

J-GEM collaboration: an optical-infrared follow-up observation network

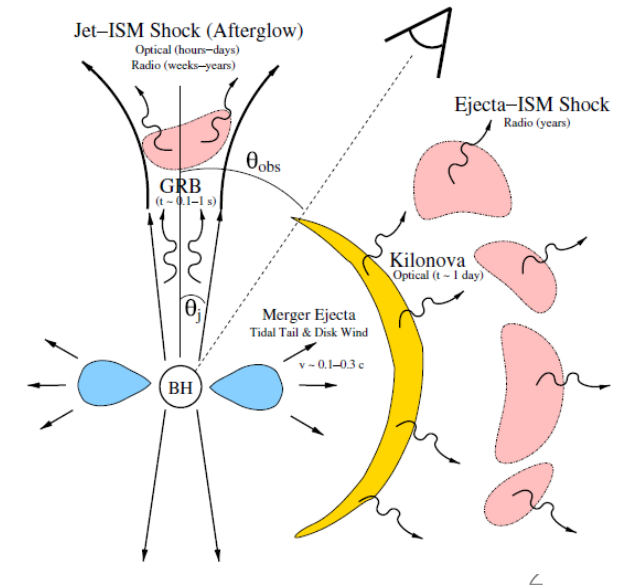
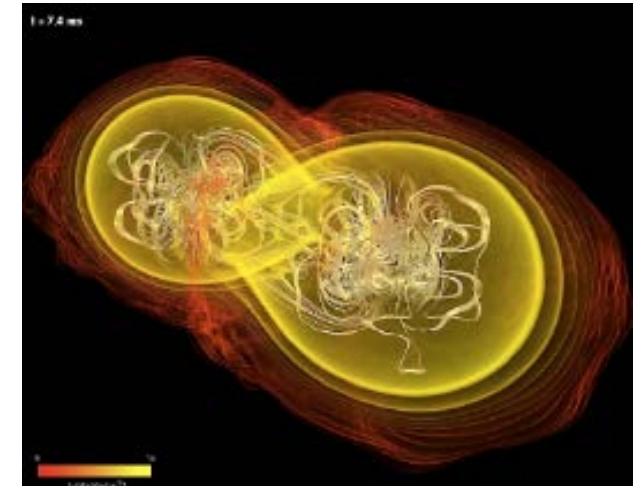
Michitoshi Yoshida

Subaru Telescope, National Astronomical Observatory of Japan

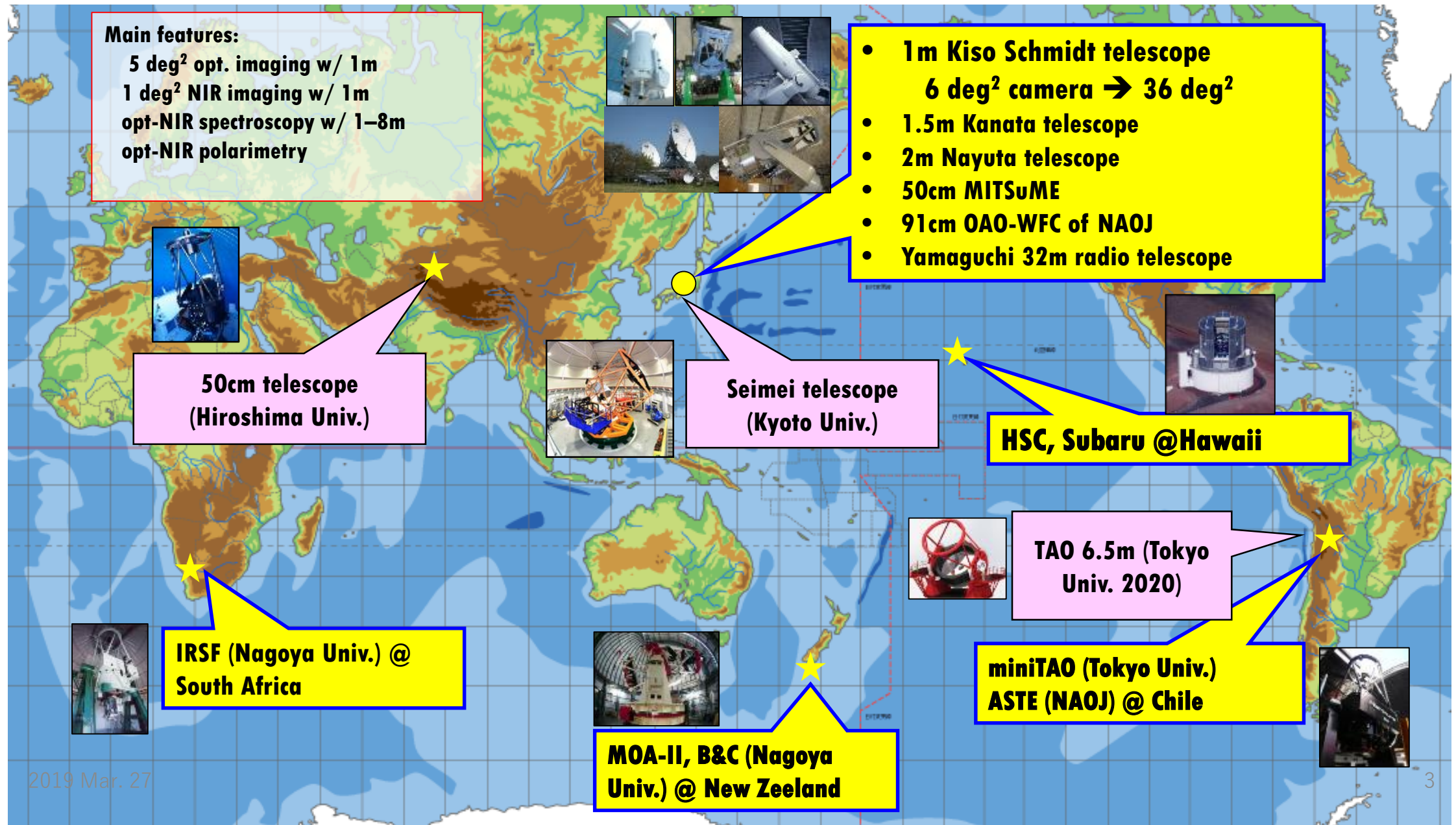
Importance of EM follow-up of GW events

EM identification may provide

- Where it comes from,
 - Accurate localization
 - Accurate distance
 - Their environments (where it is in a galaxy, which type of galaxy, metallicity, density, etc.)
- Information of the accompanying physics and progenitors
 - Equation of state of neutron star
 - Physics of explosion associated with GW
 - r-process nucleosynthesis



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



Purpose of J-GEM

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

Requirements

- **Wide field survey capability (> 10 sq. degrees)**
- **Low latency for identification of optical counterparts for GW events.**

Approach

- **Coordination of many Japanese telescopes.**
- **Cooperation with world-wide telescope networks**

J-GEM Observation for GW170817

- J-GEM succeeded to observe the EM counterpart of GW170817 by using IRSF, MOA-II, B&C and Subaru/HSC. (Utsumi+ 2017, Tanaka+ 2017, Tominaga+ 2018)

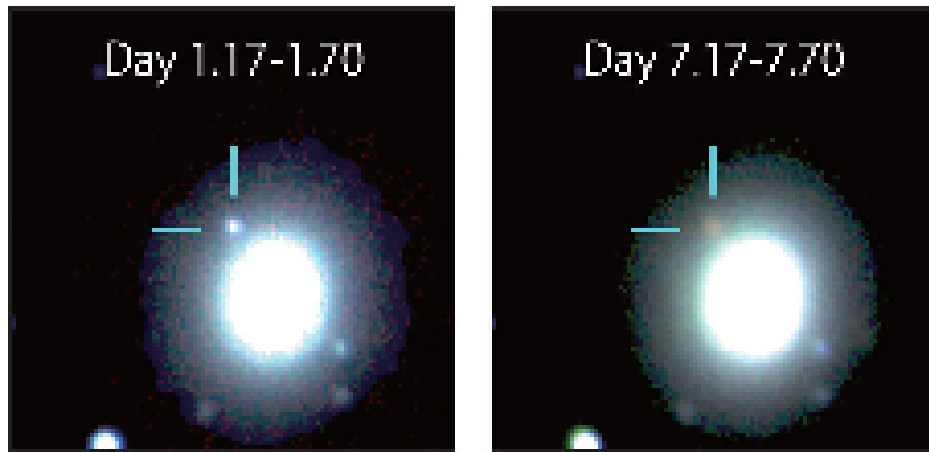
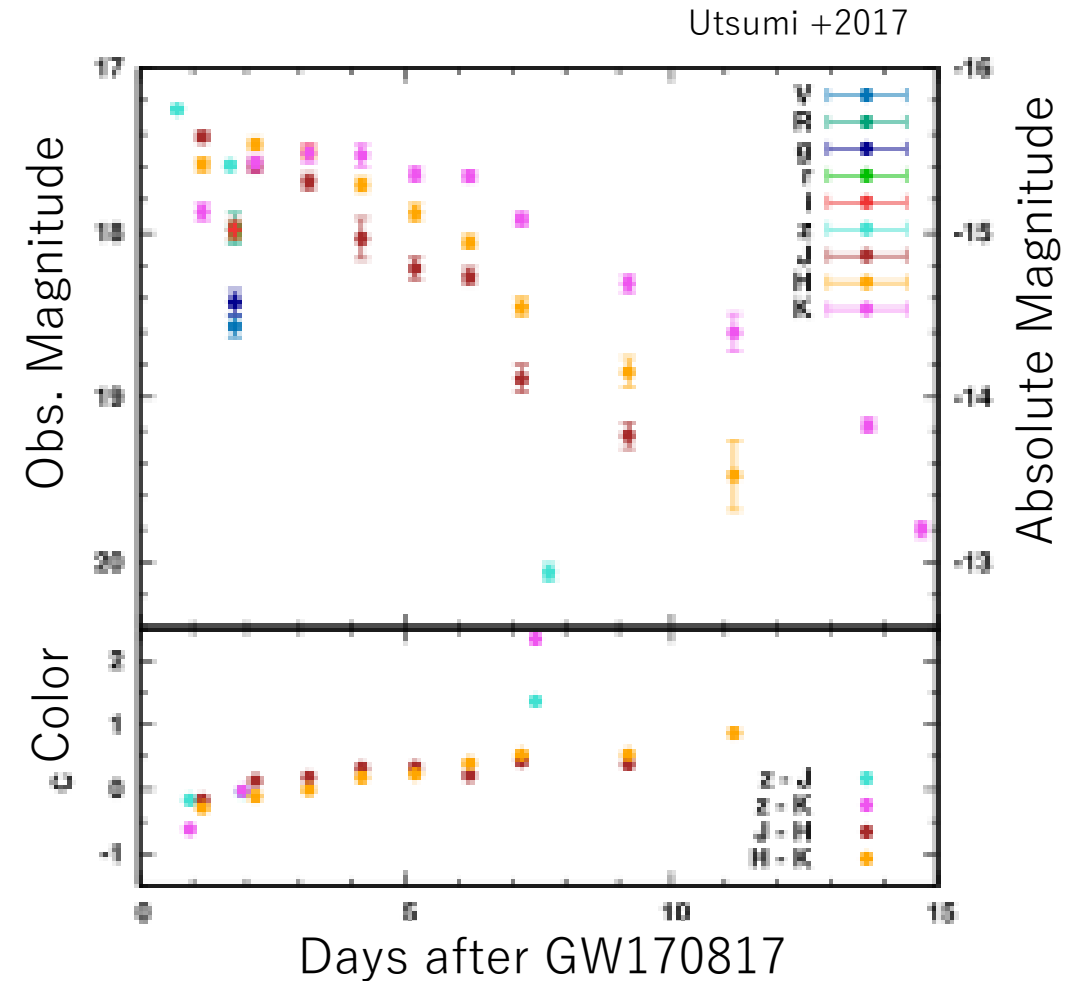
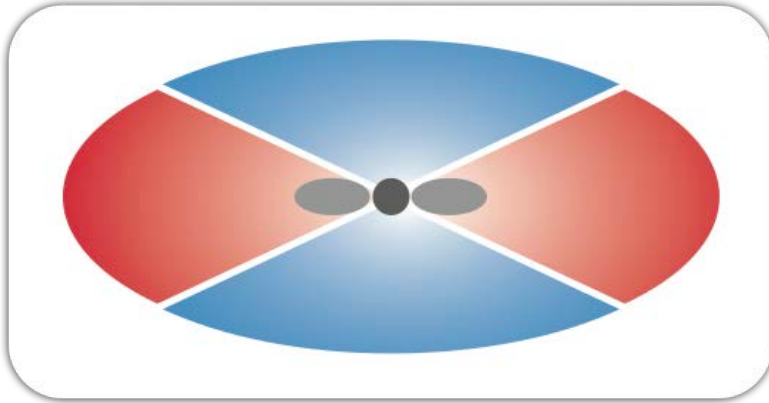


Image obtained by IRSF & Subaru/HSC



Implication from EM Observation

Two component model



Blue kilonova

$$M \sim 0.02 M_{\text{sun}}$$

$$v \sim 0.25c$$

(Tanaka+ 2018)

**Too fast as
post-merger ejecta**

Red kilonova

$$M \sim 0.03 M_{\text{sun}}$$

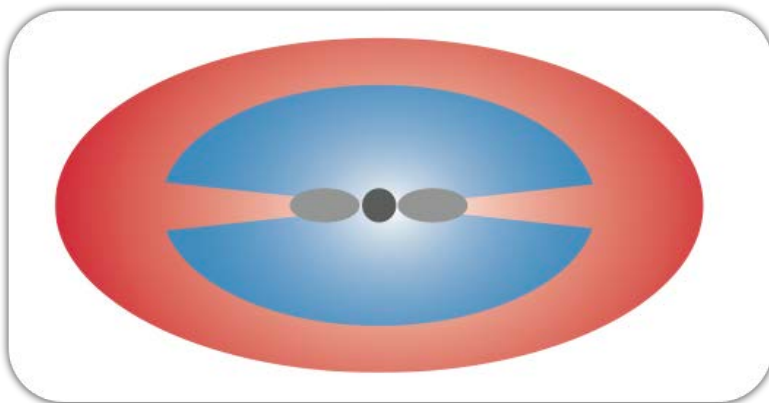
$$v \sim 0.1 c$$

**Too massive as
dynamical ejecta**



Realistic configuration (numerical relativity)

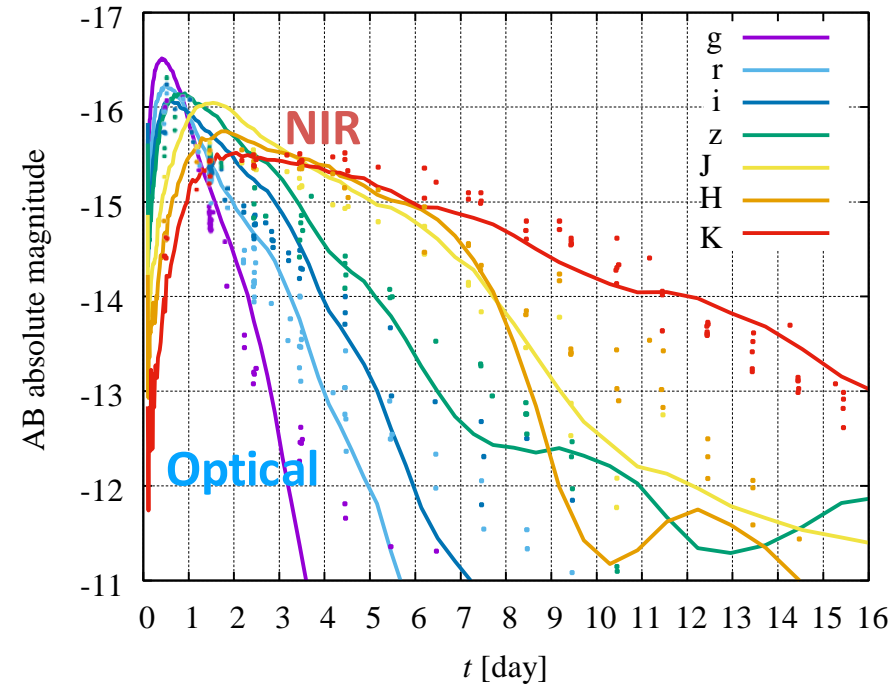
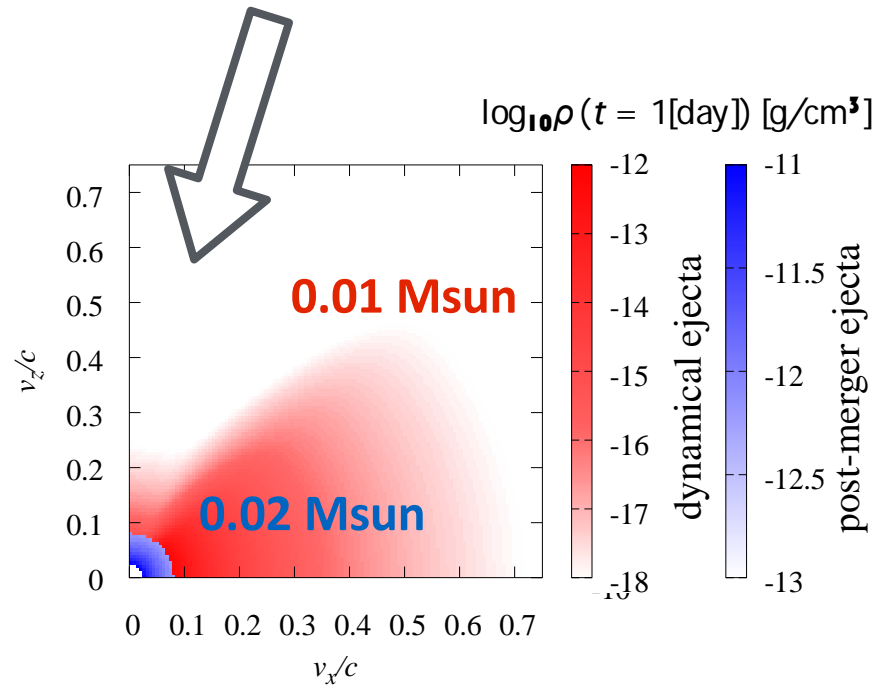
(Kawaguchi+ 2018)



**Post-merger ejecta
Inside of dynamical ejecta**

Multi-dimensional modeling w/ both dynamical and post-merger ejecta

Kawaguchi, Shibata, Tanaka 2018

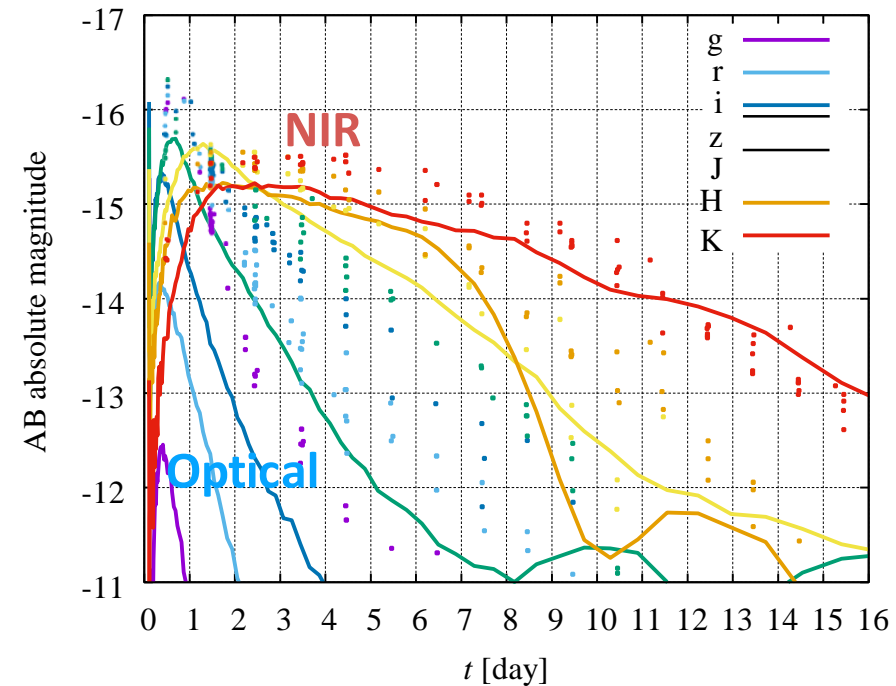
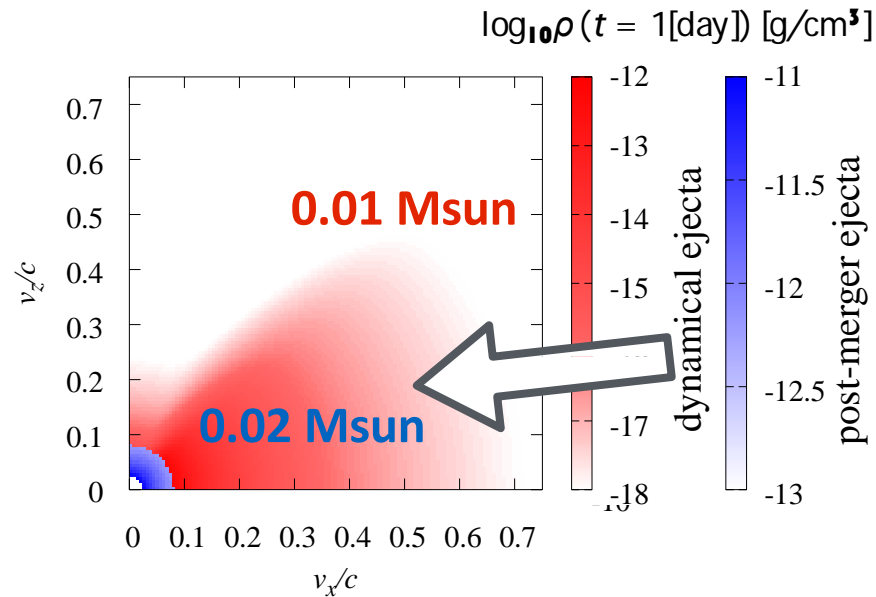


High velocity thin dynamical ejecta (red colored)

Large mass post merger ejecta (blue colored)

Multi-dimensional modeling w/ both dynamical and post-merger ejecta

Kawaguchi, Shibata, Tanaka 2018



Viewed from equator

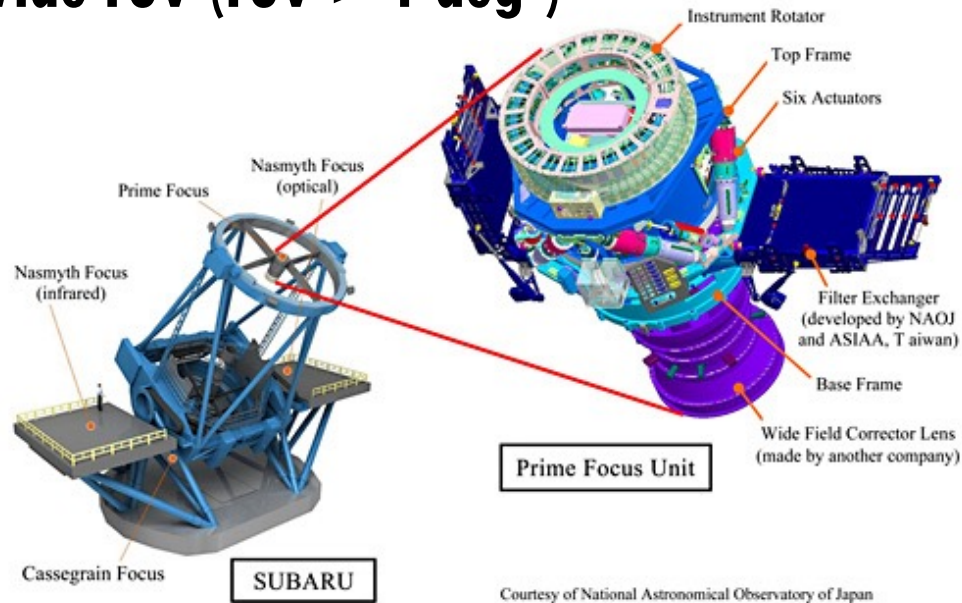
=> Blue component is significantly suppressed

(r band: ~2 mag. fainter than the pole-on case)

J-GEM Observation Strategy

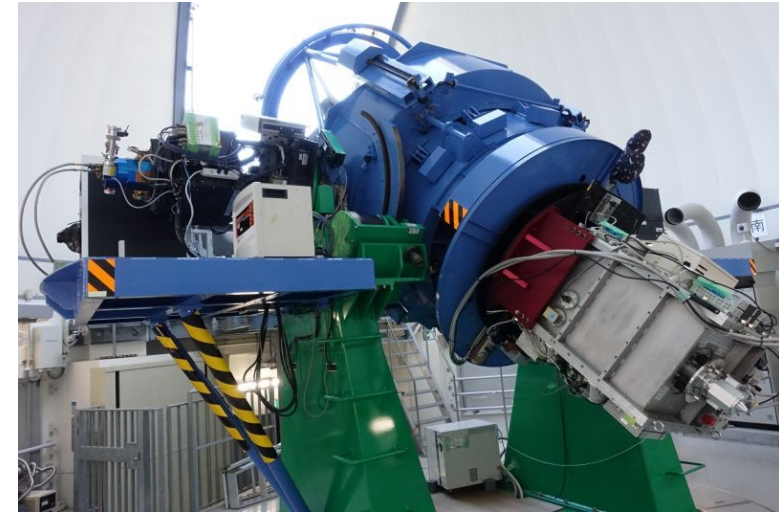
Two types of telescopes

Wide FoV ($\text{FoV} > 1 \text{ deg}^2$)



- **Subaru**
- **Kiso Schmidt**
- **MOA-II**

Narrow FoV ($\text{FoV} < 1 \text{ deg}^2$)

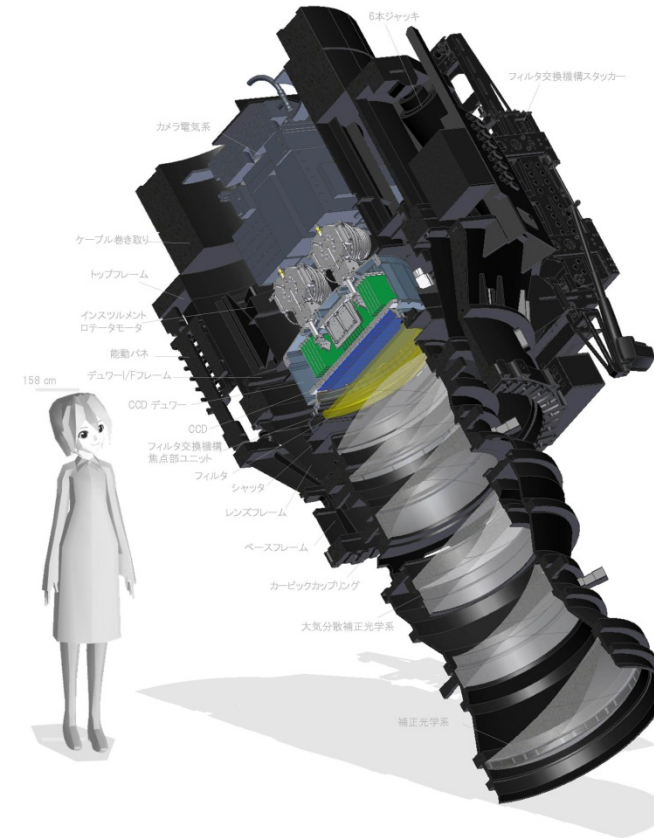
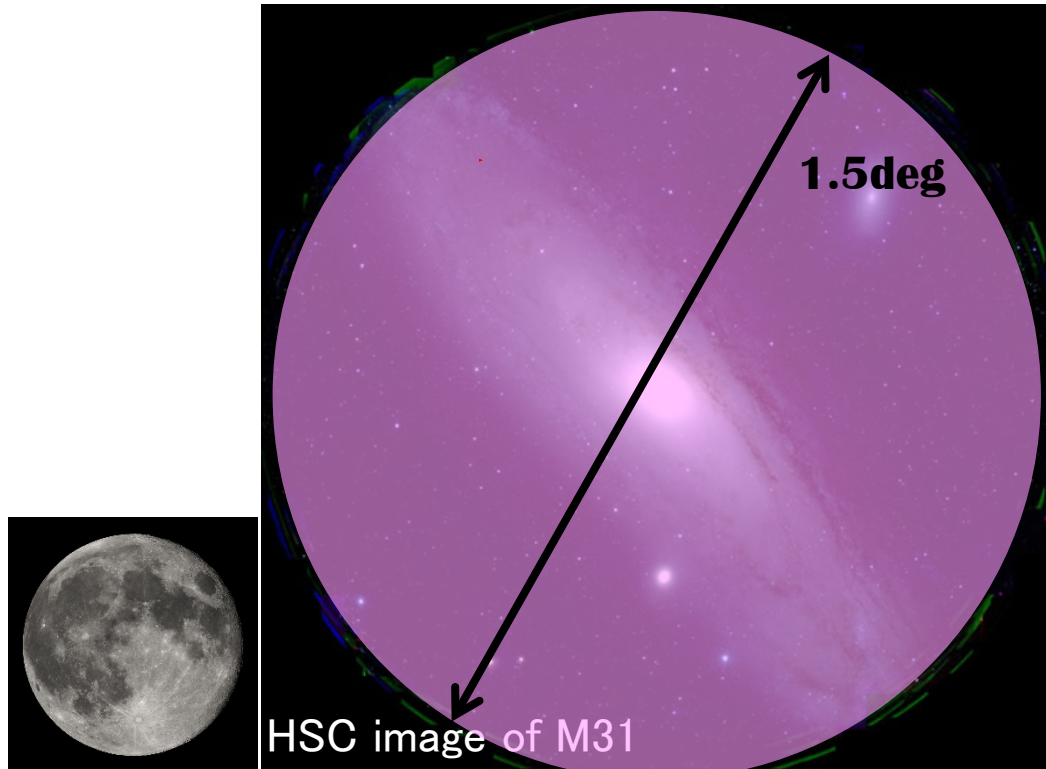


- | | | |
|-----------------|----------------------|------------------|
| • Kanata | • OA0 WFC | • B&C |
| • IRSF | • MITSuME | • SaCRA |
| • Nayuta | Akeno/Okayama | |

- **Coordination of wide-field survey and targeted observations**

Subaru/Hyper Suprime-Cam

- $\sim 60\text{deg}^2$, 2 colors (i,z) / 0.5 night (**i<24.5, z<23.8 for 60s exp**)
- Available around new moon
- 4.5 ToO nights in S19A semester

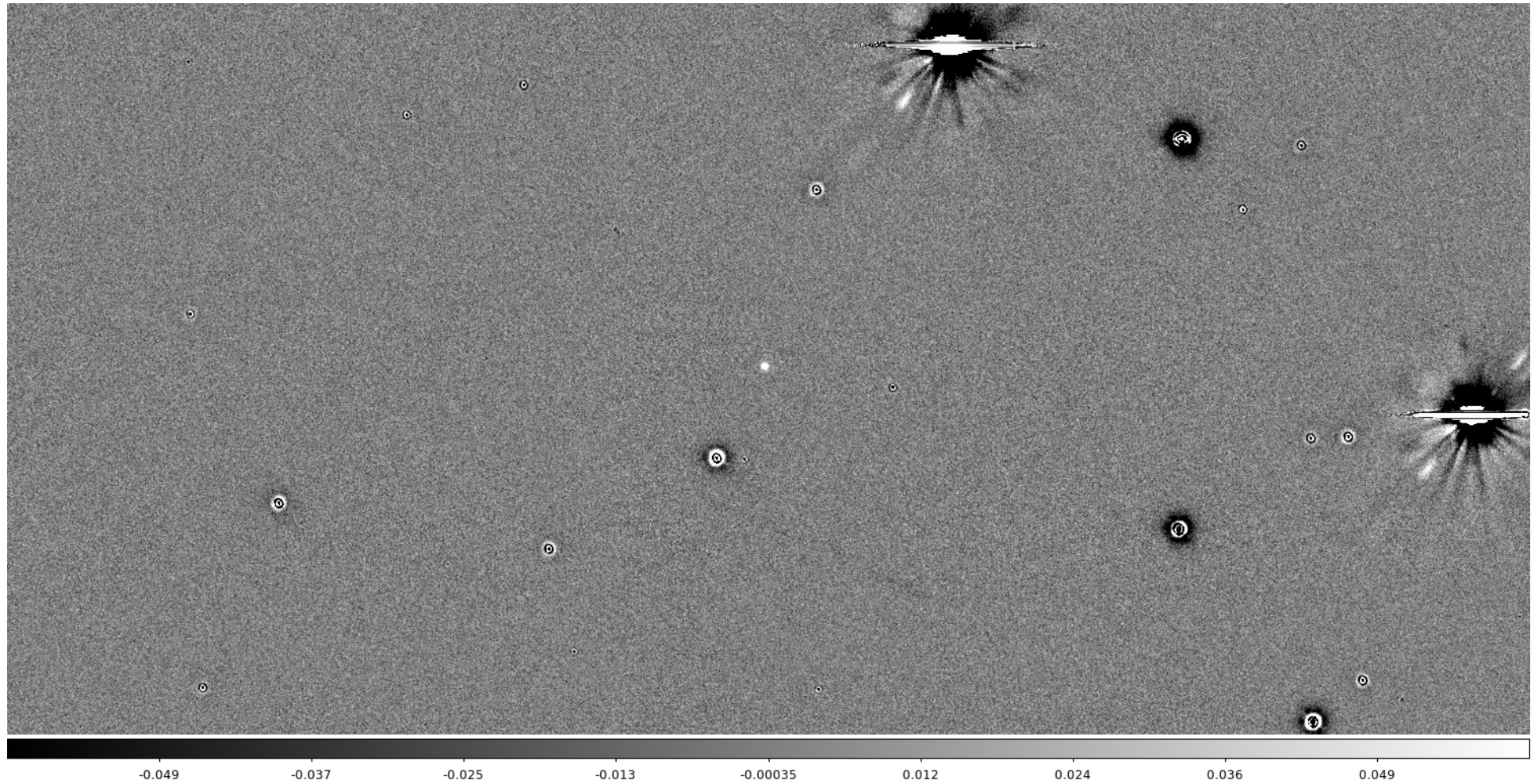


Flowchart of HSC follow-up for GW

- 1. Receive a GW alert**
- 2. Prepare Subaru operation file from LVC 3D skymap**
- 3. Trigger observations (i- and z-bands)**
- 4. Transfer data from Summit to Hilo/IPMU/Konan (1750 cores in total)**
- 5. Analyze the data**
 - 1. Image subtraction with PS1/HSC reference images**
 - 2. Source detection**
 - 3. Remove fake sources with machine learning technique (CNN)**
 - 4. Sources detected at the same position in at least two frames will be candidates**
- 6. Make candidate lists & cutout images**
- 7. Visual check**

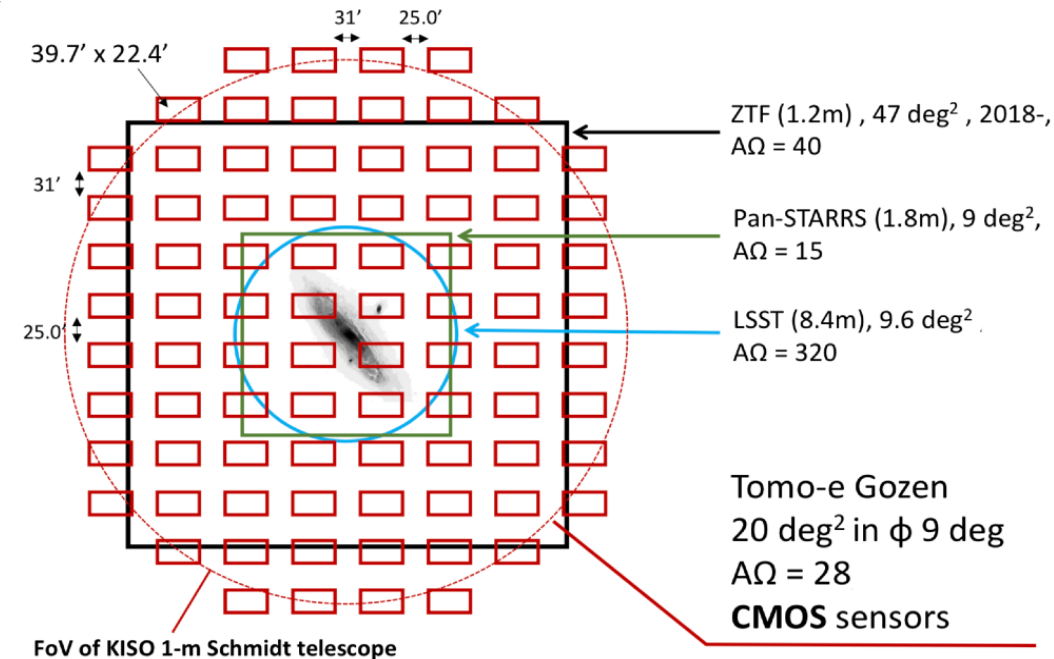
~1 - 2 days

Demonstration of Image subtraction



Tomo-e Gozen

- A wide field CMOS camera on the 1m Kiso Schmidt telescope (Sako et al. 2018, SPIE)
 - 20 deg² FoV distributed over $\Phi 9$ deg area.
 - Max. frame rate: 2Hz
 - ~ 21 mag for 15 min exposure
- Automatically surveys GW error regions triggered by VOEvent alerts
 - Monitoring by human is currently required for security reasons
- Image subtractions with PS1, or between Tomo-e Gozen images, in the automated pipeline
 - use machine learning (CNN, currently under training) to remove fake sources

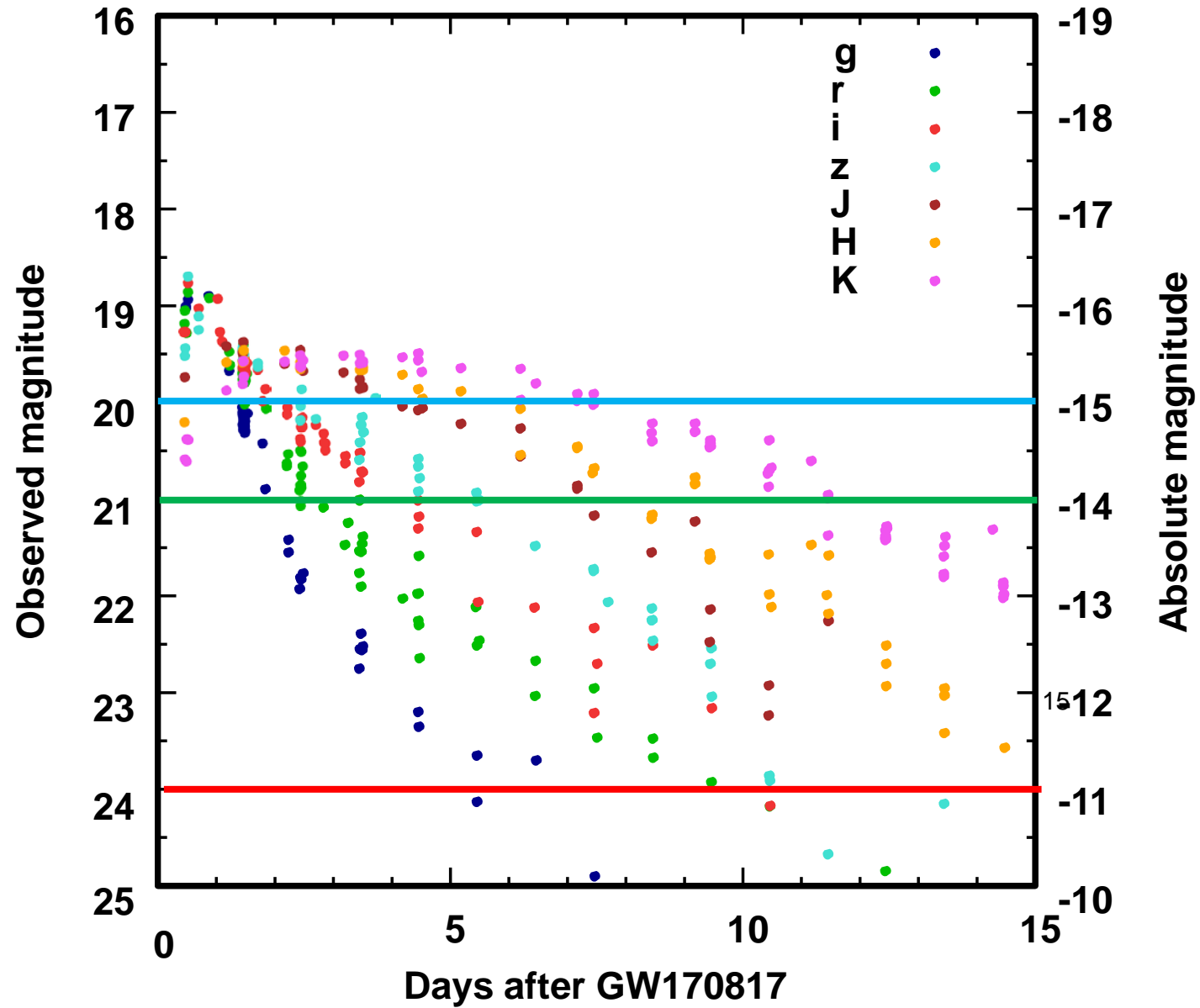


GW170817 @ 100 Mpc

MOA-II 5min ----

Tomo-e 15min --

HSC 1min ----

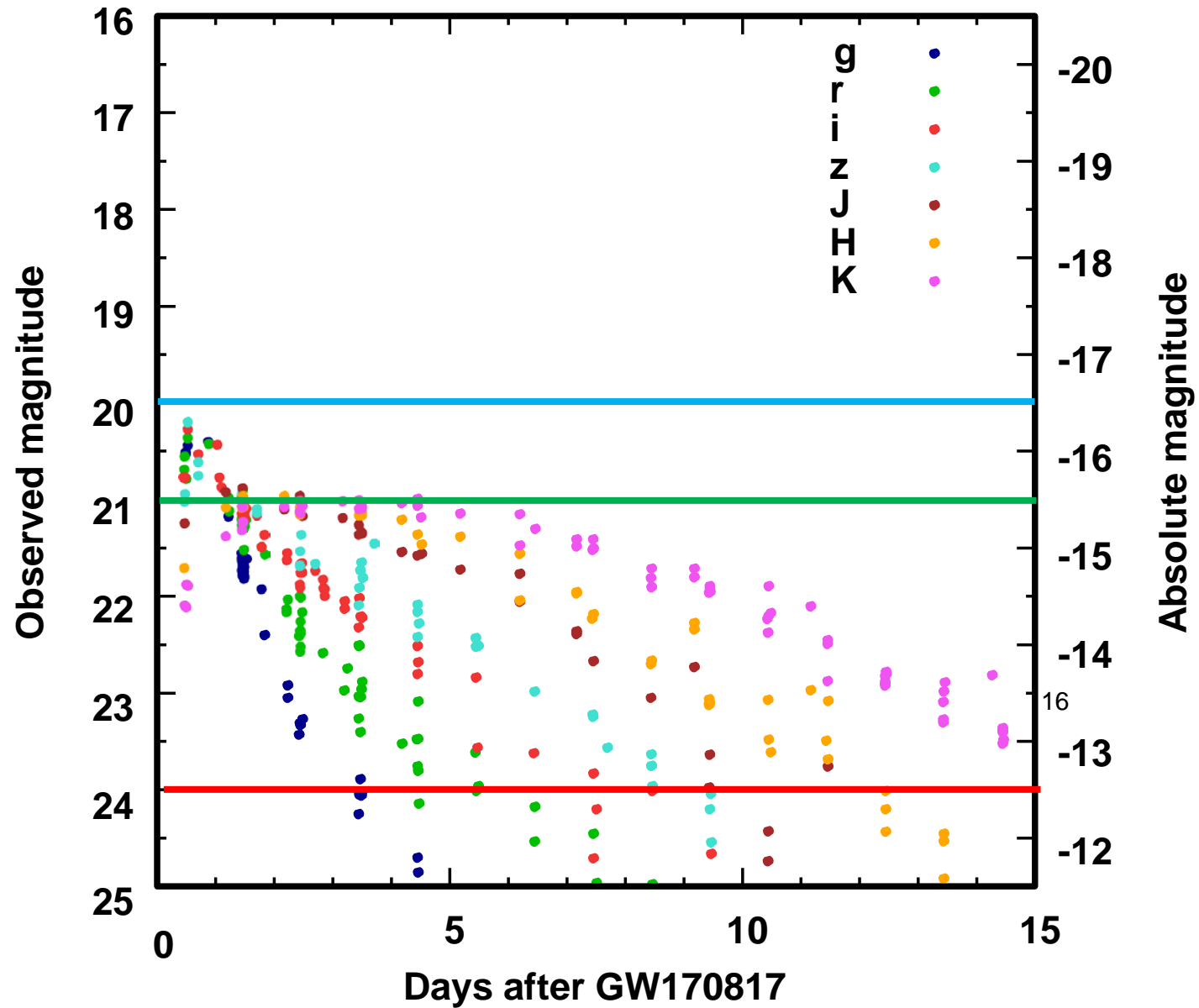


GW170817 @ 200 Mpc

MOA-II 5min ----

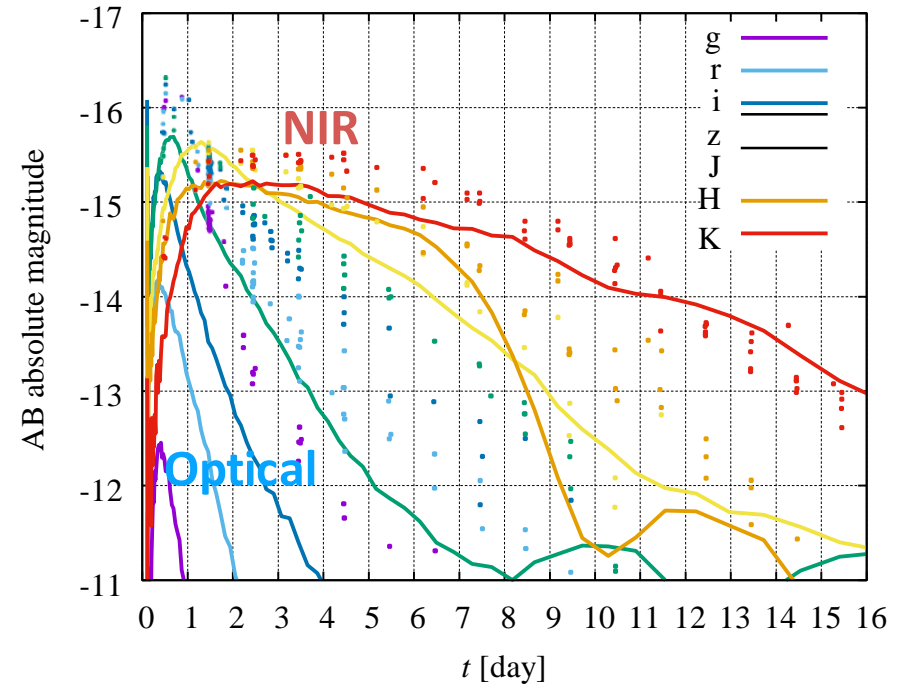
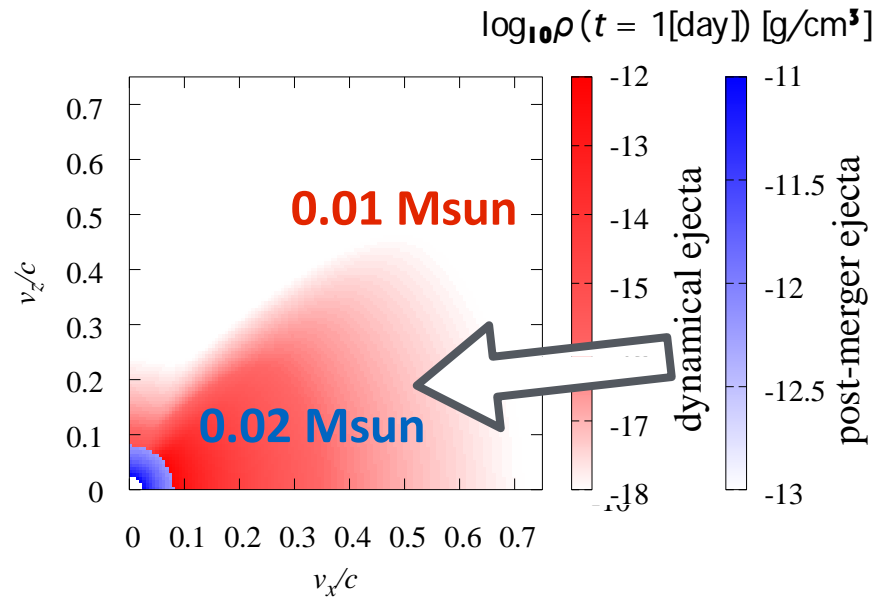
Tomo-e 15min --

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Multi-dimensional modeling w/ both dynamical and post-merger ejecta

Kawaguchi, Shibata, Tanaka 2018



Viewed from equator

**=> Blue component is significantly suppressed
(r band: ~ 2 mag. fainter than the pole-on case)**

Orchestrating narrow FoV telescopes

Planner -- targeted strategy

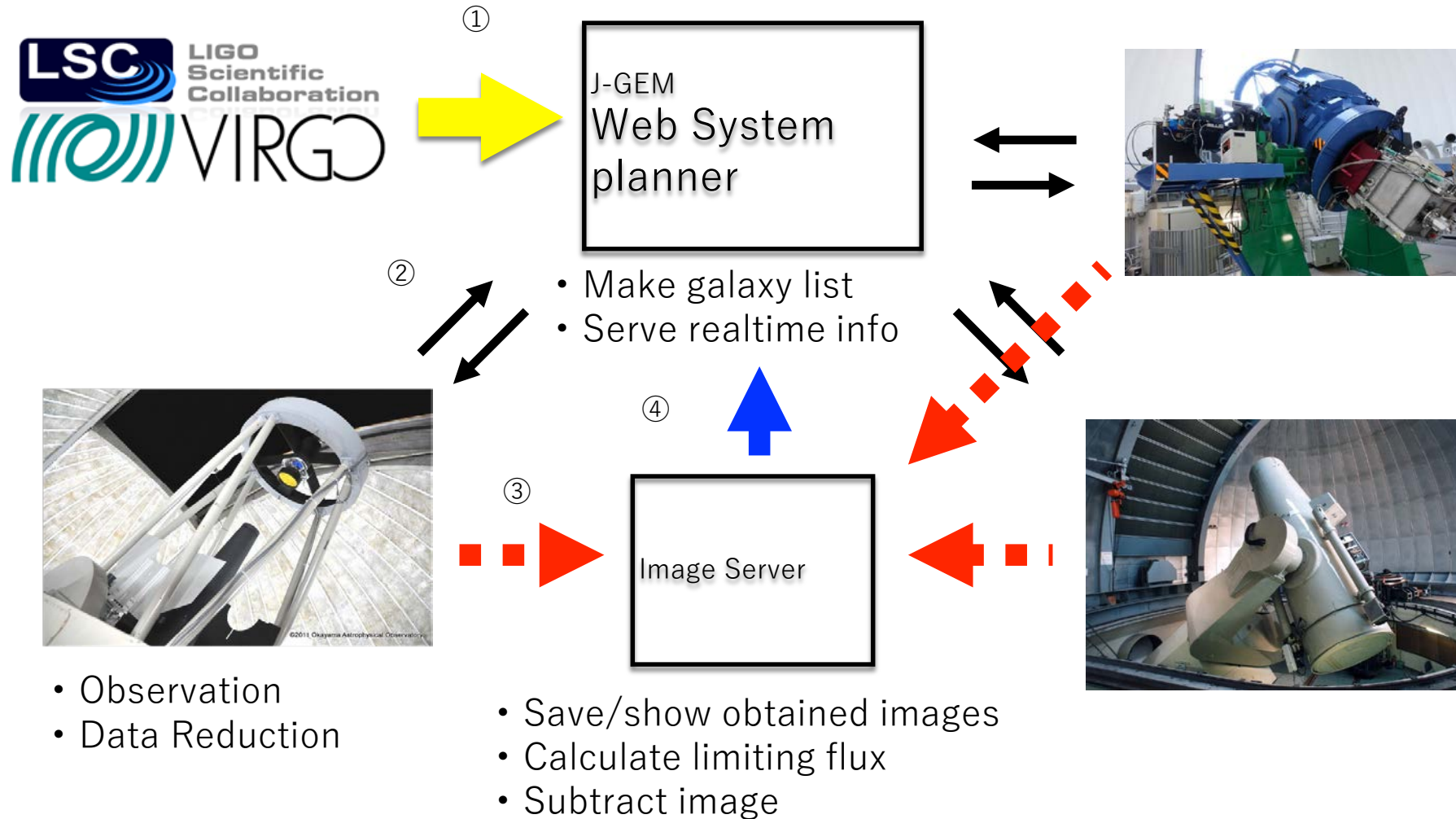
- Rank GLADE galaxies based on their 3D positions with a GW Probability map
- Distribute through a web server
- Each observatory will go unobserved galaxies exclusively

galid	eventid	prob	inserted	ra	dec	dist	OptExpected	NirExpected	state	obsids	updated	filter and depth (5 σ AB)	hastransient
GL003913+005151	U190130	0.19659	2019-01-30 00:06:02.230008	9.8058	0.8641	67.651	21.7	19.2	Curated	OAOWFC,Kanata- HONIR,Kanata	2019-01-30 11:50:48.393434	V=999.00,H=999.00,J=999.00	
GL003935+005135	U190130	0.14387	2019-01-30 00:06:02.230008	9.8951	0.8598	69.5739	21.7	19.2	Curated	Kanata- HONIR,Kanata,OAOWFC	2019-01-30 11:51:16.262694	V=999.00,J=999.00	YES
			2019-01-30								2019-01-30		

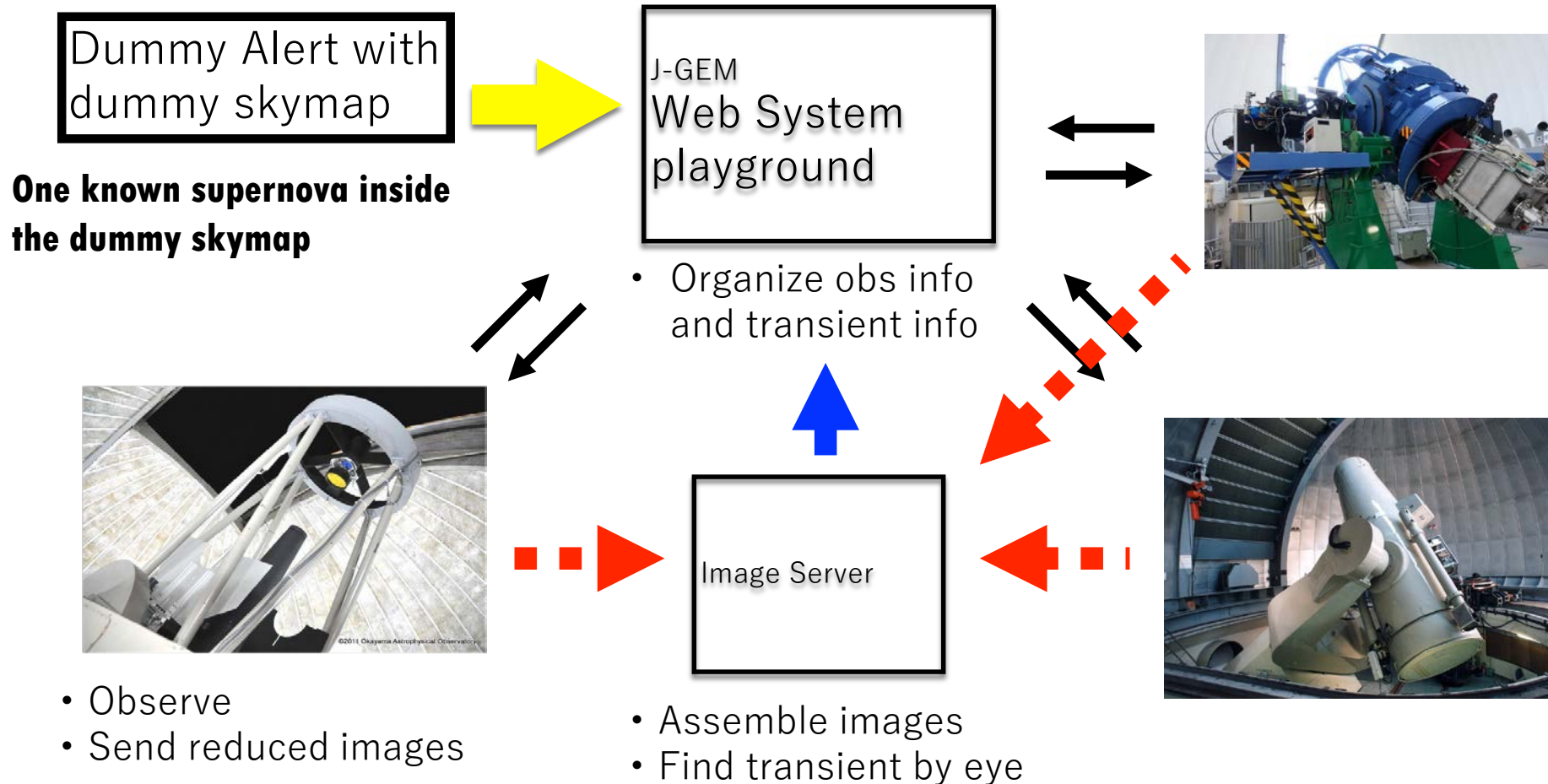
Image Server

- Images the instrumental signature removed will be gathered on a web site
- Quantifies image quality, judges if there is a transient on a diff image...
- Shifters will vet the result
- Communicate thorough E-mail / Zoom / mattermost (slack alternative)

Scheme of coordination of narrow FoV telescopes for GW follow-up



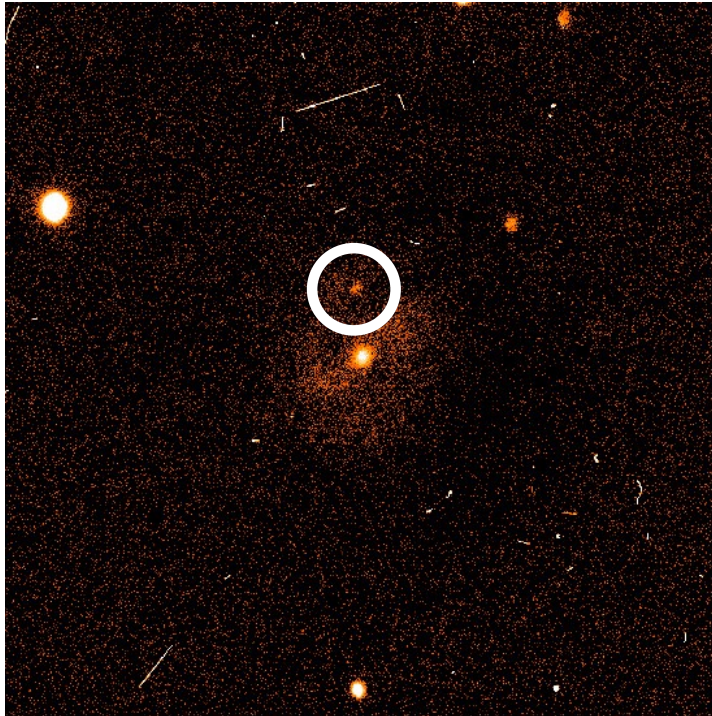
Test observations using dummy alert



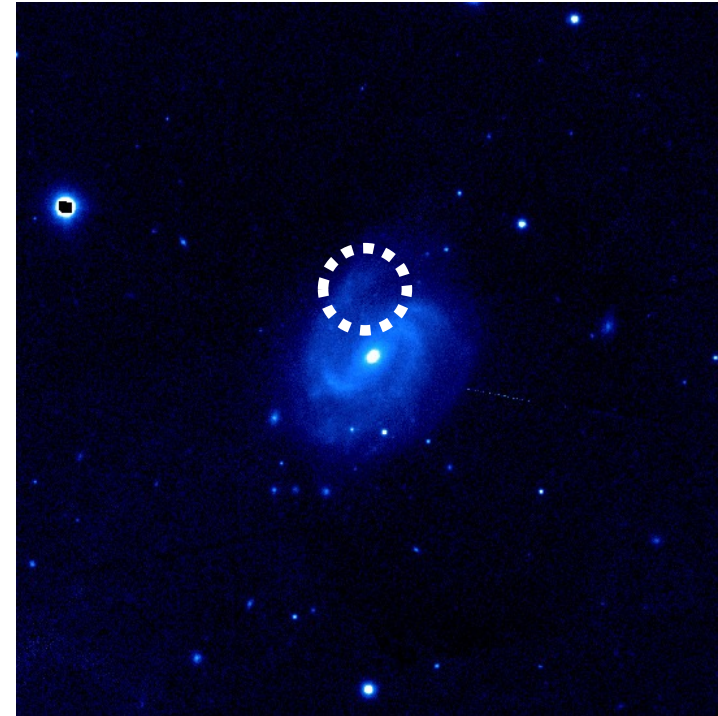
Results of the test observations

Observed 10/33 galaxies using two telescopes in three hours.

Obtained Image



Reference Image

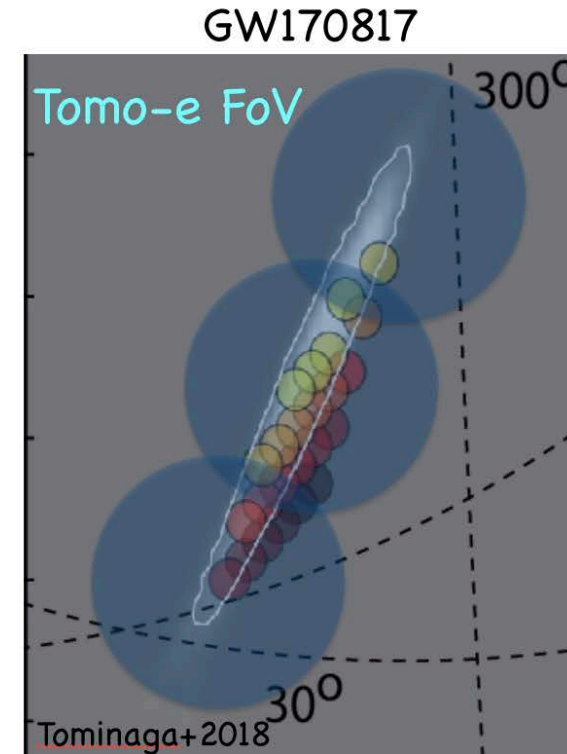
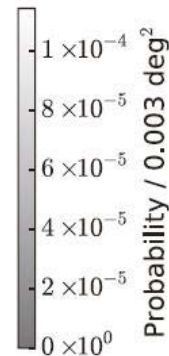
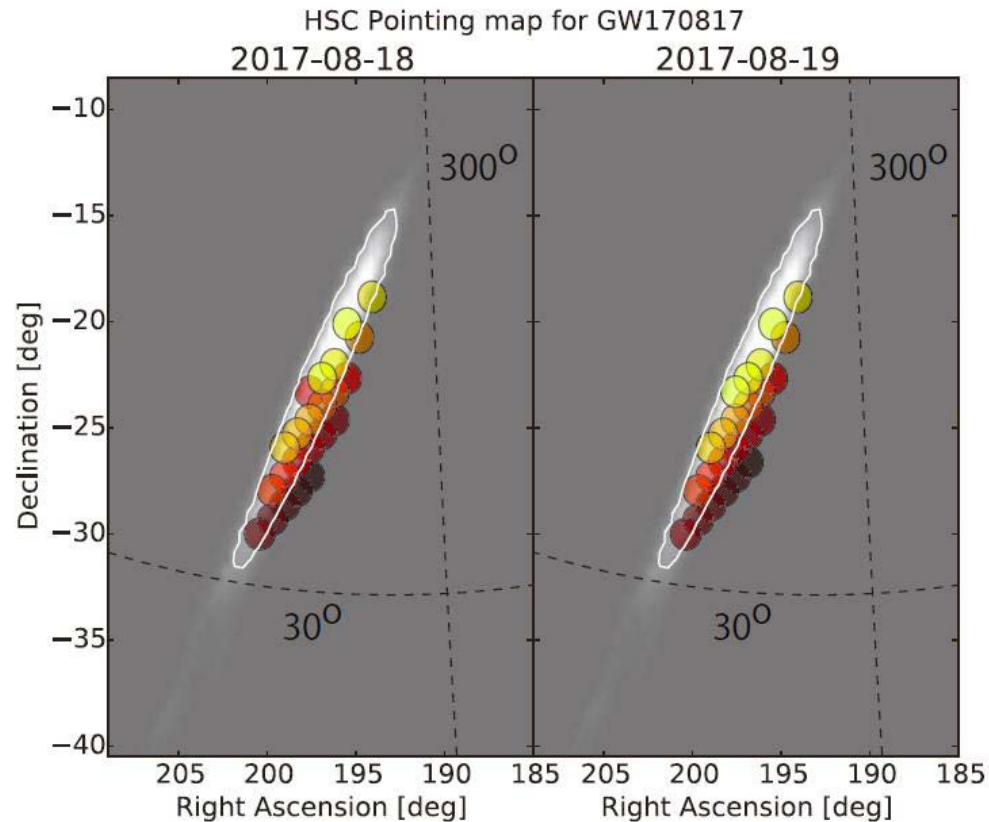


We have identified the transient (supernova, ~ 18.8 mag) 1.5 hours after starting observations.

Summary

- **J-GEM is a collaboration of Japanese telescopes to perform follow-up observations for GW sources.**
- **J-GEM consists of wide- and narrow-field FoV telescopes distributed wide longitude range.**
- **Wide-field survey capability of Subaru/HSC (24 mag. across a FOV of 60 deg² in a half night) is very powerful.**
- **Web-base systems for the coordination of the narrow FoV telescopes are developed:**
 1. **Planner:** Sharing a list of candidate galaxies in a probability area of GW event and observational information.
 2. **Imager Server:** Collect observed images and perform automatic image subtraction to identify transients.
- **Coordinated test observations with dummy alert were done.**

Wide-field survey using large FoV telescopes



Subaru HSC :
~50 deg² in 90 min.
Limit mag. ~24 mag.

Kiso Tomo-e :
~200 deg² in 120 min.
Limit mag. ~21 mag.