Observing the Universe from Underground
Gravitational Wave Telescope, KAGRA

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Overview

Gravitational Wave Detectors

• Introduction
• Gravitational wave detectors
  ▪ How the detectors work?
  ▪ Challenges for the ultimate sensitivity
• KAGRA project
  • Challenges of underground and cryogenic
  • Current status and prospect
Gravitational Waves

Dynamic distortions of the spacetime

- Emitted when heavy masses move at accelerated speed
- Propagates at the speed of light
- The distortion of the space-time is extremely tiny

(so it took 100 years to detect)
Major Discoveries So Far

Binary Black Hole (BH) Mergers

• Detected by LIGO in 2015
• BH ~ 30M☉

Binary Neutron Star (NS) Mergers

• Detected by LIGO-VIRGO network in 2017
• Confirmed kilonova (r-process) from binary NSs
• Hubble constant, speed of GWs
Sky Localization by the network

Using the arrival times of the GW signals, the sky position of the GW source can be identified.

More detector is better to cover the whole sky!
Better Sky Localization with VIRGO

GW170104 (LLO, LHO)
LVT151012 (LLO, LHO)
GW151226 (LLO, LHO)
GW170817
LLO, LHO, VIRGO
GW150914 (LLO, LHO)

GW170814
LLO, LHO, VIRGO

LIGO/Virgo/NASA/Leo Singer
(Milky Way image: Axel Mellinger)
With the 4th Detector, KAGRA

- Improve the sky localization of the source

Wen and Chen, arXiv: 1003:2504, assuming similar sensitivities for the detectors

- KAGRA single observation started on 25th Feb, with a limited sensitivity
- Planning for an observation brake for 2 weeks from today, aiming to join LIGO-VIRGO Observation3 (O3, 1st April 2019 – 30th April 2020)
How to Detect the GWs?

Space-time distortion
=> Distances between masses change
Signals are EXTREMELY Small !!

"Strain" (how much the stretch-squeeze per meter)

\[ \frac{10^{-10} \text{m}}{10^{11} \text{m}} = 10^{-21} \]
Detector: Laser Interferometer

- Laser Source
- Beam Splitter
- Mirror (Yend)
- Y arm
- Mirror (Xend)
- X arm
- L
- Optical sensor detecting the length difference between X and Y arms
- Dark (Lasers from X and Y destructively interfere)

EDSU
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Detector: Laser Interferometer

Optical sensor detecting the length difference between X and Y arms
“Actual” Modern Detectors

Test mass (mirror)
hung by a large suspension
to be isolated from seismic motions

Power-recycling mirror
to enhance the effective laser circulating power

Fabry-perot cavities
to accumulate the effective light path length

Beam splitter

Stabilized Laser

Signal-recycling mirror
to tune the frequency response

Very long arm (km)
(bigger is better!)

Photo Detector
“Actual” Sensitivity

Note that the detector directionality isn’t taken into account for GW170817 line

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EDSU
"Actual" Sensitivity

Note that the detector directionality isn’t taken into account for GW170817 line

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Reducing Seismic Noise

KAGRA
Tower type Large suspension

Ground motion of underground site

![Graph showing seismic motion vs frequency for different locations: Atotsu entrance office, Mozumi entrance office, CLIO (Center of Kamioka mine), Kashiwa (suburb of Tokyo).]
Reducing Thermal Noise

Thermal noise level $\propto \sqrt{T/Q}$

- Cool mirrors down to 20K
- Sapphire mirrors $Q \Rightarrow$ big in cryogenic
The 4th Detector, KAGRA in Kamioka, Japan

Underground and Cryogenic Detector
Laser Room

Frequency stabilization
Laser spatial mode cleaning
Mode matching to the main interferometer...etc
Unexpected (1): Floods!

Laser room flooded by underground spring water!

April 2015

March 10th, 2020
Unexpected (1): Floods!

Additional construction to build drainage ditches under the room was applied.

Now it is good, however...

Underground water possibly produces "Newtonian Noise" in near future.
Sensitivity Improvements

- Omitting one recycling mirrors
- Mirrors are not cooled
- Sensitivity ~500 kpc for binary neutron star inspirals
- 2-week noise hunting (obs. brake) aiming 1Mpc to join L-V
- Avg duty~46% (2/25-3/9)
### Prospects of Current Facilities

<table>
<thead>
<tr>
<th>Year</th>
<th>LIGO</th>
<th>VIRGO</th>
<th>KAGRA</th>
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<tbody>
<tr>
<td>2015</td>
<td>-</td>
<td>~25Mpc</td>
<td>-</td>
</tr>
<tr>
<td>2016</td>
<td>~80Mpc</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2017</td>
<td>~100Mpc</td>
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<td>~120Mpc</td>
<td>~80Mpc</td>
<td>250kpc~1Mpc</td>
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<td>O1</td>
<td>O3</td>
<td>65-115Mpc</td>
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<tr>
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<td>O2</td>
<td>O4</td>
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<tr>
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<td>O4</td>
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</tr>
<tr>
<td>2024</td>
<td>O4</td>
<td>O4</td>
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- Observation and commissioning (sensitivity improvement) happens
- After O3, all the detectors go on the commissioning
- KAGRA will reach more reasonably sensitivity for the next run