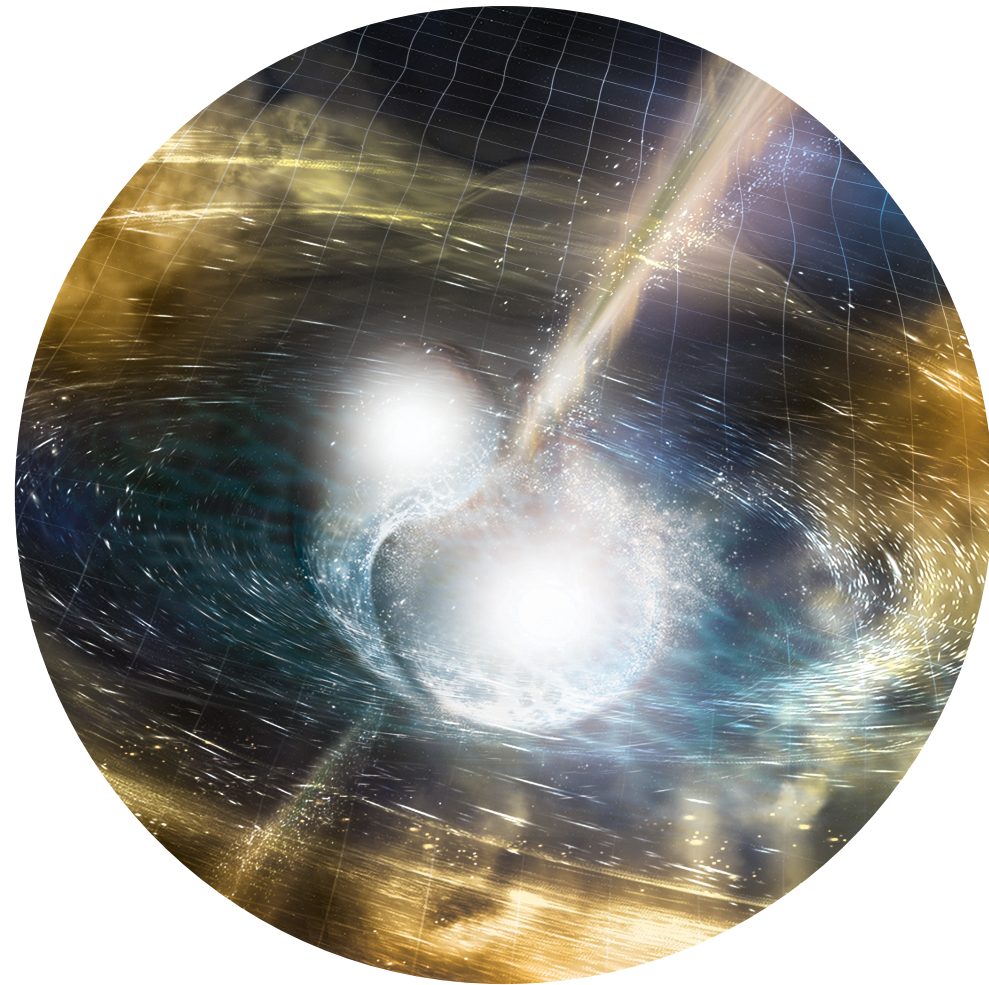
Koji Kawabata (Hiroshima U.), Kouji Ohta (Kyoto U.),

Yoichi Yatsu (Titech), Kotaro Niinuma (Yamaguchi U.), Tomoki Morokuma (CIT)

- **Roles of optical and infrared observations**
- **Gravitational wave sources**
- **High-energy neutrino sources**

Multi-messenger astrophysics: roles of optical/IR observations

Gravitational wave



(C) NSF/LIGO/
Sonoma State University/A Simonnet

High-energy neutrino



(C) IceCube/NASA

Accurate position

(high angular resolution, \sim arcsec)

Accurate redshift

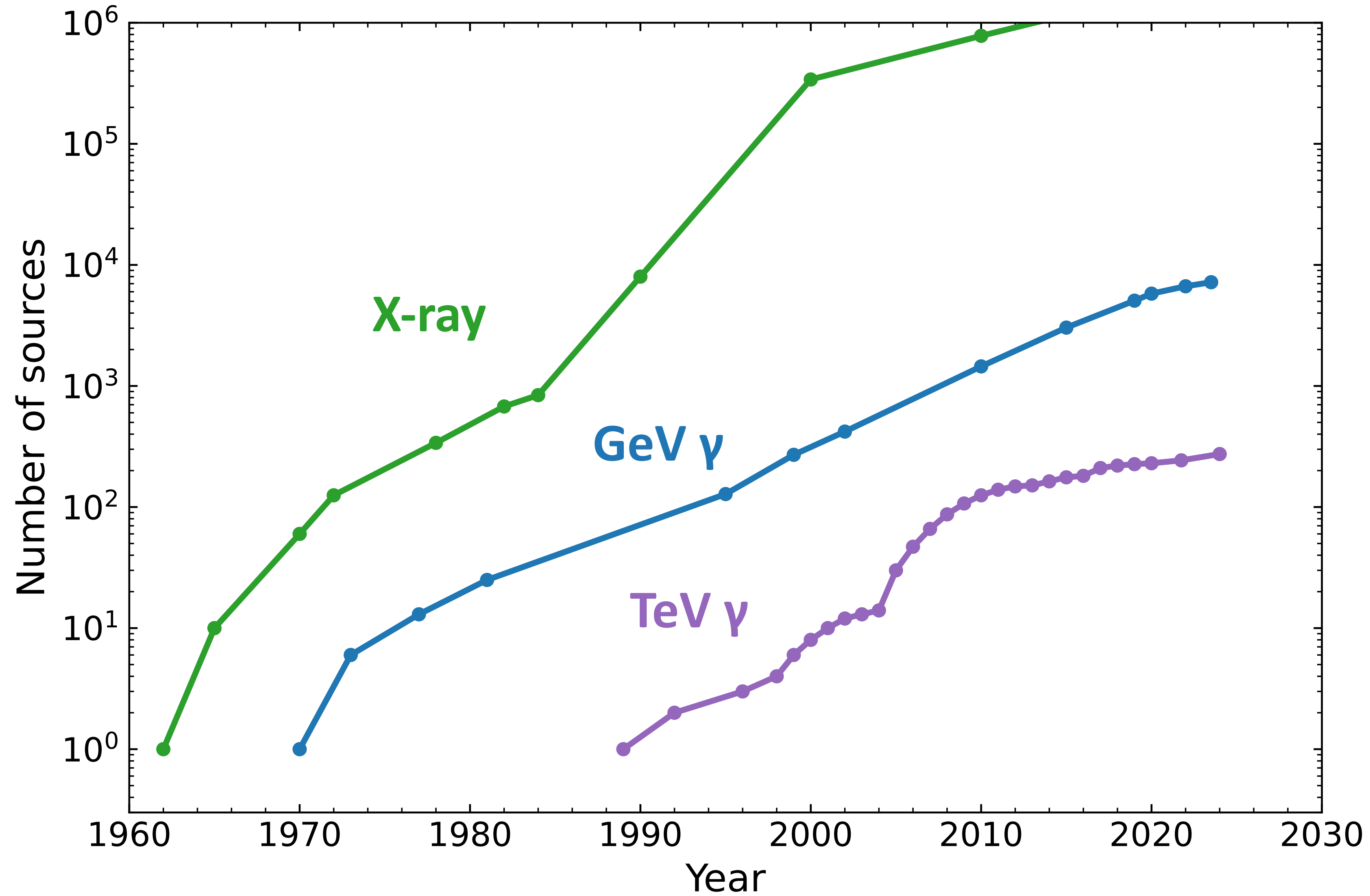
(high spectral resolution, $\lambda/\Delta\lambda > 1,000$)

**Nucleosynthesis in
neutron star mergers**

**Identification of
High-E neutrino sources**

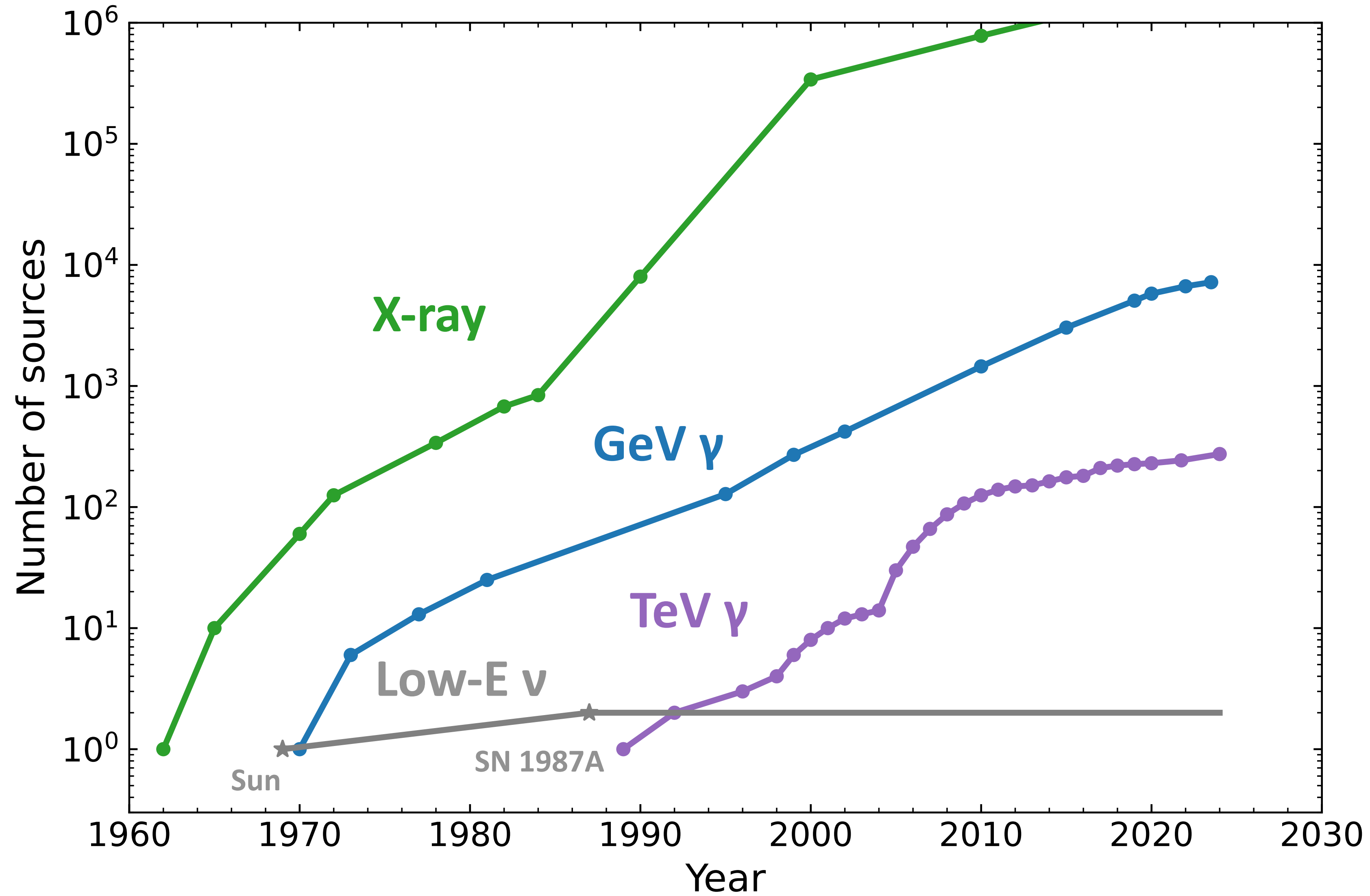
Multi-messenger “Kifune plot”

X, gamma: Data compilation by Stephen Fegan
(<https://github.com/sfegan/kifune-plot>)



Multi-messenger “Kifune plot”

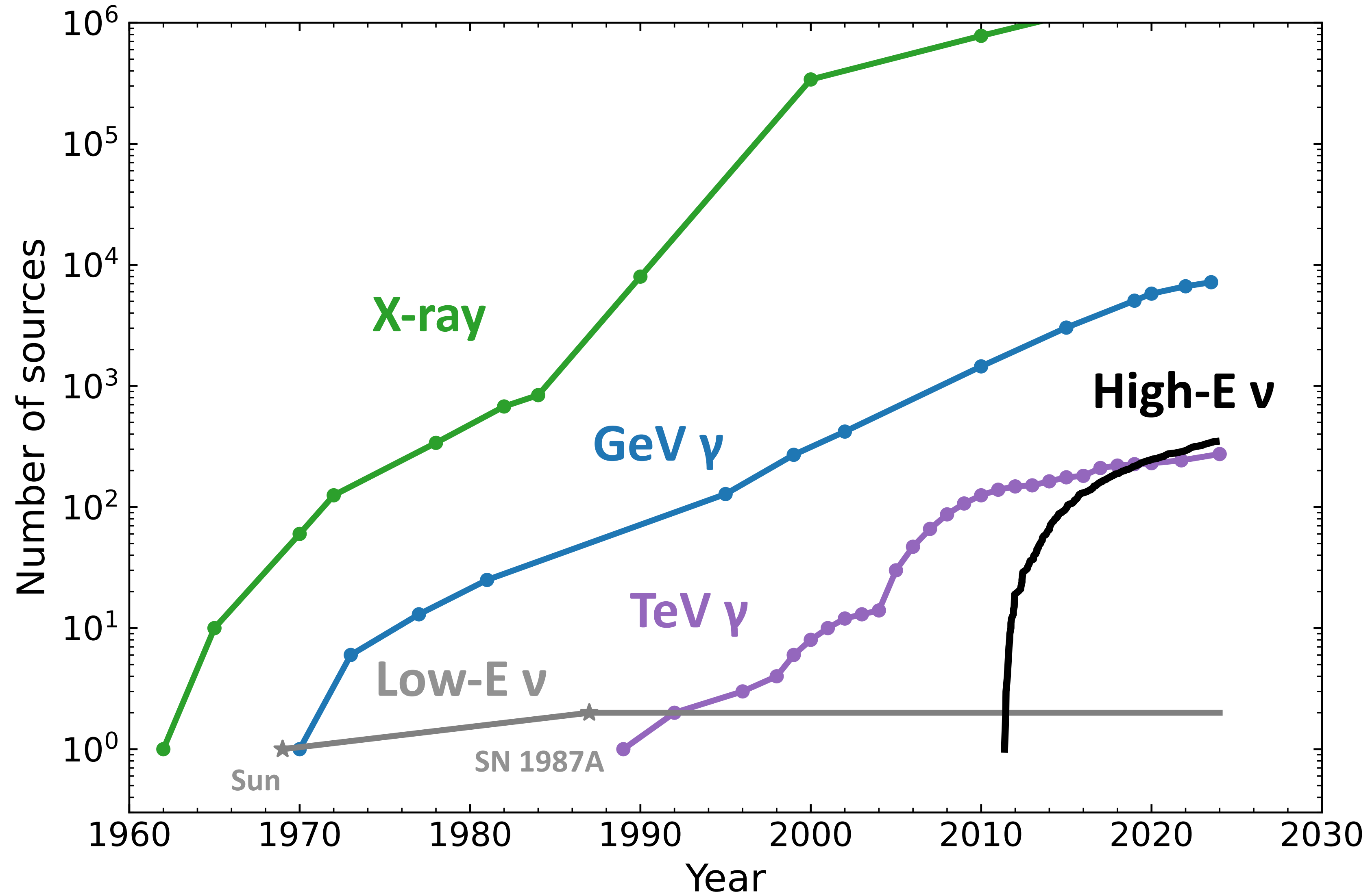
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High-E nu: ICECAT-1: the IceCube Event Catalog of Alert Tracks

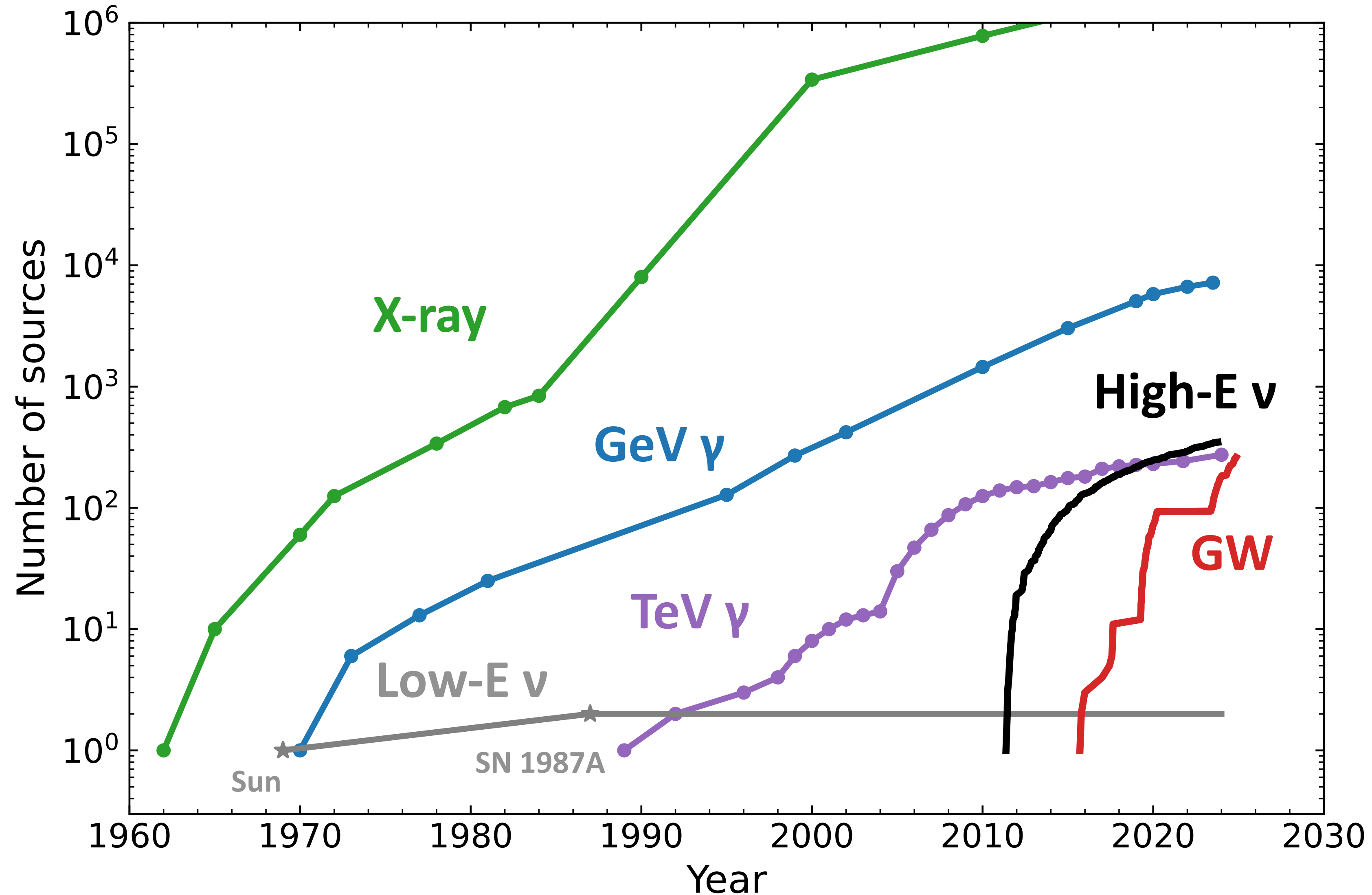


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GW: GWTC1-3 + O4 alert (FAR < 2 / year)

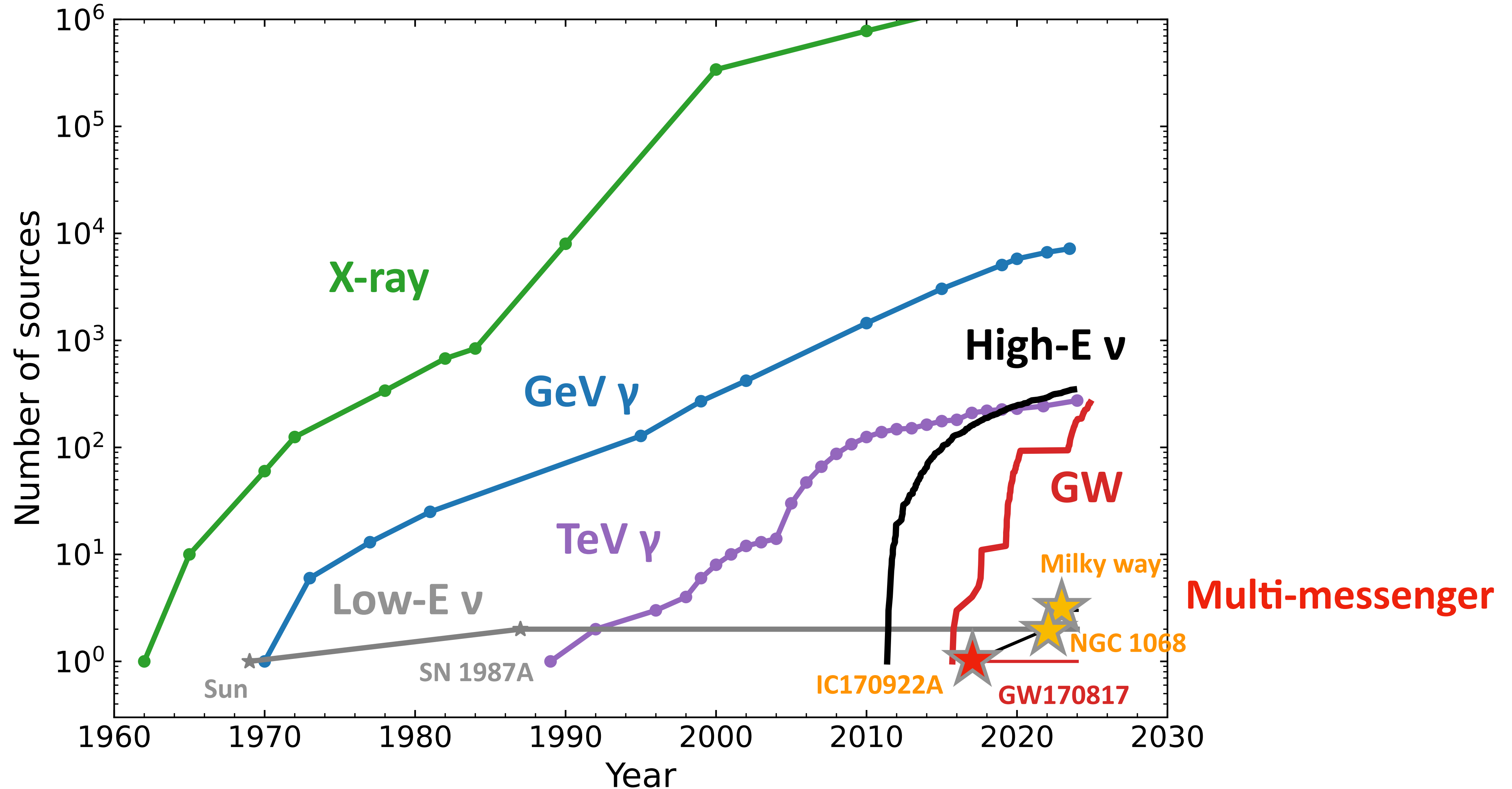


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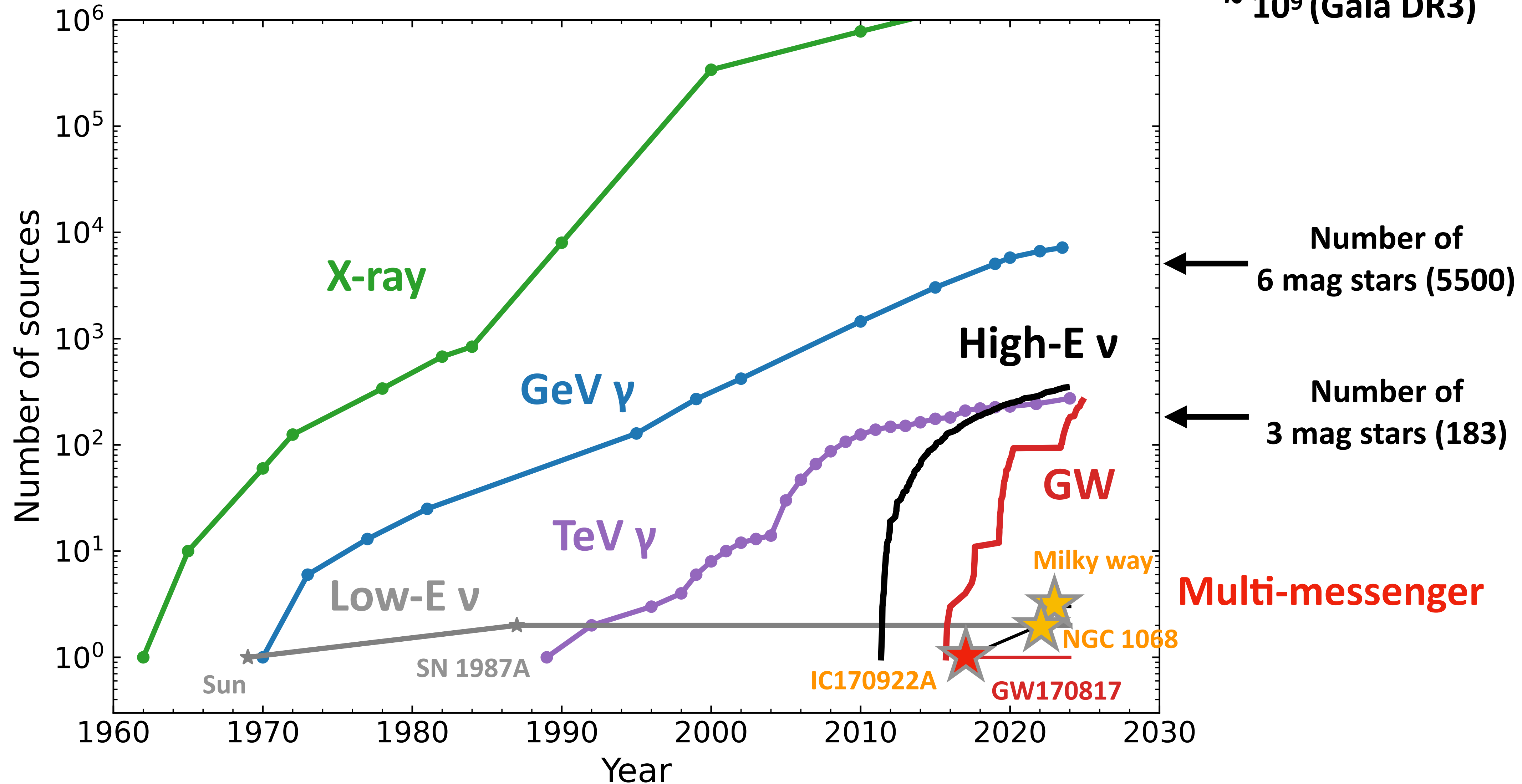
Multi-messenger “Kifune plot”

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High-E nu: ICECAT-1: the IceCube Event Catalog of Alert Tracks

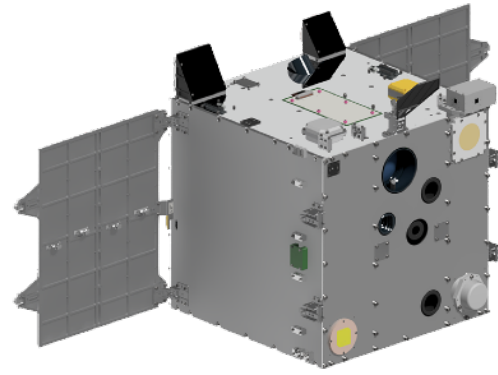
GW: GWTC1-3 + O4 alert (FAR < 2 / year)

Optical
 ~ 10^9 (Gaia DR3)



A03: Optical/IR/Radio follow-up with multiple facilities

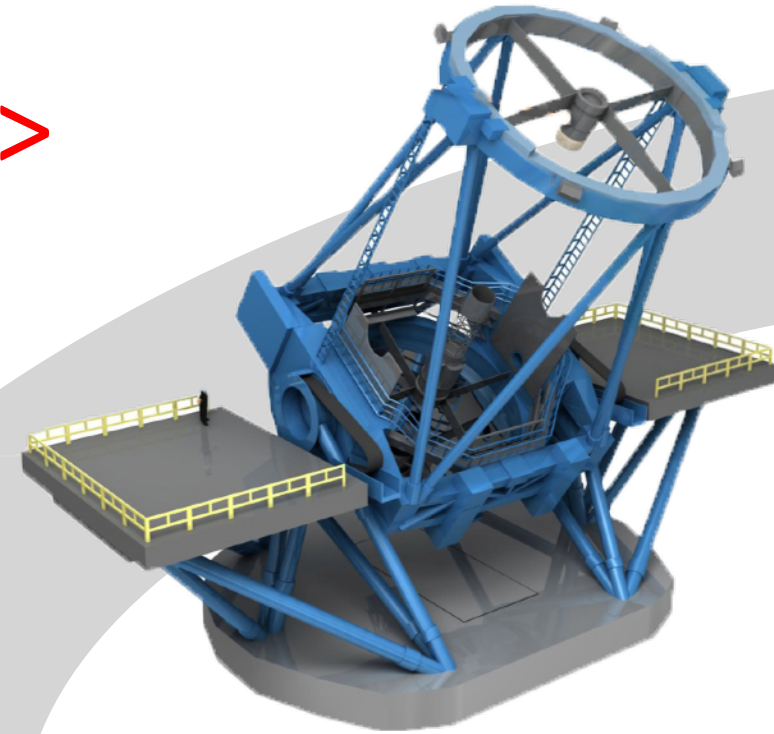
Wide field (HSC)
Spectroscopy (PFS)



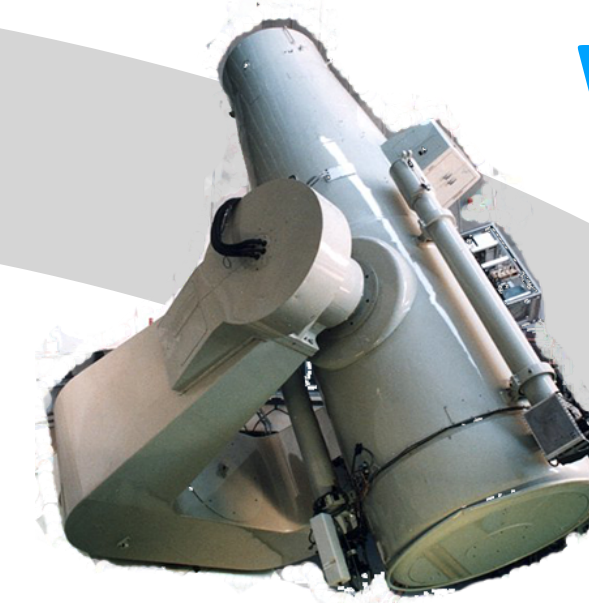
Wide field

PETREL

Talk by H. Zhang =>

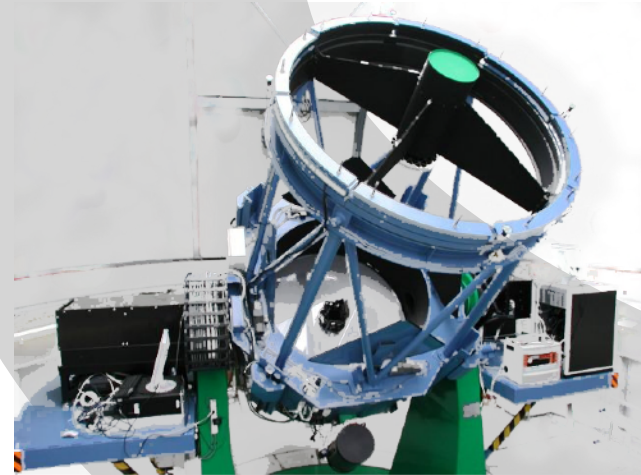


Subaru (8.2 m)



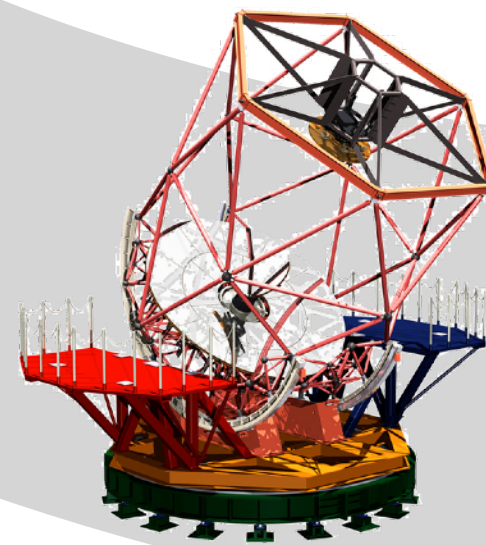
Wide field

Kiso (1 m)

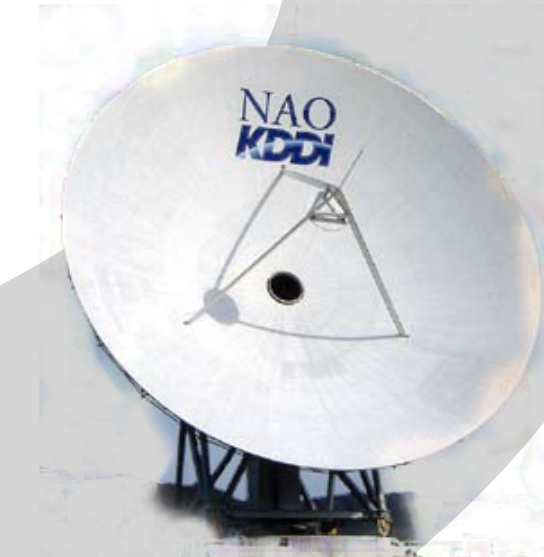


Kanata (1.5 m)

Spectroscopy
/monitoring



Seimei (3.8 m)



EA VLBI



TAO (6 m)

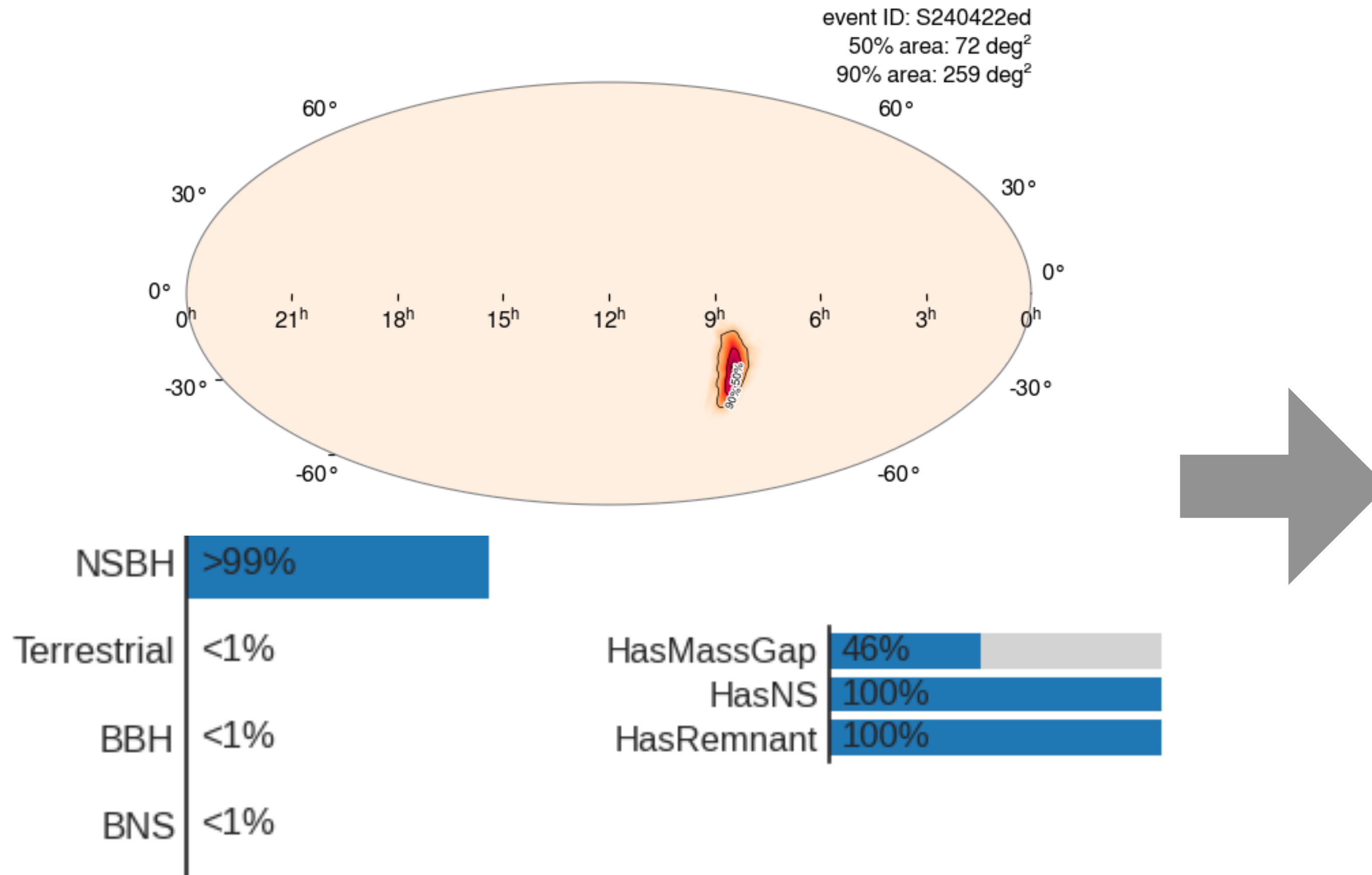
Talk by K. Taguchi =>

<= Poster by
K. Matsubayashi

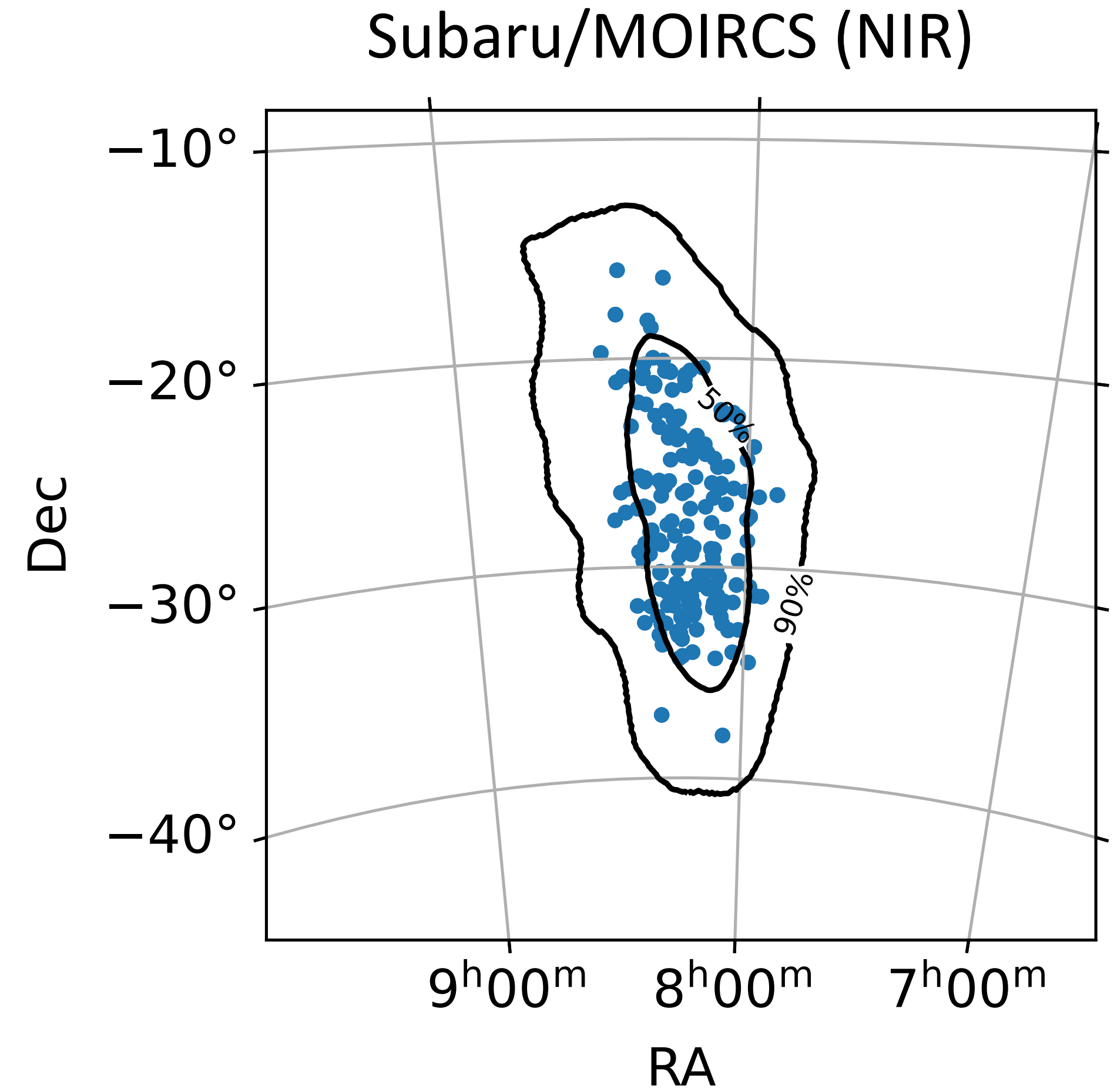
- **Roles of optical and infrared observations**
- **Gravitational wave sources**
- **High-energy neutrino sources**

Follow-up observations for S240422ed

See the posters by Ichiro Takahashi and Mahito Sasada



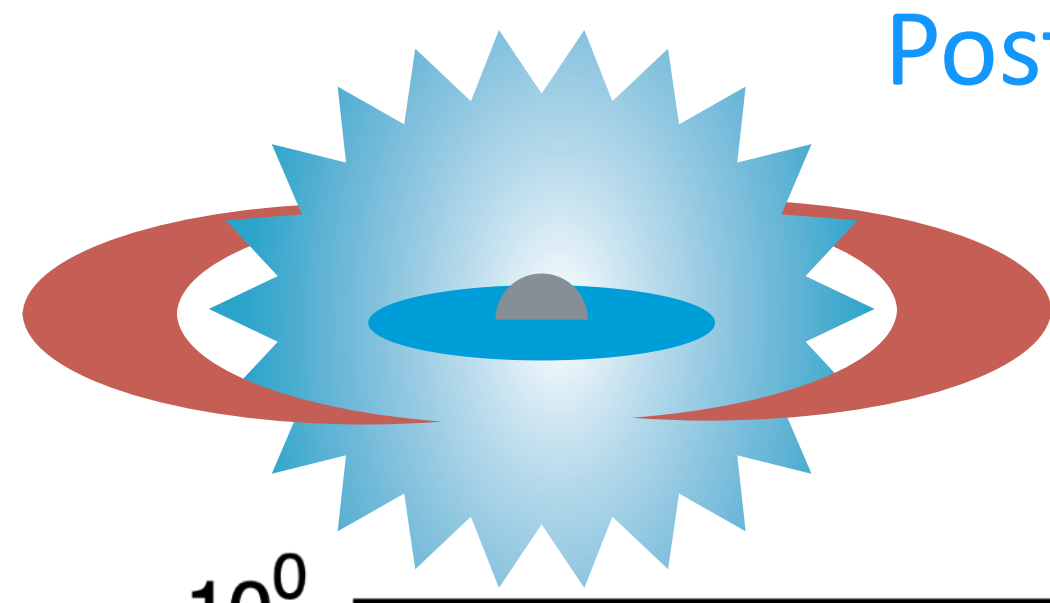
<https://gracedb.ligo.org/superevents/S240422ed/view/>



Takahashi, Morokuma+ in prep.

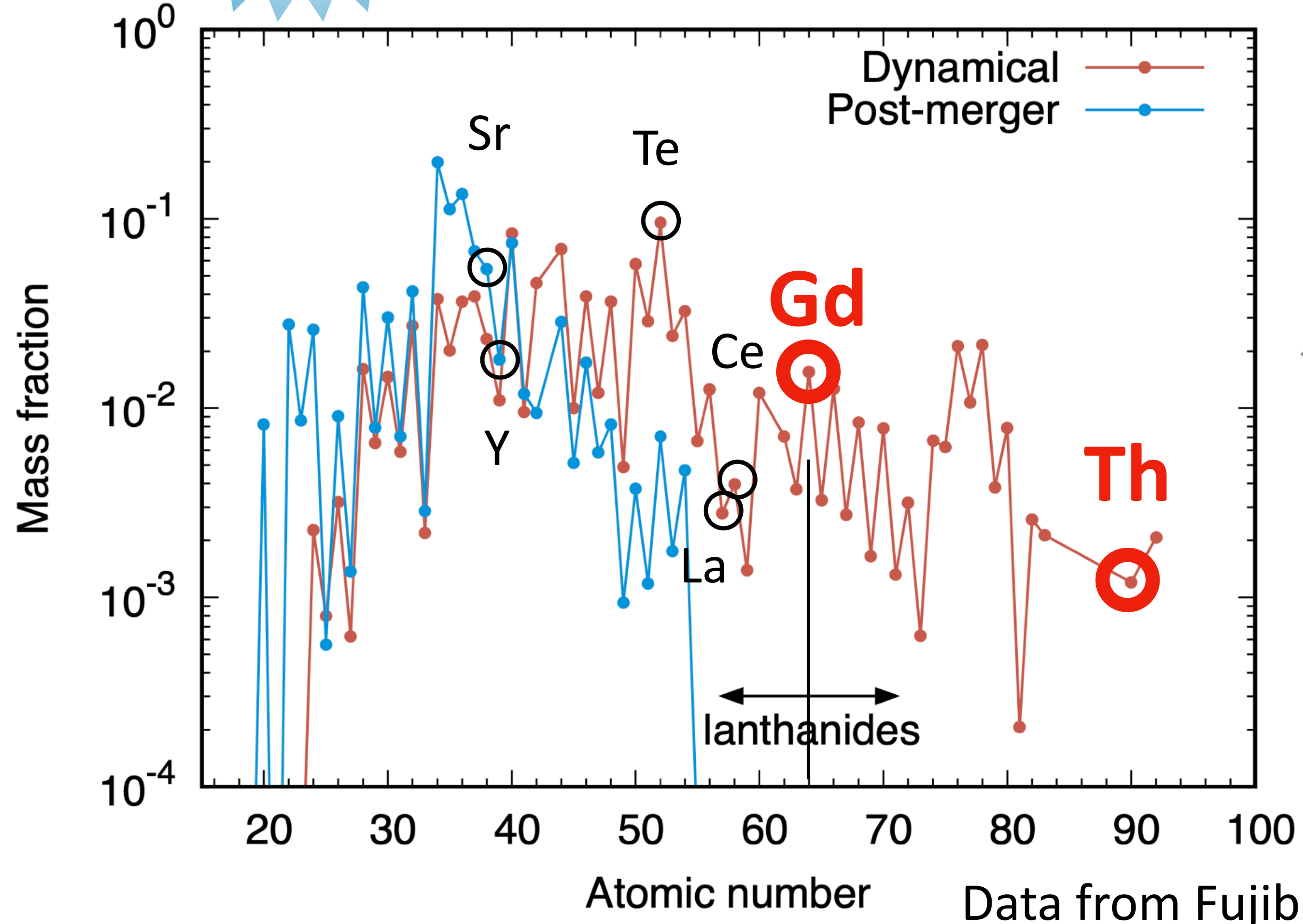
Good test case for deep NIR follow-up observations with Subaru

Constraining the nucleosynthesis in NS merger

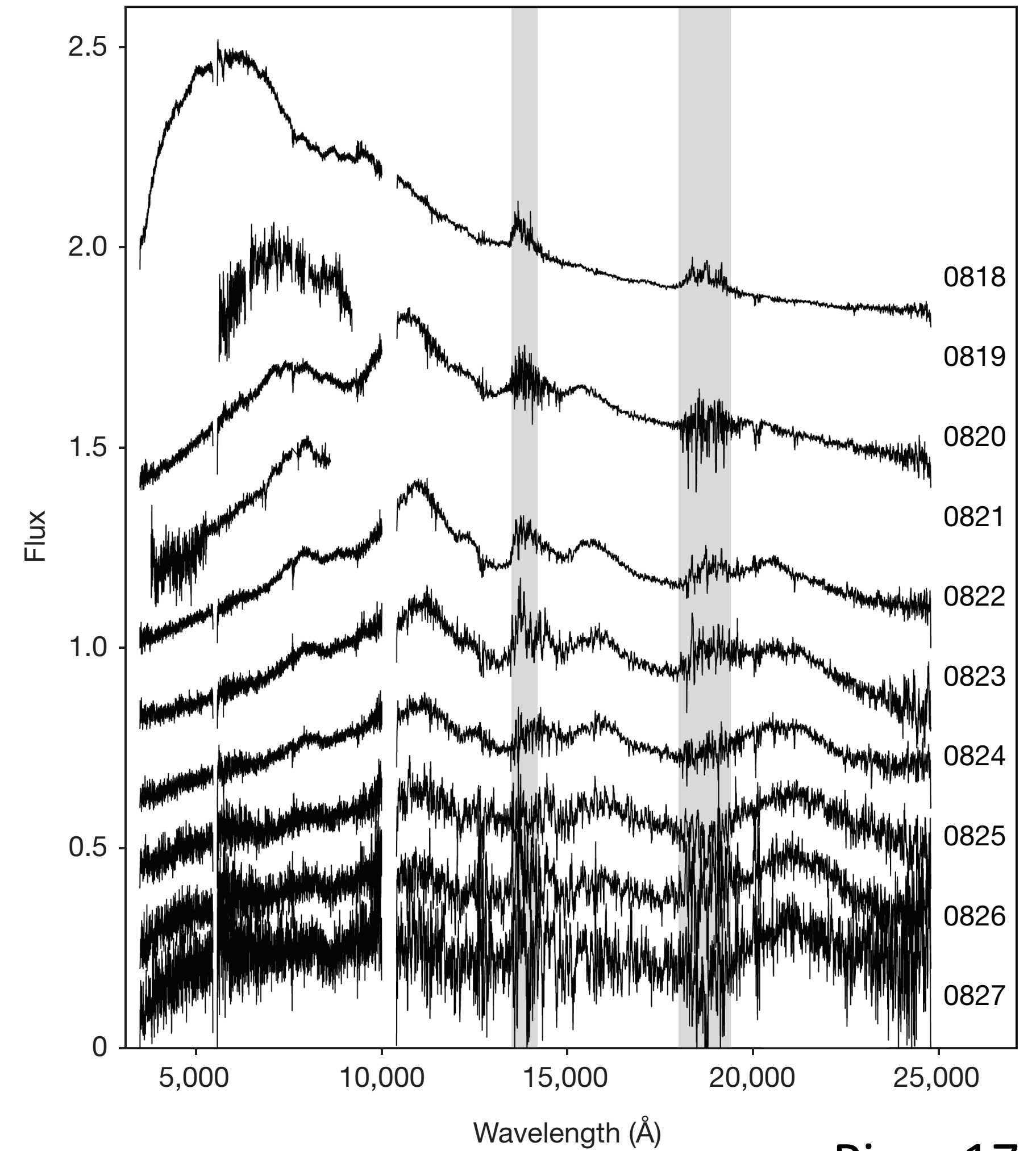


Post-merger ejecta
less n-rich

Dynamical ejecta
more n-rich



Kilonova spectra

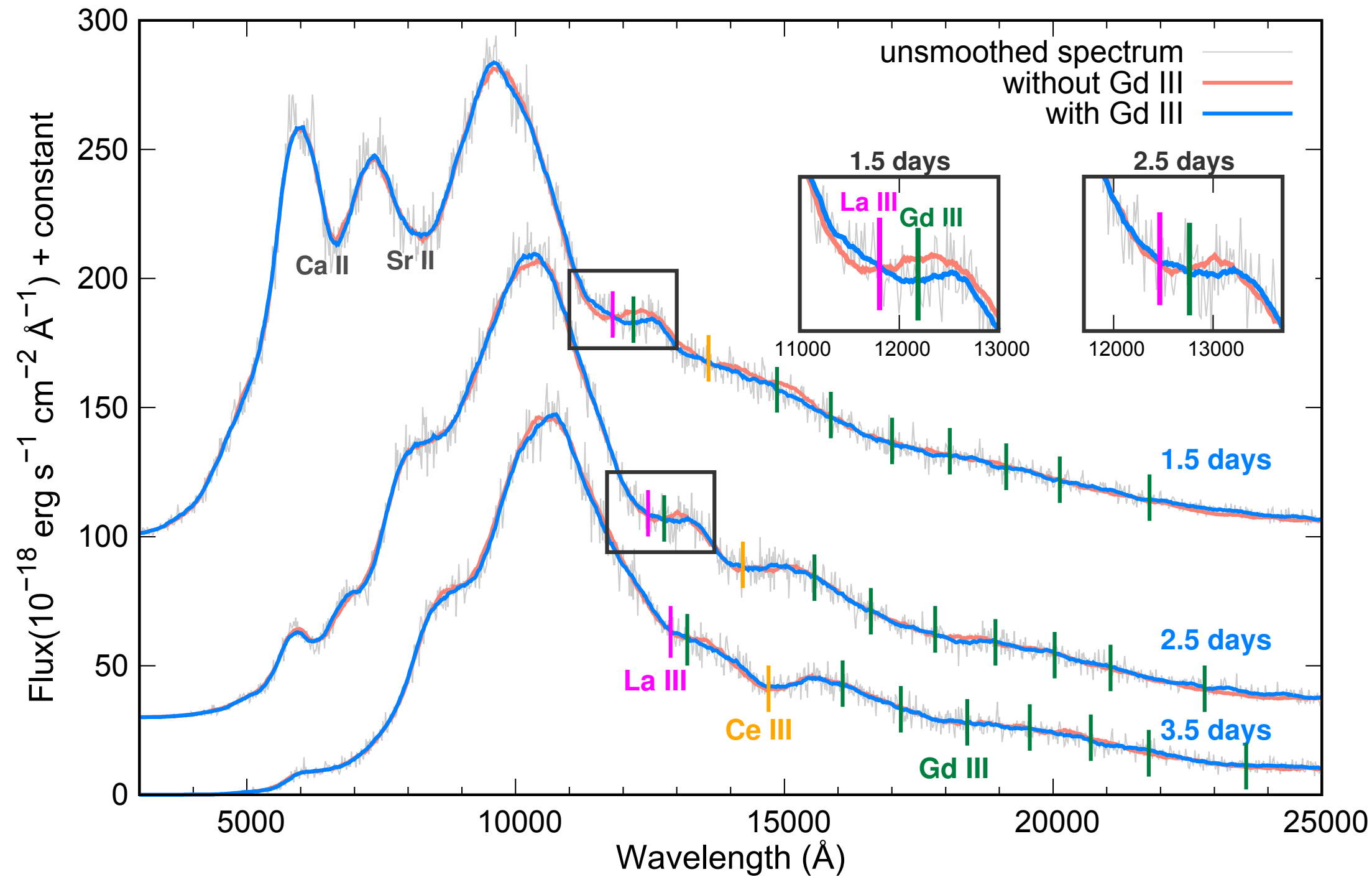


Pian+17

Element identifications in neutron star mergers

Collaboration with C02 (Kenta Hotokezaka)

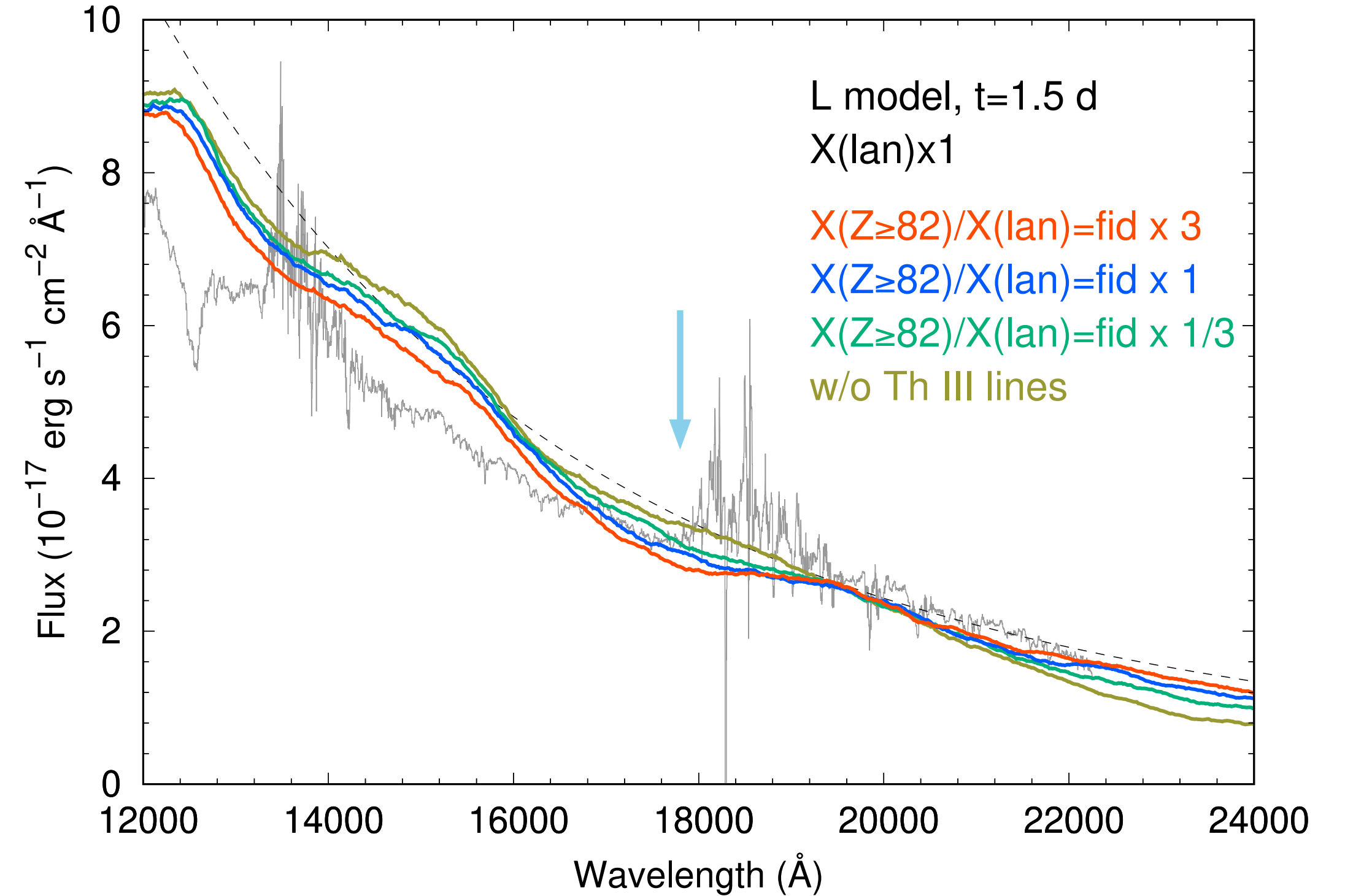
Gd (Z=64)



Rahmouni+ submitted

Poster by Salma Rahmouni

Th (Z=90)



Domoto+ submitted

Poster by Nanae Domoto

Both features are affected by the Earth's atmosphere

=> Spectroscopy with TAO and JWST!

- **Roles of optical and infrared observations**
- **Gravitational wave sources**
- **High-energy neutrino sources**

Identifying transient neutrino sources with optical surveys

$z \sim 0.5-1.0$

=> Talks by
N. Shimizu and S. Toshikage

Multiplet

Yoshida+22

$z \sim 0.15$

Singlet

Supernova (SN)

**Tidal disruption event
(TDE)**

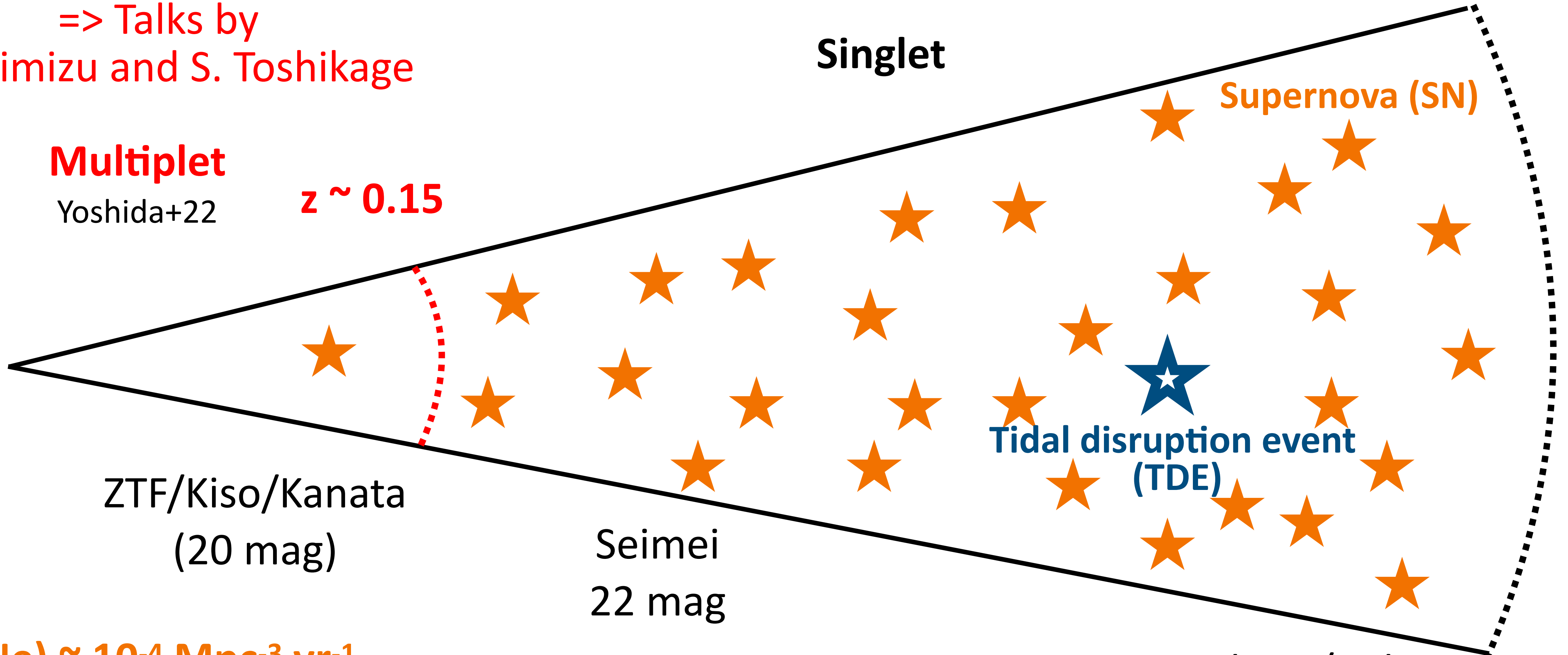
ZTF/Kiso/Kanata
(20 mag)

Seimei
22 mag

Subaru/Rubin
(25 mag)

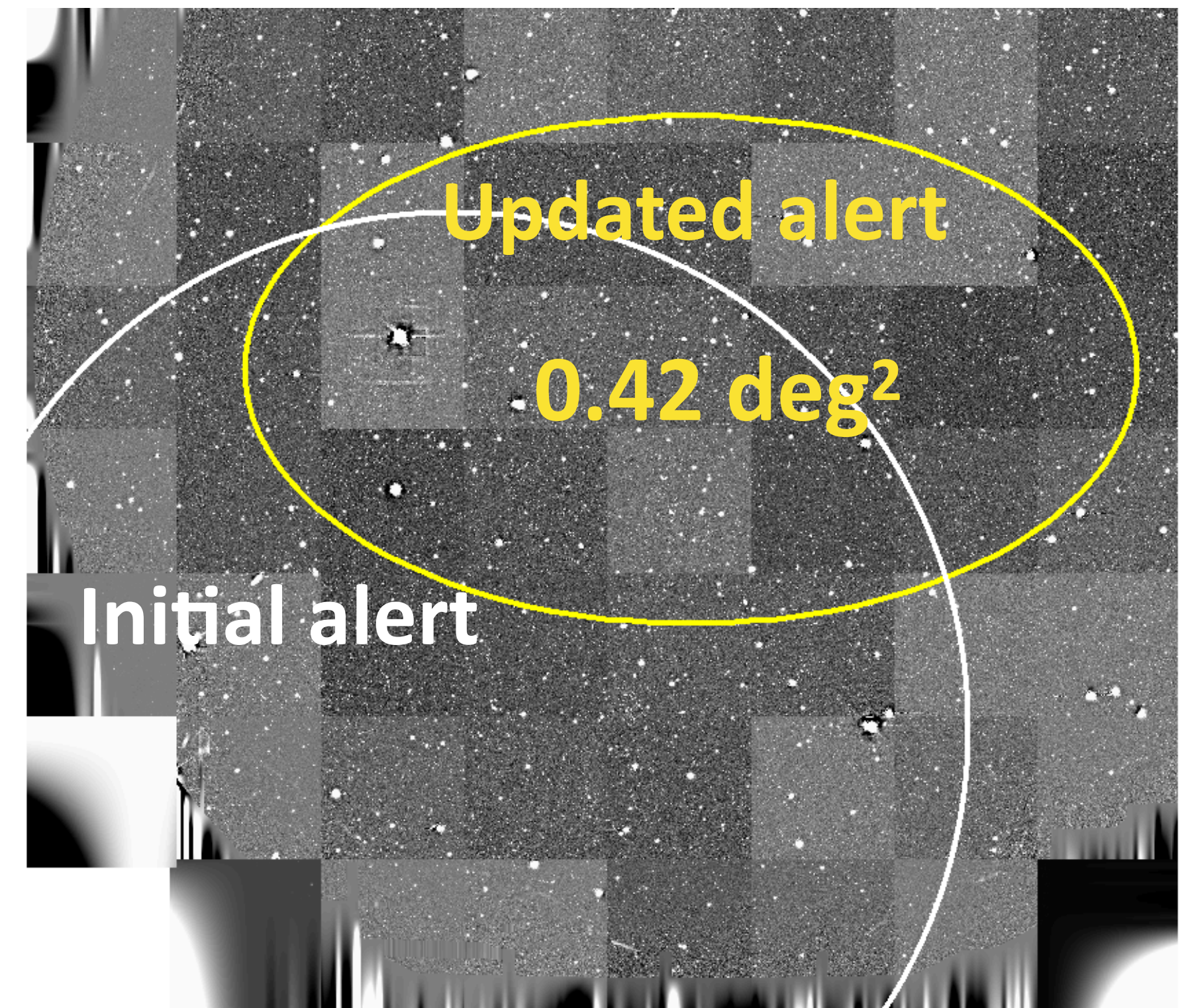
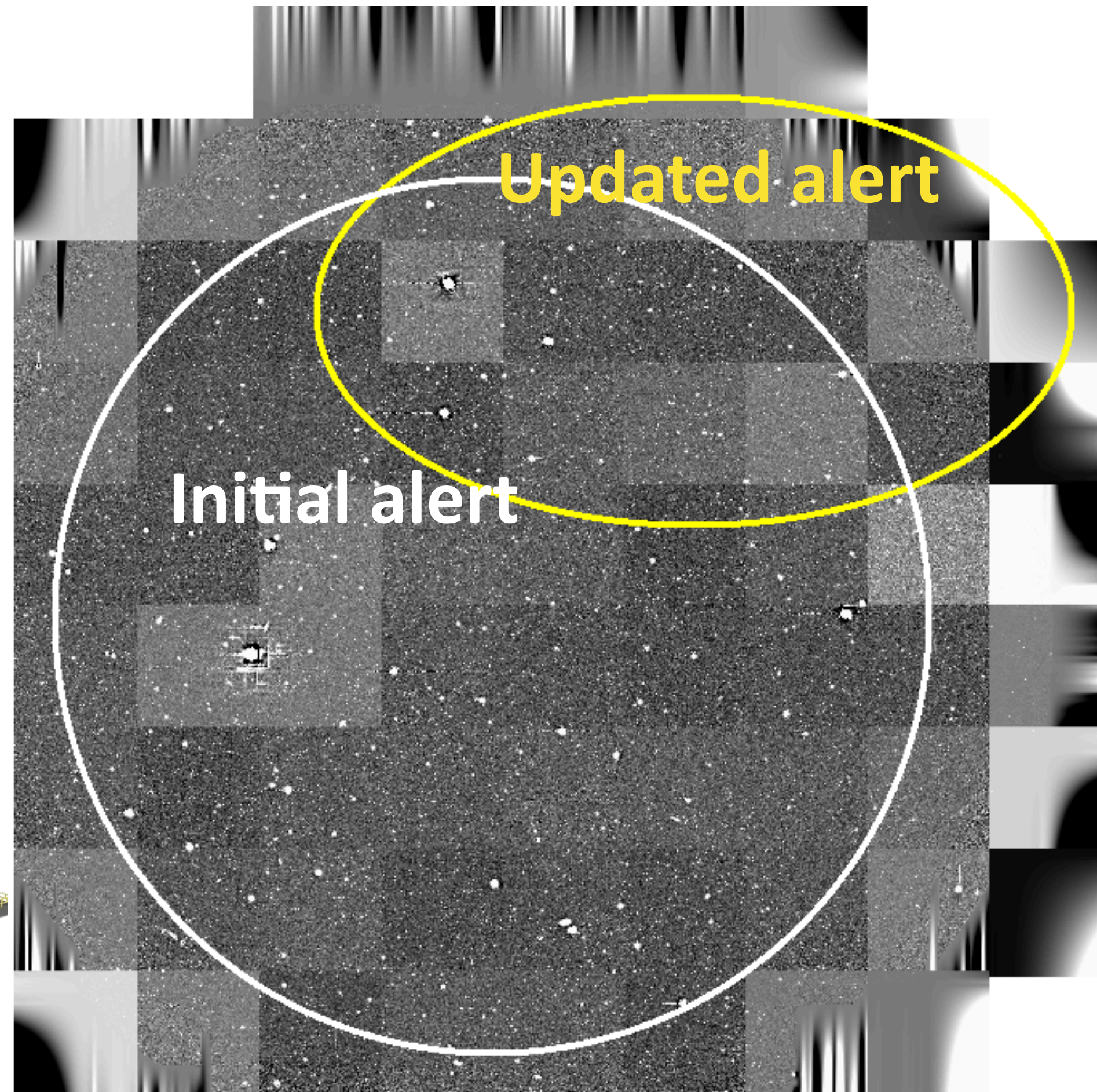
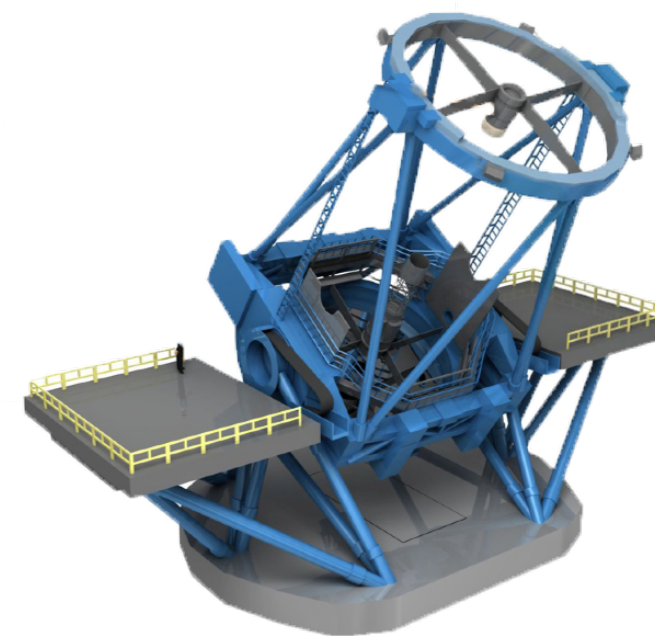
$R(\text{SNe}) \sim 10^{-4} \text{ Mpc}^{-3} \text{ yr}^{-1}$

$R(\text{TDE}) \sim 10^{-7} \text{ Mpc}^{-3} \text{ yr}^{-1}$



IceCube-230724A: observations with Subaru/HSC

Led by Shigeo Kimura (C01)



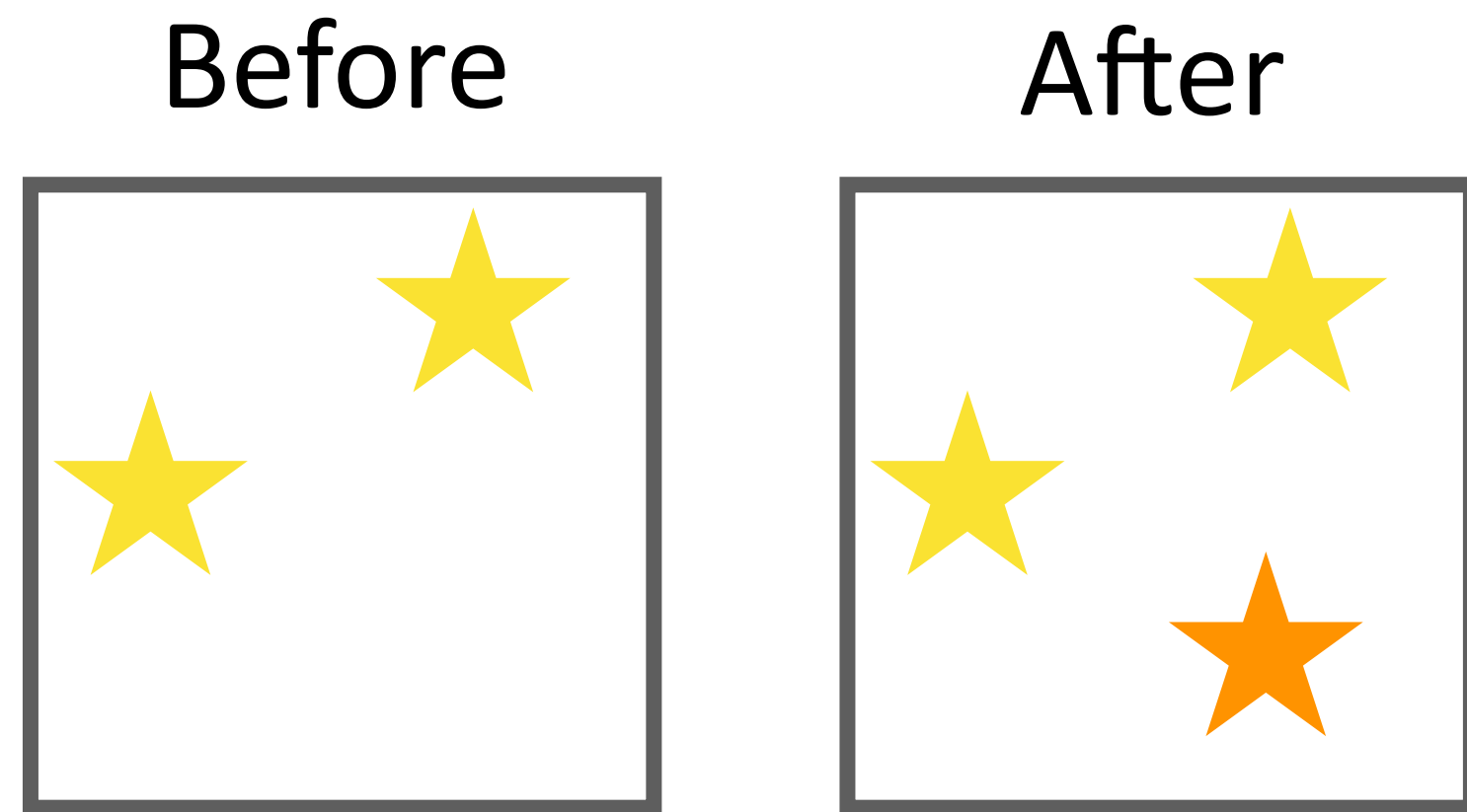
~1 deg

Gold alert (signalness = 0.526, E = 190 TeV) with a good localization

Unfortunately, only 2-epoch follow-up due to the prime mirror issue of Subaru in 2023

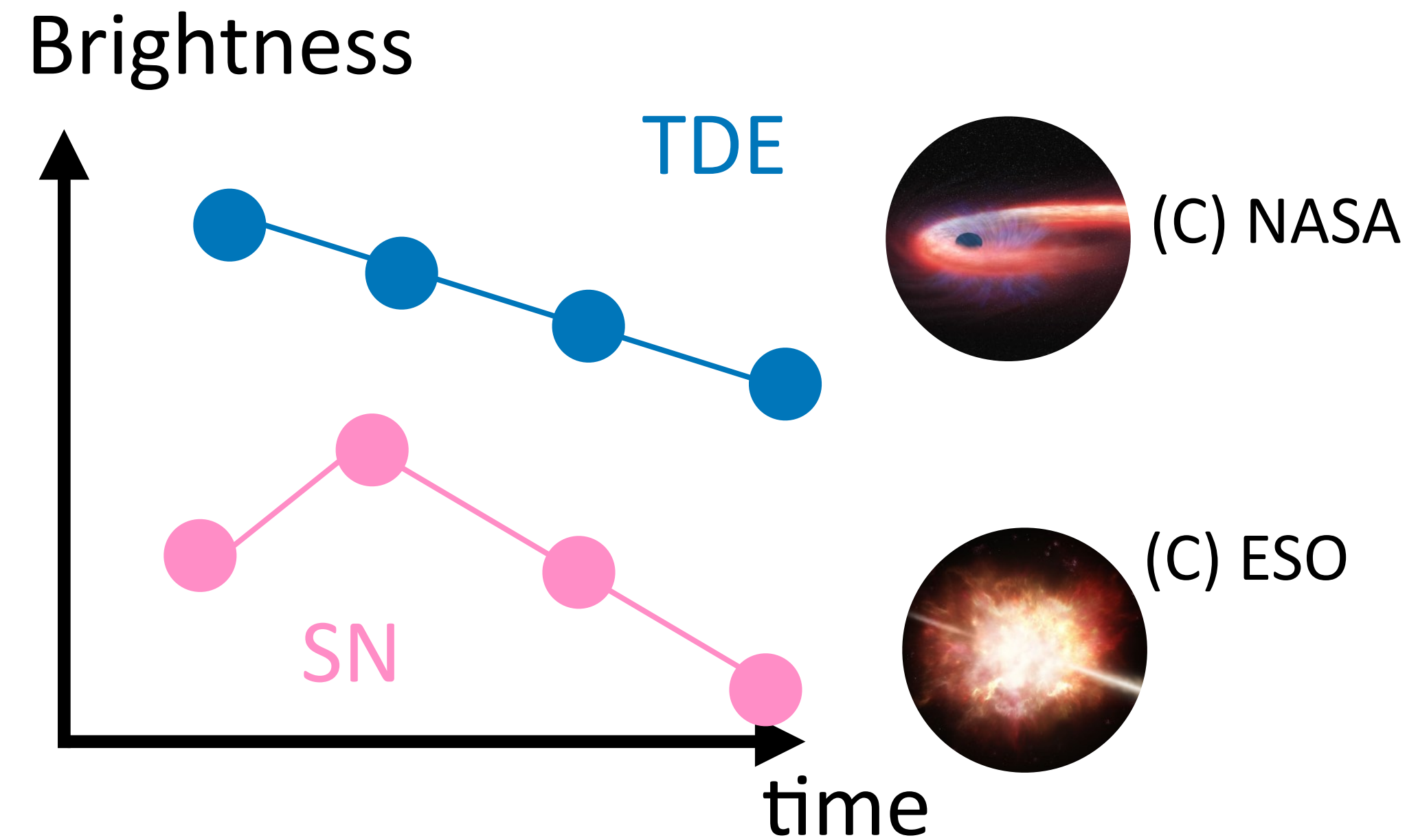
Road to the TDE identification

Step 1: Transient detection



By MT, Tomoki Morokuma, Nozomu Tominaga

Step 2: Source classification



By Shigeo Kimura (C01) and Seiji Toshikage

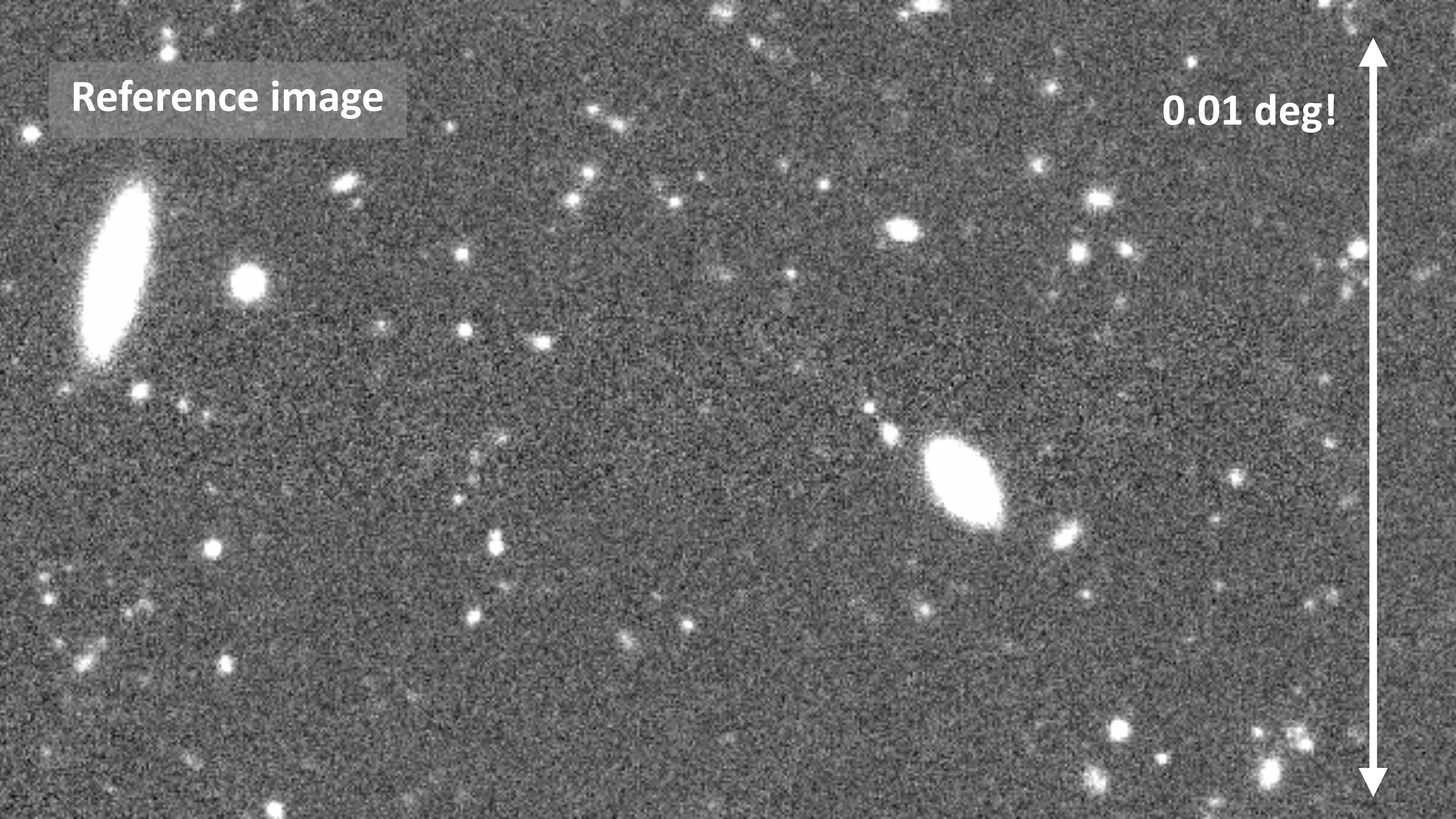
Development of the entire analysis flow by using the “background” region

(A) Number of background events: how many unrelated sources remain

(B) True positive rate (or passing rate): how high fraction of true events remain

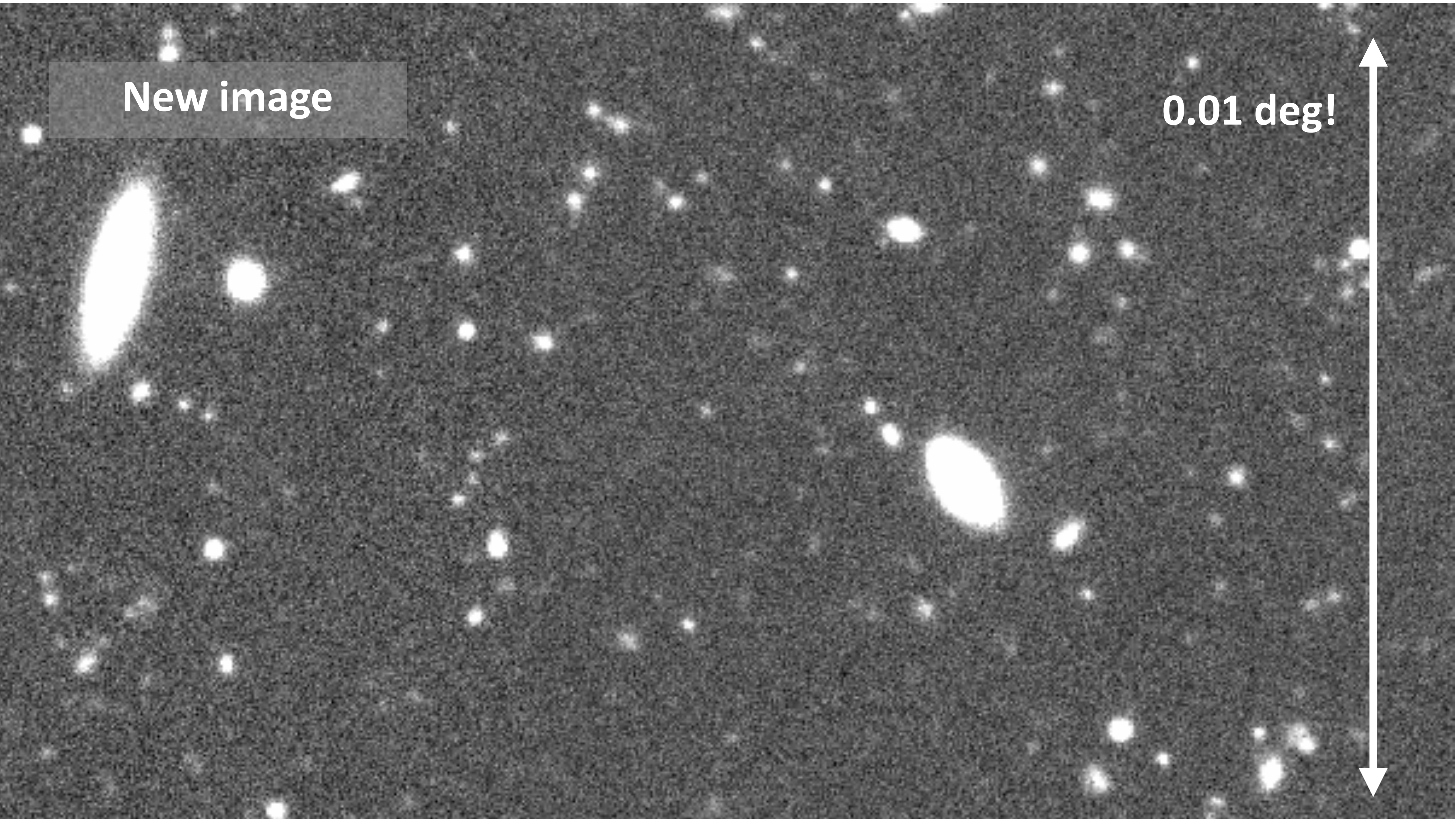
Reference image

0.01 deg!



New image

0.01 deg!



Difference image

0.01 deg!



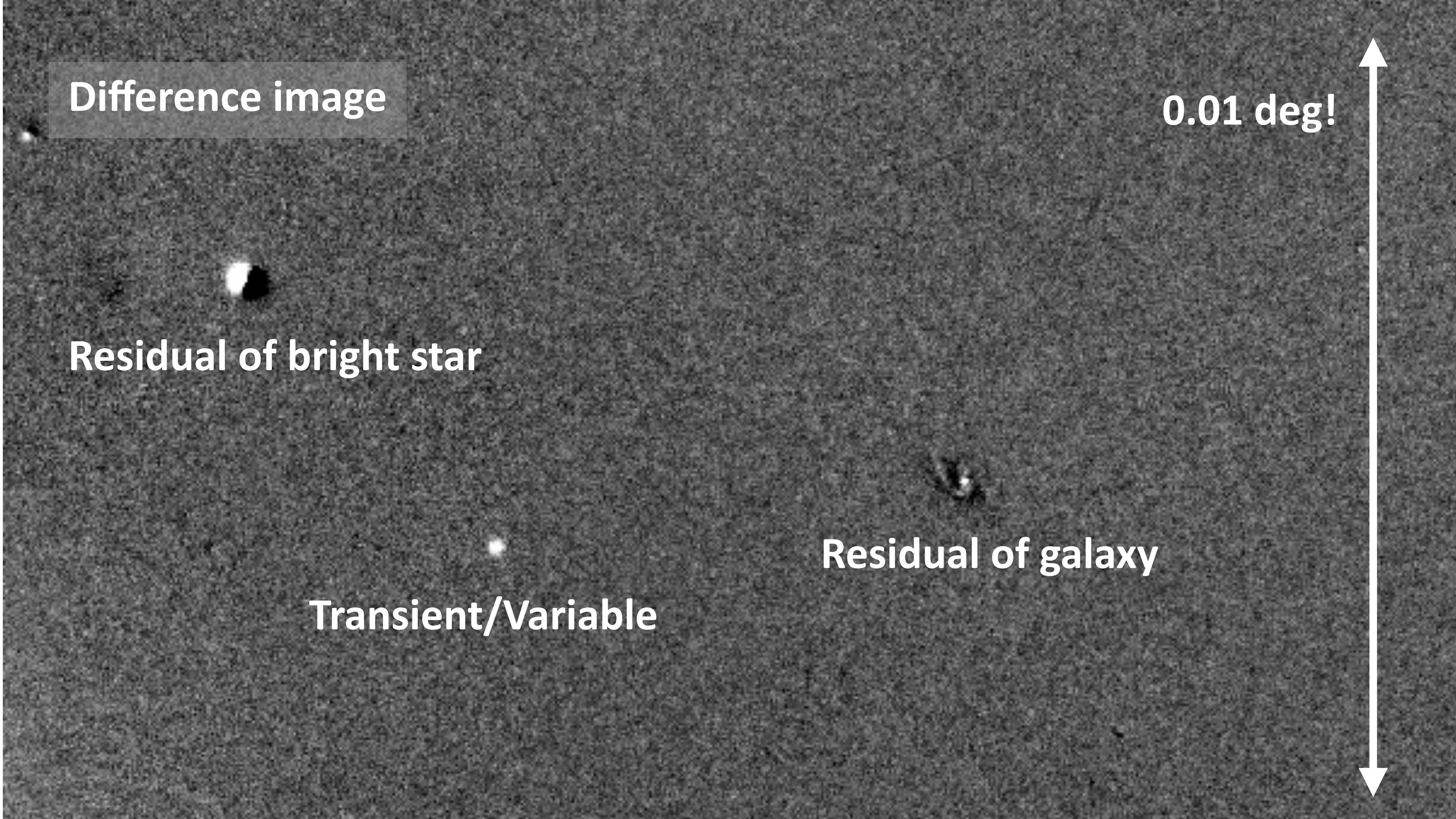
Difference image

0.01 deg!

Residual of bright star

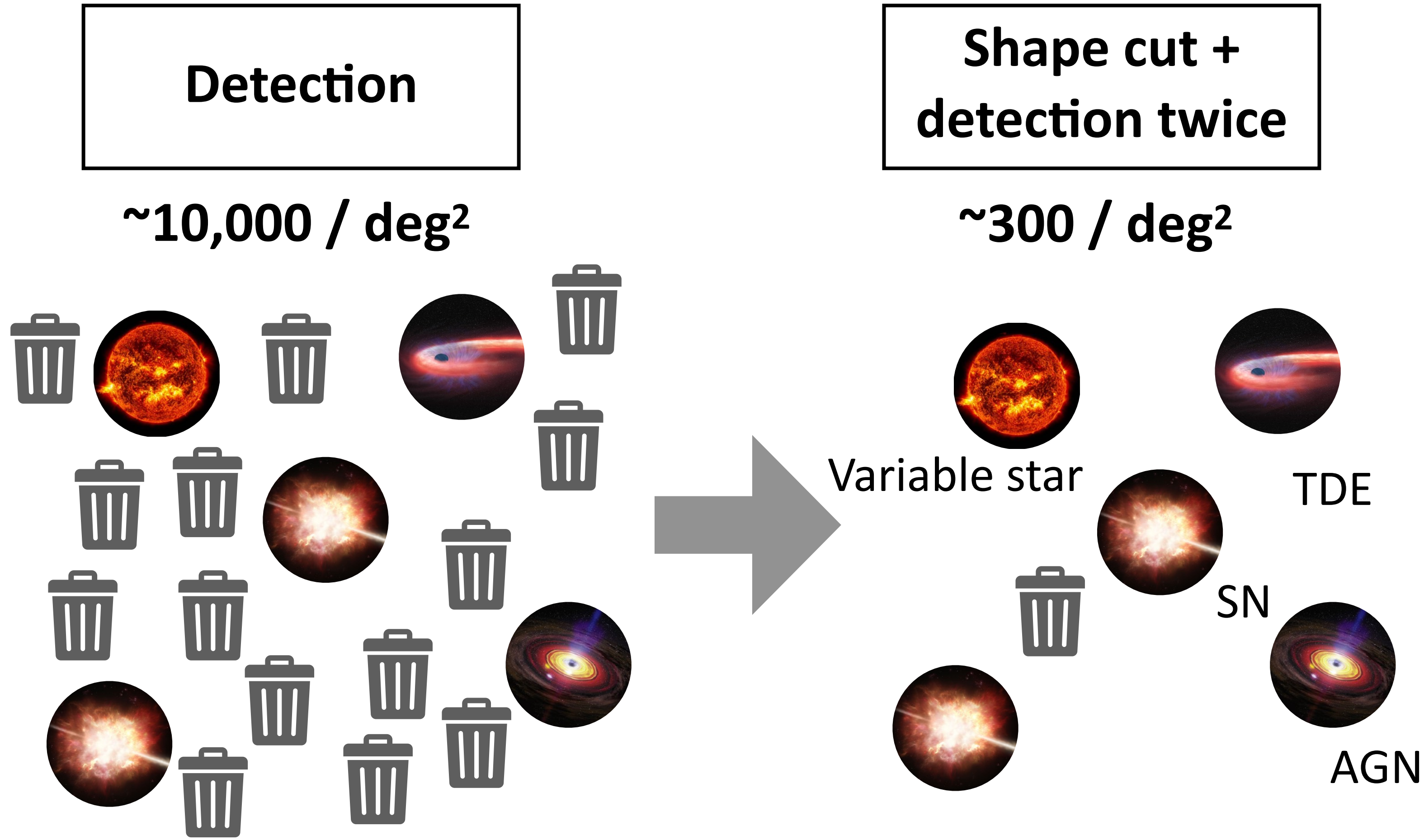
Residual of galaxy

Transient/Variable



Step 1: Transient detection

(A) Number of background

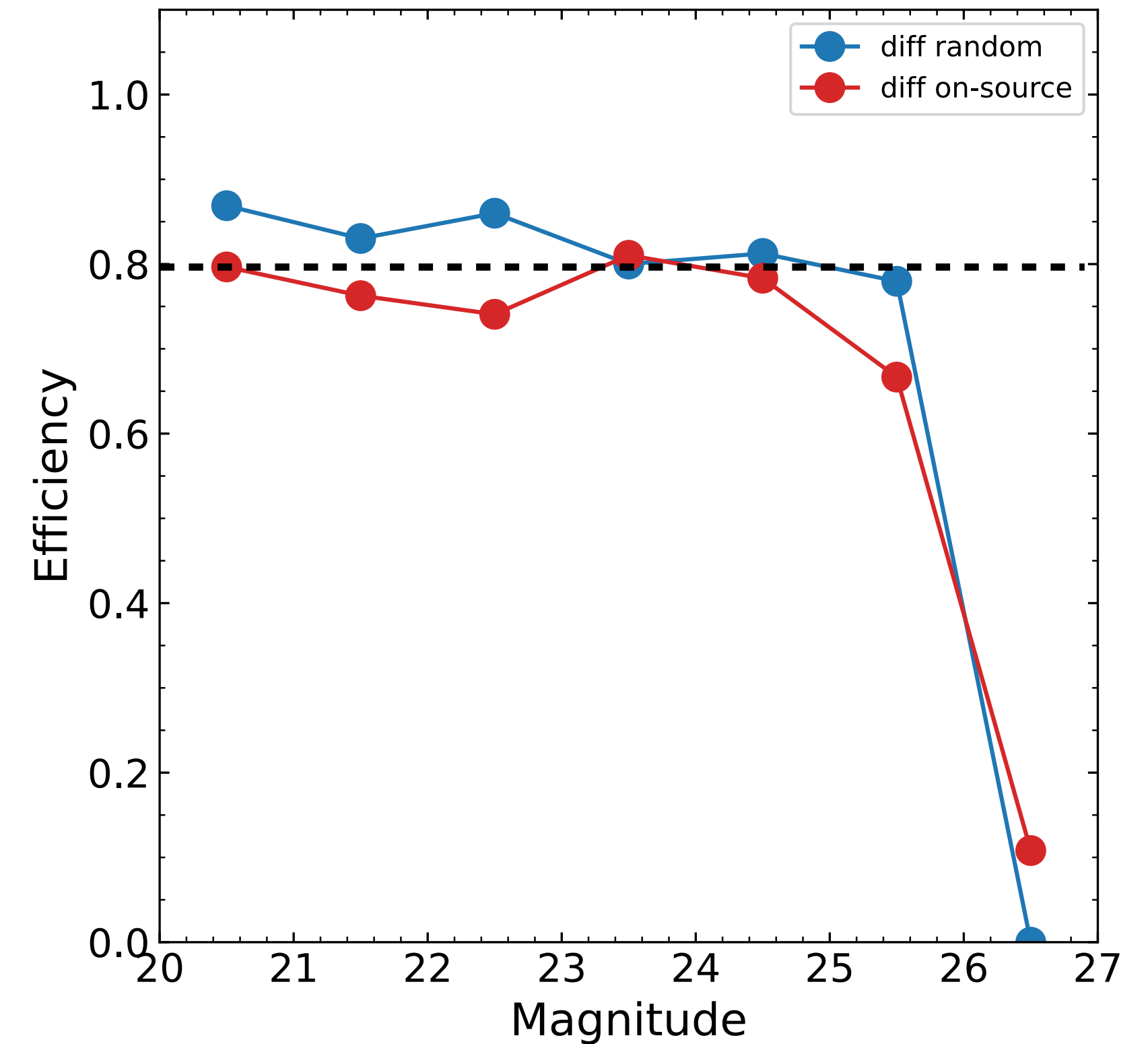


Shape cut: source size, elongation,
match with PSF, positive-negative pattern, ...

Preliminary

(B) True positive rate

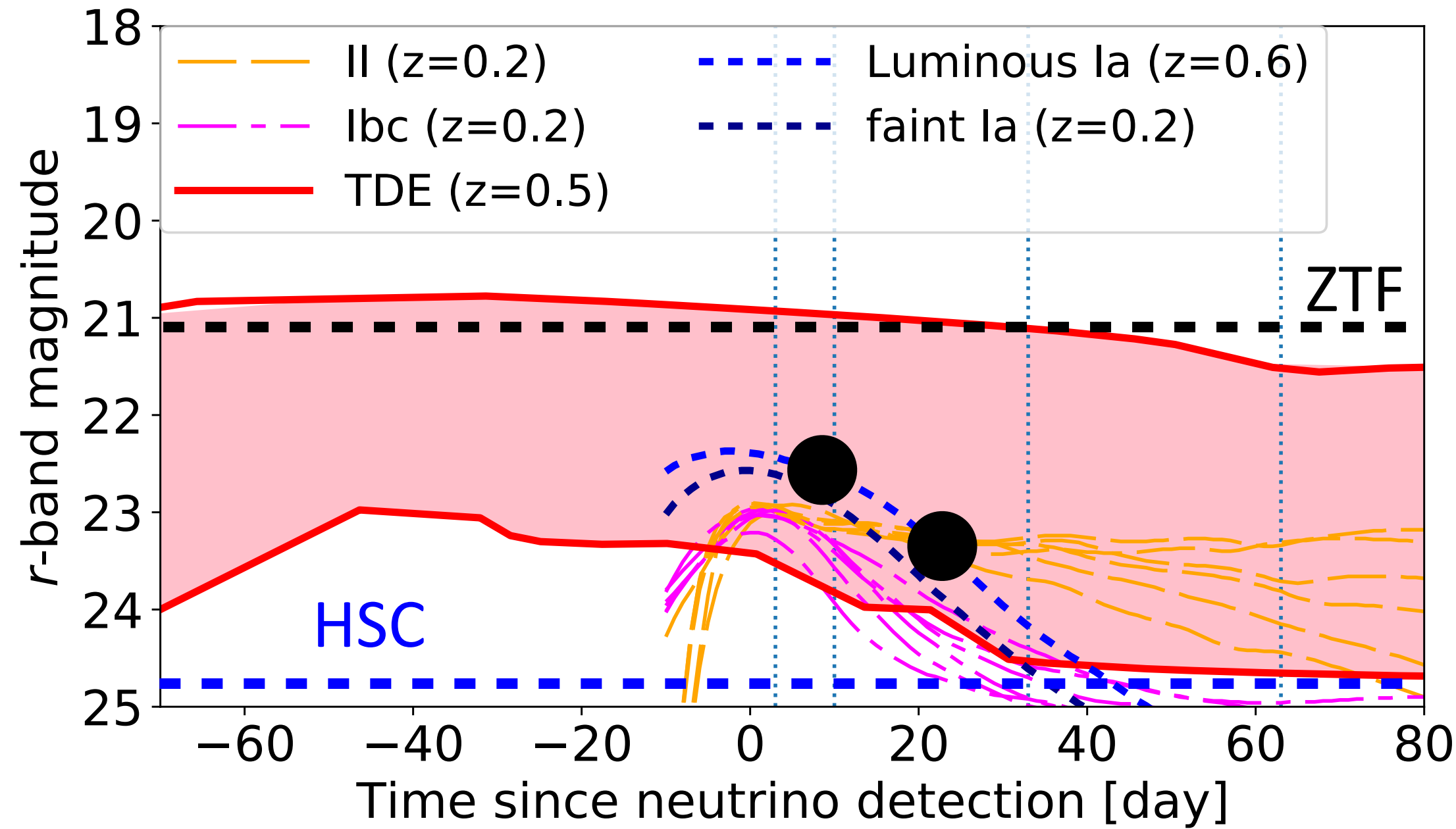
Measured by injecting
artificial stars



TPR \sim 0.8

Step 2: Source classification

Developed By Shigeo Kimura (C01)



Light curve cut: blue color, monotonic decline, ...

Only with 2 epoch data

Preliminary

(A) Number of background

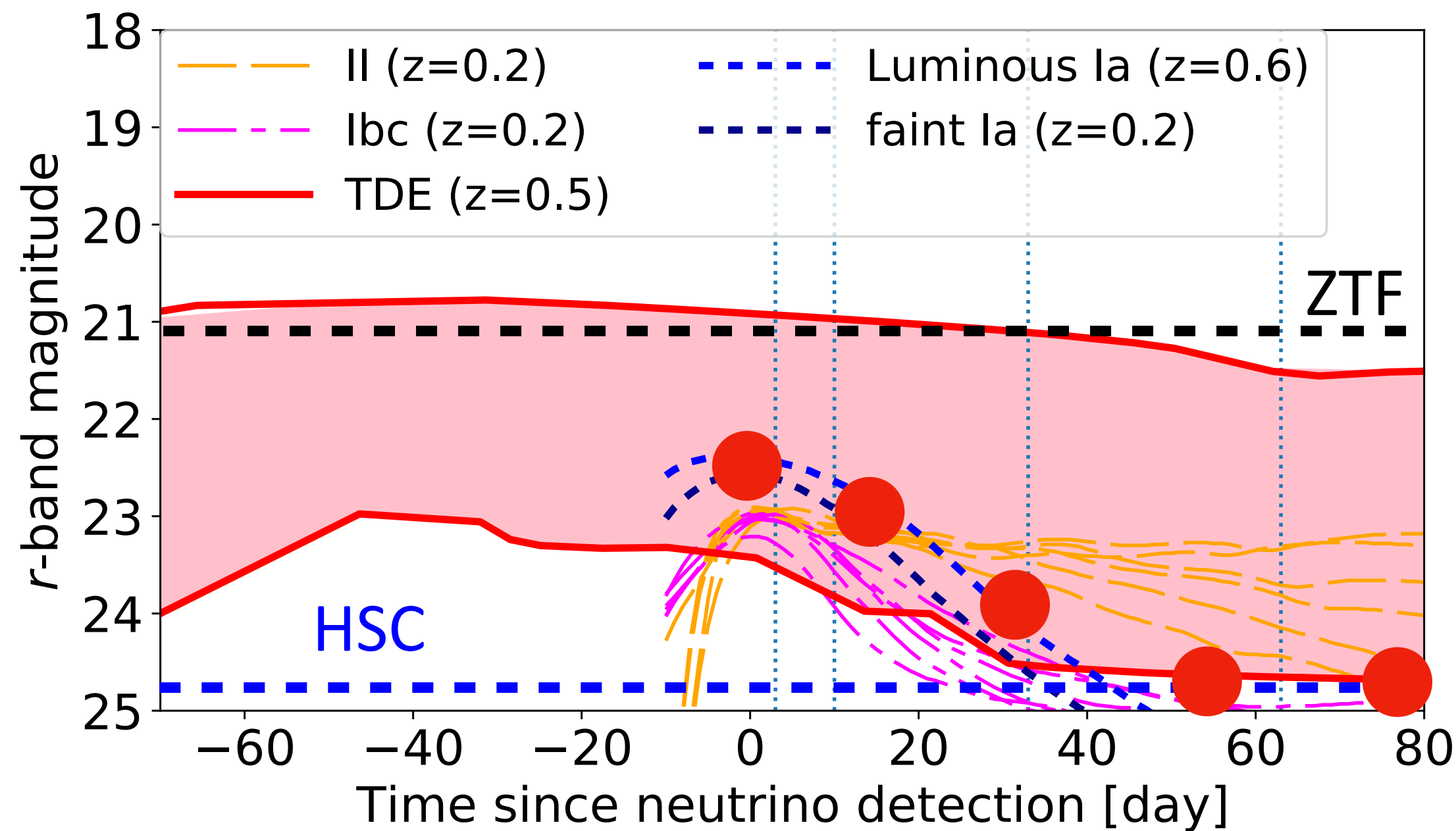
Transient type	# of detected transients / deg ²	# of transients passing the criteria / deg ²
SNe	85	< 0.03
AGN	300	0.53 Main background...
TDE (unrelated)	0.26	0.028

(B) True positive rate (of TDE)

TPR ~ 0.42

Step 2: Source classification

Developed By Shigeo Kimura (C01)



Light curve cut: blue color, monotonic decline, ...

5 epoch data (original plan)

**TDE scenario is testable with several trials
(significant exclusion requires > 5 trials)**

Preliminary

(A) Number of background

Transient type	# of detected transients / deg ²	# of transients passing the criteria / deg ²
SNe	85	< 0.03
AGN	300	0.03
TDE (unrelated)	0.26	0.01

(B) True positive rate (of TDE)

TPR ~ 0.47

Summary

- **Optical and infrared observations**

- Wide-field survey + spectroscopy with the telescope network
- Optical spectrograph for TAO + Rapid data analysis system for Subaru/PFS and Seimei

- **Gravitational wave**

- No good neutron star merger event in O4 (\Rightarrow A02)
- Heavy element identification in kilonova spectra (\Rightarrow C02)

- **High-energy neutrino sources**

- Subaru observations for IC singlet event (\Rightarrow A01, C01)
 - Background analysis for transient detection and source classification
- Optical data analysis for multiplet events (\Rightarrow A01, C01)

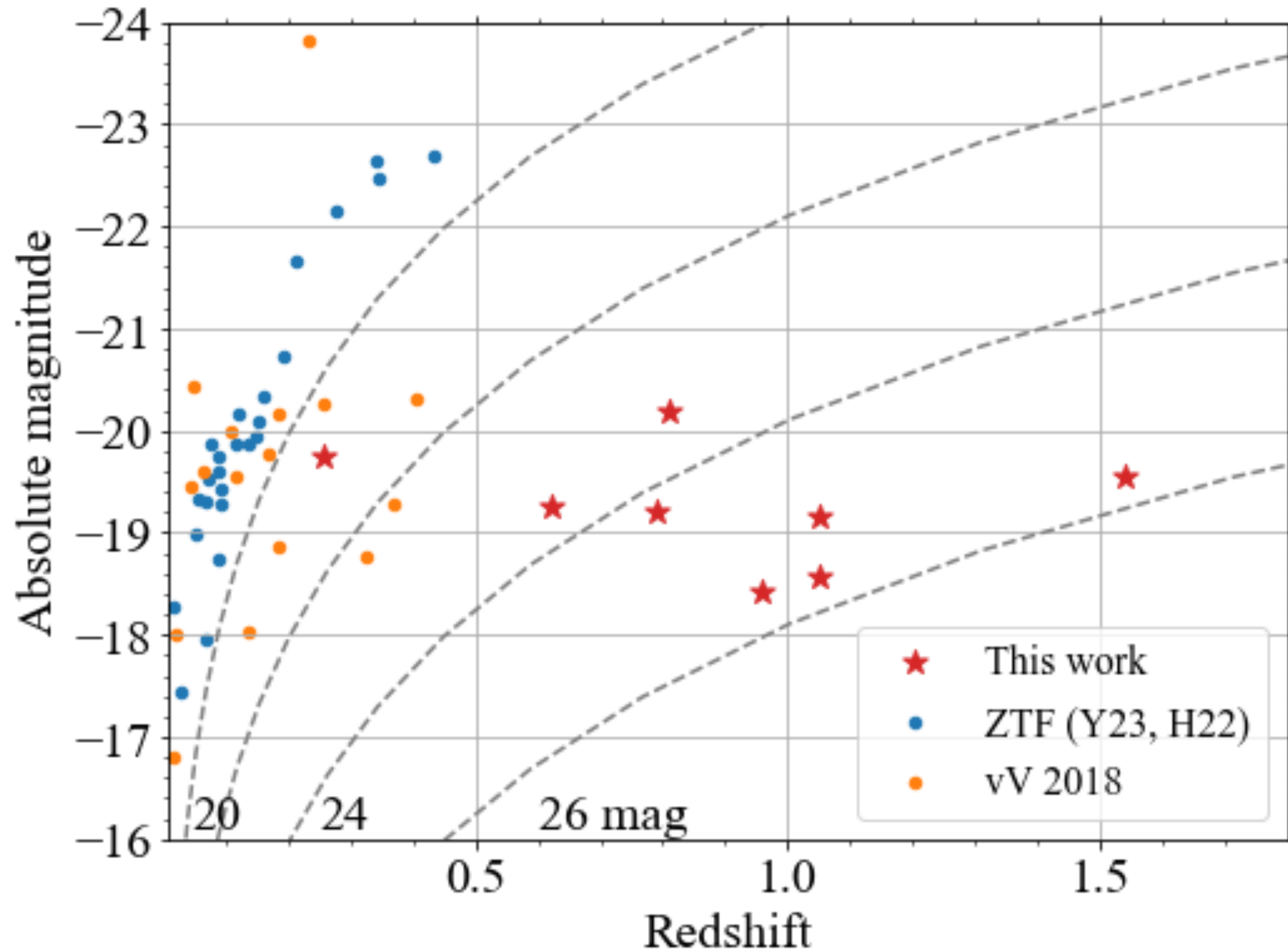
Appendix

Event rate of TDE?

=> Survey with Subaru/HSC

Redshift distribution of TDEs

By Seiji Toshikage



Extended the redshift of TDE samples beyond $z=1$!

Light-curve of TDE candidates

By Seiji Toshikage

