KAGRA Large-scale Cryogenic Gravitational wave Telescope Project in Japan

KAGRA Collaborators

ICRR, Univ. of Tokyo
National Astronomical Observatory of Japan,
High Energy Accelerator Research Organization,
Phys.S. Univ. of Tokyo,
GSFS Univ. of Tokyo,
F.Eng. Univ of Tokyo,
Tokyo Institute of Technology,
Osaka City Univ.,
Phys.S. Kyoto Univ.,
Electro Communication Univ.,
ERI. Univ of Tokyo,
Astro. Univ. of Tokyo,
Hosei Univ., AIST, NICT,
Phys.S. Osaka Univ.,
YITP Kyoto Univ.,
Phys.S. Ochanomizu Univ.,
ARISH Nihon Univ.,
S.Niigata Univ.,
Yamanashi-Eiwa Univ.,
CIT Nihon Univ.,
FST Hiroasaki Univ.,
S. Tohoku Univ.,
S. Rikkyo Univ.,
S. Hiroshima Univ.,
S. Ryukyu Univ.,
FSE Waseda Univ.,
Gunma Astronomical Observatory,
Sokendai, Teikyo Univ.,
Max Plank Inst. AEI,
California Institute of Technology,

KAGRACollaborators

Phys.S. Univ. of Western Australia,
Louisiana State Univ.,
CCRG Rochester Institute of Technology,
Beijing Normal Univ.,
Inter-University Center for Astronomy and Astrophysics, Moscow Univ.,
LATMOS/CNRS,
Univ. of Science and Technology of China,
Inst. for High Energy Physics of Chinese Academy of Sciences,
Peking Univ.,
CMS ITR Taiwan,
Maryland Univ.,
Columbia Univ.,
Glasgow Univ.,
Sannio Univ.,
Shanghai Normal Univ.,
National Tsing Hua Univ.,
Korea Univ., KIAS,
Inje Univ., Korea Univ.,
Yongji Univ.,
Seoul National Univ.,
Korea Atomic Energy Research Institute,
Hanyang Univ.,
Pusan National Univ.,
KISTI, Korea NIMS,
Kyungpook National Univ.,
Kunsan National Univ.,
KIAS, IISER-TVM,
Recycled Fabry-Perot Michelson Interferometer with Resonant Sideband Extraction Technique.

- Fabry Perot Cavity
  - For Multi-reflection
- Power Recycling Technique
  - To reduce Shot noise
- RSE Technique
  - To modify Frequency response for GW
Km scale-GWDs in the world
Merits of GW detection network

- Convincing “True detection”
  - By coincidence of independent detectors.

- Determination of
  - Arrival time,
  - Polarization of GWs,
  - (in case of inspiral binary,) absolute amplitude and inclination angle of orbit.

- Duty time of observation
  - More GW events,
  - Chance of follow up observation.

- Sky coverage enhancement
KAGRA highlights that are different from other GWDs such as aLIGO, a VIRGO are...

1. **Underground**
   → Stable Operation owing to low seismic noise.

2. **Usage of Cryogenic Mirrors and suspensions**
   → Reduce Thermal Noises

3. **Collaboration with Geophysical Laser Strain-meter**
Merits (& demerits ) of Underground

• Out-band frequency range seismic noise at low frequency has nonlinear effect on in-band frequency range sensitivity in GWD. So lower seismic noise in out-band is desirable.
   → Smaller low-frequency motion of mirror
   → Lower gain of control system necessary
   → Lower in-band noise imposed by control system

• Low Gravity Gradient Noise
  on the other hand,

• We found the “water” in the mountain is annoying source in many practical aspects.
• We should check the “Gravity Gradient Noise” due to water flow near mirrors
Low Seismic noise Underground

By Rana (LIGO)
Kamioka Seismic Noise

Strain Meter Data (< 20Hz)

070215 : Stormy day
070213 : fine day

10 times enhancement of micro seismic noise due to ocean waves can be observed.

Both are limited by system noise over 1Hz.
Cryogenic Mirror and Suspension

• Thermal noise reduction using cryogenic mirror and mirror suspension.
• CLIO proto-type verified these properties.

Suspension Thermal Noise

Mirror Thermal Noise
KAGRA Road Map

2013

- Tunnel Excavation

2014

- Vacuum (15/3)

2015

- Type-A Cryo
- MI (15/12)
- DRMI
- Sapphire Test mass preparation

2016

- Under reconstruction

2017

- Tuning And Observation
- RSE
- Cryo-RSE

2018

- b-KAGRA

Experience of km-scale laser interferometer.
Michelson Interferometer Construction

Introduction of cryogenic mirrors and RSE technique to reach the targeted sensitivity.
initial-KAGRA (2010~2015.12)

- Construction Phase.
  - Tunnel
  - Vacuum
  - Facility

- Interferometer component design.

- 3km arm Michelson Interferometer construction.
  - Mirrors and suspension are set at 300K.
  - SiO2 Mirrors.
  - 2W level laser sources
  - Simple Mirror Suspension

- Short Observation (for thrashing out problems)
baseline-KAGRA (2016~2017, 18)

- Toward the Targeted Sensitivity ~ 280Mpc
  - Cryogenic mirrors and suspensions (sapphire)
  - 200W~ 25W Laser (Mitsubishi-Amp or Fiber-Amp)
  - RSE technique (Broadband or Detuned in Variable RSE)
  - DC readout technique
  - Output Mode Cleaner
  - SAS full operation
Inspiral Range of KAGRA

LCGT detection range (VRSE-D)

Detection Range (with optimal direction)
for CBC
for BH QNM
SNR=3
SNR=8
SNR=100

Cosmological Redshift, z
1.4M_{Solar} (Typical Neutron Star)

Luminosity Distance

mass of one star [M_{Solar}]
(BH mass = 2M)

280Mpc
Construction Status of KAGRA

- Mirror Cooling and suspension (CRY, CRY-p)
- Scattered light control (AOS)
- Large scale vacuum system (VAC)
- Seismic Noise Isolation (VIS)
- Input Output Optics (IOO)
- Sapphire Mirror (MIR)
- High Power and Stable Laser (LAS)
- IFO control, Data management, Data Analysis, Data Characterization (DGS, AEL, MIF, DMG, DAS, Det-char)
- Large scale vacuum system (VAC)
Excavation has started in May 2012.

Sometimes, we got a lot of water.
Blasting for 22 months from May 2012
Tunnel Excavation around 2013 August
Tunnel Completed in March 2014

Total 7700m excavation

Atotsu parking and SR-BS area

Atotsu Entrance
- **Slope of 1/300** was selected to drain the water to rivers.
- **Horizontal planes** for each station are prepared for easiness during installing vacuum tanks.
New Building for GWPO

KAGRA Control, Monitoring, Data Storage Room
~250 vacuum duct units (L=12m, d=0.8m) formed 3km arm, using metal gaskets. No leak was found. No baked, but ECB was adopted inside to minimize outgas.

Almost vacuum tanks have been set at their final position.

Minimum number of vacuum pumps will be prepared.
Vacuum Ducts and Chambers Set in FY2014

Y arm tunnel and vacuum tubes
Leak check was completed.

X arm tunnel and vacuum tubes
Leak check was completed.

Signal Recycling Tanks

Input Optics Tanks

Beam Splitter Tank in Clean Booth

VAC Group
Seismic noise isolation is one of essential requirements in GWDs. Not only in-band frequency range (10Hz ~ several kHz), but also out-band frequency (below 10Hz), it is important to obtain low seismic noise to avoid “up-conversion seismic noise”.

- Highest performance SAS for the main four sapphire mirrors (type-A).
- Less performance isolators than Type-A for silica mirrors that form main parts of IFO (Type-B, Type-Bp, Type-Bp’).
- Simple isolators for MC mirrors and small optics. (Type-C)
Super Attenuation System (Type-A) - for sapphire mirrors -

- Upper tunnel containing pre-isolator (short IP and top filter)
- 1.2m diameter 5m tall borehole containing standard filter chain
- Lower tunnel containing cryostat and payload
Super Attenuation System (Type-A) - for sapphire mirrors -

Payload

Top filter [Filter0] and Inverted Pendulum (IP)

Geometric Anti-Spring (GAS)
Filter1 (Filter1~3 in Type-A)
Pendulums (Type-B)

- Simplified Type-A -

Pre-isolator

- Top filter [Filter0]
- Inverted Pendulum (IP)

Filter chain

- Geometric Anti-Spring (GAS)
- Filter1 (Filter1~3 in Type-A)

Payload

- Bottom Filter (BF)
- Intermediate Mass (IM)
- Intermediate Recoil Mass (IRM)
- Test Mass (TM)
- Recoil Mass (RM)

VIS Group
Blades and fishing rod are mounted onto the base plate.

Maraging blade springs made by NAOJ-ATC

Assembled bottom filters in ATC
All of system was assembled with cabling by the side of the chamber. The full system was hung by a crane and installed into the chamber from the top. The system is working in vacuum now.
Pre-stabilized laser (PSL) was developed and tested at Kashiwa, and the performance was OK.

PSL is being installed in Kamioka. The pre-mode cleaner was locked.

Input Faraday isolator has been assembled, and the performance was measured to be OK.

The mode cleaner suspensions were assembled and tested at NAOJ. One suspension system has been installed in Kamioka.
Laser Source for bKAGRA

Laser should have...

- Power > 180 W
- Single frequency of 1064 nm
- Low frequency noise
- Stable linear polarization
- Stable single transverse mode (TEM00)

- Low intensity noise
- Wide-band control for stabilization systems
  - About 1 MHz for frequency control
  - About 100 kHz for intensity control

![Diagram of laser source for bKAGRA](image)
• 78.9 W was achieved by coherent addition
• 210 W was achieved by solid-state amplifiers
• Coherent addition was maintained for 8 hours
• Output power changed in time
• Atmosphere temperature changed in time
• Noise peak in Intensity & phase noise–18 kHz
• Stabilize output power–Stabilize temperature?
• Evaluate the noise of the 210-W beam
• Beam quality is ugly.
• Diminish the 18 kHz noise peak–Change fiber stretchers?
**Laser Quality**

- **78.9 W Coherent Addition Laser**
- **190 W amplified and mode improved Laser (210 W -> 190W because of realignment of the Amplifiers)**
Digital Control System

DGS is indispensable for GWD control including many of freedoms, quick trouble shooting, quick trial and error, data storage, GW signal analysis and GW signal evaluation.

- KAGRA DGS is based on aLIGO helps.
- Real time control of SAS, IFO length and alignment, pre-stabilized laser using reflective memory, and sequence control of an interlock system.
- Data taking and storage of IFO output (= GW signals) and many detector characterization data in IFO,
- Timing control.
- Mainly signals less than ~10kHz management.
LIGO Digital Control System Introduction
And it's Demonstrated in CLIO

• AutoLock -> Measure -> Improve process by using script.
Network Design for Controls and DAQ

RFM RT control signal: very low latency
DAQ GW data: huge amount, low latency
Timing: Synchronization for all RT PC and ADC/DAC
TCP/IP: EPICS, NFS, network boot

GWADW 2013 at Elba, Osamu Miyakawa
Remote Control Room in DAB

- Computer room at front area in the mine: end of December of 2014
- Cooler in the computer room: beginning of January of 2015
- Movement of racks, computers, DC powers: Jan.15
- Network connection: Feb.18~
- Start of supplying main power: Feb.19
- Construction of electric panel for 20A: Feb-March of 2015
- Connection to VIS, needs some circuits→ June? by budget limit.

DGS Group
Cryostats

Cryostat for mirror cooling is essential in KAGRA. Requirement for cryostats are …

- Temperature of the test mass/mirror < 20 K.
- Inner radiation shield have to be cooled < 8 K.
- The mirror have to be cooled without introducing excess noise, especially vibration from the cryo-coolers.
- Accessibility and enough volume for the installation work around the mirror.
- Satisfy ultra high vacuum specification < 10^{-7} Pa.
Conceptual Cooling System

- Four 4K cryocooler units per one cryostat
- Baffles against wide scattering is cooled via 8K shield.

CRY Group
**Cryostat Installation in KAGRA**

Progress of the cryostat assemble:

- **EXC & EYC** were assembled as vacuum vessels *without* duct shields and cryo-coolers from the end of 2014.11 to the end of 2015.1.
- **IYC & IXC** were assembled *with all of components such as duct shields and cryo-cooler units* from the end of 2015.2 to the mid of 2015.4.
Cryostat Installation in KAGRA

Assembled Cryostat Photos

Reached pressure in the Y-front cryostat: 3.7x10^-7 kPa

CRY Group
Cryostat and Clean Booths

Y arm End Cryostat

Y arm Near Cryostat

X arm End Cryostat

X arm Near Cryostat
Leak Test of Cryostats

X&Y-end cryostats
• Leak test were cleared based on KAGRA requirement
  \( < 1 \times 10^{-10} \text{ Pa} \cdot \text{m}^3/\text{sec} \)
• No excess leak found above the background
  \( \sim 1 \times 10^{-12} \text{ Pa} \cdot \text{m}^3/\text{sec} \)

X&Y-front cryostats
• At leak test,
  two small leak spots \( < 1 \times 10^{-9} \text{ Pa} \cdot \text{m}^3/\text{sec} \) were founded by the reason of malfunction of gaskets.
• It should be replace until mid of September 2015.
Sapphire Mirror Suspension

Sapphire mirror suspension is essential in KAGRA. Requirement for sapphire mirror suspension (wires) are...

- High tolerance for tension to suspend 30kg sapphire mirror.
- High thermal conductivity to extract heat from the mirror.
- Low mechanical loss of fibers (wires) and their fixing on mirrors ($< 10^{-8}$).
- Easy assembly.
- Satisfy ultra high vacuum specification $< 10^{-7}$ Pa.

The solution is to use sapphire fibers (almost rods)
Mirror Suspension using Sapphire Fibers

- KAGRA Sapphire mirrors are designed to be suspended by sapphire fibers to obtain heat drain path and to reduce suspension thermal noise.
- Because bonding attachment is hopeless for sapphire fibers, nail heads shape is desired to huck sapphire mirrors.

Property Checks are required about ...
- Mechanical Loss
- Thermal Conductivity
- Strength (bending, sheer, tensile)

in Univ. of Tokyo, Jena Univ. and Roma Univ.
Mirror Suspension using Sapphire Fibers

1. Sapphire lop-eared suspension
   - A part of cryo-payload
   - Main sapphire mirrors are included.
   - All parts are made from sapphire.
Auxiliary Optics

IFO control is supported by many auxiliary systems including...

- Stray Light Control (SLC) mainly to reduce scattered light noise in the sensitivity, and to avoid hazard (damage on optics, fibers) in IFO and suspension.
- Beam Reducing Telescopes to handle the large diameter laser beam from the both Fabry-Perot cavities in small size optics to monitor the FP cavity resonance and stability.
- Optical Levers to identify the mirror alignment at their local position to keep IFO mirrors’ best positions.
- Viewports to inject and extract laser beams into/from vacuum area.
- Monitors (CCD cameras) and Illumination to know the many cavities resonances in IFO from the brightness on mirrors.
Scattered Light Control and Others

- Viewports
- Optical Levers (OpLev)
- iKAGRA Beam Reducing Telescopes (BRT)
- Stray Light Control (SLC)
- Beam Reducing Telescopes (BRT)
- Baffle for SLC
Mirror Substrate for b.KAGRA

- Al2O3 -

Sapphire for b.KAGRA ( = KAGRA)

• A-axis crystal (φ22 cm x t15 cm) has been obtained.
• Max size of C-axis crystal is now φ22cm x t15cm; this size is limited by the height of the boules of a machine in Crystal Systems LAOS Inc.
• Several C-axis crystals (φ22 cm x t15 cm) have been also obtained. Now the quality check is on going.
• Shinkosha (Japanese Company) might be able to large size low loss sapphire substrate. Shinkosya can make C-axis growing crystal.
Mirror Substrate for Others

- SiO2 -

• SiO2 Mirrors (Ø250 x t100) for PR2, PR3, SR2, SR3 (Corning), ITMs and ETMs (Heraeus).
• Coating was done in ICRR and LMA.
• Polishing by ZYGO.

On the other hand.

• BS (Ø370 x t80),
• PRM, SRM
• MC(Ø100 x t30, flat & R=37.3m, w2.5deg) were produced by “Asahi Glass”
AQ2 Quality in Japan.
• Polishing and Coating by ZYCO, CIT, ICRR …
## Mirror Summary

<table>
<thead>
<tr>
<th>#</th>
<th>optic type</th>
<th>diameter (mm)</th>
<th>thickness (mm)</th>
<th>wedge (degrees)</th>
<th>mass</th>
<th>ROC</th>
<th>substrate</th>
<th>drawing</th>
<th>figure (mm) / aperture (mm)</th>
<th>micro roughness</th>
<th>test report</th>
<th>scatter (T/S)</th>
<th>absorption (coating)</th>
<th>HR transmission</th>
<th>AR reflection</th>
<th>absorption (bulk)</th>
<th>notes</th>
<th>status</th>
<th>location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S3</td>
<td>92.48</td>
<td>90.48</td>
<td>00716</td>
<td></td>
<td></td>
<td>ACO AQ2</td>
<td>D4-2225</td>
<td>S1: 159.7Tm@2020mm, S2: 179.6Tm@2020mm</td>
<td>0.20 µm</td>
<td>E5-E6 ppm</td>
<td>41.5%@1054mm, 62.9%@529mm</td>
<td>(3)ppm@1054mm, 0.63%@529mm</td>
<td></td>
<td></td>
<td>completed, being characterized</td>
<td>OT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>ET M01</td>
<td>250.75</td>
<td>99.65</td>
<td>2</td>
<td>7.26 km</td>
<td>Corning 7380</td>
<td></td>
<td></td>
<td>S1: 0.705R@2020mm, S2: 158.9R@2020mm</td>
<td>0.20 µm</td>
<td>E5-E6 ppm</td>
<td>41.5%@1054mm, 62.9%@529mm</td>
<td>(3)ppm@1054mm, 0.63%@529mm</td>
<td></td>
<td></td>
<td>WA4-K-X as is</td>
<td>JPR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>ET M02</td>
<td>250.98</td>
<td>99.93</td>
<td>2</td>
<td>7.32 km</td>
<td>Corning 7380</td>
<td></td>
<td></td>
<td>S1: 0.705R@2020mm, S2: 158.9R@2020mm</td>
<td>0.20 µm</td>
<td>E5-E6 ppm</td>
<td>41.5%@1054mm, 62.9%@529mm</td>
<td>(3)ppm@1054mm, 0.63%@529mm</td>
<td></td>
<td></td>
<td>WA4-K-Y as is</td>
<td>JPR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>TM05t</td>
<td>250.97</td>
<td>5042</td>
<td>(+001)</td>
<td>1.35 km</td>
<td>Heraeus Suprasil 3125</td>
<td></td>
<td></td>
<td>S1: 0.804Tm@2020mm, S2: 5.043Tm@225mm</td>
<td>0.20 µm</td>
<td>E5-E6 ppm</td>
<td>41.5%@1054mm, 62.9%@529mm</td>
<td>(3)ppm@1054mm, 0.63%@529mm</td>
<td></td>
<td></td>
<td>WA4-K-X modified</td>
<td>JPR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>TM05n</td>
<td>250.95</td>
<td>2045</td>
<td>(+001)</td>
<td>1.35 km</td>
<td>Heraeus Suprasil 3125</td>
<td></td>
<td></td>
<td>S1: 0.804Tm@2020mm, S2: 5.043Tm@225mm</td>
<td>0.20 µm</td>
<td>E5-E6 ppm</td>
<td>41.5%@1054mm, 62.9%@529mm</td>
<td>(3)ppm@1054mm, 0.63%@529mm</td>
<td></td>
<td></td>
<td>WA4-K-Y modified</td>
<td>JPR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>FR1</td>
<td>249.98</td>
<td>84.4 (center)</td>
<td>2.019</td>
<td>249.185Tm@220mm</td>
<td>Corning 7340</td>
<td>D4-2225</td>
<td></td>
<td>S1: 0.804Tm@2020mm, S2: 5.043Tm@225mm</td>
<td>0.20 µm</td>
<td>E5-E6 ppm</td>
<td>41.5%@1054mm, 62.9%@529mm</td>
<td>(3)ppm@1054mm, 0.63%@529mm</td>
<td></td>
<td></td>
<td>being coated LMA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>FR2</td>
<td>249.97</td>
<td>84.3 (center)</td>
<td>2.042</td>
<td>249.185Tm@220mm</td>
<td>Corning 7340</td>
<td>D4-2225</td>
<td></td>
<td>S1: 0.804Tm@2020mm, S2: 5.043Tm@225mm</td>
<td>0.20 µm</td>
<td>E5-E6 ppm</td>
<td>41.5%@1054mm, 62.9%@529mm</td>
<td>(3)ppm@1054mm, 0.63%@529mm</td>
<td></td>
<td></td>
<td>being coated LMA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>SR1</td>
<td>249.83</td>
<td>84.5 (center)</td>
<td>2.029</td>
<td>249.185Tm@220mm</td>
<td>Corning 7340</td>
<td>D4-2225</td>
<td></td>
<td>S1: 0.804Tm@2020mm, S2: 5.043Tm@225mm</td>
<td>0.20 µm</td>
<td>E5-E6 ppm</td>
<td>41.5%@1054mm, 62.9%@529mm</td>
<td>(3)ppm@1054mm, 0.63%@529mm</td>
<td></td>
<td></td>
<td>being coated LMA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>SR2</td>
<td>250.48</td>
<td>95.1 (center)</td>
<td>2.098</td>
<td>-2.991Tm@40mm</td>
<td>Corning 7340</td>
<td>D4-2225</td>
<td></td>
<td>S1: 0.804Tm@2020mm, S2: 5.043Tm@225mm</td>
<td>0.20 µm</td>
<td>E5-E6 ppm</td>
<td>41.5%@1054mm, 62.9%@529mm</td>
<td>(3)ppm@1054mm, 0.63%@529mm</td>
<td></td>
<td></td>
<td>being coated LMA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>MCe</td>
<td>95.45</td>
<td>29.45 (thick end)</td>
<td>2.5</td>
<td>29.45Tm@30mm</td>
<td>ACO AQ2</td>
<td></td>
<td></td>
<td>0.30mm@500nm (w/o cover)</td>
<td>0.129mm@70mm</td>
<td>1.5ppm@100mm</td>
<td>4.7ppm@center</td>
<td>17+3ppm@600mm</td>
<td>N/A</td>
<td></td>
<td>completed JPR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>MG</td>
<td>95.97</td>
<td>52.45 (thick end)</td>
<td>2.5</td>
<td>52.45Tm@30mm</td>
<td>ACO AQ2</td>
<td></td>
<td></td>
<td>0.30mm@500nm (w/o cover)</td>
<td>0.069mm@500mm</td>
<td>4.6ppm@600mm</td>
<td>40.0@600ppm</td>
<td>41.0@600ppm</td>
<td>N/A</td>
<td></td>
<td>completed JPR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>MCe</td>
<td>95.95</td>
<td>29.50 (thick end)</td>
<td>2.5</td>
<td>29.50Tm@30mm</td>
<td>ACO AQ2</td>
<td></td>
<td></td>
<td>0.30mm@500nm (w/o cover)</td>
<td>0.101mm@70mm</td>
<td>2.8ppm@600mm</td>
<td>0.69@2ppm</td>
<td>30.0@30ppm</td>
<td>N/A</td>
<td></td>
<td>completed JPR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>ET M01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CSIL505</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>JPR</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>ET M02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CSIL505</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>JPR</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>TM01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CSIL505</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>JPR</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>TM02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CSIL505</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>JPR</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>ET M01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CSIL505</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>JPR</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>ET M02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CSIL505</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>JPR</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>TM01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CSIL505</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>JPR</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>TM02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CSIL505</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>JPR</td>
<td></td>
</tr>
</tbody>
</table>
MIR (Mirror)

Check: surface radius, roughness, homogeneity, birefringence, heat absorption.

Beam Splitter
(37cm x 8cm, SiO₂)

Sapphire
(22cm x 15cm, Al₂O₃)
Detector Characterization

• Development of monitor tools
  • Non-gaussianity monitor tools and ν estimation process (non-gaussianity parameter) was verified using non-gaussian noise model.
  • Online DetChar cluster is installed.
  • Almost all important diagnostics tools are prepared.
  • Magnetic fields and seismic activities at the KAGRA site were measured.
Data Analysis

- **Compact Binary Coalescence (CBC) status**
  - Frequency domain matched filtering (MF) (ICRR Cluster): pipeline development.
  - Low latency analysis (time domain MF) (Osaka CU): components preparation.
  - Bayesian parameter estimation: Basic study with KOREAN group
  - Alert sending system for EM partners (multi-messenger astronomy): investigation about LIGO VIRGO case.

- **Burst status**
  - Development of single detector search pipeline.
  - Data Retrieving, Data Conditioning, Event Selection: implemented.
  - Parameter Estimation: In progress.

- **Continuous Wave(CW) status**
  - Study of LAL.
  - Development of Matlab codes using the resampling technique.
  - Radiometry GPGPU code has been developed.

- **KAGALI Development**
  KAGRA data analysis subsystem develops our own data analysis library called KAGra Algorithmic Library or “KAGALI” in short.
Data Management

- Data transfer between each computer system (ICRR-KAGRA, ICRR-Kashiwa, OCU, RESCEU).

- GRID transfer Tests (Nagaoka, RESCEU)
  - Simple transfer test succeeded in 2014.
  - Overview design is proceeding.
  - Software (DMG pipeline) development must be done fast!
  - Pipeline includes a processing of ‘calibrated data’.
Baseline Interferometer

Purpose and Targets

1. Baseline monitor for KAGRA (Tides, earthquakes, crustal deformation... in the middle of Niigata Kobe Tectonic Zone)
2. Fault-creep monitor for the Atotsu fault
3. Deep interior of Earth (Monitoring Earth’s free oscillations)
1500m Baseline IFOs in both arms
Iodine-stabilization System in CLIO

Frequency stability $dv/v \sim 10^{-13}$
Construction Status in KAGRA

- **Site construction (X-arm)**
  - Clean booth construction underway

- **I$_2$ stabilized lasers**
  - Two units being ready for stability evaluation (beat measurement)

- **Optical components**
  - In-vacuum optics: to be installed after vacuum test
  - Out-vacuum optics: ready for installation
Summary

- Fundamental techniques for KAGRA have been prepared by TAMA and CLIO and KAGRA Collaborators.
- KAGRA started in 2010.
- Tunnel was finished in FY2013, facility including clean booths and vacuum system were done in FY2014.
- The iKAGRA is planed in December 2015.
- The bKAGRA will start after iKAGRA short observation.
- Although there are many to do in the future tasks and problems in the finished tasks, we keep proceedings and improving them step by step.