Simultaneous event detection rate by electromagnetic and gravitational wave detectors in the Advanced Era of LIGO and VIRGO

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Introduction

- **Short Gamma-ray bursts (GRBs)**
  - Progenitor: coalescence of binaries neutron stars?
  - Powerful, but rare in the local universe
  - Defined by duration and hardness

- **Era non-photonic**
  - Gravitational wave detectors in construction
  - Advanced LIGO in 2015 and Advanced VIRGO in 2017

- **Link between gravitational waves and short GRBs**
  - Improving knowledge about short GRB progenitors
  - Rate estimation of simultaneous detection by gravitational wave and gamma ray needed
Sample

- Sample based on Swift observations
  - Redshift measurement
- Derivation of a sample of "true short" bursts
  - Use of the rest frame duration
  - Selection by hardness ratio
  - Bursts presenting a soft tail removed from sample to avoid long GRBs
- Initial sample size: 32
  - Reduced to 16 bursts
  - 4 added with this method
  - 4 bursts « fake short » removed
- Best short GRB sample derived from NS-NS progenitor
Results for the rate of short GRBs

- **Fit of this distribution**
  - Correction for the volume to get burst density
  - Model: power law with Poisson Statistic
  - Power law index: \(-1.3 \pm 0.3\)

- **Estimation of occurrence rate in the local Universe:**
  \(0.12^{+0.05}_{-0.03}\) sGRB GPe\(^{-3}\) yr\(^{-1}\)

- **Instrumental bias to take into account**
  - Partial field of view (\(\approx 10\%\))
  - Corrected occurrence rate of Swift:
    \(1.1^{+0.4}_{-0.2}\) sGRB GPe\(^{-3}\) yr\(^{-1}\)
• **Instrumental bias**
  - Induce a limit of detection at high $z$ ($z > 3.3$)
  - Each instrument has its own sensitivity and specifications

• **Redshift bias**
  - 27.7% of GRB with known $z$
  - Induce a correction factor in the rate: $3.8$
  - Final occurrence rate corrected:
    \[
    4.1^{+1.8}_{-1.0} \text{ sGRB GPC}^{-3} \text{ yr}^{-1}
    \]
Rate for several gravitational wave detectors

<table>
<thead>
<tr>
<th>Detectors</th>
<th>Horizon (MPC)</th>
<th>Horizon (z)</th>
<th>Comobile volume (Gpc³)</th>
<th>Occurrence rate EM (events / year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced VIRGO</td>
<td>150</td>
<td>0.035</td>
<td>0.013</td>
<td>0.05 ±0.03 -0.02</td>
</tr>
<tr>
<td>Adv. LIGO/Adv. VIRGO</td>
<td>355</td>
<td>0.08</td>
<td>0.154</td>
<td>0.6 ±0.3 -0.2</td>
</tr>
</tbody>
</table>

Statistic validation

- Adding a burst at low redshift (z=0.04) : the rate increased by a factor 2
- Adding a burst at high redshift (z=3.5) : no changes

- Rate estimation robust and statistically validated
## Others missions: BATSE, FERMI, SVOM, LOFT

<table>
<thead>
<tr>
<th>Missions</th>
<th>Swift F.o.V.</th>
<th>BATSE Energy band</th>
<th>FERMI Energy band</th>
<th>LOFT Energy band</th>
<th>SVOM Energy band</th>
</tr>
</thead>
<tbody>
<tr>
<td>F.o.V.</td>
<td>1.4 sr</td>
<td>(\pi) sr</td>
<td>9.5 sr</td>
<td>(\pi) sr</td>
<td>2 sr</td>
</tr>
<tr>
<td>Estimated rate</td>
<td>0.46 +0.19</td>
<td>7.5 +3.3</td>
<td>18 +8</td>
<td>1.35 +0.60</td>
<td>0.86 +0.38</td>
</tr>
<tr>
<td>(sGRB GPC^-3 yr^-1)</td>
<td>-0.12</td>
<td>-1.9</td>
<td>-5</td>
<td>-0.33</td>
<td>-0.22</td>
</tr>
</tbody>
</table>

**Common detectability EM/ GW:**

- **Current missions:**
  - Low detectability with Swift
  - Larger possibility of detection with Fermi

- **Planned missions:**
  - Both SVOM and LOFT provide a fair detectability
  - Small advantage for LOFT due to larger field of view
Comparison with other rates

<table>
<thead>
<tr>
<th></th>
<th>Adv. LIGO/Adv. VIRGO combined</th>
<th>Adv. LIGO</th>
<th>Adv. VIRGO</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. NS EM</td>
<td>0.6 +0.3 -0.2</td>
<td>0.12 +0.06 -0.03</td>
<td>0.05 +0.03 -0.02</td>
</tr>
<tr>
<td>B. NS Beam 5°</td>
<td>41.5 +18.2 -10.2</td>
<td>7.5 +3.4 -1.9</td>
<td>3.6 +1.6 -0.9</td>
</tr>
<tr>
<td>B. NS Beam 15°</td>
<td>4.7 +2.1 -1.2</td>
<td>0.85 +0.38 -0.21</td>
<td>0.41 +0.18 -0.10</td>
</tr>
<tr>
<td>B. NS Beam 30°</td>
<td>1.3 +0.6 -0.4</td>
<td>0.23 +0.11 -0.06</td>
<td>0.11 +0.05 -0.03</td>
</tr>
</tbody>
</table>

Comparison with published rates:
- Coward et al. 2012: agreement if small or medium beaming
- Guetta et al. 2008: agreement if small beaming

Results consistent with previous work
Conclusion

- Rate estimation of simultaneous detection by gravitational wave and gamma ray

- Final occurrence rate corrected: \( 4.1^{+1.8}_{-1.0} \) sGRB GPc\(^{-3}\) yr\(^{-1}\)

- Rate estimation robust and statistically validated: 0.6\(^{+0.3}_{-0.2}\) for gravitational waves transient with Advanced LIGO / VIRGO combined per year

- Larger possibility of simultaneous detection with Fermi: 18\(^{+8}_{-5}\) sGRB GPc\(^{-3}\) yr\(^{-1}\)

- LOFT Rate estimation: 1.35\(^{+0.60}_{-0.33}\) sGRB GPc\(^{-3}\) yr\(^{-1}\) for short GRB detection (corrected from redshift bias)