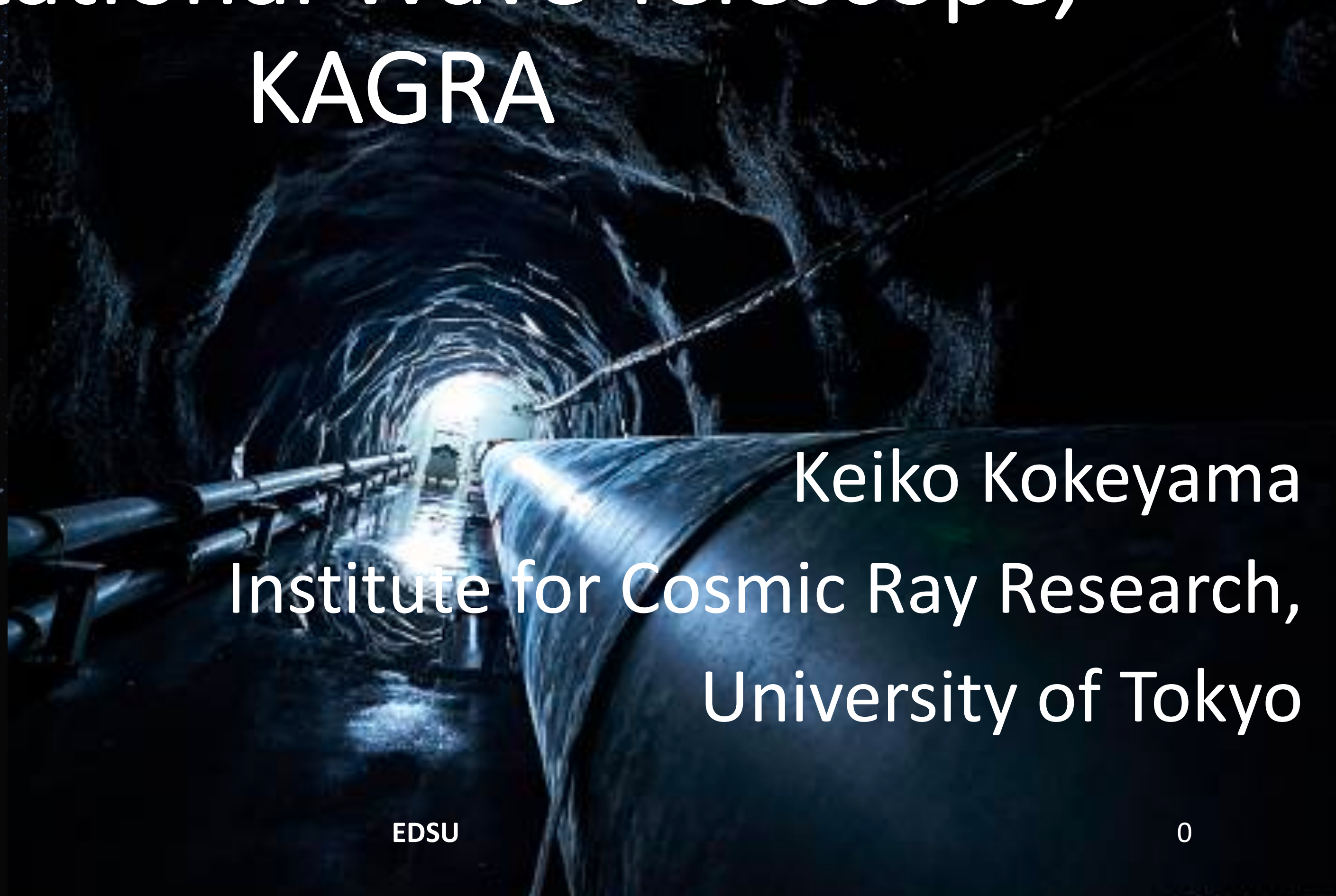
Observing the Universe from Underground Gravitational Wave Telescope, KAGRA



Keiko Kokeyama

Institute for Cosmic Ray Research,

University of Tokyo

Overview

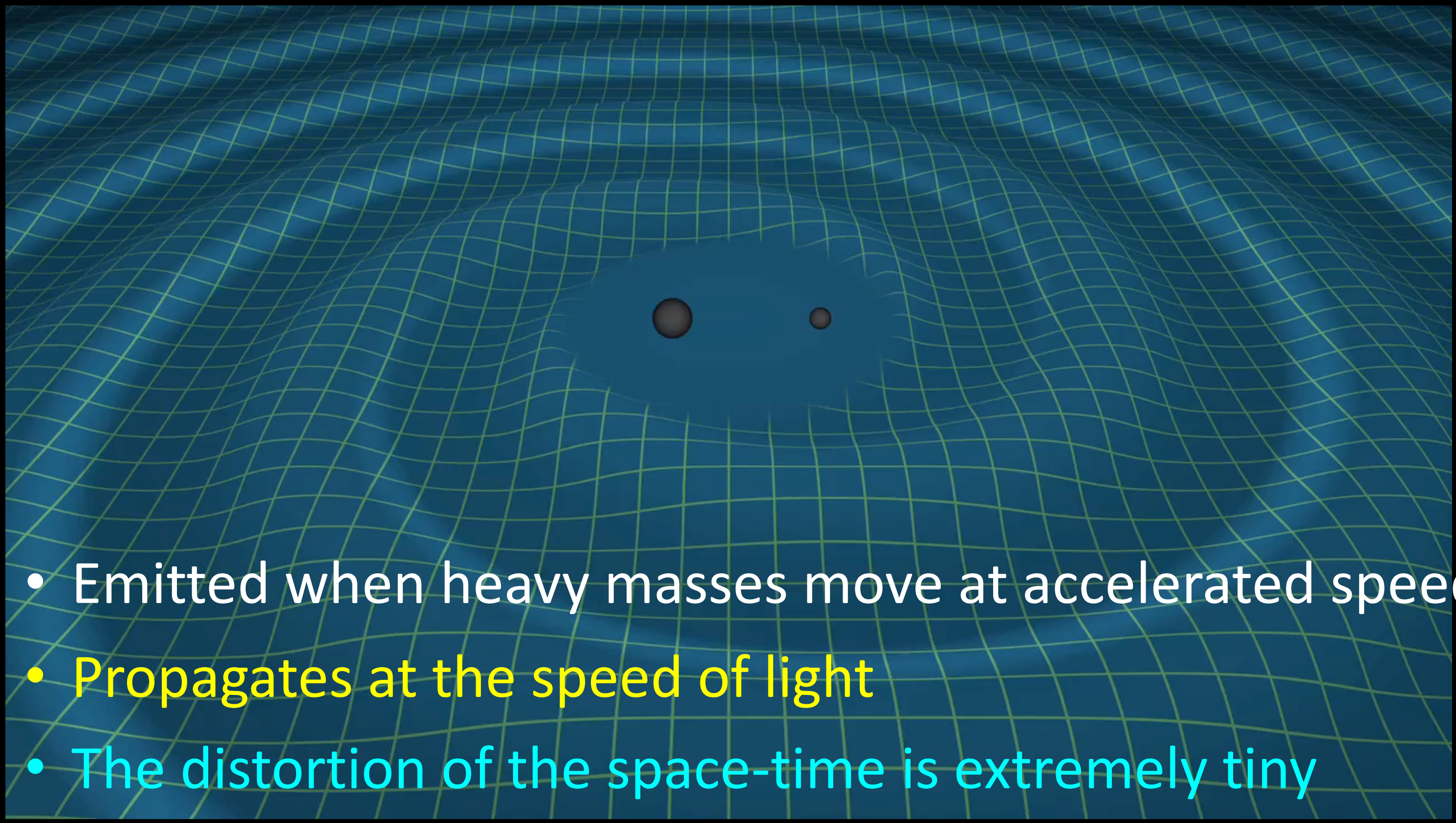
Gravitational Wave Detectors

- 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

Credit: LIGO-VIRGO

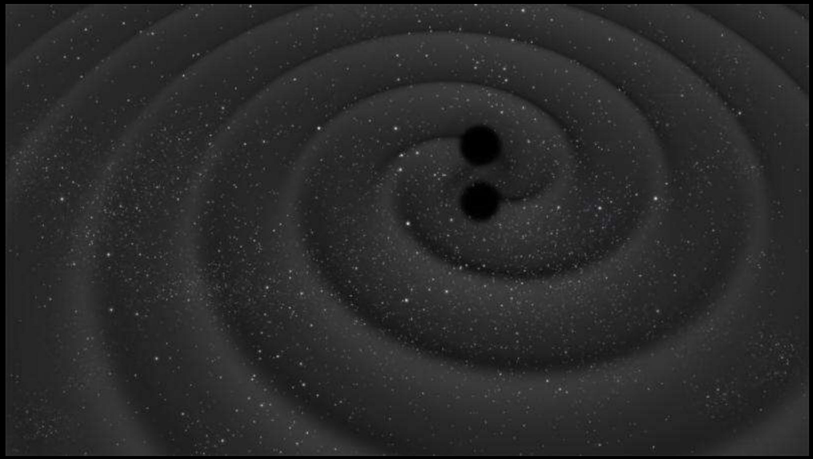


- Emitted when heavy masses move at accelerated speed
- Propagates at the speed of light
- The distortion of the space-time is extremely tiny

(so it took 100 years to detect)

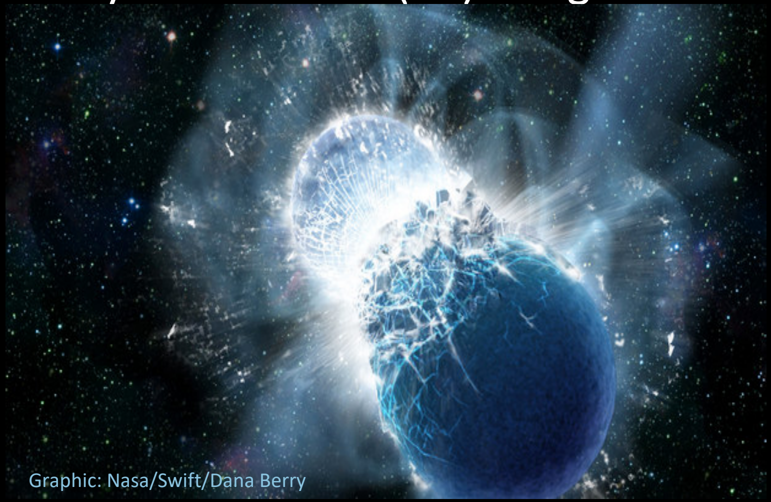
Major Discoveries So Far

Binary Black Hole (BH) Mergers



- Detected by LIGO in 2015
- BH ~ $30M_{\odot}$

Binary Neutron Star (NS) Mergers



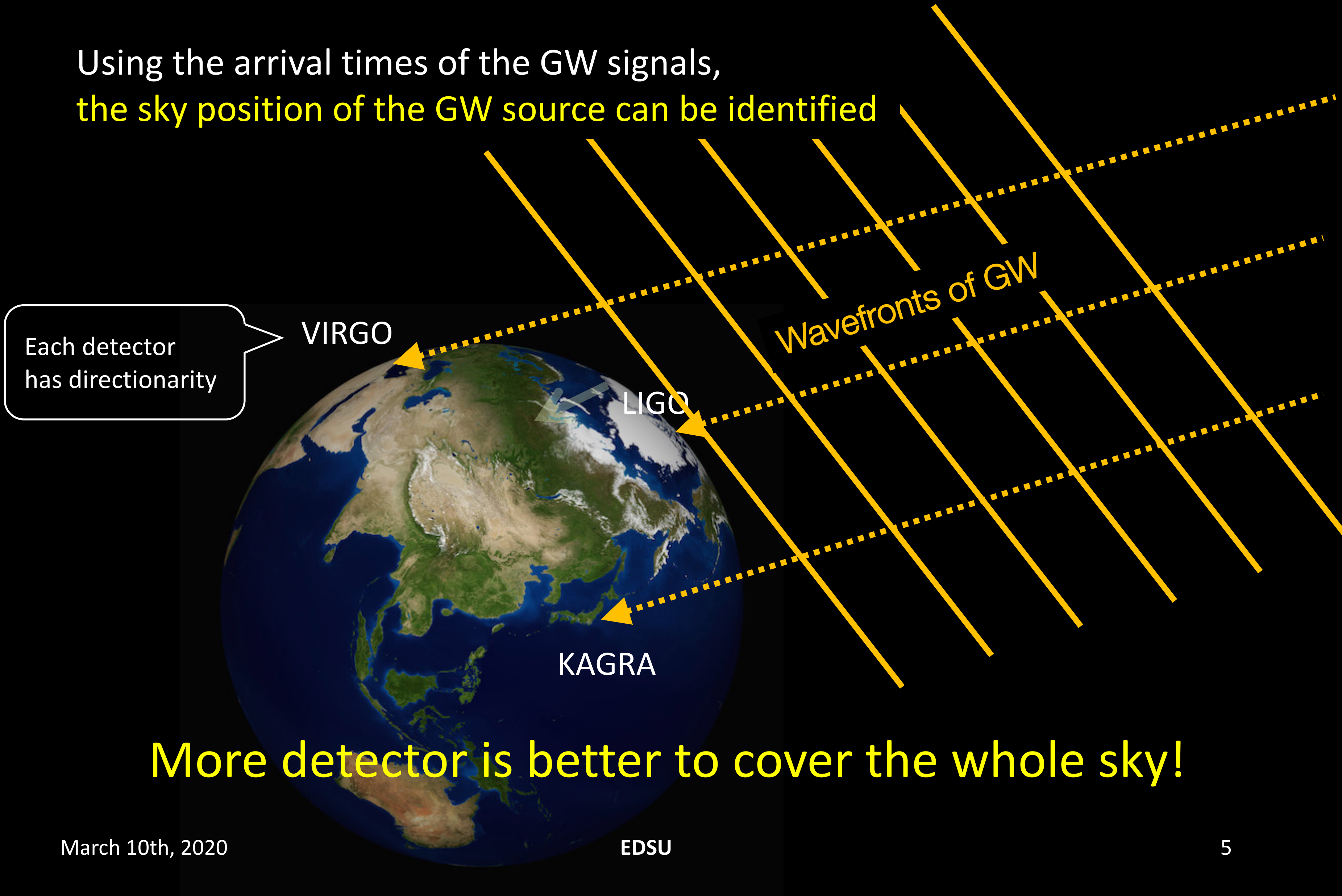
Graphic: Nasa/Swift/Dana Berry

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

Worldwide Detector Network

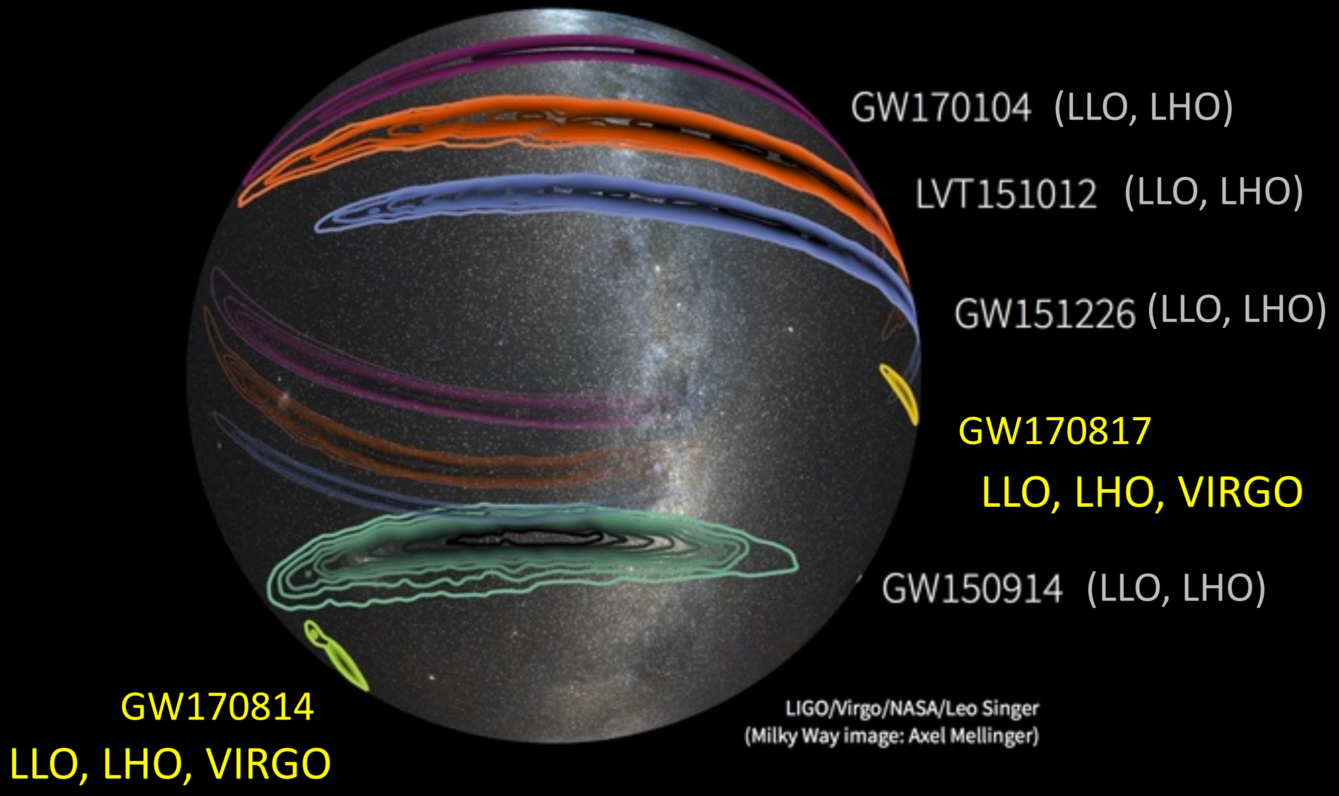
Sky Localization by the network

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!

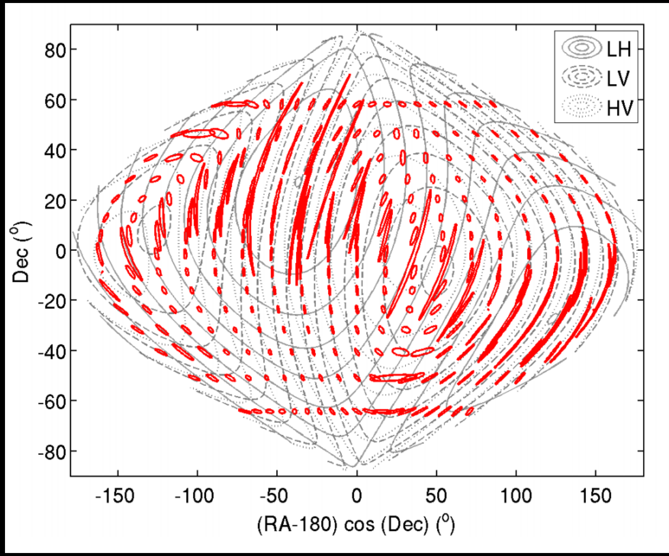
Better Sky Localization with VIRGO



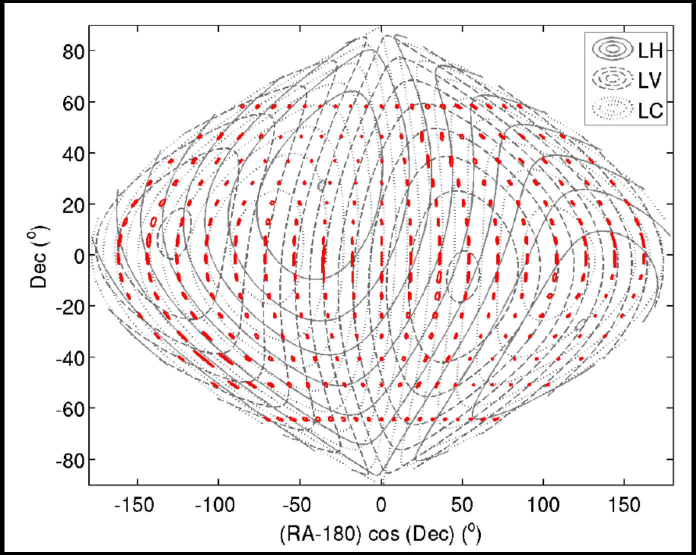
With the 4th Detector, KAGRA

- Improve the sky localiztion of the source

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



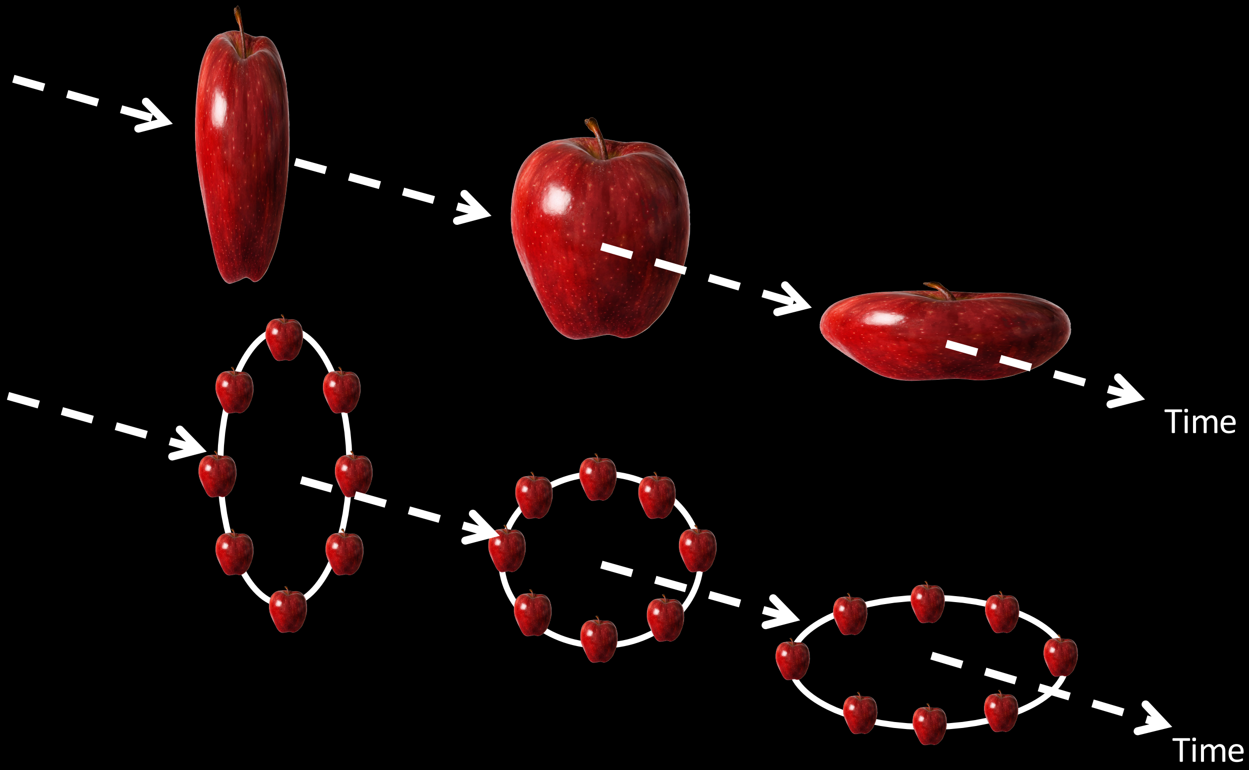
LIGO (L+H) + VIRGO



LIGO (L+H) + VIRGO + KAGRA

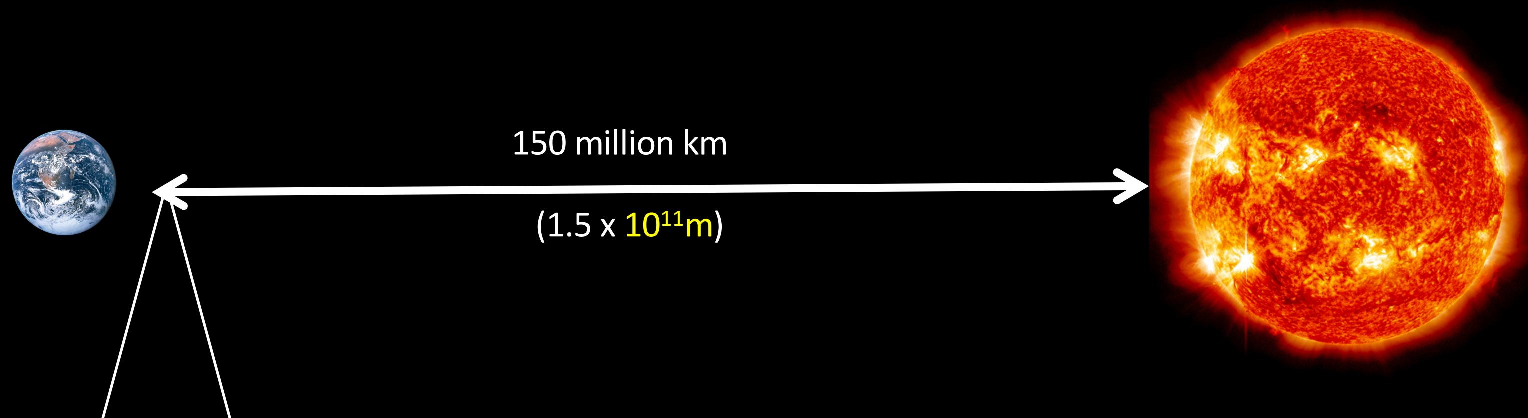
- KAGRA single observation started on 25th Feb, with a limited sensitivity
- Planning for an observation brake for 2 weeks from today, aiming to join LIGO-VIRGO Observation3 (O3, 1st April 2019 – 30th April 2020)

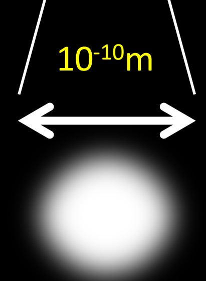
How to Detect the GWs?



Space-time distortion
=> Distances between masses change

Signals are EXTREMELY Small !!



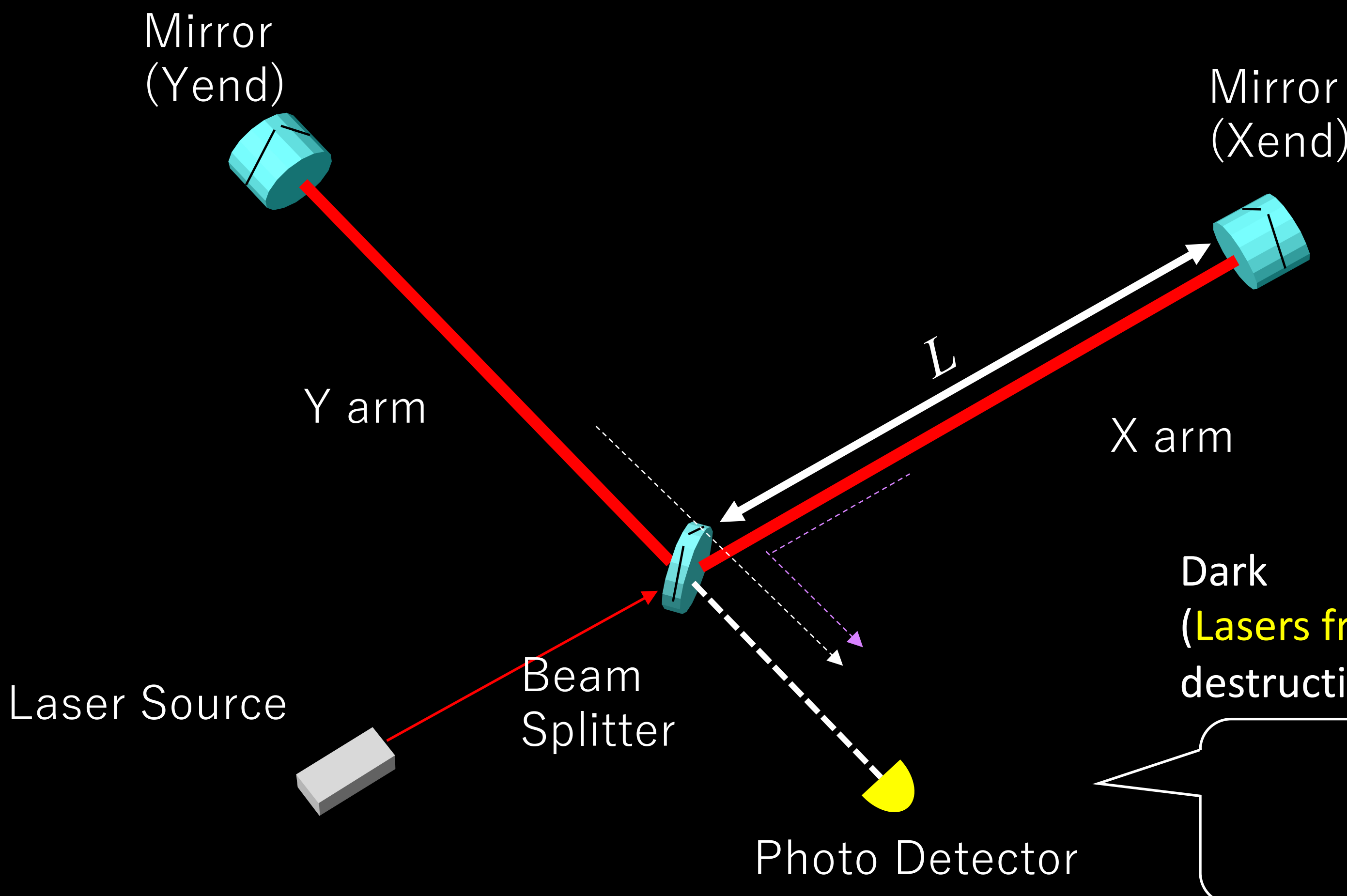


"Strain" (how much the stretch-squeeze per meter)

$= 10^{-10}m \; / \; 10^{11}m$

$= 10^{-21}$

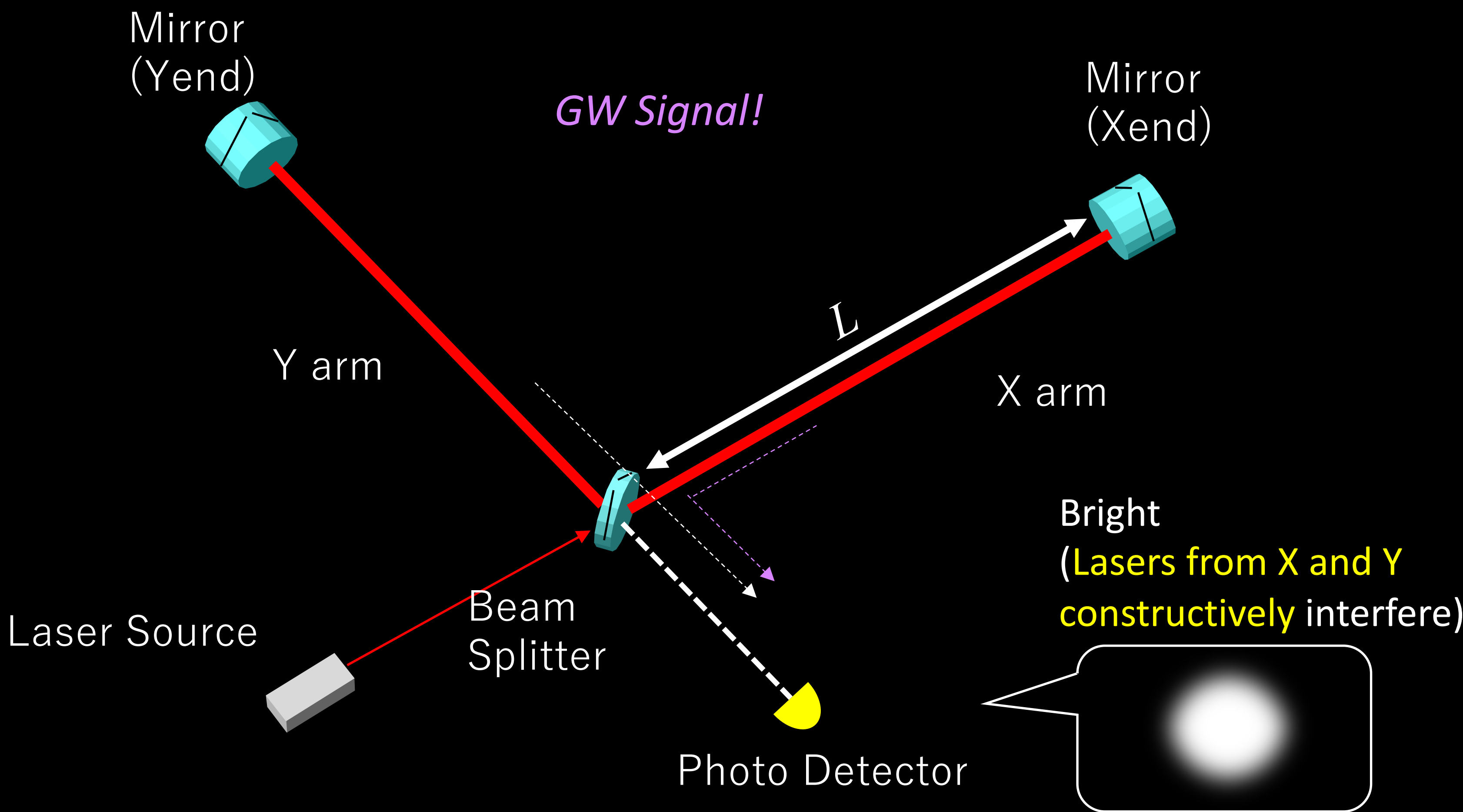
Detector: Laser Interferometer



Dark
(Lasers from X and Y
destructively interfere)

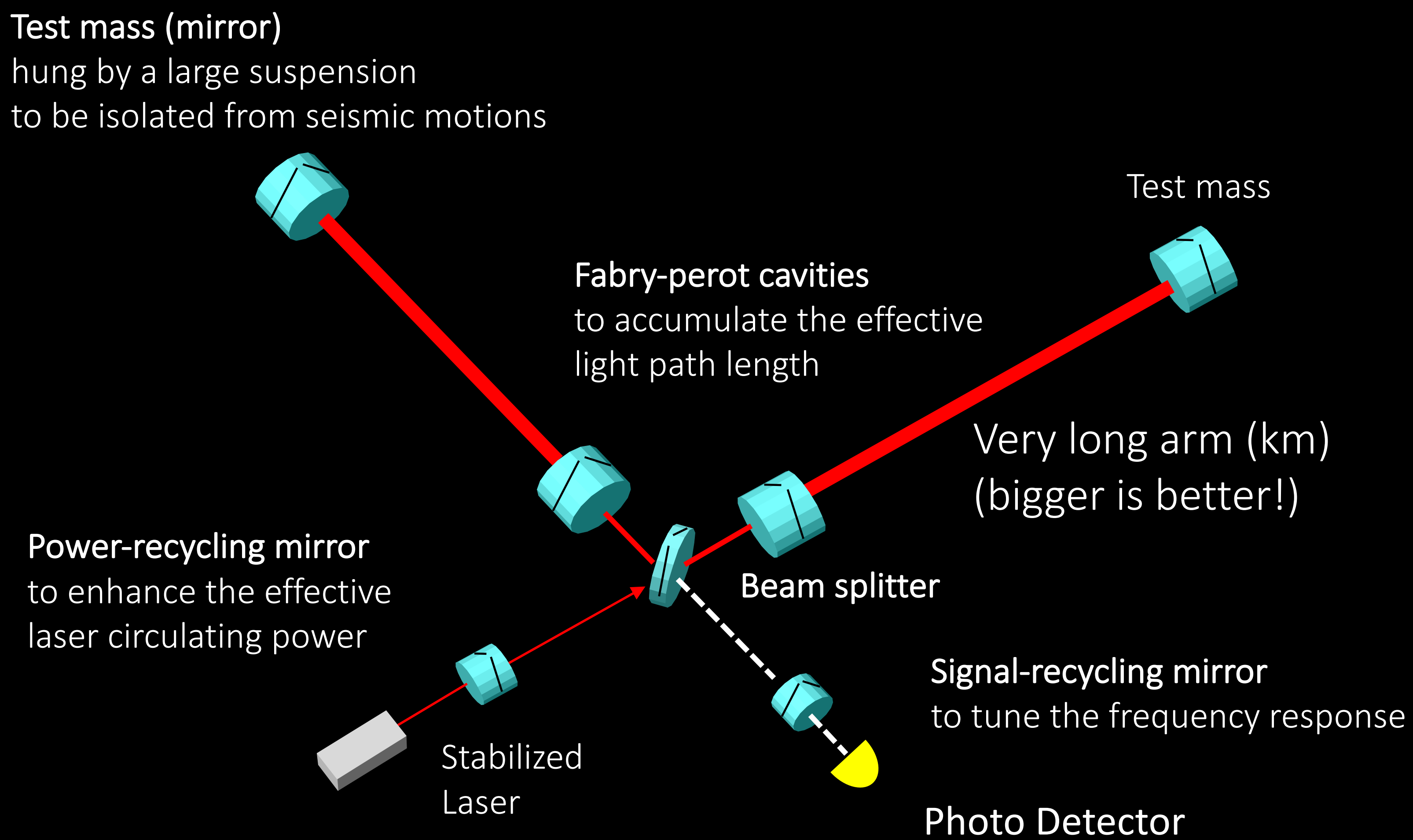
Optical sensor detecting the length difference between X and Y arms

Detector: Laser Interferometer

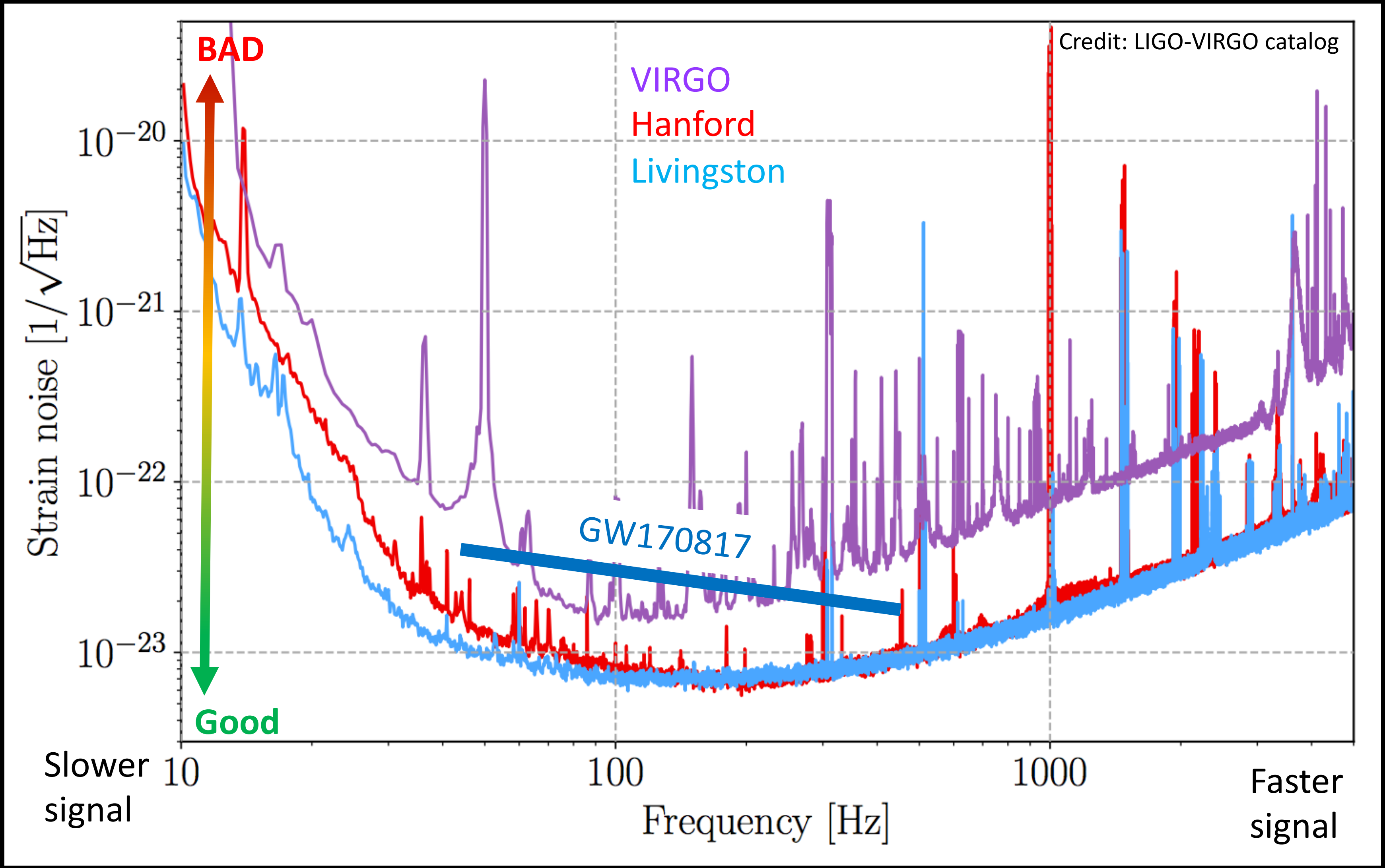


Optical sensor detecting the length difference between X and Y arms

"Actual" Modern Detectors



“Actual” Sensitivity

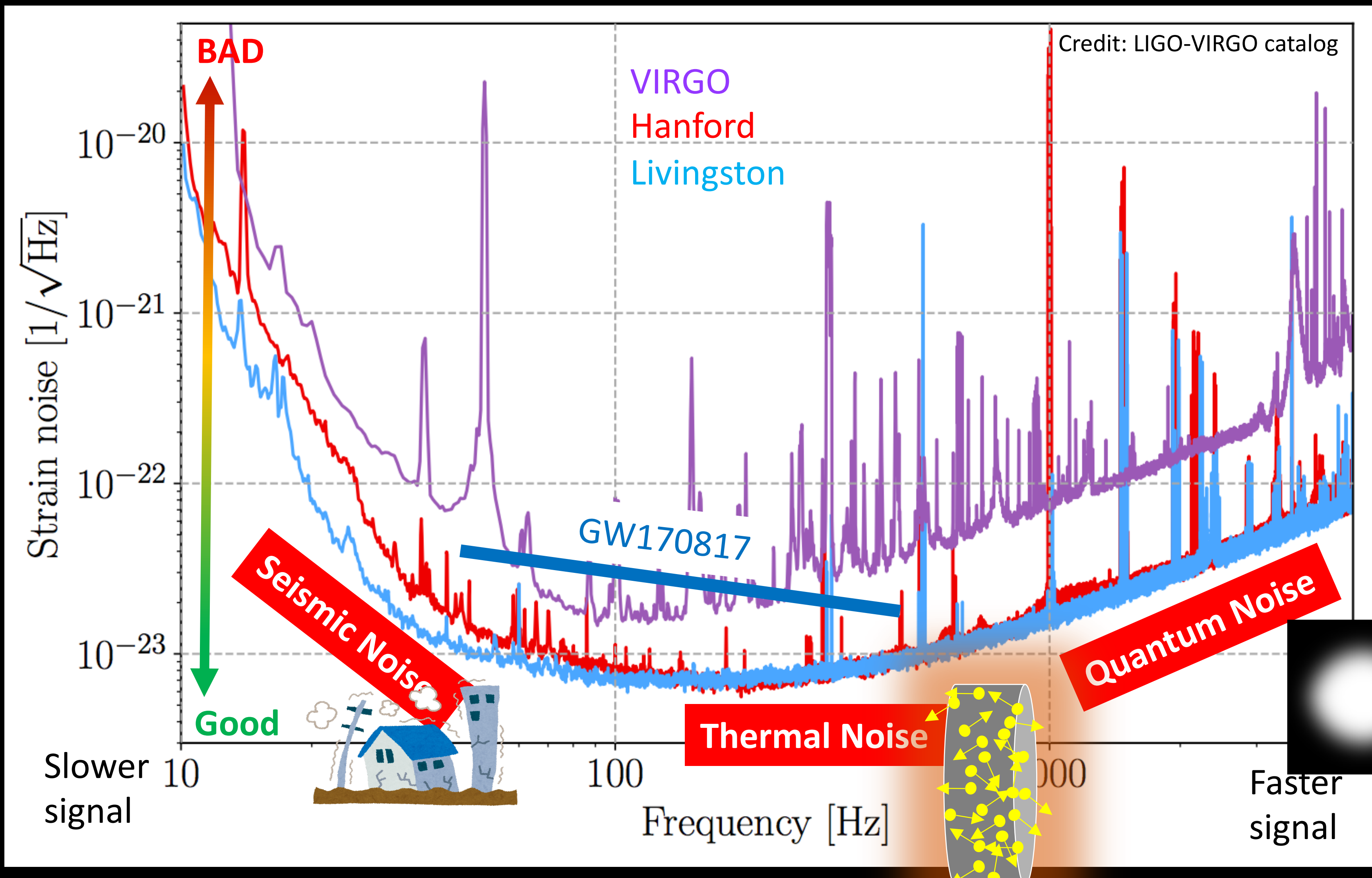


Slower signal

Faster signal

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

“Actual” Sensitivity

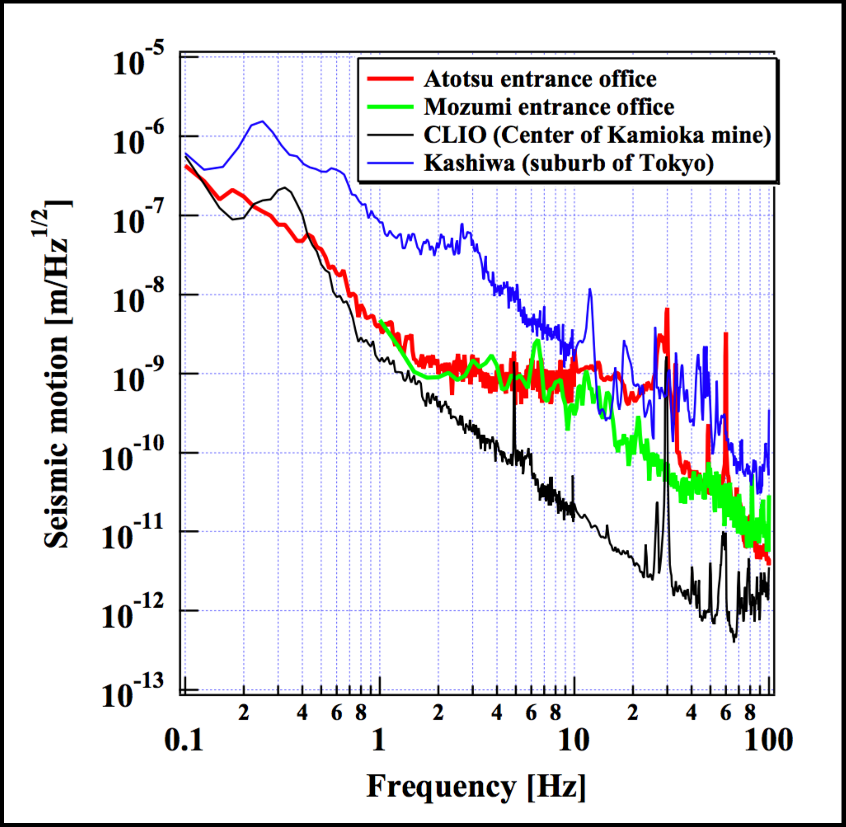


Note that the detector directionality isn’t taken into account for GW170817 line

Reducing Seismic Noise

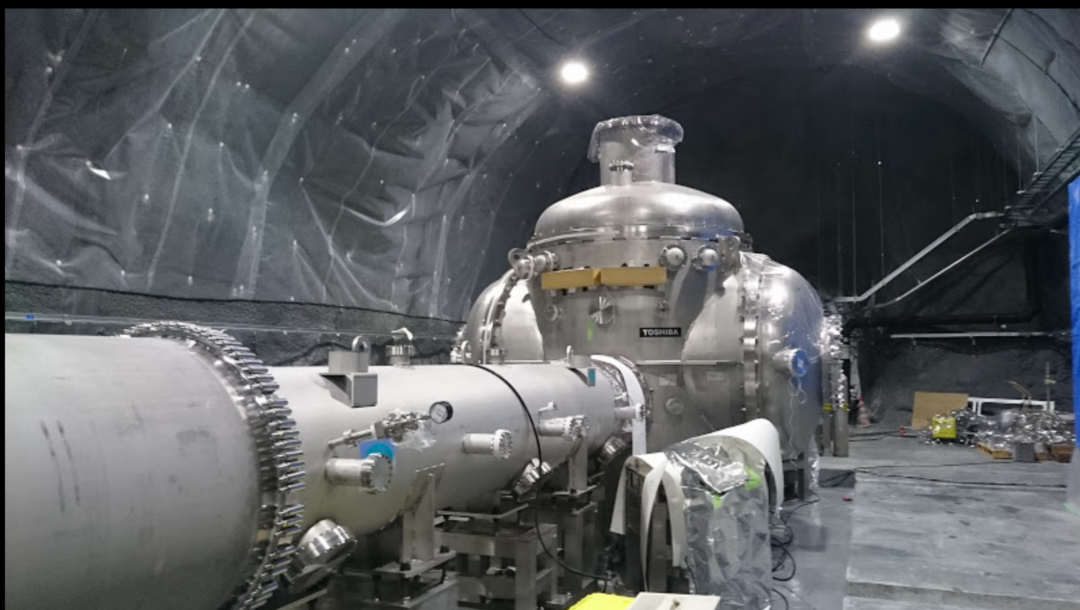
◀ KAGRA
Tower type Large suspension

▼ Ground motion of underground site

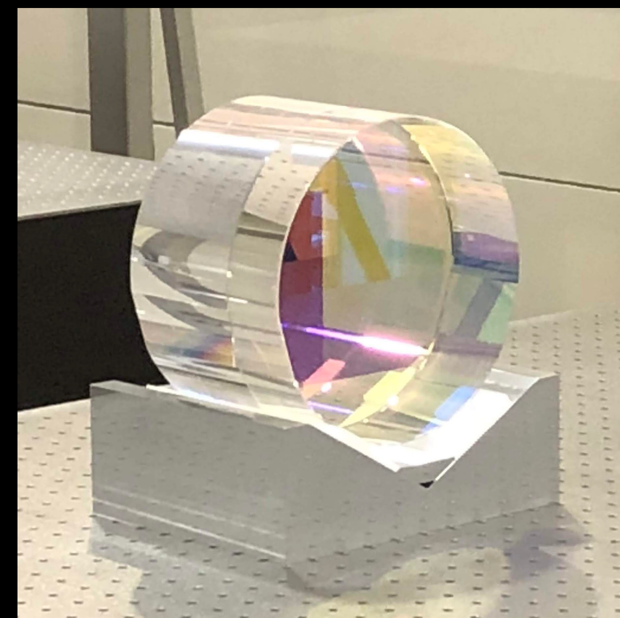


Reducing Thermal Noise

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

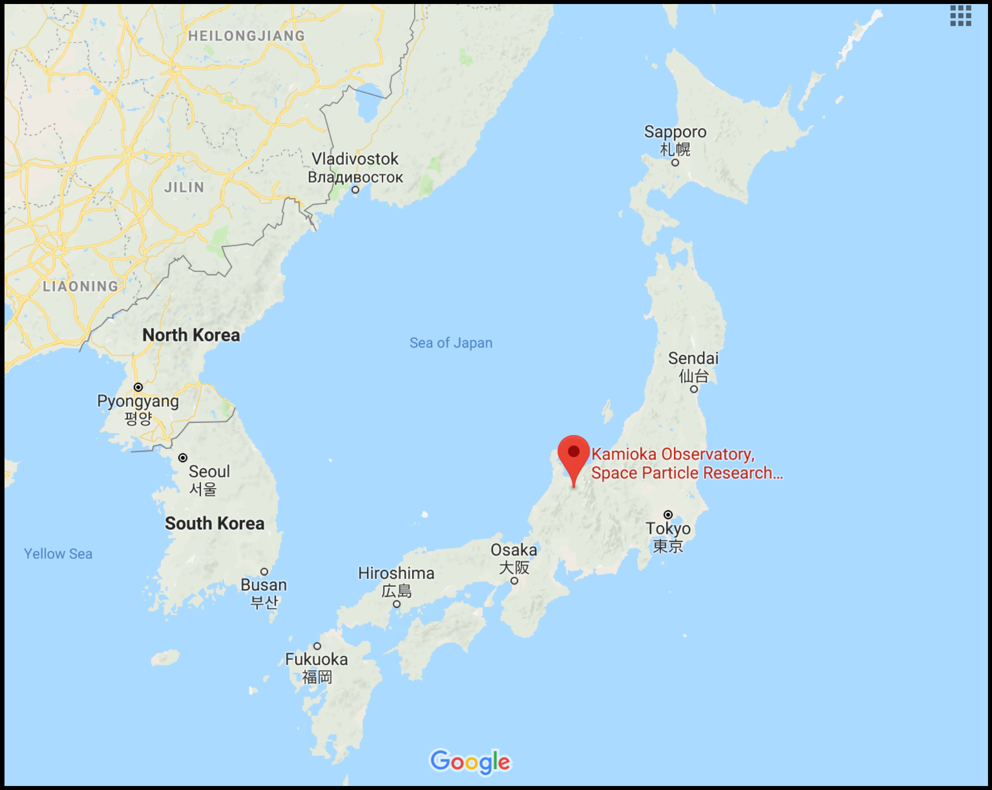


Cool mirrors down to 20K



Sapphire mirrors
Q=>big in cryogenic

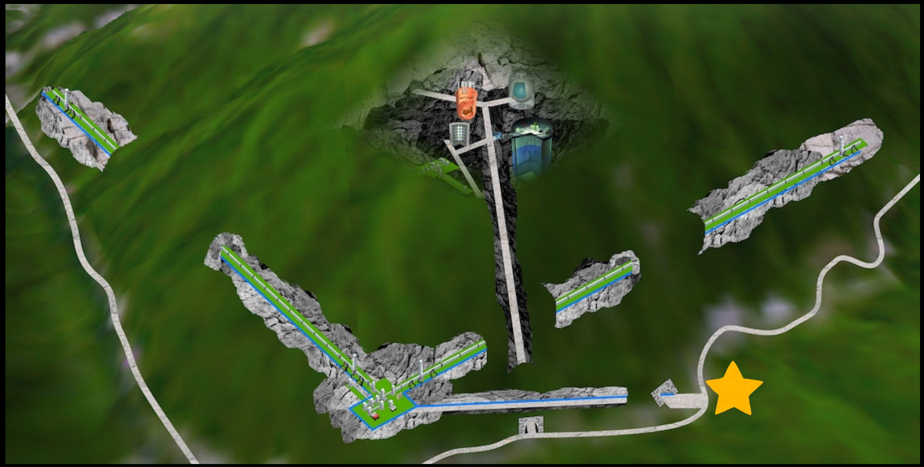
The 4th Detector, KAGRA in Kamioka, Japan

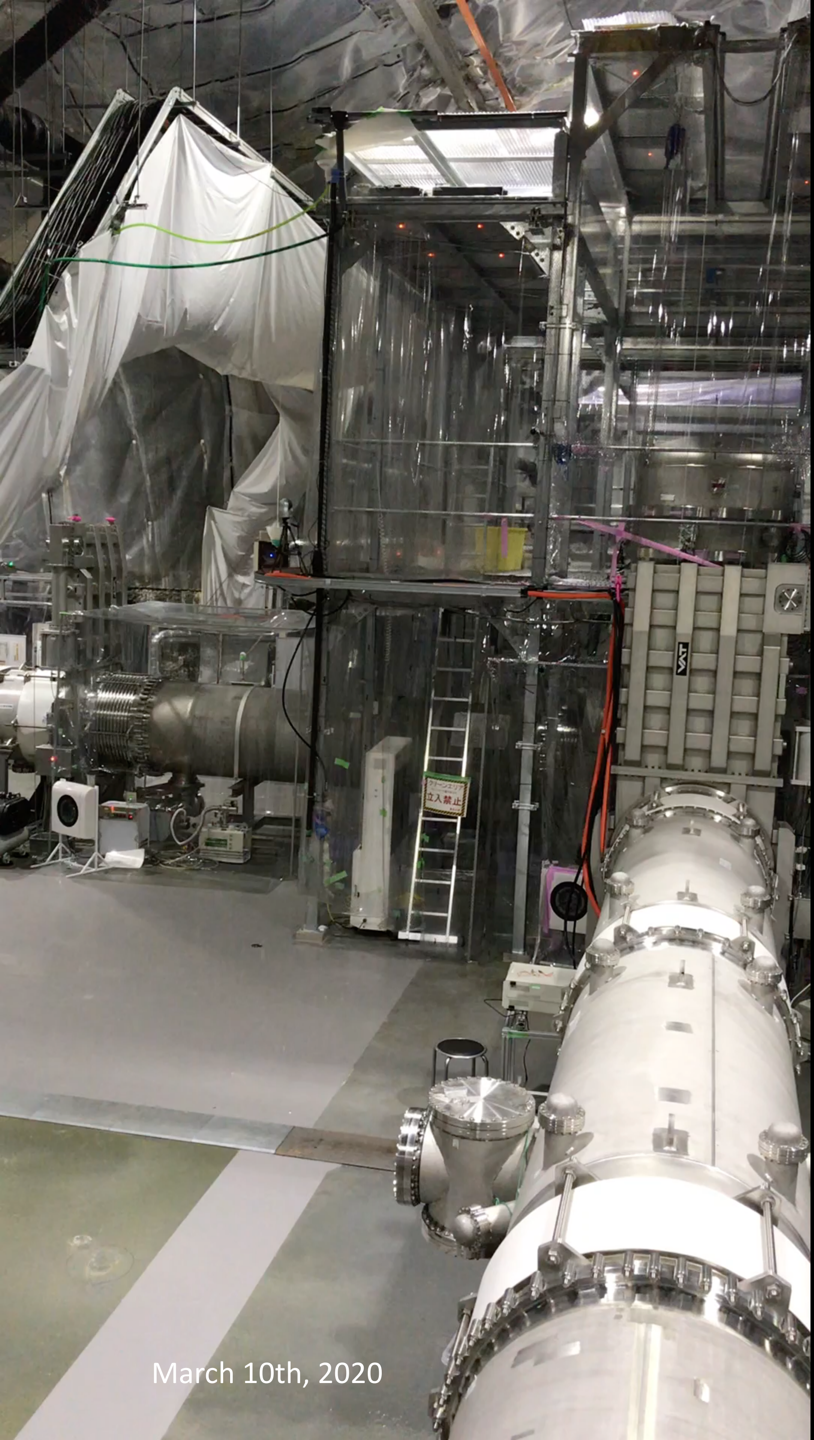


Underground and Cryogenic Detector


KAGRA Map
Toyama bay
Toyama city
Mt. Ikenoyama
Other
Underground
experiments
3km tunnel
3km tunnel
Route 41
Tunnel
Entrance

離合場所
禁止





Laser Room

Pre-Mode cleaner

Intensity noise stabilization

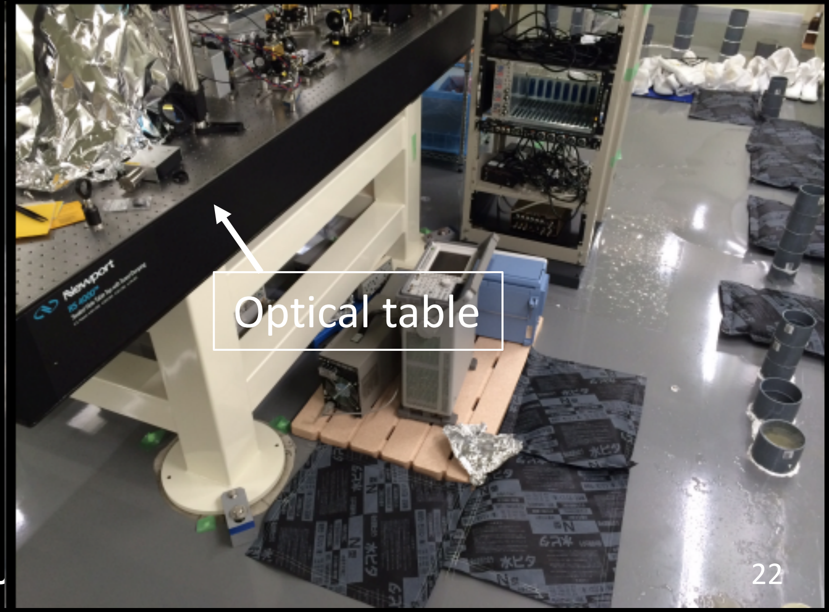
Mach-Zehnder Modulator

Frequency stabilization Reference cavity

Frequency stabilization
Laser spatial mode cleaning
Mode matching to the main interferometer…etc

Unexpected (1): Floods!

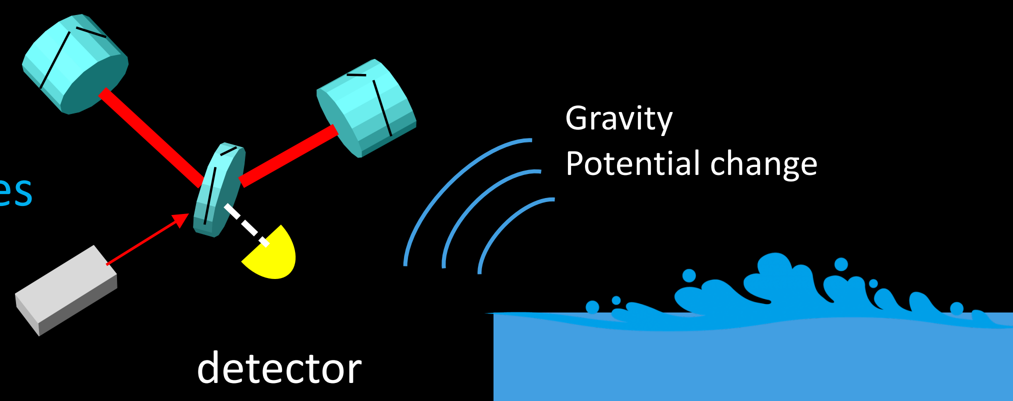
Laser room flooded by underground spring water!



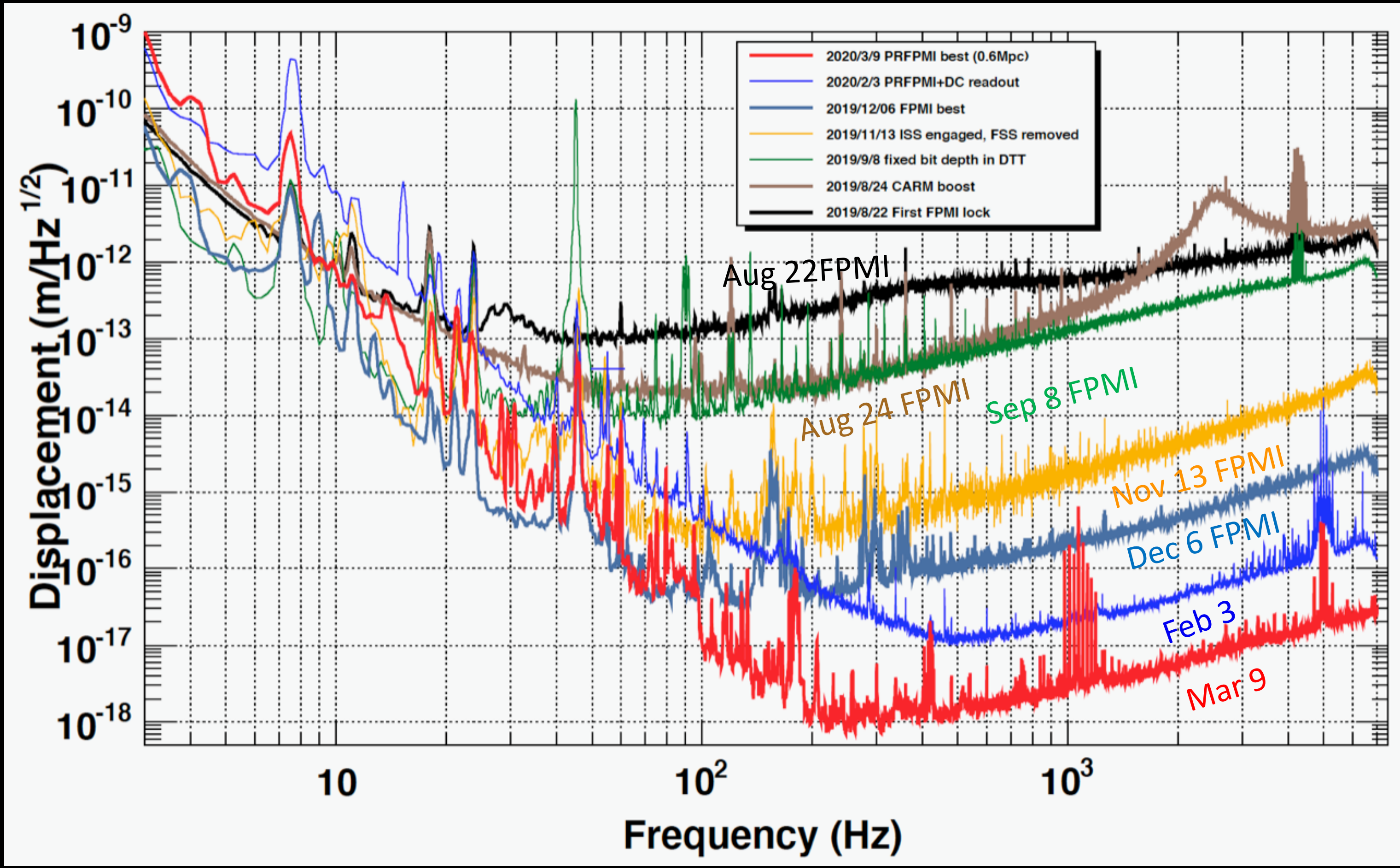
Unexpected (1): Floods!

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

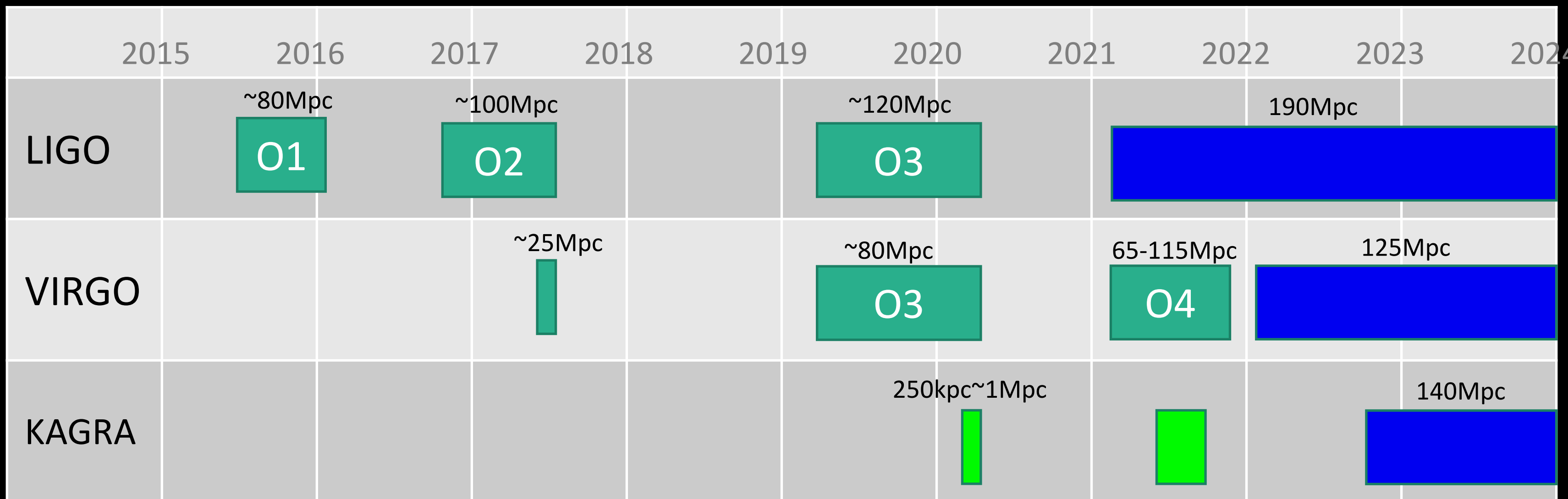


Sensitivity Improvements



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

Prospects of Current Facilities



Living Reviews in Relativity volume 21, Article number: 3 (2018)

- Observation and commissioning (sensitivity improvement) happens
- After O3, all the detectors go on the commissioning
- KAGRA will reach more reasonably sensivitiy for the next run