Current Strategy of Search for Gravitational-Wave Counterpart by Optical and NIR Observations

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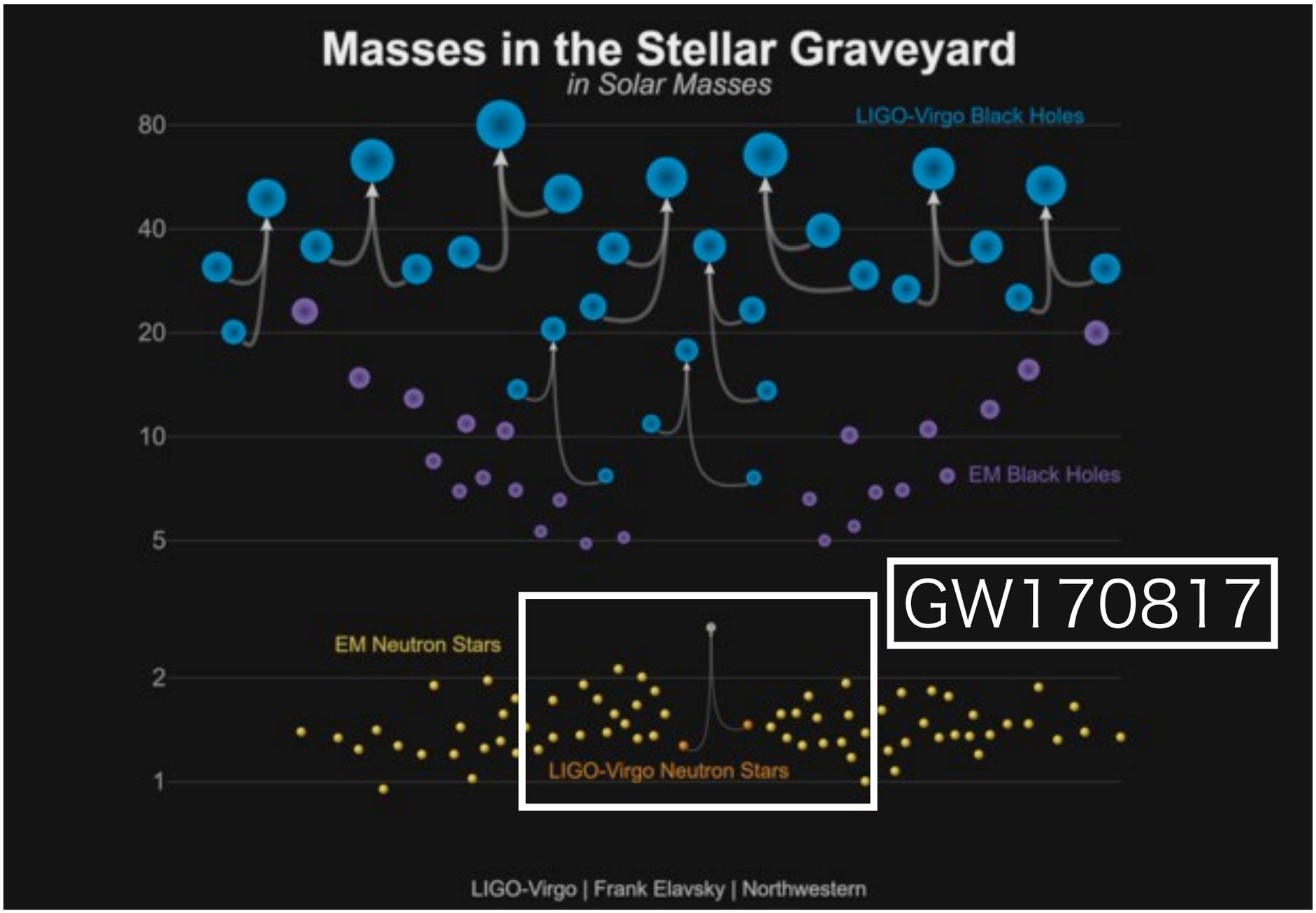
on behalf of J-GEM Team

Electro-magnetic counterpart for GW phenomenon

Gravitational-wave source

- Since Nov. 2015, LIGO/Virgo have detected gravitational-wave (GW) signals from the Universe.
- Those would come from astronomical phenomena, for example mergers of black hole-black hole, black hole-neutron star, and neutron star-neutron star pairs.
- The GW-radiated phenomena are expected to radiate electro-magnetic (EM) emission.
- Multi-messenger observation can reveal the physical background of GW sources.

GW sources discovered by LIGO/Virgo

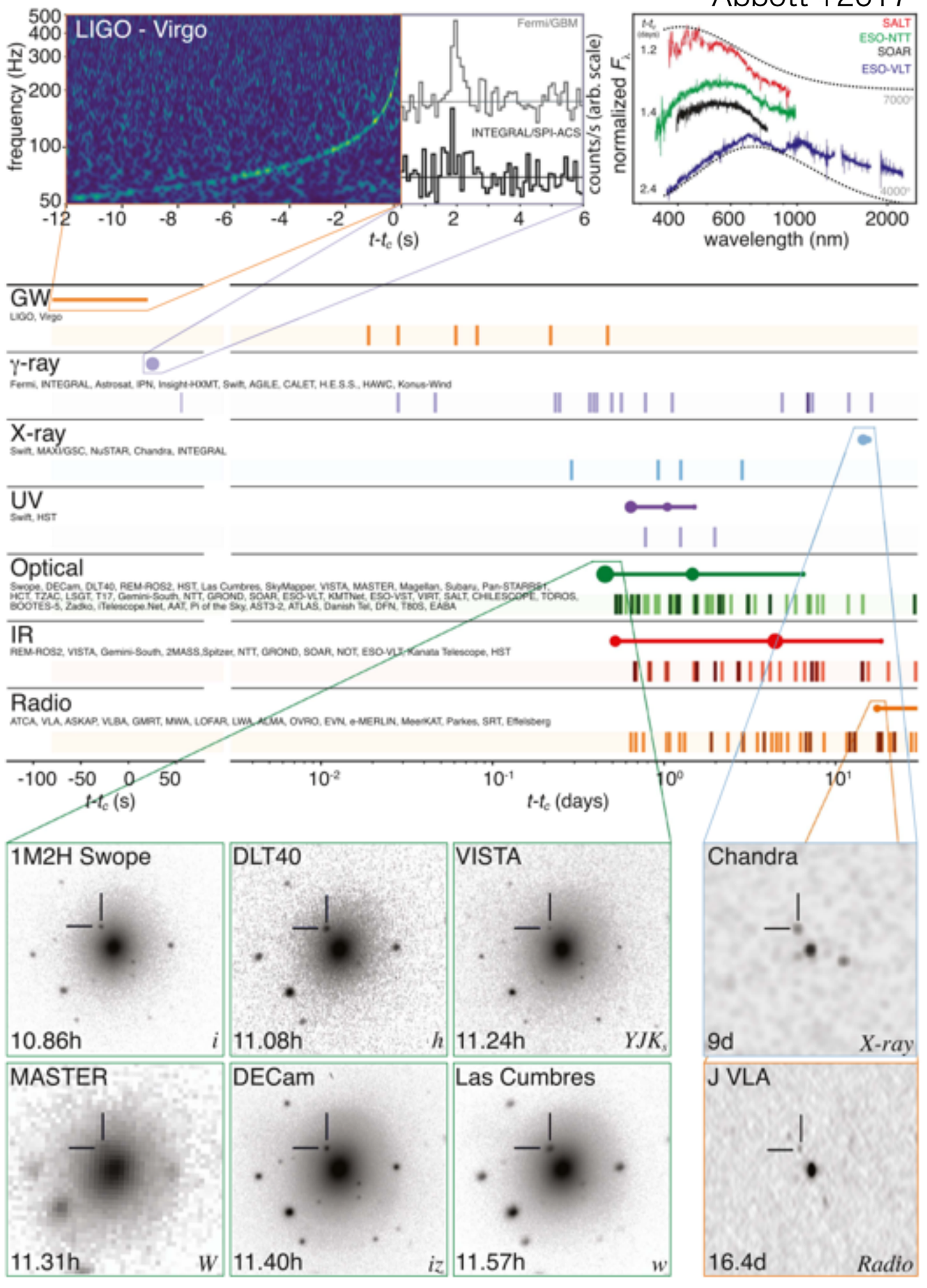


Credits: LIGO/Virgo/Northwestern Univ./Frank Elavsky

GW170817

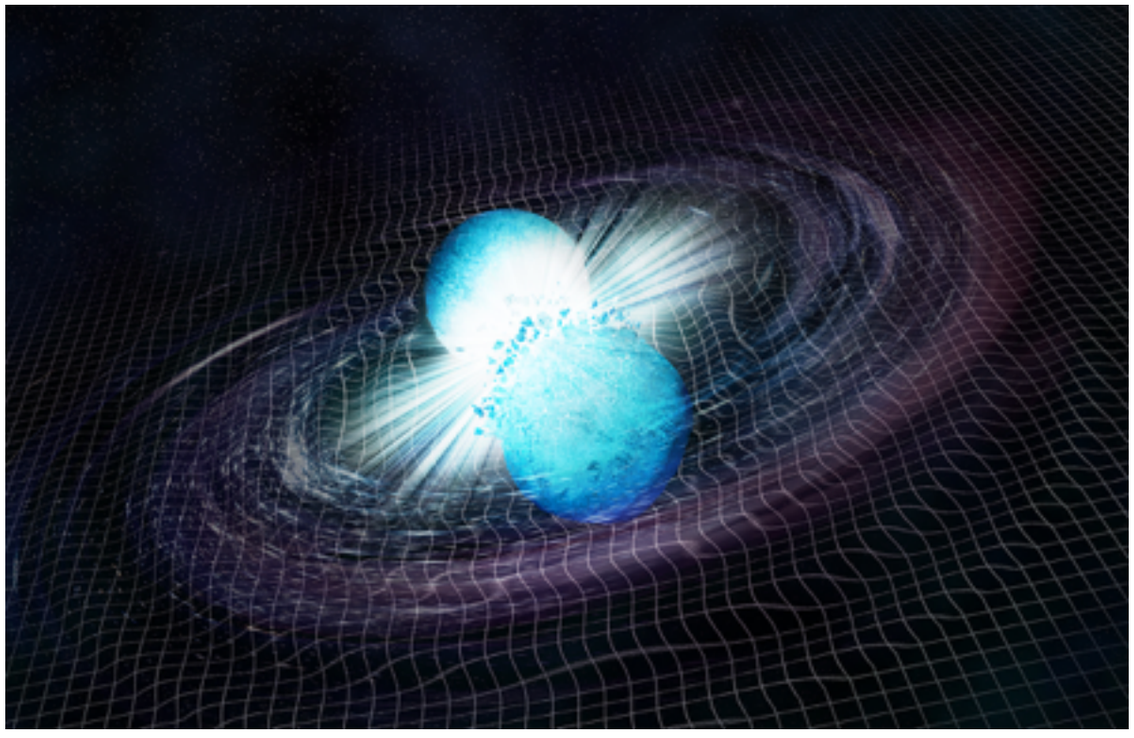
- LIGO/Virgo detected the GW on 17 Aug. 2017.
- GW170817 was identified as the EM counterpart in the entire wavelength.
- Gamma-ray: Detect gamma-ray emission after 1.74 seconds of GW detection.
- X-ray: Detect after 9 days of GW detection.
- Optical and NIR: Identify optical counterpart after 10.87 hours.
- Radio: Detect after 17 days.

Abbott +2017



Neutron-Star Merger

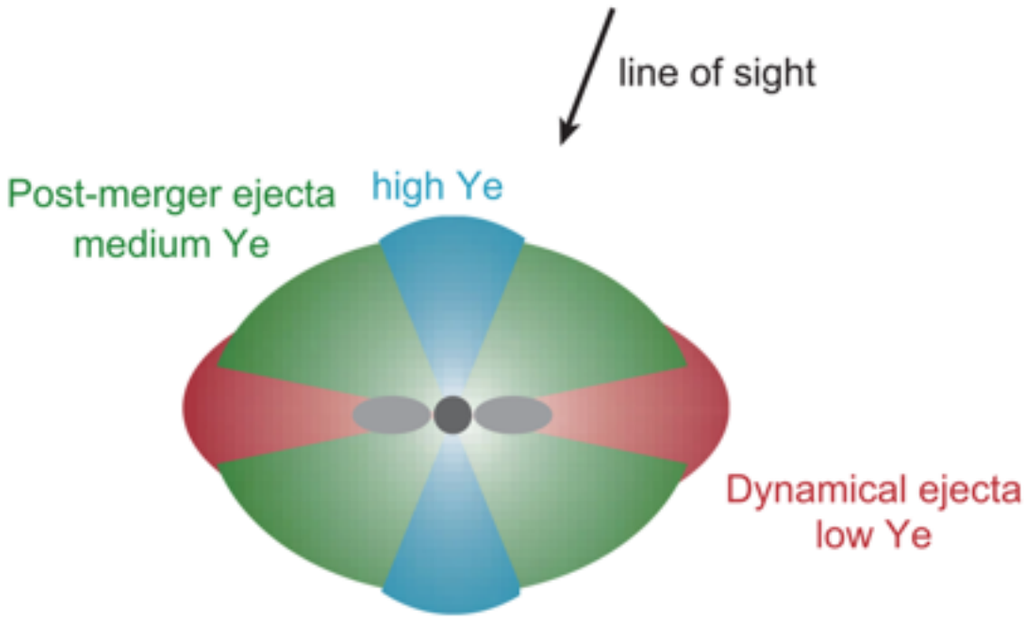
NASA/CXC/M.Weiss



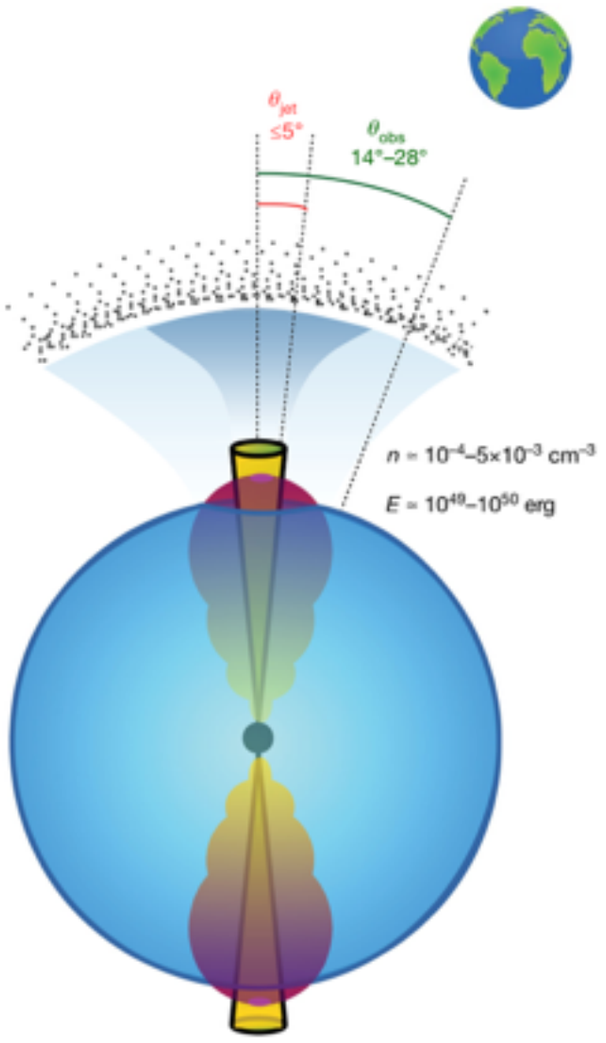
- The obtained GW indicated that the GW was generated by the binary neutron-star (BNS) merger.

Implication from EM Observation

- Optical and IR emissions can be generated by the radioactive decays of r-process nuclei. (Kilonova model)
- Radio, X-ray and gamma-ray emissions would come from the relativistic jet which was generated by the BNS merger.



Tanaka+ 17

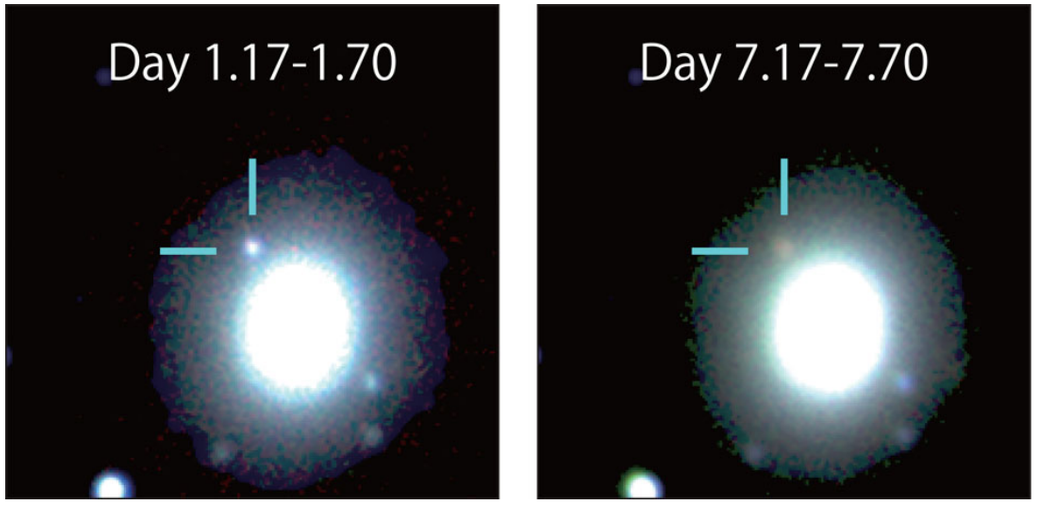


Mooley+ 18

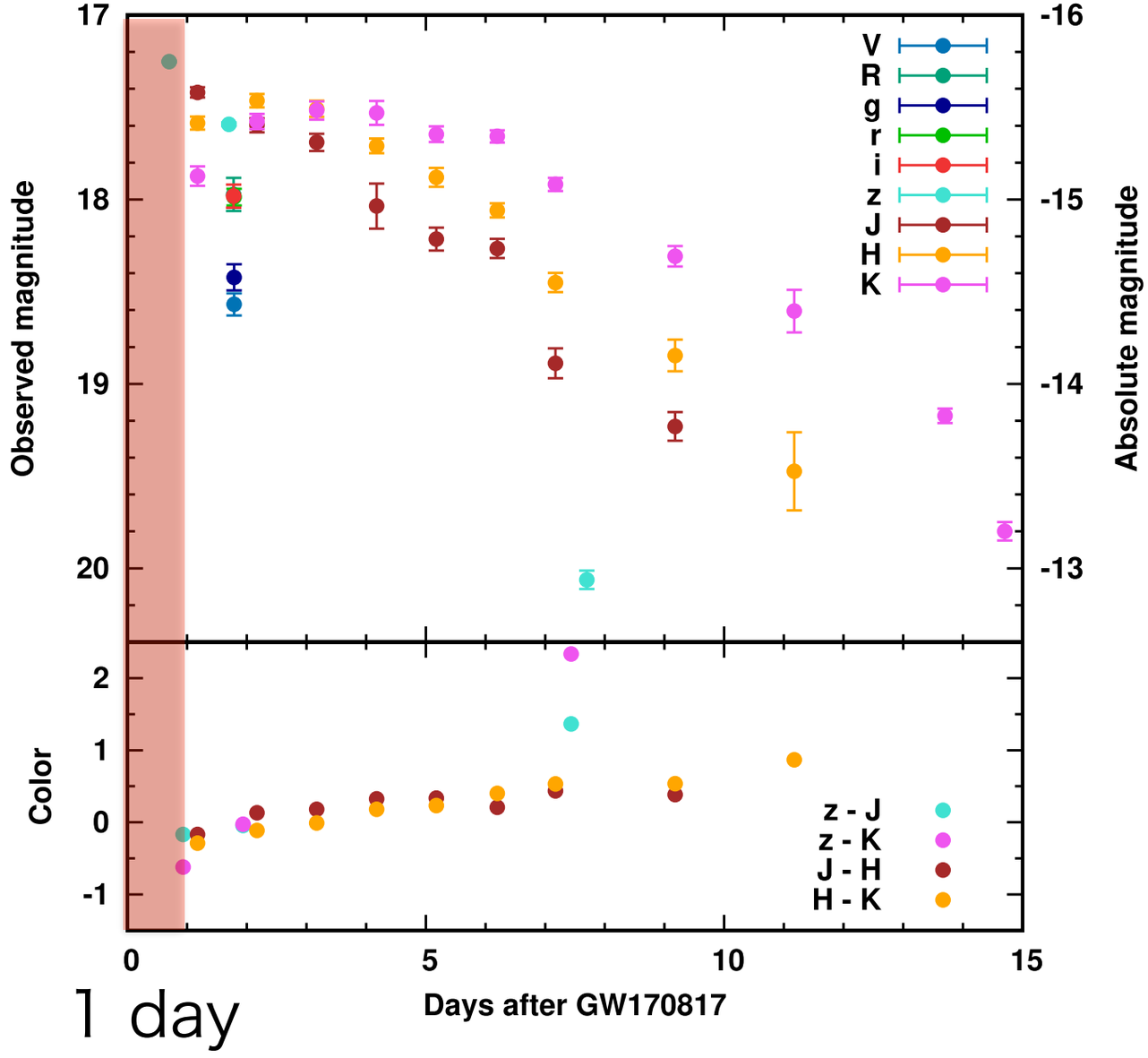
J-GEM Observation for GW170817

- J-GEM succeeded the observation for GW170817 by using IRSF, MOA, B&C and Subaru/HSC.
- Our aim is to observe the optical counterpart of GW source before 1 day.

Constrain a physical mechanism of GW counterpart.

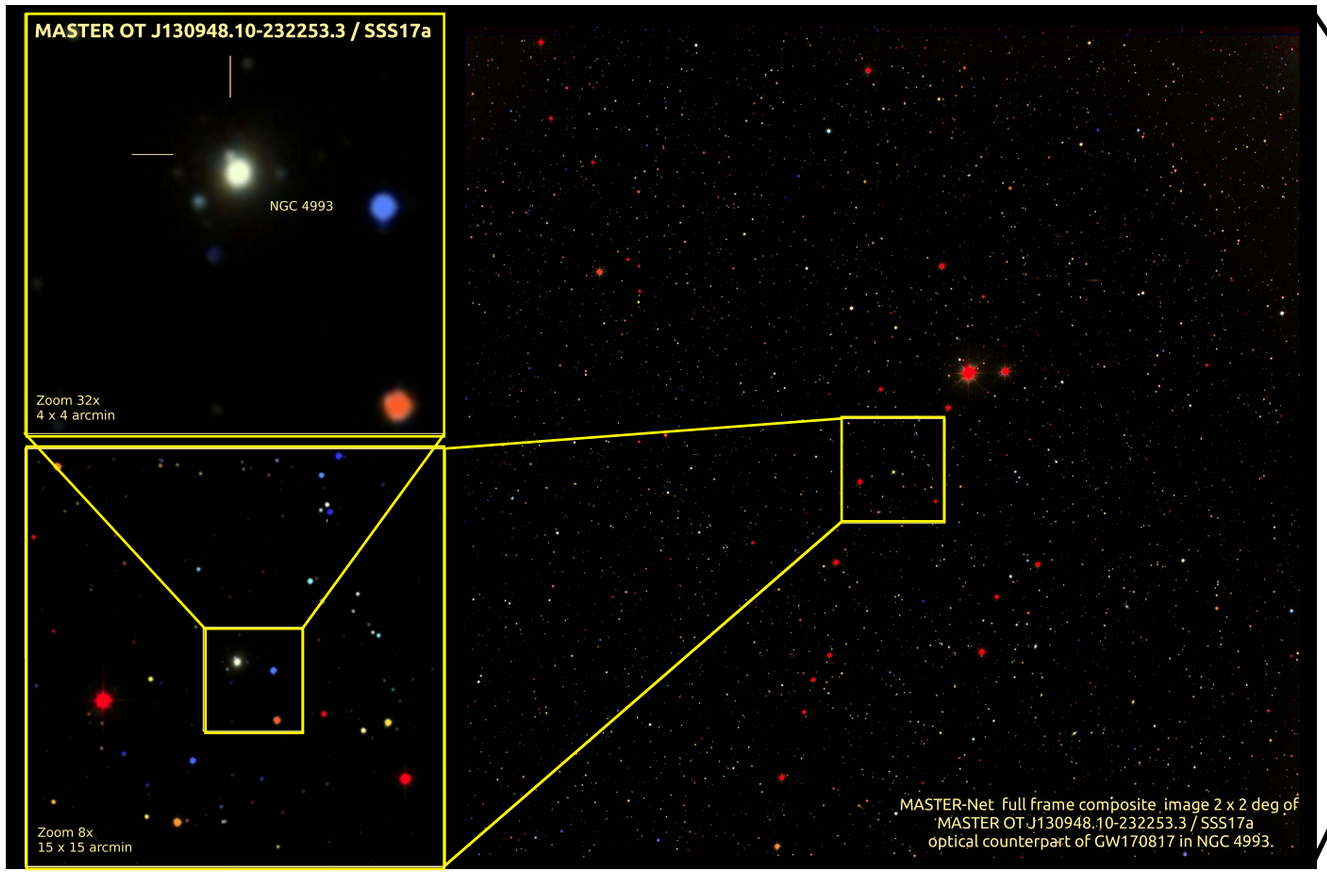


Utsumi +2017

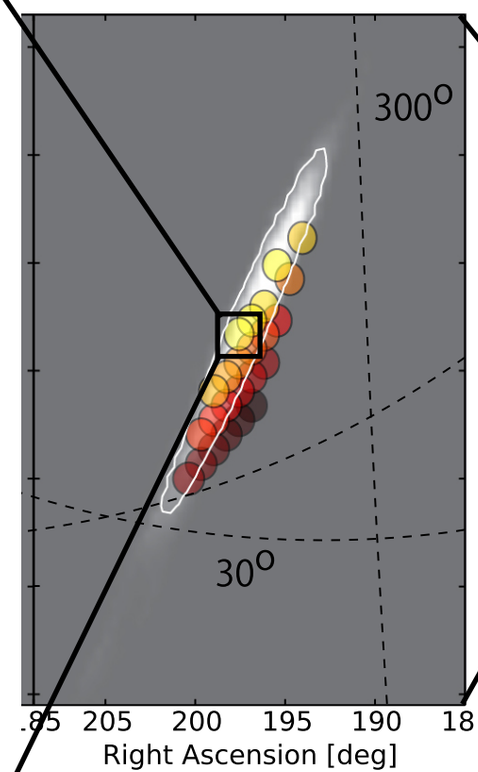


1 day

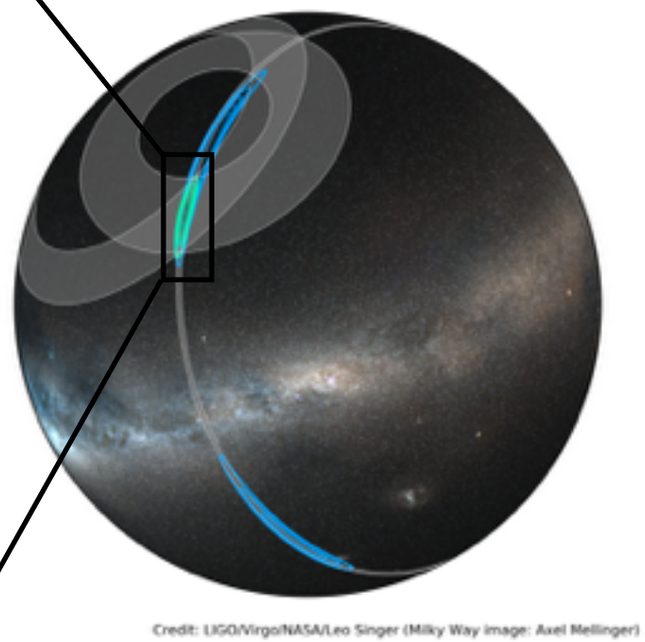
How to Identify Optical Counterpart



Lipunov+ 2017



Area of GW170817



Tominaga+ 2018

- There are many stars and galaxies within the probable region of GW170817.
- It is not easy to identify an optical transient from the obtained image.

J-GEM (Japanese collaboration for Gravitational-wave Electro-Magnetic follow-up)

A part of the project "Multi-messenger Observations of GW sources"
* collaborating with the KAGRA data analysis team

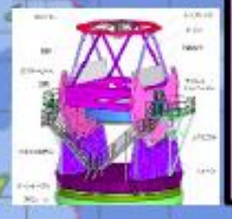
Main features:
- 5 deg^2 opt. imaging w/ 1m
- 1 deg^2 NIR imaging w/ 1m
- opt-NIR spectroscopy w/ 1–8m
- opt-NIR polarimetry

- 1m Kiso Schmidt telescope
  5 deg^2 camera ➔ 20 deg^2
- 1.5m Kanata telescope
- 2m Nayuta telescope
- 50cm MITSuME
- 91cm OAO-WFC of NAOJ
- Yamaguchi 32m radio telescope

50cm telescope
(Hiroshima Univ. 2016)

3.8m telescope
(Kyoto Univ. 2017)

HSC, Subaru @Hawaii



TAO 6.5m (Tokyo Univ. 2018)

IRSF (Nagoya Univ.)
@ South Africa

MOA-II, B&C (Nagoya Univ.) @ New Zeeland

miniTAO (Tokyo Univ.)
ASTE (NAOJ) @ Chile

Purpose of J-GEM

Purpose

- Multi-messenger observation to reveal the physical background of GW sources
- Detect and observe an optical counterpart of GW source

Requirements

- Survey huge area (> 10 sq. degrees), because of a low sky-position accuracy of GW observatories.
- Identify the optical counterpart as soon as possible to understand an early phase of GW event.

Approach

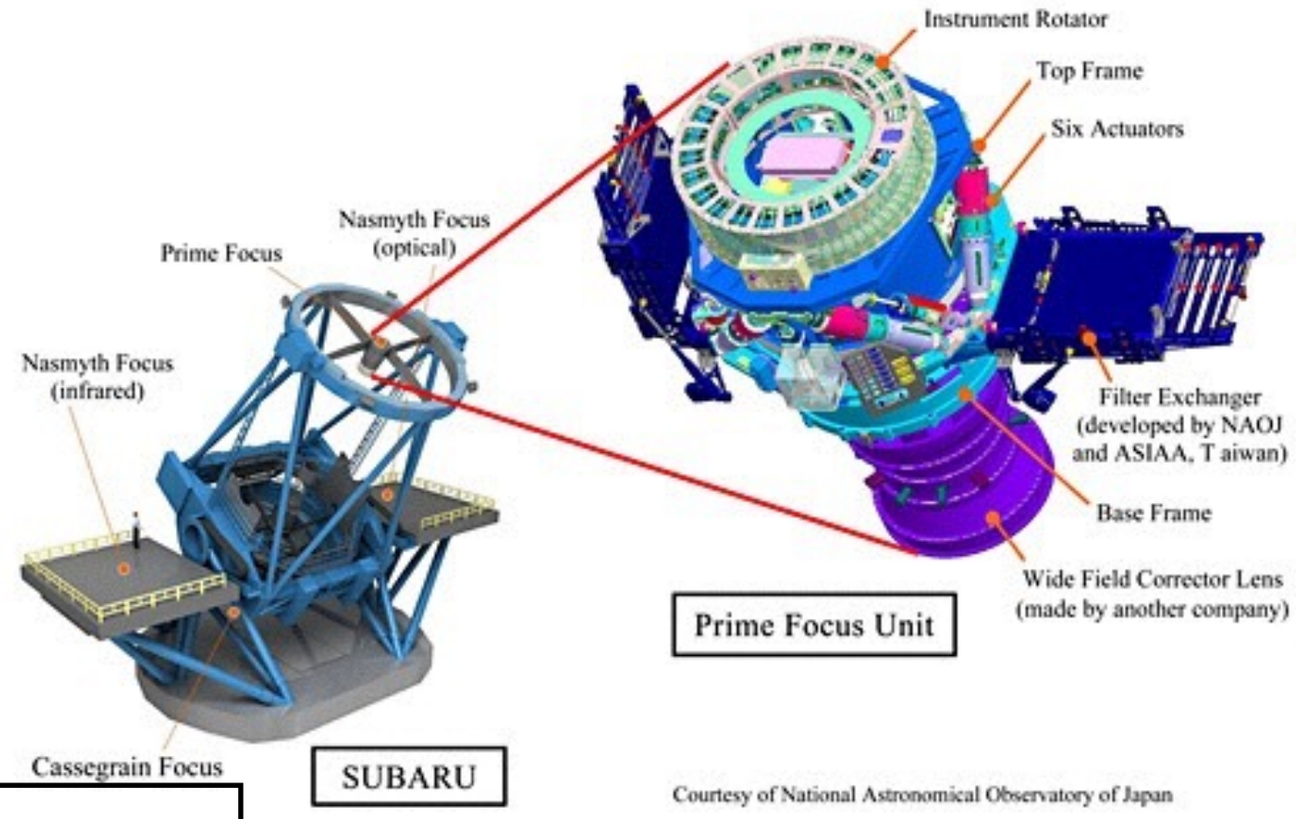
- We do a survey observation by using many Japanese telescopes

Two types of telescope

Normal Telescope (FoV < 1 deg^2)

- Kanata
- IRSF
- Nayuta
- OAO WFC
- MITSuME Akeno/Okayama
- B&C
- Saitama SaCRA

Telescope having large FoV (FoV > 1 deg^2)



Courtesy of National Astronomical Observatory of Japan

- Subaru
- MOA
- Kiso Tomo-e

Different strategies depending on telescopes

Identify the EM counterpart using both types of telescopes

Strategy for Normal Telescope

The survey area may be so huge that a normal optical telescope can not cover the entire survey area.

- Optical counterpart should be associated with a host galaxy.
  ➡ Observe candidate galaxies, and identify the associated transient **(Targeted Observation)**.
  GW170817 was discovered by the similar way.

- Survey the huge area
  ➡ List candidate galaxies, and observe with many collaborate telescopes

- Do not duplicate candidate host galaxy to survey efficiently.
  ➡ Share a list of candidate host galaxies, and realtime observing information

Strategy for Normal Telescope

LSC LIGO Scientific Collaboration

VIRGO

①

J-GEM

Web System

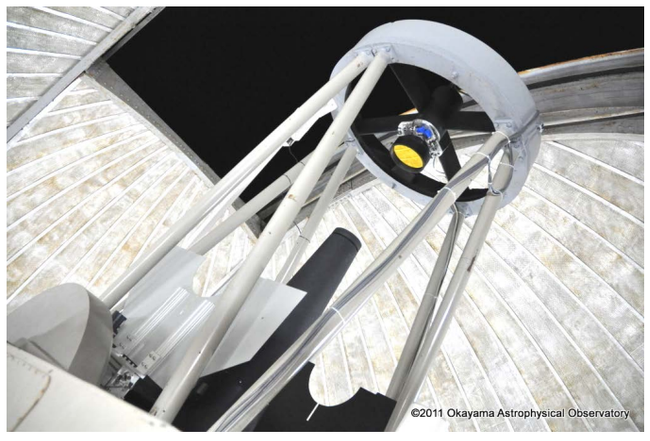
planner

②

・Make galaxy list

・Serve realtime info

④



③

Image

Server

・Observe

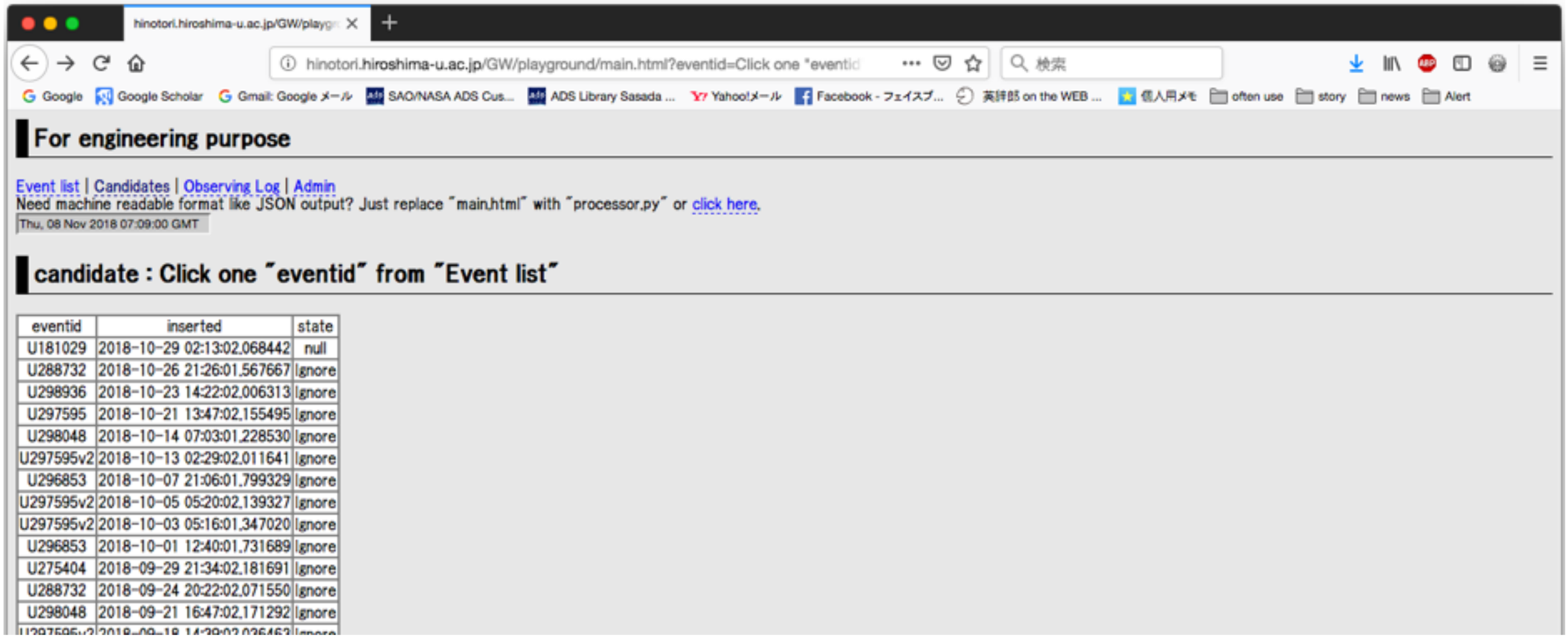
・Reduction

・Save/show obtained images

・Calculate limiting flux

・Subtract image

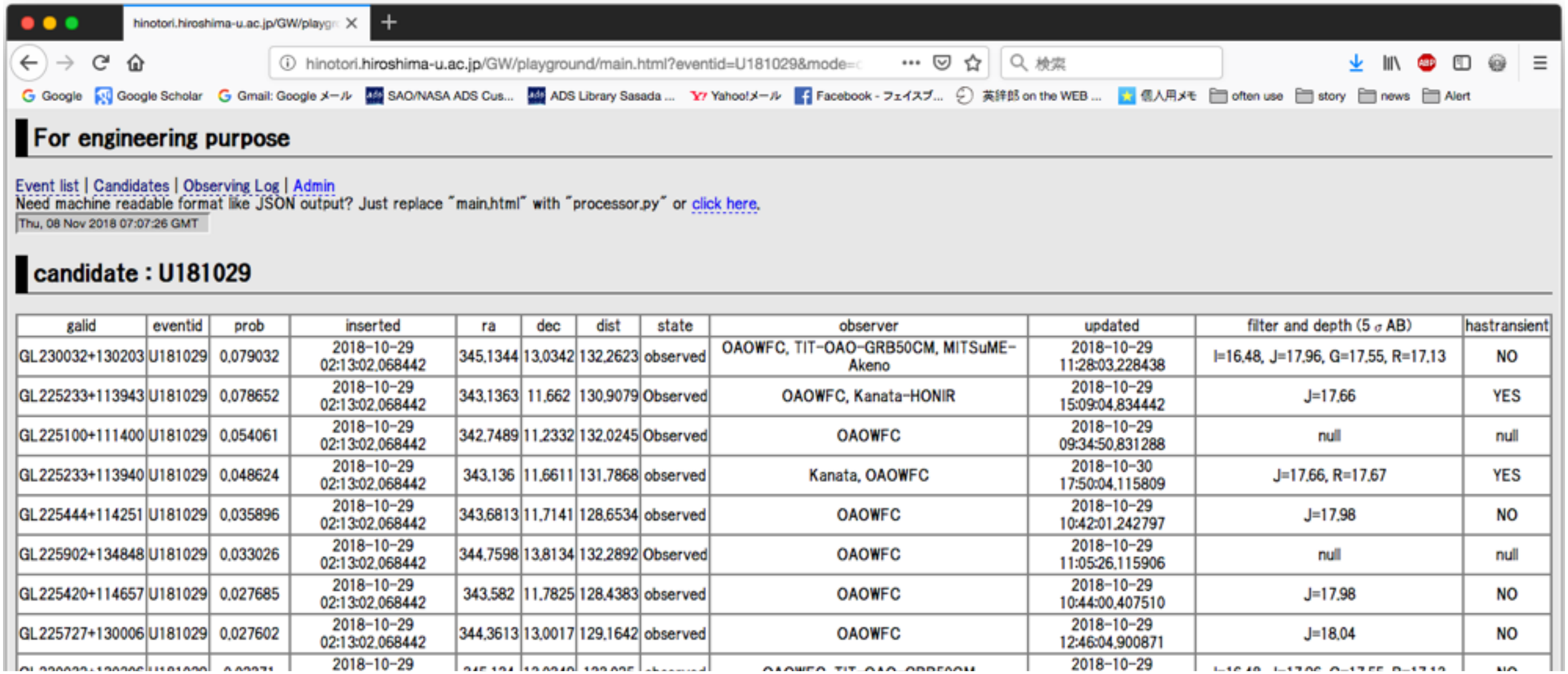
Alert Information System; planner



eventid	inserted	state
U181029	2018-10-29 02:13:02.068442	null
U288732	2018-10-26 21:26:01.567667	Ignore
U298936	2018-10-23 14:22:02.006313	Ignore
U297595	2018-10-21 13:47:02.155495	Ignore
U298048	2018-10-14 07:03:01.228530	Ignore
U297595v2	2018-10-13 02:29:02.011641	Ignore
U296853	2018-10-07 21:06:01.799329	Ignore
U297595v2	2018-10-05 05:20:02.139327	Ignore
U297595v2	2018-10-03 05:16:01.347020	Ignore
U296853	2018-10-01 12:40:01.731689	Ignore
U275404	2018-09-29 21:34:02.181691	Ignore
U288732	2018-09-24 20:22:02.071550	Ignore
U298048	2018-09-21 16:47:02.171292	Ignore

Web-base system. Communicate through command line

Sharing Information of Observation

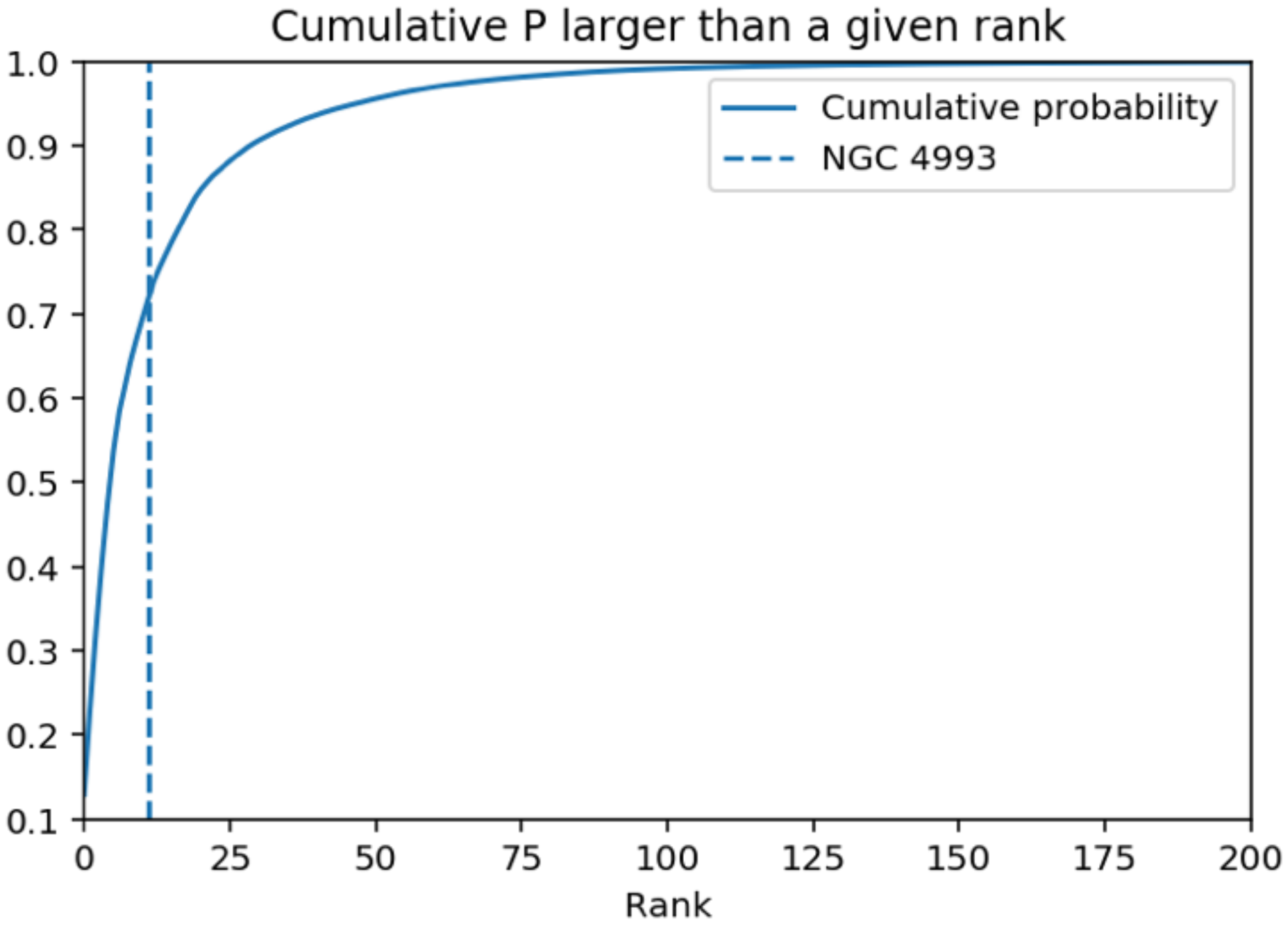


galid	eventid	prob	inserted	ra	dec	dist	state	observer	updated	filter and depth (5 σ AB)	hastransient
GL230032+130203	U181029	0.079032	2018-10-29 02:13:02.068442	345.1344	13.0342	132.2623	observed	OAOWFC, TIT-OAO-GRB50CM, MITSuME-Akeno	2018-10-29 11:28:03.228438	I=16.48, J=17.96, G=17.55, R=17.13	NO
GL225233+113943	U181029	0.078652	2018-10-29 02:13:02.068442	343.1363	11.662	130.9079	Observed	OAOWFC, Kanata-HONIR	2018-10-29 15:09:04.834442	J=17.66	YES
GL225100+111400	U181029	0.054061	2018-10-29 02:13:02.068442	342.7489	11.2332	132.0245	Observed	OAOWFC	2018-10-29 09:34:50.831288	null	null
GL225233+113940	U181029	0.048624	2018-10-29 02:13:02.068442	343.136	11.6611	131.7868	observed	Kanata, OAOWFC	2018-10-30 17:50:04.115809	J=17.66, R=17.67	YES
GL225444+114251	U181029	0.035896	2018-10-29 02:13:02.068442	343.6813	11.7141	128.6534	observed	OAOWFC	2018-10-29 10:42:01.242797	J=17.98	NO
GL225902+134848	U181029	0.033026	2018-10-29 02:13:02.068442	344.7598	13.8134	132.2892	Observed	OAOWFC	2018-10-29 11:05:26.115906	null	null
GL225420+114657	U181029	0.027685	2018-10-29 02:13:02.068442	343.582	11.7825	128.4383	observed	OAOWFC	2018-10-29 10:44:00.407510	J=17.98	NO
GL225727+130006	U181029	0.027602	2018-10-29 02:13:02.068442	344.3613	13.0017	129.1642	observed	OAOWFC	2018-10-29 12:46:04.900871	J=18.04	NO

Galaxy ID | Probability | Galaxy Info | Obs Teles | Obs Info | Flag

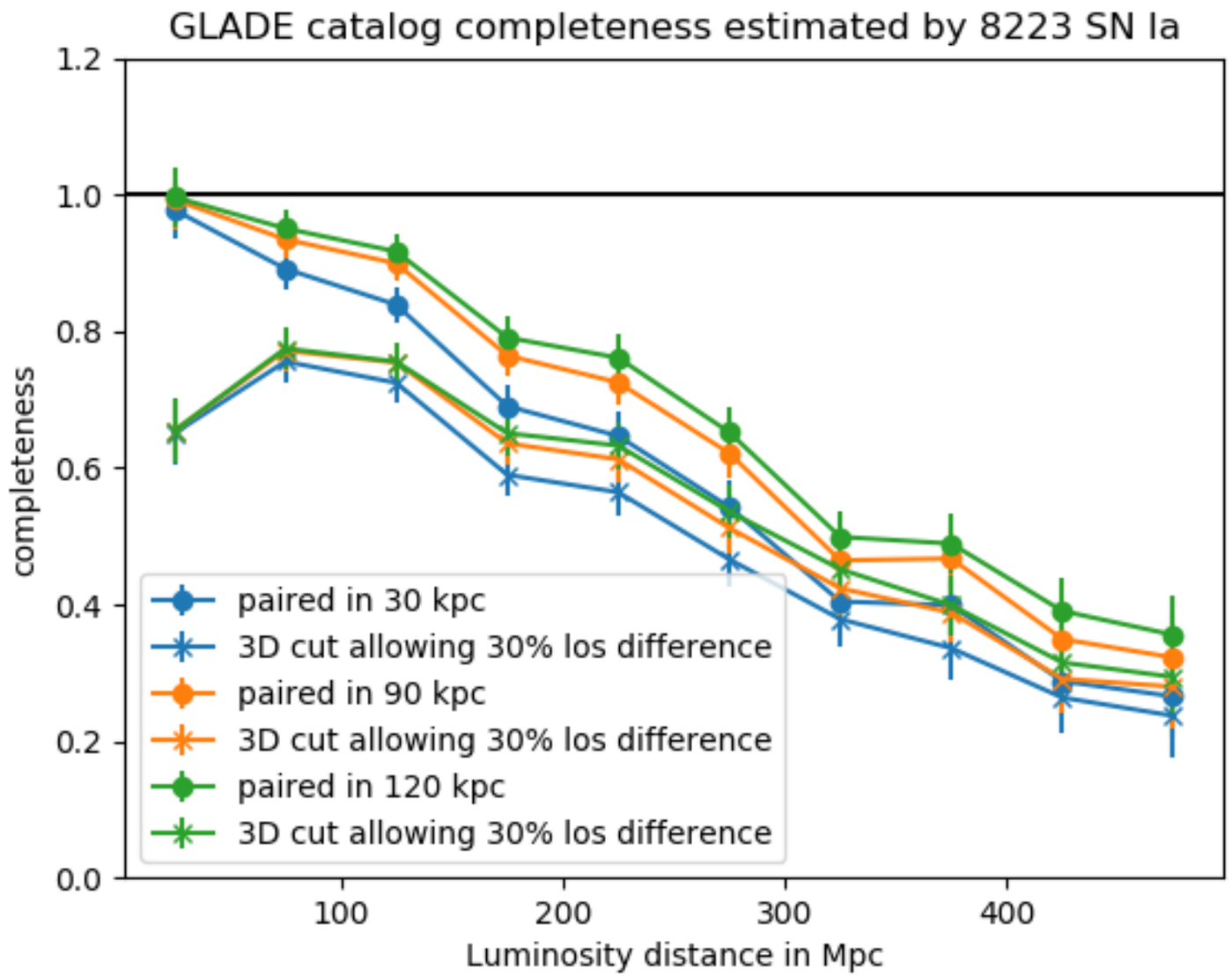
Share information to avoid duplication of observation

J-GEM Ranking on GW170817



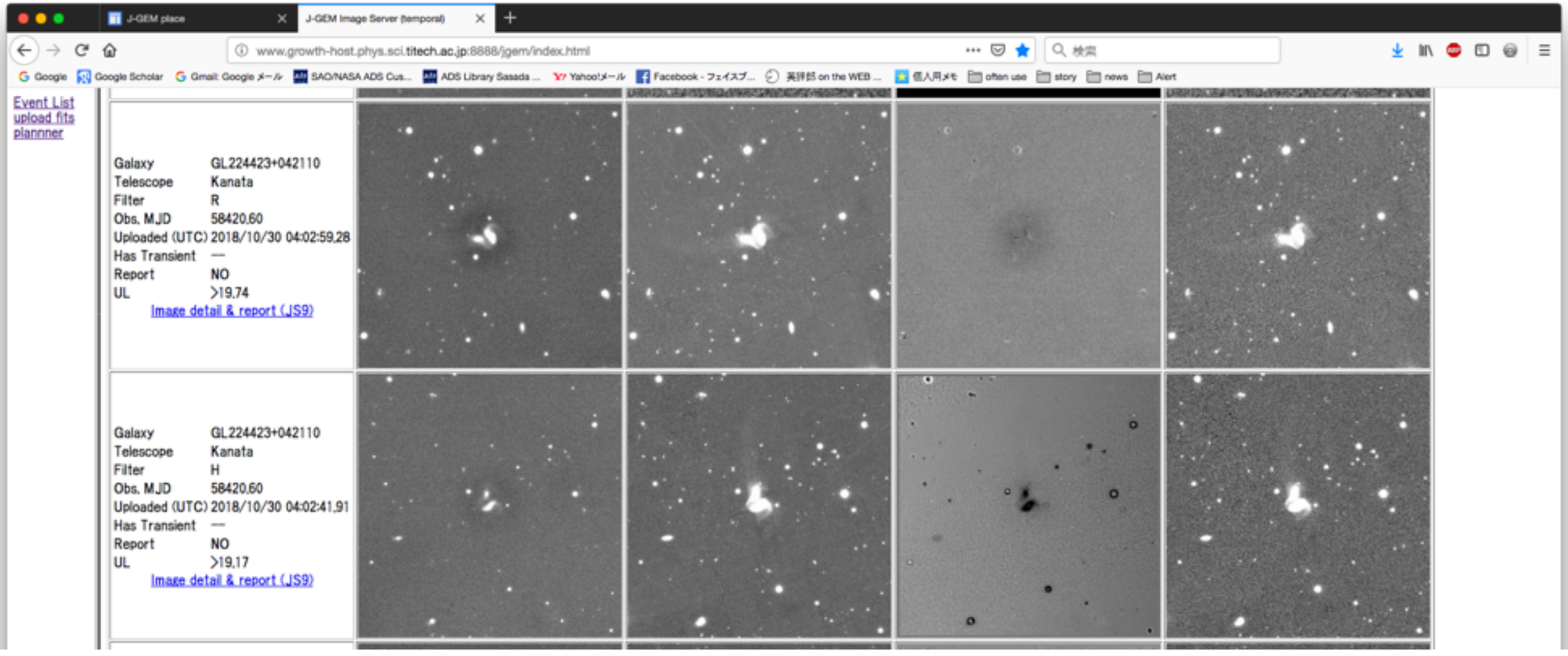
- NGC 4993 got 11-th rank based on GLADE galaxies with 3D probability and B-mag

How complete?



- 8223 SN Ia are used to validate GLADE completeness
- Targeted observation with planner is promising for GW events up to 200Mpc

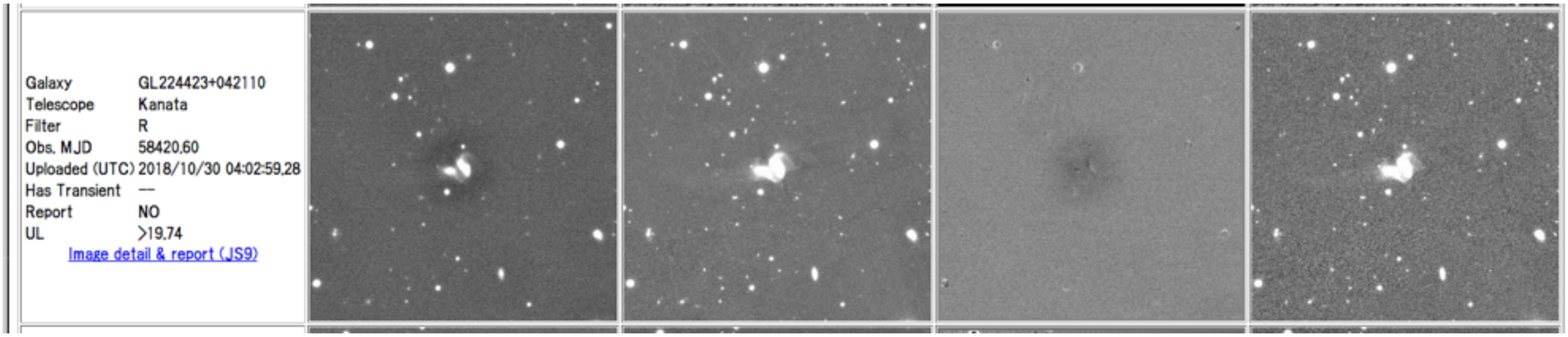
Image Subtraction



Web-base image server system.

Assemble images obtained by each telescope.

Identification



- Reference image obtained by PanSTARRS
- Image subtraction
- Compare between obtained and reference images.

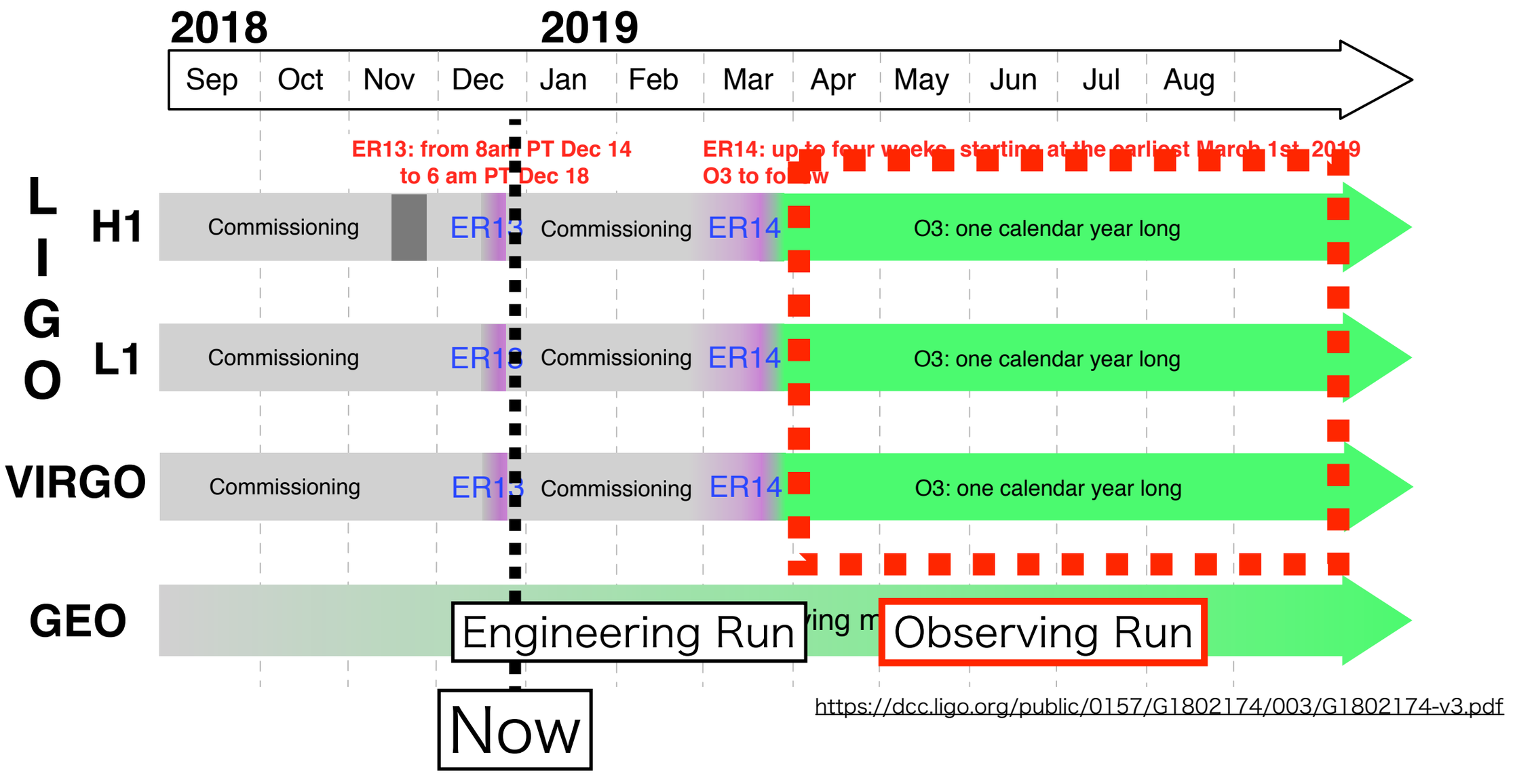
Schedule for O3 Run

LIGO-VIRGO Joint Run Planning Committee

LIGO-G1801056

Working schedule for O3

(Public document G1801056-v4, based on G1800889-v7)



https://dcc.ligo.org/public/0157/G1802174/003/G1802174-v3.pdf

We have done two times of test observations for GW alert.

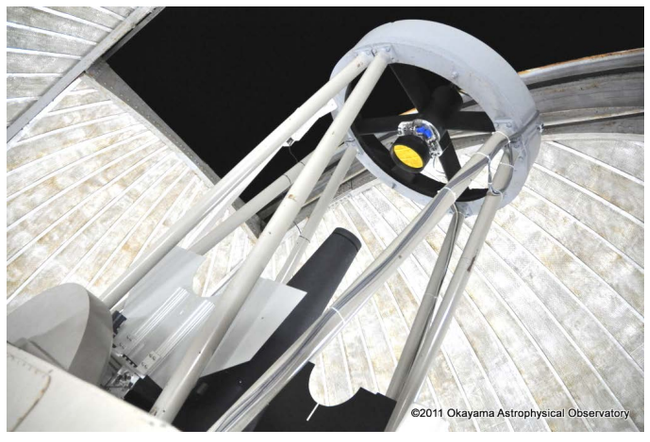
Coordinated Observation for GW Alert

Dummy Alert

Including supernova as transient

J-GEM
Web System
playground

・Organize obs info and transient info



・Observe
・Send obtained images

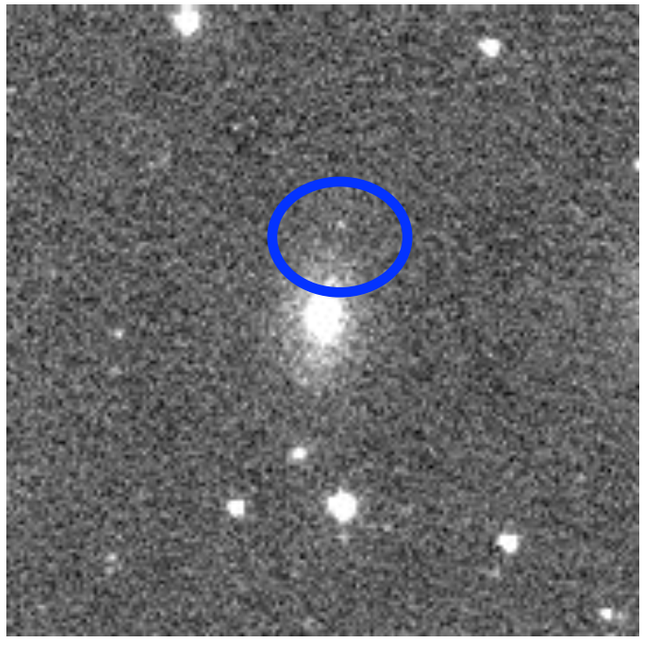
Image
Server

・Assemble images
・Find transient by eye

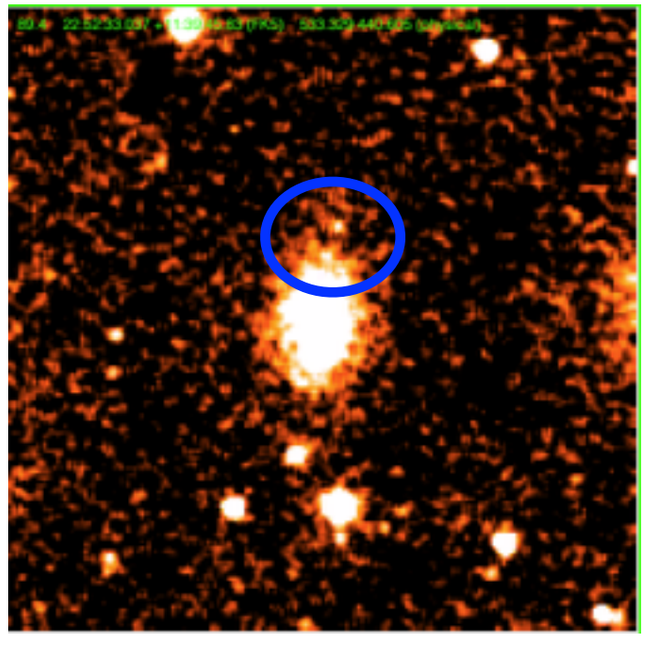
Lesson from Coordinated Observation

Observed 45/137 galaxies using four telescopes in one night.

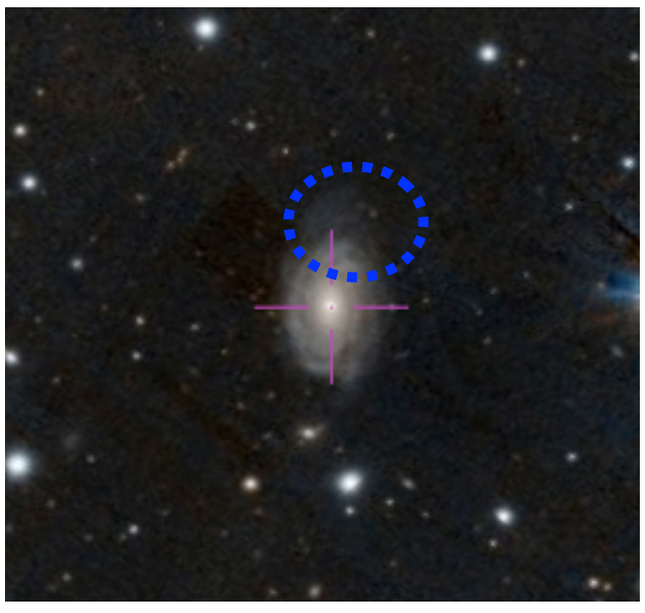
Obtained Image



Smoothing Image



Reference Image



BUT, we passed over the new transient at that time.

Modify the observation scheme and image subtraction system.

Engineering Run (ER13)

- LIGO/Virgo team expects rates of GW events:
  - Binary neutron stars ; 1/month to 1/year
  - Binary black holes ; few/week to few/month
  - Neutron-star black-hole binaries ; uncertain

- Engineering Run (ER13) was conducted at the last week (from 12/15 to 12/18).

There was no alert of GW event during ER13.

Summary

- Construct observational systems both for normal and wide-field FoV telescopes to observe an optical counterpart of GW source.
- Made web-base systems:
  1. Share a probability field of GW event and observational information.
  2. Assemble observed images and subtract from reference to identify the transient.
- Did coordinated test observations with dummy alert of GW event.
- There is no public alert during ER13.

Thank you for your attention