GRB Beaming and Gravitational-Wave Observations

Hsin-Yu Chen\textsuperscript{1} Daniel E. Holz\textsuperscript{2}

\textsuperscript{1}Department of Astronomy and Astrophysics, University of Chicago

\textsuperscript{2}Enrico Fermi Institute, Department of Physics, and Kavli Institute for Cosmological Physics, University of Chicago

\textit{22\textsuperscript{nd} Midwest Relativity Meeting, 2012}
Beaming angles limit from event rates limit. . .

- Compact binary coalescences rates upper limit:
  - Non-detection from LIGO S6/VSR2 established upper limits on the event rates in local Universe (Abadie et al. 2011).

- Short GRB beaming angles lower limit:
  - Fraction of sky covered by beamed gamma rays:
    \[ f_b = 1 - \cos \theta_j \]
  - Apply observed rate density of GRB:
    \[ \mathcal{R} = \mathcal{R}_{\text{GRB}} / f_b = \mathcal{R}_{\text{GRB}} / (1 - \cos \theta_j) \]
Beaming angles limit from event rates limit...

- Compact binary coalescences rates upper limit:
  - Non-detection from LIGO S6/VSR2 established upper limits on the event rates in local Universe (Abadie et al. 2011).

- Short GRB beaming angles lower limit:
  - Fraction of sky covered by beamed gamma rays:
    \[ f_b = 1 - \cos \theta_j. \]
  - Apply observed rate density of GRB:
    \[ \mathcal{R} = \mathcal{R}_{\text{GRB}} / f_b = \mathcal{R}_{\text{GRB}} / (1 - \cos \theta_j). \]
Beaming angles limit from event rates limit...

- Compact binary coalescences rates upper limit:
  - Non-detection from LIGO S6/VSR2 established upper limits on the event rates in local Universe (Abadie et al. 2011).

- Short GRB beaming angles lower limit:
  - Fraction of sky covered by beamed gamma rays:
    \[ f_b = 1 - \cos \theta_j. \]
  - Apply observed rate density of GRB:
    \[ \mathcal{R} = \mathcal{R}_{GRB} / f_b = \mathcal{R}_{GRB} / (1 - \cos \theta_j). \]
Assumed $\mathcal{R}_{\text{GRB}} = 10 \text{ Gpc}^{-3} \text{yr}^{-1}$, $\theta_j \geq 1^\circ$ for NS-NS, and $\theta_j \geq 4^\circ$ for NS-BH($\sim 20 M_\odot$).
Advanced LIGO/Virgo

- Improve expected detection rates:
  - Higher sensitivity: high laser power, seismic isolation.
  - Detector network: LIGO-India, KAGRA (~2020).
  - Beamed GRB: expected rates is improved by 7 times if $\theta_j \sim 30^\circ$, 60 times if $\theta_j \sim 10^\circ$.

<table>
<thead>
<tr>
<th>Network</th>
<th>$\theta_j = 10^\circ$</th>
<th>$\theta_j = 30^\circ$</th>
<th>$\theta_j = 90^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>[conservative] HL(no SRM)</td>
<td>15/yr</td>
<td>1.7/yr</td>
<td>0.23/yr</td>
</tr>
<tr>
<td>HLV</td>
<td>50/yr</td>
<td>5.6/yr</td>
<td>0.75/yr</td>
</tr>
<tr>
<td>[optimistic]   HLVJI</td>
<td>104/yr</td>
<td>12/yr</td>
<td>1.6/yr</td>
</tr>
</tbody>
</table>
**Advanced LIGO/Virgo**

- **Improve expected detection rates:**
  - Higher sensitivity: high laser power, seismic isolation.
  - Detector network: LIGO-India, KAGRA (∼2020).
  - Beamed GRB: expected rates is improved by 7 times if \( \theta_j \sim 30^\circ \), 60 times if \( \theta_j \sim 10^\circ \).

<table>
<thead>
<tr>
<th>Network</th>
<th>( \theta_j = 10^\circ )</th>
<th>( \theta_j = 30^\circ )</th>
<th>( \theta_j = 90^\circ )</th>
</tr>
</thead>
<tbody>
<tr>
<td>[conservative]</td>
<td>HL(no SRM)</td>
<td>15/yr</td>
<td>1.7/yr</td>
</tr>
<tr>
<td></td>
<td>HLV</td>
<td>50/yr</td>
<td>5.6/yr</td>
</tr>
<tr>
<td>[optimistic]</td>
<td>HLVJI</td>
<td>104/yr</td>
<td>12/yr</td>
</tr>
</tbody>
</table>
Pros and cons of triggered detections

- **Pros**
  - lower SNR threshold due to known time and sky location.
  - higher SNR due to almost on-axis detection.

- **Con**
  - Only on-axis GRBs/binaries are observed.
Pros and cons of triggered detections

Pros
- lower SNR threshold due to known time and sky location.
- higher SNR due to almost on-axis detection.

Con
- Only on-axis GRBs/binaries are observed.
Pros and cons of triggered detections

Pros
- lower SNR threshold due to known time and sky location.
- higher SNR due to almost on-axis detection.

Con
- Only on-axis GRBs/binaries are observed.
We expect to have a few or more untriggered detections per year in the near future!
We expect to have a few or more untriggered detections per year in the near future!
(Abadie et al. 2011, Phys Rev D85.082002)

\[ \mathcal{R} \lesssim 8 \times 10^{-5} \, \text{Mpc}^{-3}\text{yr}^{-1} \text{ for NS-NS.} \]

\[ \mathcal{R} \lesssim 7 \times 10^{-6} \, \text{Mpc}^{-3}\text{yr}^{-1} \text{ for NS-BH}(\sim 10M_\odot). \]
Coincident to Coherent Search

- Find effective SNR threshold if applied coherent search (Schutz 2011): $\rho_{\text{network}} \sim 10.7\text{--}12.2$.
- NS-BH: $4.5 \times 10^{-4} \text{ Mpc}^{-3}\text{ yr}^{-1}$ for $M_{\text{total}} \sim 3 M_\odot$, and $6.5 \times 10^{-5} \text{ Mpc}^{-3}\text{ yr}^{-1}$ for $M_{\text{total}} \sim 22 M_\odot$. 
<table>
<thead>
<tr>
<th>Network</th>
<th>$V_0$ (Gpc$^3$)</th>
<th>$\theta_j = 10^\circ$</th>
<th>$\theta_j = 30^\circ$</th>
<th>$\theta_j = 90^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HL (no SRM)</td>
<td>0.027</td>
<td>15/yr</td>
<td>1.7/yr</td>
<td>0.23/yr</td>
</tr>
<tr>
<td>HLV (no SRM)</td>
<td>0.046</td>
<td>26/yr</td>
<td>2.9/yr</td>
<td>0.39/yr</td>
</tr>
<tr>
<td>HLV</td>
<td>0.092</td>
<td>50/yr</td>
<td>5.6/yr</td>
<td>0.75/yr</td>
</tr>
<tr>
<td>HLVJ</td>
<td>0.14</td>
<td>74/yr</td>
<td>8.4/yr</td>
<td>1.1/yr</td>
</tr>
<tr>
<td>HLVII</td>
<td>0.14</td>
<td>77/yr</td>
<td>8.7/yr</td>
<td>1.2/yr</td>
</tr>
<tr>
<td>HLVIIJ</td>
<td>0.19</td>
<td>104/yr</td>
<td>12/yr</td>
<td>1.6/yr</td>
</tr>
</tbody>
</table>

**Table:** Mean detectable volume and expected detection rates (per year) for $1.4 \, M_\odot - 1.4 \, M_\odot$ binaries.
Observed GRB Beaming Angles

(Nicuesa Guelbenzu et al. arXiv:1206.1806)