J-GEM Optical and NIR Follow-Up in Gravitational-Wave Third Observing Run

Mahito Sasada (Hiroshima University) on behalf of J-GEM Team
GW170817

- GW170817 was identified as the EM counterpart in the entire wavelength.
  - Detected in all wavelengths
    - Gamma-ray
    - X-ray
    - Optical and NIR
    - Radio
  - No Detection in IceCube neutrino.
Light curves in Optical and NIR

NIR : ~ 10 days

Optical : < 5 days

On 2017 August 17, 12:41:04 GMT, the LIGO (Laser Interferometer Gravitational-Wave Observatory) and the Virgo observatory (LHO) identified a GW candidate in an NS (Neutron Star) merger (The LIGO Scientific Collaboration and the Virgo Collaboration). The gravitational wave signal was confirmed by electromagnetic follow-up observations of SSS17a. All magnitudes are given using the method specified in Blanton and Roweis (2001). The size of the image is 56 arcseconds."
Identification of Optical Counterpart

- There are many stars and galaxies within the probable region of GW170817 (28 sq. deg).
- It is not easy to identify an optical transient from the obtained image.
J-GEM (Japanese collaboration for Gravitational-wave Electro-Magnetic follow-up)

Main features:
- 5 deg² opt. imaging w/ 1m
- 1 deg² NIR imaging w/ 1m
- opt-NIR spectroscopy w/ 1–8m
- opt-NIR polarimetry

- 1m Kiso Schmidt telescope
- 5 deg² camera ➔ 20 deg²
- 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

IRSF (Nagoya Univ.) @ South Africa

MOA–II, B&C (Nagoya Univ.) @ New Zealand

TAO 6.5m (Tokyo Univ. 2018)

miniTAO (Tokyo Univ.)
ASTE (NAOJ) @ Chile
Purpose of J-GEM

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

**Requirements**
- Survey huge area (> 10 sq. degrees)
- Identify the optical counterpart as soon as possible to understand an early phase of GW event.

**Approach**
- We do a survey observation for GW possible region by using many Japanese telescopes
Two types of telescope

Normal Telescope (FoV < 1 deg^2)

- Kanata
- OAO WFC
- IRSF
- MITSuME
- Nayuta
- Akeno/Okayama
- Seimei

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

- Subaru
- MOA-II
- Kiso Tomo-e

Galaxy-targeted survey

Wide-field survey
Scheme of Transient Survey

1. **J-GEM Web System planner**
   - Make galaxy list
   - Serve realtime info

2. **Image Server**
   - Save/show obtained images
   - Calculate limiting flux
   - Subtract image

3. Observe
4. Reduce
User interface: planner

For normal operation

- Event list
- Candidates
- Observing Log
- Cross Table
- GCN template
- All Observing Log
- Groups
- Depths
- Transients
- Admin

Need machine readable format like JSON output? Just replace "main.html" with "processor.py" or click here.

[candidate : S190426c]

- List candidate galaxies from GLADE catalog.
- Share information to avoid a duplication of observations
User interface: Image Server

- Show an observing and reference image (PanSTARRS and 2MASS).
- Image subtraction
- Compare between obtained and reference images using subtracted image and blinking gif image.
Third Observing Run (O3)
### Schedule of O3

**Commissioning O3**: one calendar year long

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Detector Operational Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>Sep</td>
<td>Commissioning</td>
</tr>
<tr>
<td></td>
<td>Oct</td>
<td>ER13</td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>Commissioning</td>
</tr>
<tr>
<td></td>
<td>Dec</td>
<td>ER14</td>
</tr>
<tr>
<td>2019</td>
<td>Jan</td>
<td>Commissioning</td>
</tr>
<tr>
<td></td>
<td>Feb</td>
<td>O3: one calendar year long</td>
</tr>
<tr>
<td></td>
<td>Mar</td>
<td>O3: one calendar year long</td>
</tr>
<tr>
<td></td>
<td>Apr</td>
<td>O3: one calendar year long</td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>O3: one calendar year long</td>
</tr>
<tr>
<td></td>
<td>Jun</td>
<td>O3: one calendar year long</td>
</tr>
<tr>
<td></td>
<td>Jul</td>
<td>O3: one calendar year long</td>
</tr>
<tr>
<td></td>
<td>Aug</td>
<td>O3: one calendar year long</td>
</tr>
</tbody>
</table>

- **ER13**: from 8am PT Dec 14 to 6 am PT Dec 18
- **ER14**: up to four weeks, starting at the earliest March 1st, 2019
- **O3 to follow**

**Detector Operational Modes**

- **24/7 observing mode** (Observing Run, Open Public Alerts in low-latency)
- **Detector not producing data** (downtime)
- **Detector in observing mode for a fraction of the time during Engineering Runs (ERs), possible GW alerts with human vetting**
- **~70% observing mode**

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**O3 has been performed since Apr. 2019. Many GWs have been detected.**
# LIGO/Virgo O3 Public Alerts

Detection candidates: 35

<table>
<thead>
<tr>
<th>Event ID</th>
<th>Possible Source (Probability)</th>
<th>UTC</th>
<th>GCN</th>
<th>Location</th>
<th>FAR</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>S19110af</td>
<td></td>
<td>Nov. 10, 2019 23:06:44 UTC</td>
<td>GCN Circulars</td>
<td>No public skymap image found.</td>
<td>1 per 12.681 years</td>
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<tr>
<td>S191110x</td>
<td>MassGap (&gt;99%)</td>
<td>Nov. 10, 2019 18:08:42 UTC</td>
<td>GCN Circulars</td>
<td></td>
<td>1 per 1081.7 years</td>
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<tr>
<td>S191109d</td>
<td>BBH (&gt;99%)</td>
<td>Nov. 9, 2019 01:07:17 UTC</td>
<td>GCN Circulars</td>
<td></td>
<td>1 per 2.062e+05 years</td>
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<td>S191105e</td>
<td>BBH (95%), Terrestrial (5%)</td>
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<td>GCN Circulars</td>
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<td>1 per 1.3881 years</td>
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<tr>
<td>S190930t</td>
<td>NSBH (74%), Terrestrial (26%)</td>
<td>Sept. 30, 2019 14:34:07 UTC</td>
<td>GCN Circulars</td>
<td></td>
<td>1 per 2.0536 years</td>
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Localization of GW170817

- Localization: **28 sq. deg**
- Distance: **40 Mpc**
- Brightest Magnitude: **17~18 mag**
BNS Event: S190425z

- First BNS event
- Distance: 155±45 Mpc
- 90% area: 7461 sq. deg
- Observe 23 galaxies listed in GLADE catalog
- Percentage of coverage: 1.1%
- The ToO observations were performed by Subaru/FOCAS.
- GCN circular; #24192, 24230, 24328
154 galaxies obtained by Subaru/FOCAS
Results of Subaru/FOCAS and Other Group

- Survey 154 galaxies to discover the optical counterpart of the GW event S190425z associated with a host galaxy.
- Limiting magnitude is 23 --- 24 mag for 5-sigma detection

- Other group also tried to identify electromagnetic counterpart.

Did not find any optical counterpart of S190425z
<table>
<thead>
<tr>
<th>Type</th>
<th>Distance (Mpc)</th>
<th>Localization (deg²)</th>
<th>Observation (Gal. number)</th>
<th>Cumulative Prob (%)</th>
<th>GCN</th>
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</thead>
<tbody>
<tr>
<td>S190408an</td>
<td>BBH</td>
<td>1473±358</td>
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<tr>
<td>S190412m</td>
<td>BBH</td>
<td>812±194</td>
<td>156</td>
<td>197</td>
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<tr>
<td>S190425z</td>
<td>BNS</td>
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<tr>
<td>S190426c</td>
<td>BNS, NSBH</td>
<td>377±100</td>
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<td>106</td>
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<tr>
<td>S190510g</td>
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<tr>
<td>S190521r</td>
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<tr>
<td>S190814bv</td>
<td>NSBH</td>
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<tr>
<td>S190930t</td>
<td>NSBH</td>
<td>108±38</td>
<td>24220</td>
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</tbody>
</table>

Did follow-ups to 17 GW alerts
We have submitted 13 reports for 8 GWs to GCN Circular.
Summary

• Our observational systems both for normal and wide-field FoV telescopes work well.

• Web-base and communication systems:
  1. planner: Share a list of candidate galaxies and observational information.
  2. Image Server: Assemble observed images and subtract from reference.

• We are following up the GW alerts, especially having-NS events.

• We submitted 13 reports of our follow-up to the GCN Circular.
Thank you for your attention