Simulation Study for Cross-Talk Noise between Two Detectors of LCGT on Detection of GW

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Plan of Talk

Brief Introduction to LCGT

Motivation

Coincidence and Cross Talk Noises

Simulation

Model of Cross Talk Noises

Generation of Noise

Process Noise by Matched Filter for GW event search

Evaluate the fraction of Accidental Coincidence
Large-scale Cryogenic Gravitational Telescope (near!) Future Plan in Japan

Cryogenic interferometer
- Mirror temperature: 20K
- Reduce thermal noise

Underground site
Kamioka mine,
1000m underground
- Reduce seismic noise
- Stable operation

Large-scale interferometer
Two interferometers
- Baseline length: 3km
- High-power laser
- Better sensitivity
- Fake-reduction with coincidence
Single detector of LCGT will reach to 200Mpc for binary inspiral.
LCGT Board

Institute for Cosmic Ray Research, University of Tokyo (ICRR)
High Energy Accelerator Research Organization (KEK)
National Astronomical Observatory JAPAN (NAOJ)
Department of Physics, University of TOKYO
Department of Advanced material Science, University of TOKYO
Earthquake Research Institute, University of TOKYO
National Institute for Advanced Industrial Science and Technique

Kyoto University
Osaka University
Osaka City University
Communication Research Laboratory

Electrical Telecommunication University
Waseda University
Niigata University
Ochanomizu University
Fake events due to noise from \textit{complete independent detectors} will be \textit{accidental coincidence} only.

Requirement of the coincidence between GW candidates triggers
\textit{---\textgreater Reject Fakes}

example:
TAMA-LISM(Kamioka20mIFO)
Reduction Rate \(\sim 10^{-4}\)

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure.png}
\caption{(\(r_{\text{TAMA}}/\sqrt{\chi^2_{\text{TAMA}}}, r_{\text{LISM}}/\sqrt{\chi^2_{\text{LISM}}}\) scatter plots. The crosses (+) are the events survived after the time selection, and the circled crosses (⊕) are the events survived after the time, mass and amplitude selections.)
\end{figure}

H.Takahashi et. al., PRD70, 042003
Possible Problem: Cross Talk between two Detectors

However, closed detectors have common source of noise, cross talk of electric signal mechanical coupling

--> cross talk (common component) of noise be contains in the data.
**Spike like** noise cross talk

--> generate fake which amplitude be proportional to the coupling

• However, it is possible to reject with the requirement of GW amplitude consistency.

• Even same spike in electric raw data, it might be not equal in h(f) or h(t).

**Stationary bulk** components of cross talk / common source of noise

--> How appear after event selection?

**inspiral GW search, Black-Hole ringdown GW search**: easy to understand, but the quantity of fake coincidence is not trivial after **Matched filtering**.

*Aim of this study*: to evaluate the influence of cross talk noise in GW event search (= check the statistical characteristics of cross talk.)
Simulation of Cross Talk Noise

Noise model:
- two detectors, each signal $s_1$ and $s_2$
  - bulk noise cross talk (stationary noise)
    - all frequency band
    - common only seismic noise

- spike noise
  - coupling factor : $R$

Monte-Carlo
- use LCGT design spectrum
- generate noise in Fourier domain
  - amplitude $\leftarrow$ design average, PDF
  - phase $\leftarrow$ random

\[
\begin{align*}
  s_1^2 &= s_{1,\text{independ}}^2 + s_{\text{common}}^2 \\
  s_2^2 &= s_{2,\text{independ}}^2 + s_{\text{common}}^2 \\
  \text{cross talk} : R &= \frac{s_{\text{common}}^2}{s^2} \\
  s_1 &= s_{1,\text{independ}} + s_{\text{spike}} \\
  s_2 &= s_{2,\text{independ}} + R \ s_{\text{spike}}
\end{align*}
\]
LCGT expected power spectrum: $S_h(f)$

Randomize (amplitude<-spectrum, phase<-uniform)

\[ \tilde{S}_1 = \sqrt{1 - R} \tilde{S}_{1,\text{independ}} + \sqrt{R} \tilde{S}_{\text{common}} \]

\[ \tilde{S}_2 = \sqrt{1 - R} \tilde{S}_{2,\text{independ}} + \sqrt{R} \tilde{S}_{\text{common}} \]
example of simulated noise (Bulk)

All frequency region

Seismic component only

30% fraction of seismic noise
Matched filter processing for simulated noise

Detector 1 signal: $s_1(f)$

Detector 2 signal: $s_2(f)$

Matched Filter

Inspiral GW

Ringdown GW

$$(h, s) = \int \tilde{h}^*(f) \cdot \tilde{s}(f) \frac{e^{i2\pi t}}{S h(f)} df$$

$$\text{SNR}(t) = \sqrt{(h_+, s)^2 + (h\times, s)^2} / \sqrt{2}$$

SNR$_1$(t)

SNR$_2$(t)

Exceed Threshold?

YES

YES

NO

Exceed Threshold?

AND

Accidental Coincidence

Check the fraction of accidental coincidence for the variance of cross talk amount!
Example of simulation: Accidental coincidence of Fake Event

Complete independent two detectors

\[ \text{SNR}_1 = \sqrt{(h_+, s_1)^2 + (h_\times, s_1)^2 / \sqrt{2}} \]
Example of simulation: Accidental coincidence with Huge cross talk

cross talk with 80% (so much!)

\[ SNR_1 = \sqrt{(h_+, s_1)^2 + (h_\times, s_1)^2/\sqrt{2}} \]

Take note:
Each PDF of SNR looks same as the case of no cross talk!
Note:

fraction for the case of independent detectors (analytic expectation)

1.93 x 10^{-3}

3.72 x 10^{-6}

1.93 x 10^{-3}
Results 1: Cross talk VS contamination

30% cross talk complicate 10 times accidental coincidence.
Results 2:
Seismic component cross talk VS contamination

Seismic component is biggest concern.

inspiral search: assume larger mass source -> integrate from $f_{\text{low}} < 10\text{Hz}$

BH ringdown: source near seismic cutoff

threshold: 2.5 sigma for each detector

All frequency region:
- inspiral 10-10 Msolar
- inspiral 1.4-1.4 Msolar
- BH ringdown $f_c=20\text{Hz}$, $Q=20$

Seismic component only:
- inspiral 10-10 Msolar
- BH ringdown $f_c=20\text{Hz}$, $Q=20$
- inspiral 1.4-1.4 Msolar

If the cross talk is seismic only, no significant contamination!
Summary and Future

We tried practical study of cross talk between two LCGT detectors.

- Even stationary bulk noise, 30% cross talk contaminate 10 times for accidental coincidence.
- Seismic component looks as no problem.

<table>
<thead>
<tr>
<th>cross talk model</th>
<th>GW source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>inspiral 1.4-1.4 Msol</td>
</tr>
<tr>
<td>all frequency band</td>
<td>30% -&gt; x 10</td>
</tr>
<tr>
<td>seismic component only</td>
<td>no effect</td>
</tr>
<tr>
<td>spike</td>
<td>proportional to cross talk</td>
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</tbody>
</table>

Future and More...

- Consider instrumental mechanism more (e.g. up-conversion of seismic trough the servo system, scattering light, etc.)
- Study for stochastic GW