Unlike Black-Hole Merger, Binary Neutron-Star Merger can not only give Gravitational Wave but also enable electromagnetic channels, such as optical light, gamma ray, ultraviolet ray, infrared ray, etc.

Neutrino detection will contribute to the multi-messenger observation and lead us to study the unknown equations of state for supranuclear-density matter.

How does neutrino be emitted from BNS merger?

Currently little has been known about the realistic spectrum of neutrinos from BNS merger. However, it has been suggested that the spectrum can be approximated by pinched Fermi-Dirac distribution for as the case of neutrino types produces from BNS merger. However, it has been suggested that the spectrum can be approximated by pinched Fermi-Dirac distribution for as the case of supernova explosions[1].

The mechanism of neutrino emission from BNS merger can be considered as:
1. $e^+/e^-$ pairs are produced from thermal photons as matter matter temperature getting high.
2. $\nu_e/\bar{\nu}_e$ emitted from $e^+/e^-$ capture on nucleons. ($\nu_e$ richness)
$$e^- + p \rightarrow \nu_e + n$$
$$e^+ + n \rightarrow \bar{\nu}_e + p$$
3. All neutrino types produces from $e^+/e^-$ annihilation.
$$e^- + p \rightarrow \nu_e + n$$

The expected neutrino energy after BNS merger[2]

Typical energy of $\nu$ is $10\sim30\text{MeV}$

$\nu$ emission has a rise time of $\sim10\text{ms}$

Peak luminosity of $\nu_e$ reaches $1\sim3 \times 10^{53}\text{erg g}^{-1}\text{s}^{-1}$

Super-Kamiokande Detector

- Built 1000m Underground
- Water Cherenkov Detector with best sensitivity to MeV neutrino
- 50kt ton ultra pure water and 22.5kton Fiducial Volume
- ~11000 PMTs in Inner Detector

Summary & Future Plan

- Neutrino signal search associated with GW170817 was done in Super-K, no significant signal found, and fluence limit has been given.
- SK-Gd will increase $\nu_e$ sensitivity by 2 order in range of a few tens MeV
- Hyper-K, a Water Cherenkov detector with 260kton volume in plan, can bring larger target for neutrino signal from BNS mergers.

GW170817

- Detected by LIGO and Virgo on August 17th 2017 at 12:41:04 UTC
- The first evident signal of a gravitational wave from the BNS merger
- Total system mass of $2.74M_\odot$ and a luminosity distance of 40Mpc
- The discovery of GW170817 marked the starting point of gravitational wave astronomy with BNS mergers
- Neutrino number in Water Cherenkov Detector is approximately expected as[1]:
$$N_\nu = 1.0 \times 10^{-3} \times f_{\nu} \times f_{\text{osc}} \times \left( \frac{M_\nu}{1\text{MeV}} \right) \times \left( \frac{E_{\text{GW}}}{10\text{MeV}} \right) \times \frac{D}{100\text{Mpc}} \times 2$$

$E_{\text{Gw}}$: fraction factor of energy range, ~0.77 when $E_{\text{Gw}}=10\text{MeV}$ in $10\sim50\text{MeV}$

$E_{\text{osc}}$: detection efficiency

$M_\nu$: detector volume

$D$: distance to the source

Neutrino signal search for GW170817 in Super-K

- Two kinds of time window are used for search: ±500s and following 14-day
- Five kinds of data reduction method are used for different energy range
- LINAC (electron beam) calibration was been carried out in August 2017, but five kinds of data reduction method are used for different energy range.
- The discovery of GW170817 marked the starting point of gravitational wave astronomy with BNS mergers.
- Due to so much low energy noises from beam work or hardware electronics in following days so 14-day search in 4–16MeV was not considered.

Event associated with GW170817 in Super-K

<table>
<thead>
<tr>
<th>Data</th>
<th>Energy Range</th>
<th>Event in ±500s</th>
<th>Event in 14-day</th>
<th>Expected BG in 14-day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar $\nu$</td>
<td>4–16MeV</td>
<td>0</td>
<td>2</td>
<td>1.53</td>
</tr>
<tr>
<td>Supernova relic $\nu$ search</td>
<td>16–100MeV</td>
<td>0</td>
<td>76</td>
<td>91.44</td>
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<tr>
<td>Fully-Contained</td>
<td>100MeV–10GeV</td>
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<td>8</td>
<td>7.35</td>
</tr>
<tr>
<td>Partially-Contained</td>
<td>100MeV–10GeV</td>
<td>0</td>
<td>13</td>
<td>16.05</td>
</tr>
<tr>
<td>Up-going $\mu$</td>
<td>1.6GeV–100eV</td>
<td>0</td>
<td>13</td>
<td>16.05</td>
</tr>
</tbody>
</table>

Zenith-dependent Fluence Limit result for Up-going $\mu$ in ±500s window[2]

- The two events found in 14-day window
- Red : LIGO public data with 90% C.L.
- Shadow : angle resolution range