Data analysis:
strategy of LCGT, and status of TAMA/CLIO

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LCGT collaboration

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Plan of the Talk

**LCGT overview**
- design sensitivity
- expected GW signature
- previous searches in TAMA

**LCGT and International Network**
- sky coverage
- study on ‘coherent’ vs ‘coincidence’

**CLIO’s new data**
- Good noise characteristics (Gaussianity and stationarity)
- Observational upper limit to GW from Vela pulser
Strain equivalent noise spectrum [1/rHz]

LCGT design:
- Broadband RSE
- Detuned RSE

Operated Detectors:
- CLIO (current, in normal temperature)
- TAMA dt9
- LIGO_I

frequency [Hz]
TAMA --> CLIO --> LCGT

Strain equivalent noise spectrum [1/\( \text{rHz} \)]

LCGT design:
- Broadband RSE
- Detuned RSE

Operated Detectors:
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frequency [Hz]
Location of LCGT

LCGT is planned to be built underground at Kamioka, where the prototype CLIO detector is placed.

LCGT: overview

Underground
• in Kamioka, Japan
• Silent & Stable environment

3km baseline

Cryogenic Mirror
• 20K
• saffhire substrate

Plan
2010-2014 : construction
2015-2016 : commissioning
2017- : observation
Design Sensitivity

Strain equivalent noise spectrum [1/rHz]

- **Broadband RSE**
- **Detuned RSE**

**Binary inspiral:**
- 1.4-1.4 Msolar, 200Mpc

**BH ringdown:** Kerr param. $a=0.95$
- 2.8 Msol
- 100 Msol

**Stellar core collapse at Galactic Centre**
- DFM waveforms
Detection Range

range >200 Mpc

S/N >8, optimal direction

Note: The range is defined for SNR=8, sources at optimal direction.
Expected Number of NS-NS events

Galactic DNS rate: \(83.0^{+209.1}_{-66.1} \times 10^{-6}\) (C.I.95%)


<table>
<thead>
<tr>
<th>Detection Range (optimal direction, S/N&gt;8)</th>
<th>Expected # of events/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCGT (BRSE) 231 Mpc</td>
<td>(3.9^{+9.82}_{-3.11})</td>
</tr>
<tr>
<td>LCGT (DRSE) 312 Mpc</td>
<td>(9.2^{+23.1}_{-7.29})</td>
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</tbody>
</table>

90% detection

[Graph showing probability of detection over observation time]
Sensitivity for Continuous Waves

- Broadband RSE, with 1yr integration
- 10yr integration
- 2weeks integration
- Detuned RSE, with 1yr integration
- 10yr integration
- 2weeks integration
- Known pulsars with maximum allowed amplitude
- LMXB etc.
Other Possible Sources

BH quasi-normal mode ringdown
• Typical mass range: several $10 \, M_{\odot}$ to $10^4 \, M_{\odot}$

Supernovae
• up to ~ a few Mpc away
• core collapse, core bounce
• 3D instability
• convection & SASI
• PNS core g-mode

Stochastic
Single detector can’t do...
• It must be done by international network.
## Previous GW searches in TAMA

<table>
<thead>
<tr>
<th>Source or GW</th>
<th>Search Method</th>
<th>Results</th>
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<tbody>
<tr>
<td>Inspiral from binary</td>
<td>Matched Filtering</td>
<td>Upper Limit: ~20 event/yr for MWG</td>
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<tr>
<td>BH Ringdown</td>
<td>Matched Filtering</td>
<td>Trigger Rate: &lt; 1 event/day for MWG</td>
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<td></td>
<td></td>
<td><strong>Phys. Rev. D 71</strong> (2005) 103005</td>
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<tr>
<td>Burst from core collapse</td>
<td>Excess Power</td>
<td>Upper Limit: 6 x 10^3 ev/sec for MWG</td>
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<td><strong>Phys. Rev. D 71</strong> (2005) 082002</td>
</tr>
<tr>
<td>Burst from core collapse</td>
<td>ALF</td>
<td>Upper Limit: 0.55 ev/day for hrss ~ 10^{-17}</td>
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<td></td>
<td></td>
<td><strong>Class. Quantum Grav. 23</strong> (2006) S715</td>
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<tr>
<td></td>
<td>TF Cluster</td>
<td>Upper Limit (partial data) 1.4 x 10^{-3} ev/sec within 10pc</td>
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<td></td>
<td></td>
<td><strong>Class. Quantum Grav. 25</strong> (2008) 184035</td>
</tr>
<tr>
<td></td>
<td>Wavelet</td>
<td>Success the Extraction of Unstable component</td>
</tr>
<tr>
<td>(Burst like noise)</td>
<td>veto with AUX ch.</td>
<td>Systematic trial was done.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Class. Quantum Grav., 24</strong> S405, (2007)</td>
</tr>
<tr>
<td>continuous GW from SN1987A</td>
<td>integration</td>
<td>h ~ 4 x 10^{-23}</td>
</tr>
<tr>
<td>remnant pulser</td>
<td></td>
<td><strong>Class. Quantum Grav. 20</strong> (2003) 645.</td>
</tr>
</tbody>
</table>

These will be extend/upgrade for LCGT.
Network of Detectors

International Network of the GW detectors is important.
LCGT would like to contribute.
Sky coverage by detector network

LIGO (Hanford)

LCGT

LCGT will make important role in the network, with a complemental sensitivity map.
Sky coverage by detector network

LIGO x2 + VIRGO

LCGT

Quadratic Sum: LCGT + LIGO x2 + VIRGO

LCGT will make important role in the network, with a complementary sensitivity map.
Study: Coherent vs Coincidence

We have been studied for basic strategy network of detectors: 'coherent' or 'coincidence'

- coherent:
  log likelihood sum

- coincidence:
  each detector output > threshold
  + events appear within error windows

\[ \Lambda = \|C\|^2 = |C^1|^2 + |C^2|^2 = (c_0^1)^2 + (c_{\pi/2}^1)^2 + (c_0^2)^2 + (c_{\pi/2}^2)^2, \]

Figures & estimation: S.Dhurandhar and H.Tagoshi
This study is supported by India DST and JSPS.

Sources are distributed within 20Mpc from the Earth.

The origin of the difference between L1 and V1 is an open question.
Recent status: CLIO

Sensitivity reach to the thermal noise at room temperature.
(See --> M.Ohashi’s talk in session GW2)
Noise characteristics test

**Gaussianity**

- skewness & kurtosis
- Extremely good in low frequency (<100Hz) band in comparison with TAMA’s previous data.

**CLIO** (April 2009)

CLIO 090427 (36Hz-99Hz)

**TAMA (DT9)**

TAMA DT9 Run142 (105Hz-175Hz)

*Figures by H.Tagoshi*
Noise characteristics test (2)

Stationarity

- Evaluation for inspiral GW search
- Non-stationary burst is less!

\[ N = \left( 4 \int \frac{f^{-7/3}}{S_n(f)} df \right)^{-1/2} \]

Figures by H. Tagoshi

Results display the advantage of silent underground site.
Search GW from Vela pulser

Vela pulser (PSR J0835-4510)
• might radiate GW at ~ 22Hz
• Search : Complex Heterodyne + Matched Filter
• Using observation data in 2007

Upper limit : $h_0 \sim 5.3 \times 10^{-20} \ (C.L.99.4\%)$

T.Akutsu et al., Class. Quantum Grav. 25 (2008) 184013
Summary & Prospect

**LCGT**
- It will be capable to detect GW events at ~200Mpc away.
- It is expected that LCGT will detect NS-NS event in 1 year observation.
- LCGT will contribute the international detector network.
  We study for coherent search.

**CLIO**
- It has a progress room temperature operation.
- Noise characteristics is extremely good in underground.
- We expect a more progress of CLIO as a prototype of LCGT.

**TAMA**
- We obtained some search results.