# Subaru/MOIRCS follow-up observation of the gravitational wave event S240422ed

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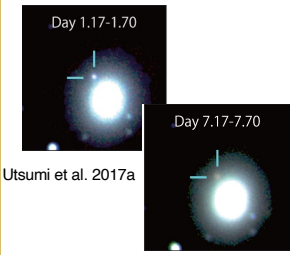
**Abstract**: While a kilonova from a neutron star binary merger was confirmed in GW170817, further observations of electromagnetic counterparts are needed to understand a diversity of mass loss, nucleosynthesis, and kilonova in binary NS mergers and BH-NS mergers. Our collaboration, Japanese Collaboration for Gravitational wave ElectroMagnetic follow-up (J-GEM), performed near-infrared follow-up observations with Subaru/MOIRCS of the GW event S240422ed, which occurred during the second half of the LIGO-Virgo-KAGRA 4th observing (O4b) run. Observations targeting about 200 nearby galaxies started 7.8 hours after the GW event. We performed transient searches with catalog matching and visual inspection, and found six candidates. Information on one of these candidates was published in the GCN Circulars four days after the event, and further follow-up observations were performed with VLT and Gemini. The photometric analysis of the candidate sources indicates inconsistencies between the observed photometric data and the kilonova models. As for the nature of these candidates, estimates of the number observed by chance leave open the possibility of supernovae and dwarf nova outbursts.

## Introduction

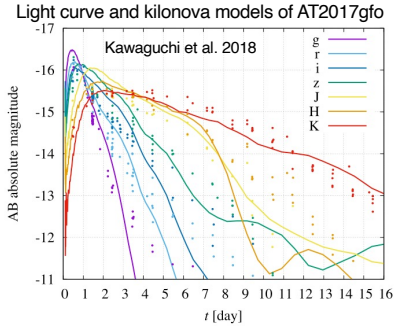
Confirmation of kilonova from a compact binary merger in the gravitational wave (GW) event GW170817

Three-color (z, H, Ks) composite images of AT2017gfo




Utsumi et al. 2017a

Light curve and kilonova models of AT2017gfo




- Further observations of the electromagnetic (EM) counterparts of GW events are needed to understand the diversity of mass ejection and nucleosynthesis in compact binary mergers.
- In the LIGO-Virgo-KAGRA GW observing run O4b (from April 2024), J-GEM is performing EM counterpart surveys.

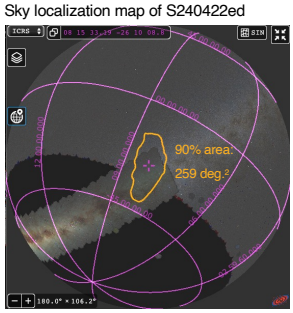
## GW event S240422ed

The results of the real-time GW data analysis for this event motivated EM follow-up observations by optical/near-infrared telescopes around the world.

- T0: 2024-04-22 21:35:13 UT
- GW source classification: NSBH (>99%)
- HasRemnant: >99%
- Distance: 188 +/– 43 Mpc
- No gamma-ray burst was detected in coincidence with the event.

J-GEM triggered ToO observations with Subaru/MOIRCS to search for EM counterpart.

Sky localization map of S240422ed




From http://mma.phys.aoyama.ac.jp

GW source classification was updated on July 3.

- Updated: Terrestrial (93%), BNS (5%), NSBH (2%)

Despite the (likely) non-astrophysical origin of this event, our observations provide a nice test case for deep NIR follow-up observations of GW events.

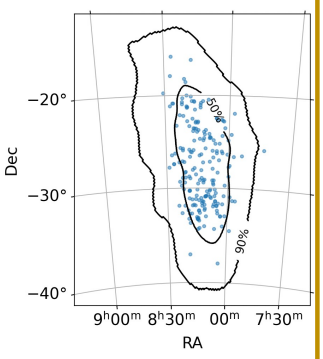
## Observations and Data analysis

### Subaru/MOIRCS observation

We conducted near-infrared imaging observations of 206 nearby galaxies with Subaru/MORICS on 2024-04-22 and 23 (Morokuma et al. 2024a, b; GCNC 36265, 36302).

Observed galaxies were selected from the GLADE v2.4 catalog (Dálya et al. 2018) based on the high probability sky area and estimated distance range of the event (see Sasada et al. 2021).

Sky localization map and observed galaxy positions




**Observation Information**

| | |
|---|---|
| Obs. start | 7.8 hours after the GW event |
| Filter | Y, $K_s$ |
| Limiting magnitude | 20-21 mag. (3σ) |
| Coverage (Considering the catalog completeness) | 23% |

### Candidate screening

To find counterpart candidates in the reduced MOIRCS data, we conducted two types of analyses.

**1. Catalog matching**

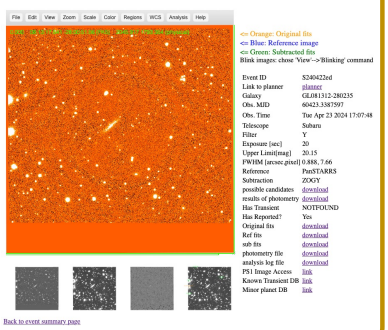
We searched for objects not in the reference catalogs or 5-sigma brighter than the catalog magnitude.

**Reference catalogs**
- Pan-STARRS (PS1)
- 2MASS
- VISTA Hemisphere survey (VHS)

No new or 5-sigma brighter objects compared to catalogs.

**2. Visual inspection**

J-GEM candidate search tool



J-GEM provides a candidate object search tool which enables visual comparison of observed images with reference and difference images (Sasada et al. 2021).

Since this event occurred near the Galactic plane in the southern sky (see sky localization map ), we used reference data from the Galactic plane surveys (DECamPS2 and VISTA VVVX) as well as PS1.

We have found 6 candidates for the EM counterpart.

## EM counterpart candidates

### Candidate: J-GEM24a

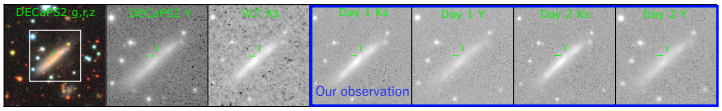
(RA, Dec.) = (122.2158 deg., –24.5164 deg.)

- We reported this candidate four days after the GW event (Takahashi et al. 2024; GCNC 36333), and it was not detected despite follow-up observations by VLT and Gemini.
  - host spec-z = 0.055 (247 Mpc) by VLT/XShooter (GCNC 36341)

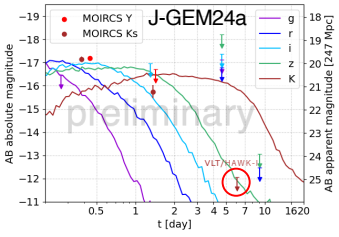

### Candidate: J-GEM24c

(RA, Dec.) = (123.2977 deg., –28.04254 deg.)

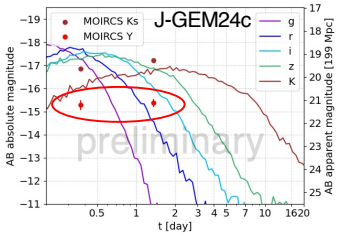
- Found in the galaxy (distance: 199 Mpc) with the highest probability in our list of candidate host galaxies.




### Photometric comparison with kilonova model




Model: BNS (Kawaguchi+2022, Shibata+2021) long-lived remnant & MHD dynamo effect, 75a




Model: BNS (Kawaguchi+2022, Shibata+2021) long-lived remnant & MHD dynamo effect, 80a

The photometric data are inconsistent with the adopted kilonova models.

### Nature of candidates

**Extragalactic transients?**

The number of supernovae that could be detected by chance is estimated to be 0.5 in our follow-up observations. J-GEM24c might be a supernova with red color. Other candidates are unlikely to be extragalactic transients.

**Galactic transients?**

We estimate the number of dwarf nova outbursts that could be observed by our survey to be 0.16 ~ 5.5. Although the number density of dwarf nova systems and their outburst frequency are highly uncertain, it is not surprising to detect a few dwarf nova outbursts in our observations.

**Moving objects?**

The candidates are all in the constellation Puppis and well off the ecliptic plane (β ~ –50 deg.). This eliminates the majority of solar system objects in the ecliptic plane from the possible sources of our candidates.