Optical followup observations of gravitational wave events
with the wide-field CMOS camera Tomo-e Gozen

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ABSTRACT

The third observing run of the gravitational wave detectors (O3) has started with 3 detectors which have
sufficient sensitivity to detect extragalactic compact binary coalescence. However, the localization errors
of the detected gravitational wave (GW) events are still as large as a few 100 deg2 in most cases, and hence
a large field-of-view (FoV) of an observing facility is required to conduct a search for an electromagnetic
counterpart of a GW event. The Tomo-e Gozen camera mounted on the 1.05 m Kiso Schmidt telescope
has extremely wide FoV (20 deg2) and high-speed readout (max 2 fps), which allow us to survey a few
100 deg2 in 1 hour down to ∼20 mag. We are conducting a GW event followup program using the Tomo-
e Gozen camera, which is a part of the Japanese collaboration for Gravitational-wave ElectroMagnetic
followup (J-GEM). Here we introduce our system for the followup observations, and report the status of
our observation in the former half of the O3 run.

KEY WORDS: gravitational waves — Optical observation

1. The Tomo-e Gozen Camera

Tomo-e Gozen is a new wide-field camera mounted on the 105 cm Schmidt telescope at the Kiso observatory,
equipped with 84 CMOS sensors (2k × 1k pixels each, Sako et al. 2018). Tomo-e Gozen is the successor instru-
ment of the Kiso Wide Field Camera (KWFC, Sako et al. 2012) which was used in followup observations of gravita-
tional wave (GW) events during previous observing runs of the GW detectors (Morokuma et al. 2016; Yoshida et
al. 2017).

The field of view (FoV) of the sensors is 20 deg2 in total, which is sparsely distributed over 9 deg area.
The fast readout capability of CMOS sensors enables Tomo-e Gozen to take an image up to twice in a second.
The wide field of view and the high-speed read of Tomo-e Gozen allow us to survey an error region of a GW event
(∼ a few 100 deg2) down to ∼ 20.5 mag within a couple of hours.

2. Automated observations for GW events

To deal with GW event alerts that may arrive anytime 24 hours a day, we develop an automated observation
system. Upon receiving an VOEvent alert (an XML format to describe astronomical transients) of a GW event,
the observation system obtains the probability skymap of the event from the GraceDB1, determine desirable tele-
scope pointings by finding the peak of the probability map recurrently, and send observation commands to the
telescope controlling system (figure 1).

Images obtained in the followup observations are processed by a pipeline software, which performs image
subtractions with reference images and find transient/variable objects. Cutout images of the objects found in the subtracted images and galaxies listed in the GLADE catalog (Dálya et al. 2018) are uploaded to data servers operated by the Kiso observatory and by the Japanese collaboration for Gravitational-wave ElectroMagnetic followup (J-GEM), respectively, for eye in-

1 https://gracedb.ligo.org
Fig. 1. The probability skymap of S190915ak (color contour). In the colored version, the red/blue portion of the color contour represents observable/unobservable region from the Kiso observatory during the first night after the alert. Black ellipses represent the telescope pointings computed by the automated observation system for this event.

3. Followup observations conducted so far
Alerts of 40 GW events have been issued from the LIGO and Virgo Collaborations (LVC) since the start of O3 (until Sep. 30; 21 BBH, 5 BNS, 4 NS-BH, 2 MassGap, and 8 false/terrestrial), and followup observations using Tomo-e Gozen have been conducted for 12 events (table 1). Unfortunately the weather condition during the summer season in the Kiso area has been very poor this year, and the observations have been hindered by clouds/rains in most of the cases. However, the automated observation system itself is working well, and it will provide us with good datasets during winter season, when the weather condition in Japan is relatively clear.

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Table 1. Followup observations of GW events conducted with Tomo-e Gozen

<table>
<thead>
<tr>
<th>event ID</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>S190408an</td>
<td>BBH, the first alert in O3, manual observation before dawn, GCN 24064</td>
</tr>
<tr>
<td>S190412m</td>
<td>BBH, covered 390 deg$^2$ (88.5%), GCN 24113</td>
</tr>
<tr>
<td>S190425z</td>
<td>BNS, a few pointings observed under a poor weather condition</td>
</tr>
<tr>
<td>S190426c</td>
<td>possibly NS-BH, 180 deg$^2$ (13.1%), GCN 24299</td>
</tr>
<tr>
<td>S190510g</td>
<td>BNS, the error region is largely updated after the initial one, 2 pointing (~ 1%), 2 pointing (~ 1%)</td>
</tr>
<tr>
<td>S190814bv</td>
<td>NS-BH, a few pointings observed next day under a poor weather condition</td>
</tr>
<tr>
<td>S190901ap</td>
<td>BNS, a few pointings observed under a poor weather condition</td>
</tr>
<tr>
<td>S190915ak</td>
<td>BBH, a few pointings observed under a poor weather condition</td>
</tr>
<tr>
<td>S190924h</td>
<td>MassGap, a few pointings observed under a poor weather condition</td>
</tr>
<tr>
<td>S190930s</td>
<td>MassGap, a few pointings observed under a poor weather condition</td>
</tr>
<tr>
<td>S190930t</td>
<td>NS-BH, poor localization (1 detector), the priority is given to S190930s on the first night, GCN 25007 based on wide field survey data taken on the next night</td>
</tr>
</tbody>
</table>

References
Morokuma, T., & Utsumi, Y. 2019, GCN Circular, 25907
Niino, Y., et al. 2019, GCN Circular, 24299
Tanaka, M., et al. 2019, GCN Circular, 24113