KAGRA

Masatake OHASHI (ICRR)

General outline of KAGRA Project

KAGRA is 3km L-shaped underground laser interferometer with cryogenic mirrors

Project framework

- ICRR hosts this project, and KEK and NAOJ co-host it to construct KAGRA for gravitational wave astronomy
  Univ. of Toyama also supports it.

Purpose of this project

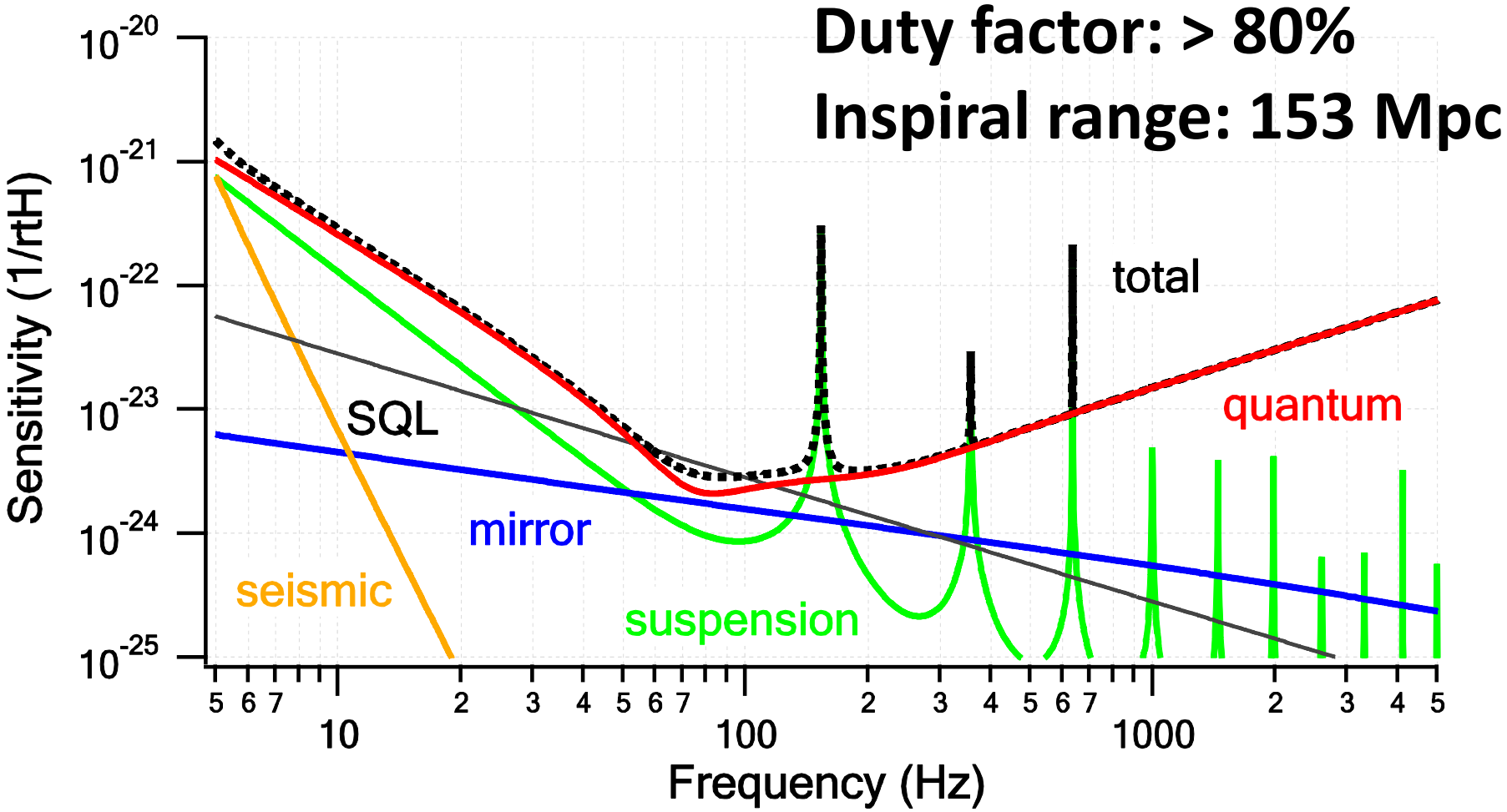
- To understand astronomical phenomena like supernovae explosion and coalescence of binary compact stars with gravitational waves .

Expected Science with Gravitational Waves

NS=Neutron star, BH=Black Hole

- Binary black hole merger
  - Testing GR（QNM, No hair theorem, . . .）
  - Testing modified theory of gravity
- BNS, BH-NS mergers
  - Relation to Gamma Ray burst
  - Equation of state and internal structure
  - Relation to r-process nucleosynthesis
- Supernova explosions
  - Explosion mechanism
- Test of polarization modes of GW
- …

Ultimate sensitivity of KAGRA



Two key features of KAGRA

1. KAGRA is constructed at underground site.

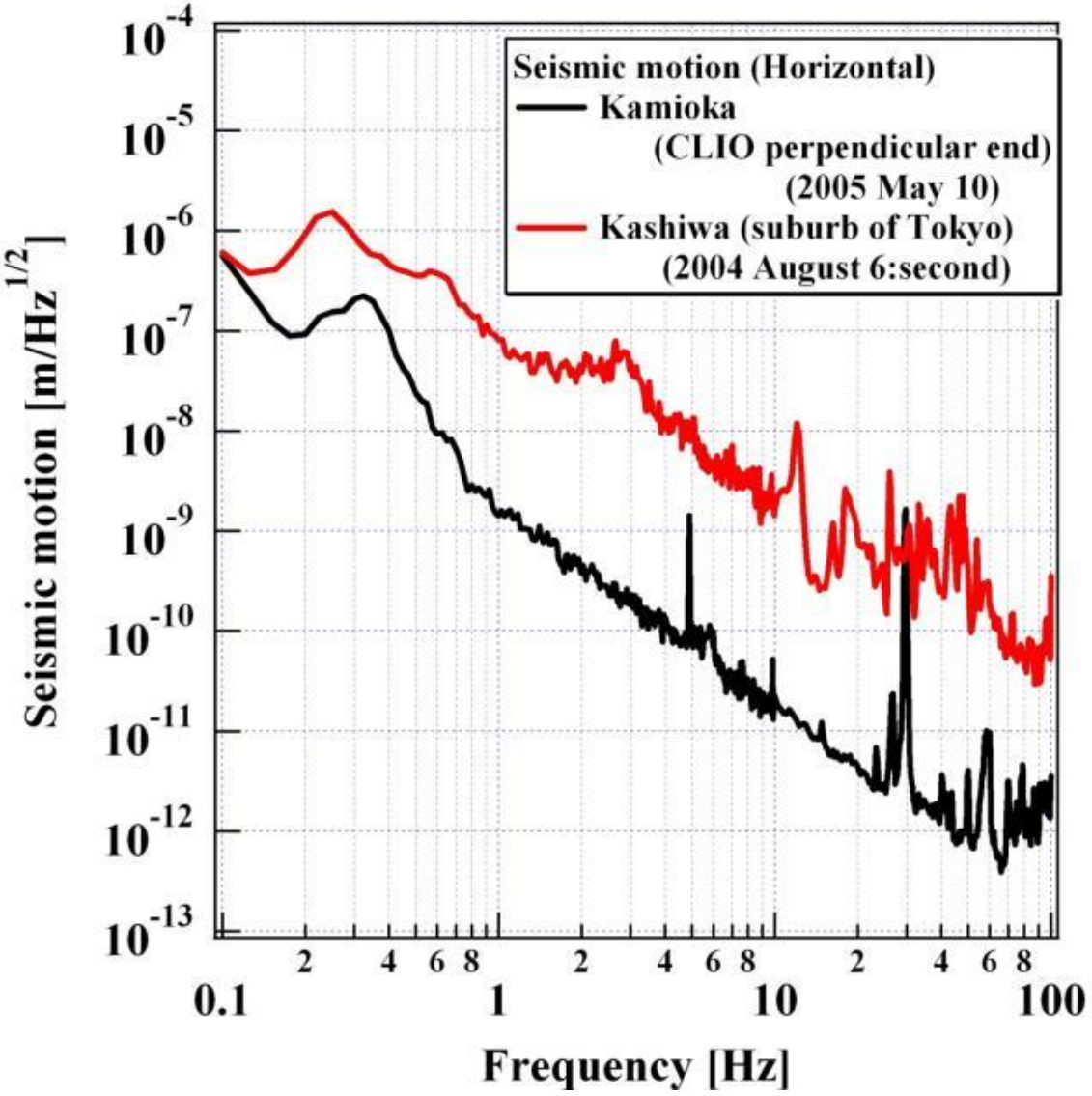
2. KAGRA uses cryogenic mirrors.

Seismic noise in Kamioka Mine

Seismic noise is serious for GW detection.

Underground site Is very quiet.

So we selected underground site for KAGRA.

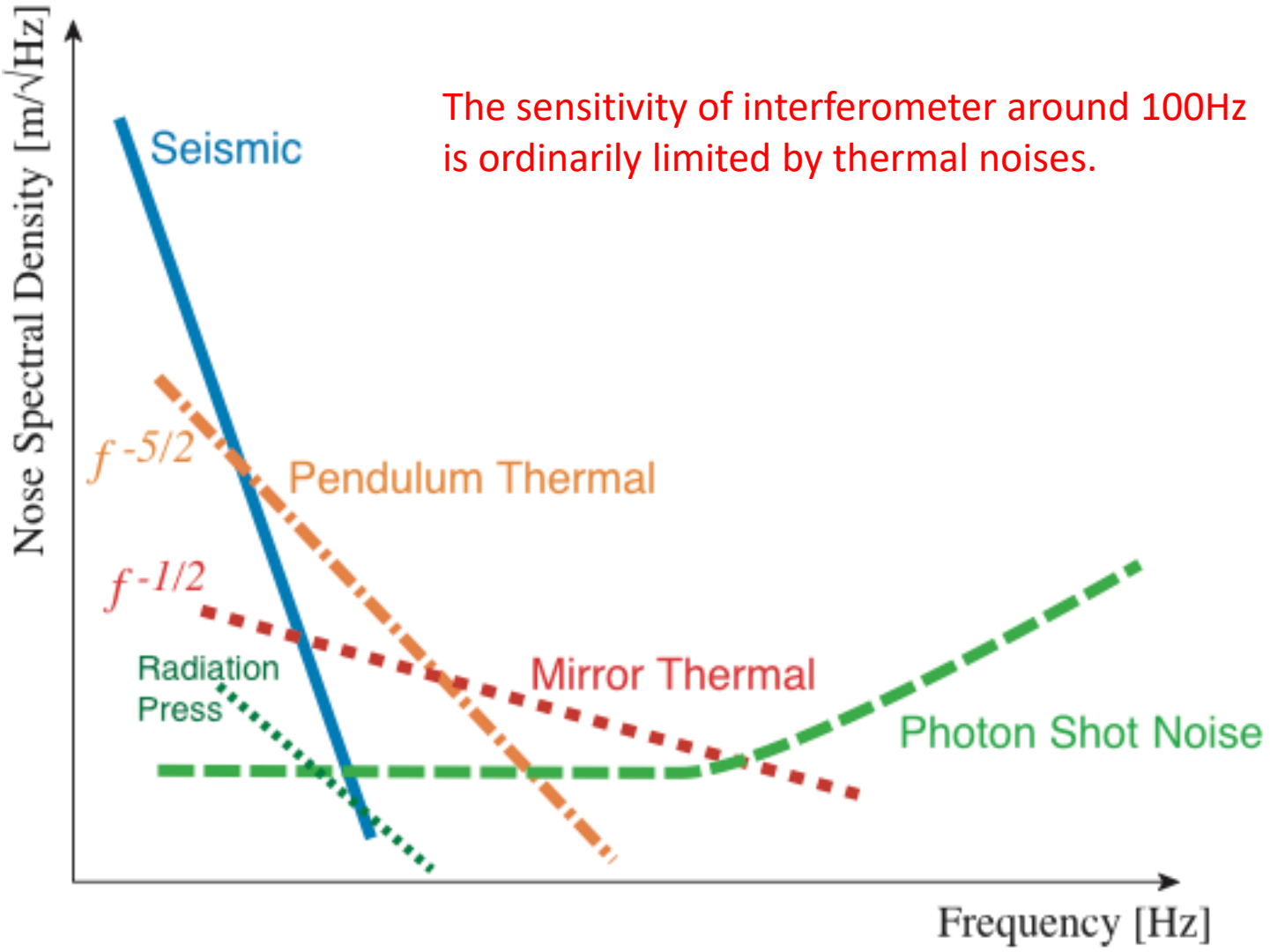


Two key features of KAGRA

1. KAGRA is constructed at underground site.

2. KAGRA uses cryogenic mirrors.

Thermal noises



The sensitivity of interferometer around 100Hz is ordinarily limited by thermal noises.

Mirror thermal noise

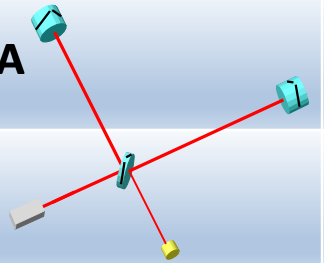
Amplitude of thermal noise is proportional to

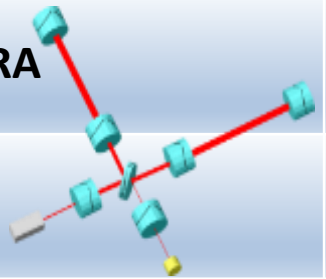
$$(T/Q)^{1/2}$$

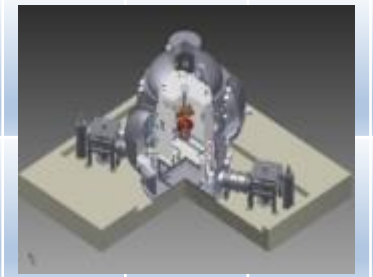
In general, *Q* (inverse number of magnitude of dissipation) depends on *T* (temperature). Sapphire Q becomes highest at low temperature. Therefore KAGRA mirrors use sapphire substrates and cooled to around 20K.

Schedule of KAGRA Project

Calendar year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Project start											
Tunnel Excavation											
iKAGRA	3km Michelson Interferometer										
				First operation							
bKAGRA						3km Cryogenic Interferometer					
							Final installation				
Commissioning and Observation											







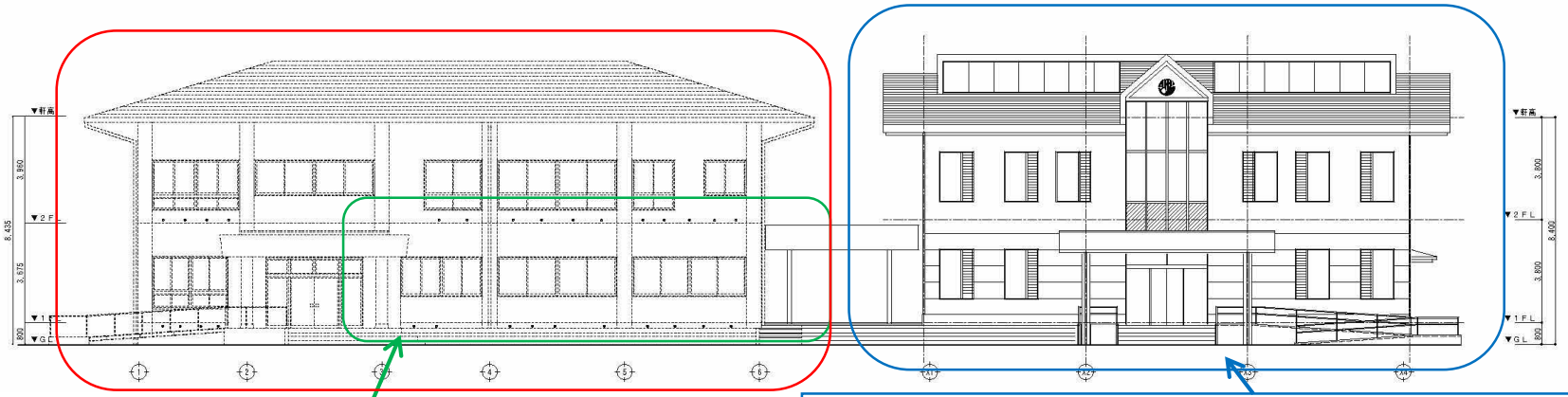
KAGRA Budget

MD=10^8 Japanese Yen

- Construction budget 164MD
- Operation budget 4.5MD/year
- Upgrade budget in future over 10MD
  (International budgets are necessary for it.)

KAGRA Surface building (KAGRA started here)

Old Public Hall (Hida-city) **KAGRA office building**



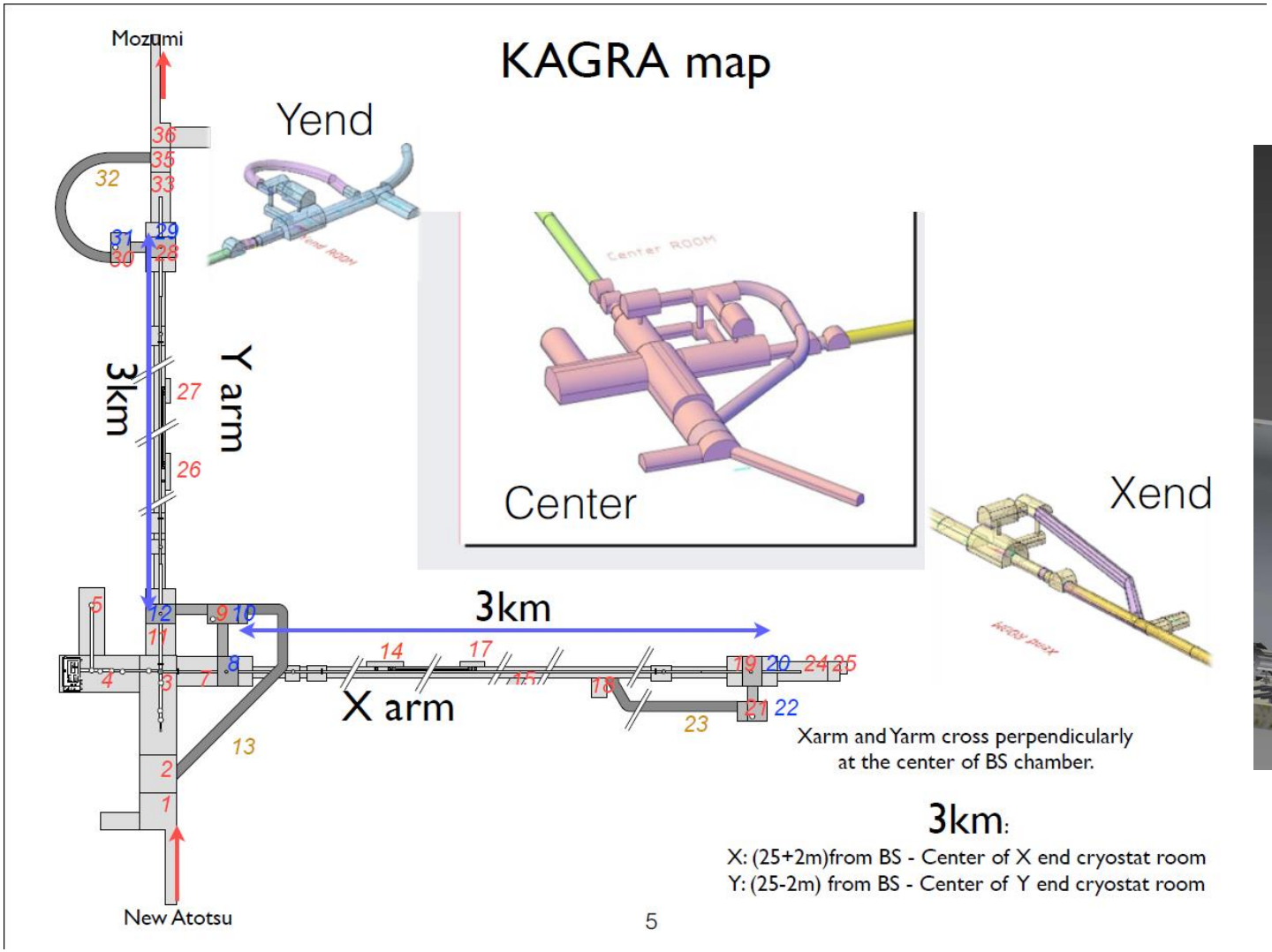
KAGRA office (since 2012, 140m^2)

KAGRA office building completed in March 2014 (340m^2).

KAGRA office (since March, 2018, donated by Hida-city)

Tunnel Excavation

3 corner stations are complicated because of tall towers for Vibration Isolation Systems.



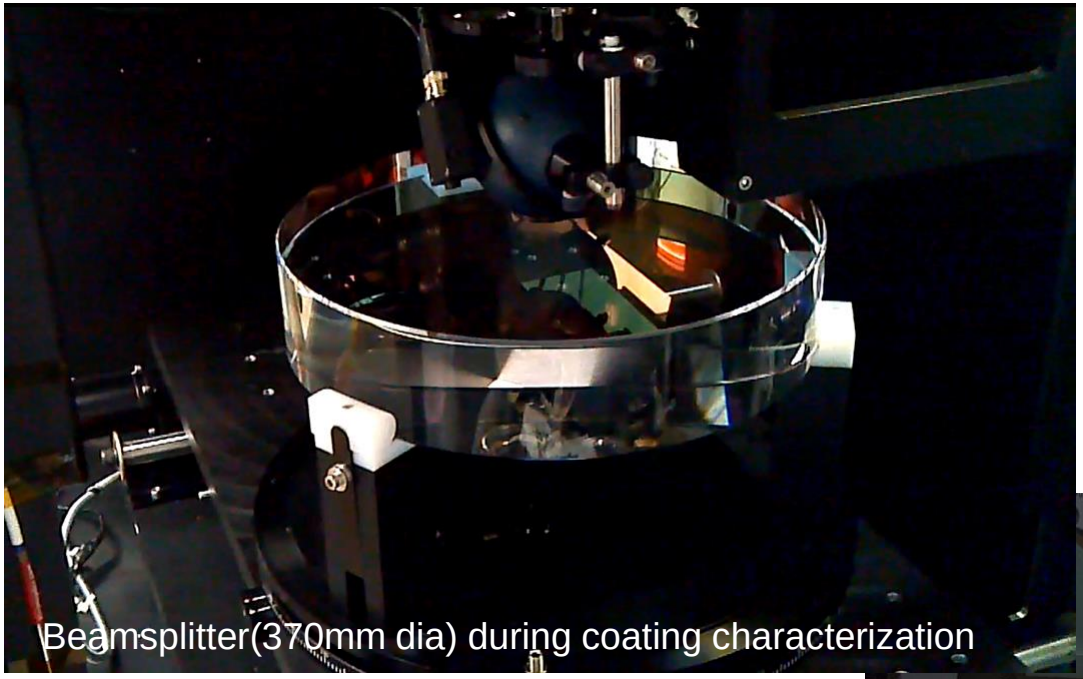
Difficulty of Underground site

Spring water from wall surfaces

All surfaces were covered by waterproof sheets.

It took 4 years to overcome spring water in the tunnel.

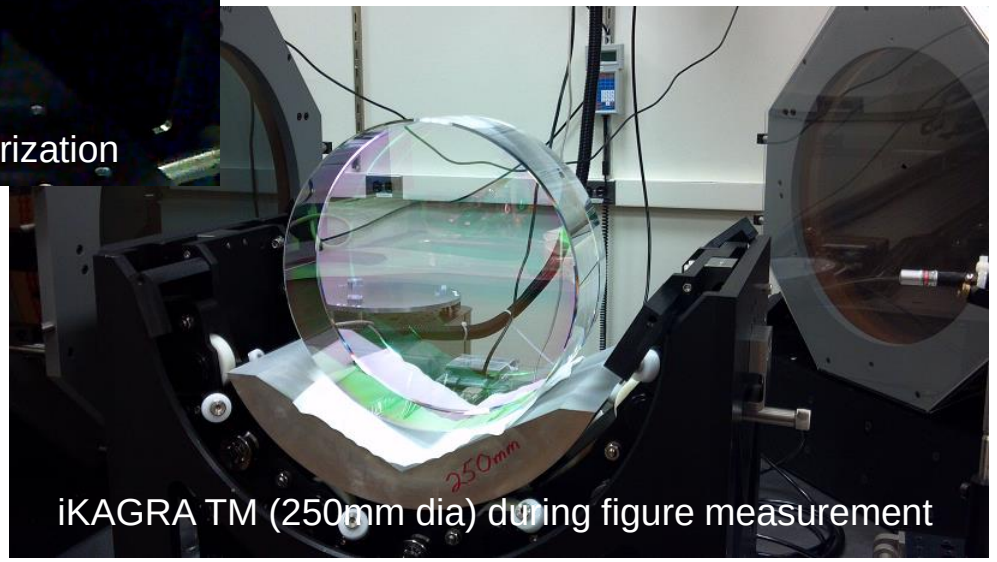
Silica Mirrors for iKAGRA



Beamsplitter(370mm dia) during coating characterization

We use sapphire substrates for bKAGRA and did not have silica substrates. By courtesy of LIGO, we used iLIGO mirrors for iKAGRA operation.

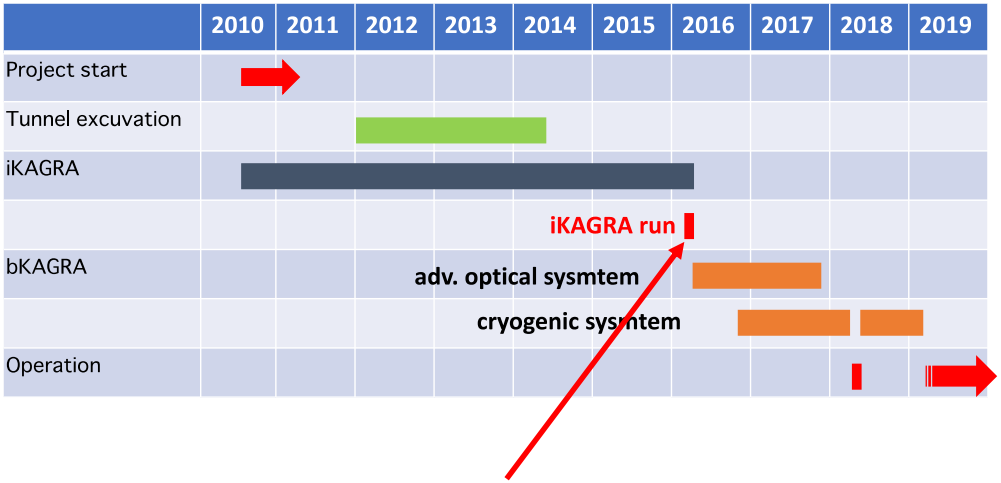
We use a silica beam splitter for both iKAGRA and bKAGRA.

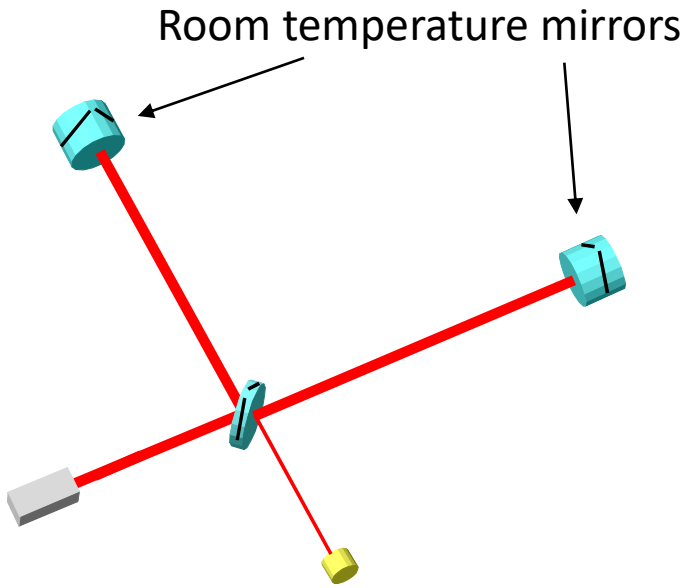


iKAGRA TM (250mm dia) during figure measurement

Courtesy of LIGO

iKAGRA Test Run





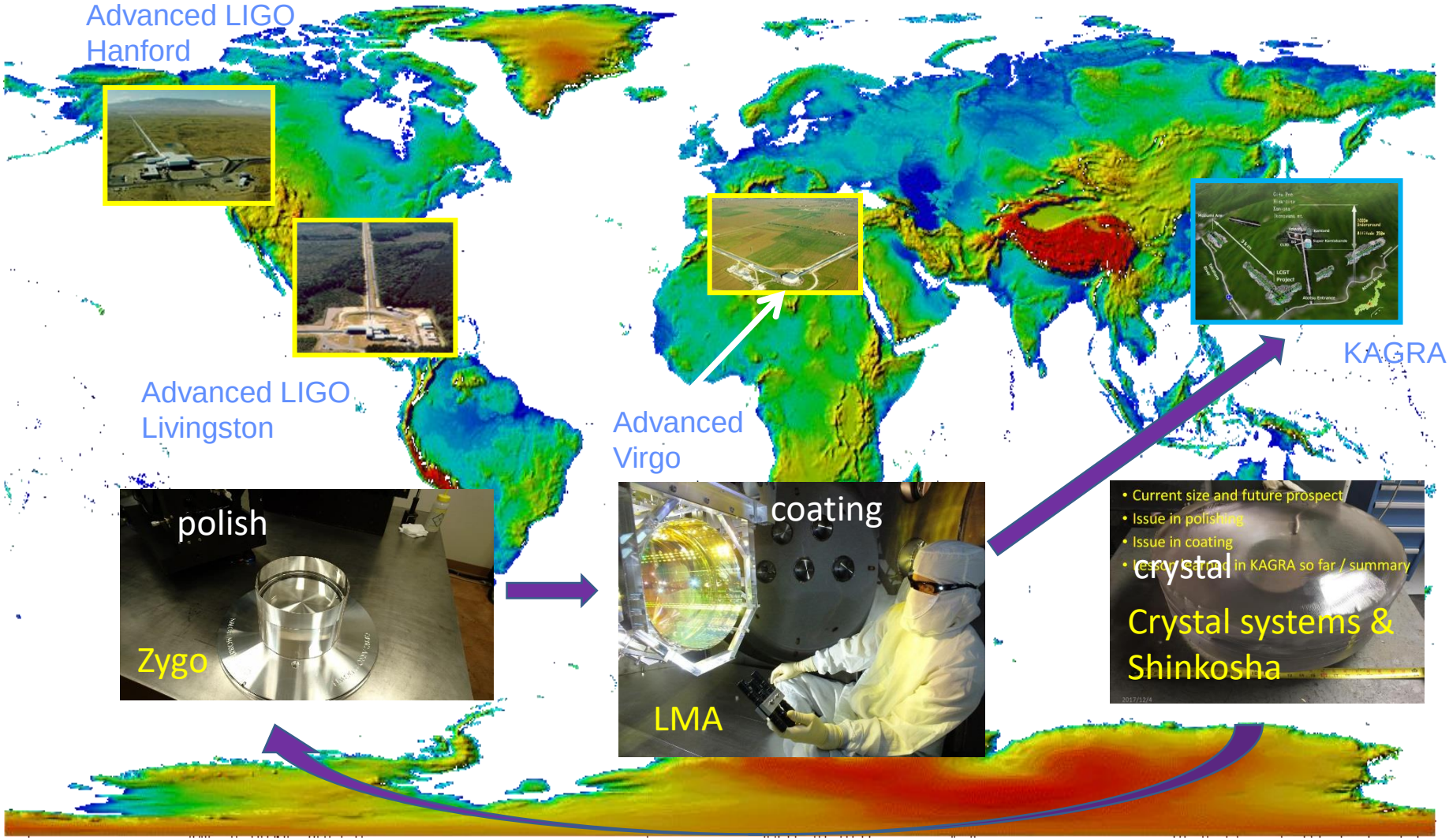
1st run : March 25 - 31, 2016

2nd run : April 12 - 25, 2016

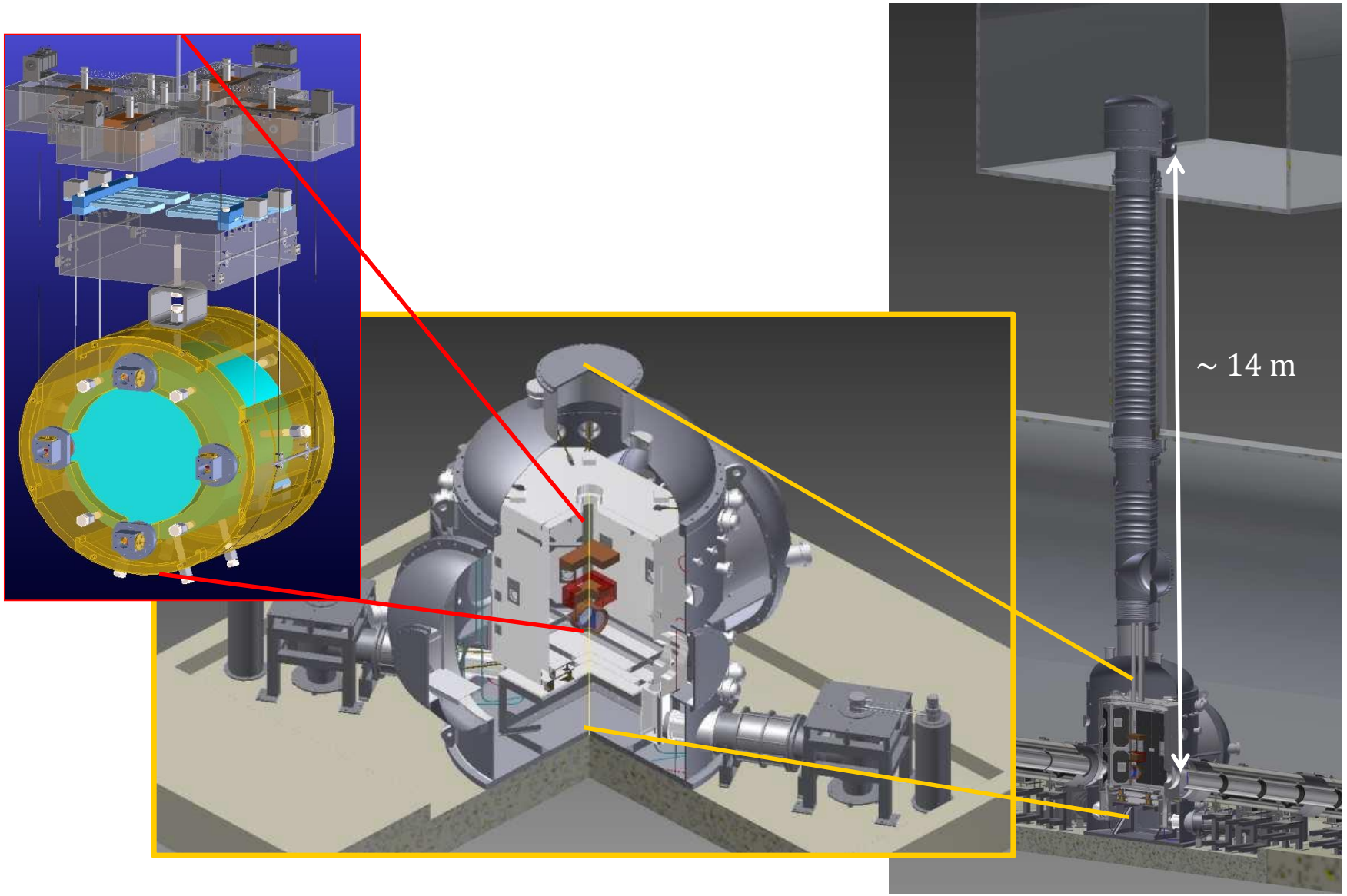
Main purpose: Demonstration of 3km interferometer operation

- 3km Michelson interferometer
- Typical sensitivity
  - 1st run: 3 x 10^{-15} $Hz^{-1/2}$ @ 100 Hz
  - 2nd run: 6 x 10^{-16} $Hz^{-1/2}$ @ 100 Hz
- Duty cycle (= (lock time)/(total time))
  - 1st run: 85.2 %
  - 2nd run: 90.4 %

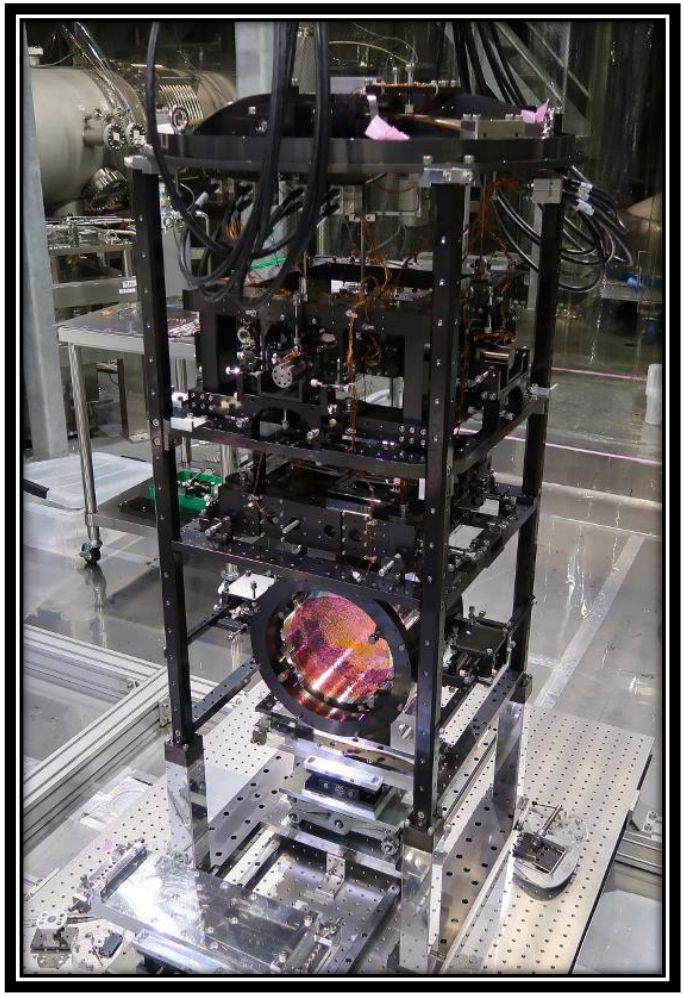
Completion of four sapphire mirrors



Cryogenic mirror suspension system

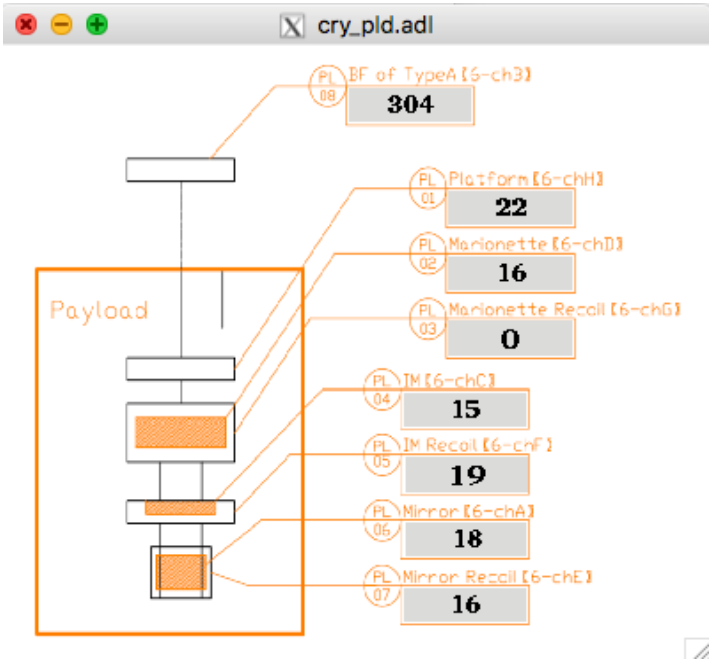


Cryogenic payload



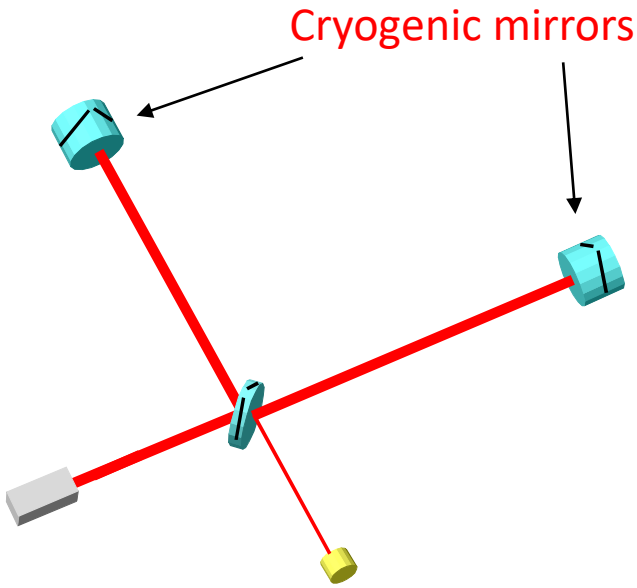
Cryogenic payload with mirror

Mirror was cooled below 20K



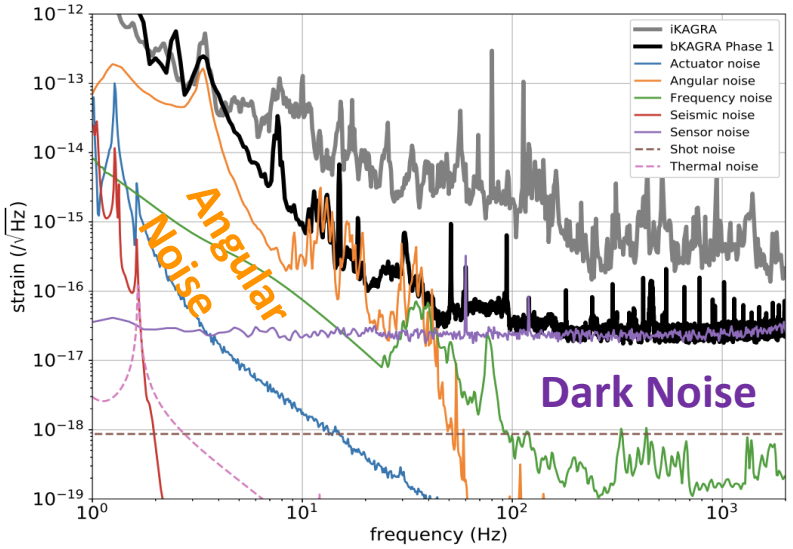
bKAGRA Phase-1

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Project start										
Tunnel excuvation										
iKAGRA										
					iKAGRA run					
bKAGRA				adv. optical sysmtem						
					cryogenic sysmtem					
Operation										



April 2016 – March 2018: Construction

March – April 2018 : test run

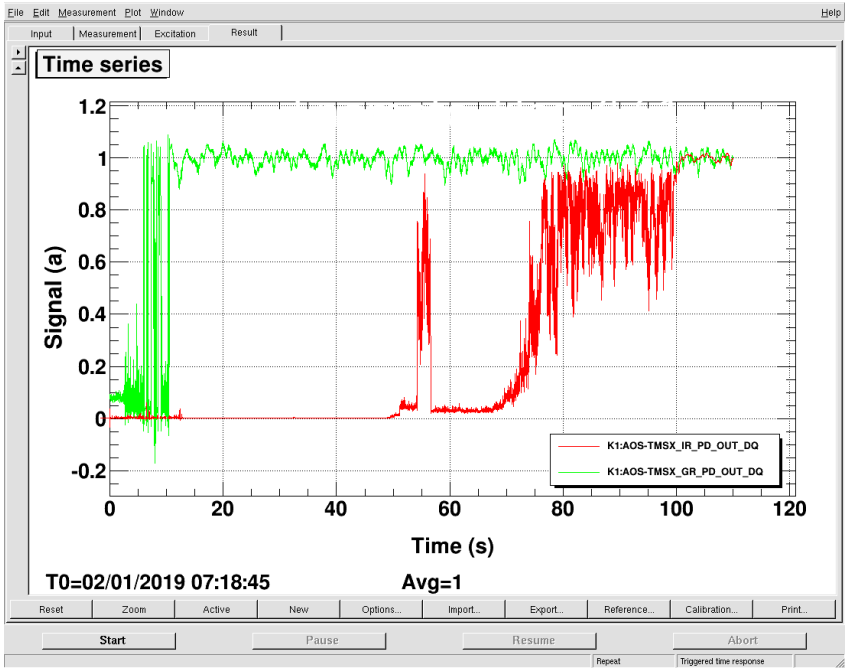


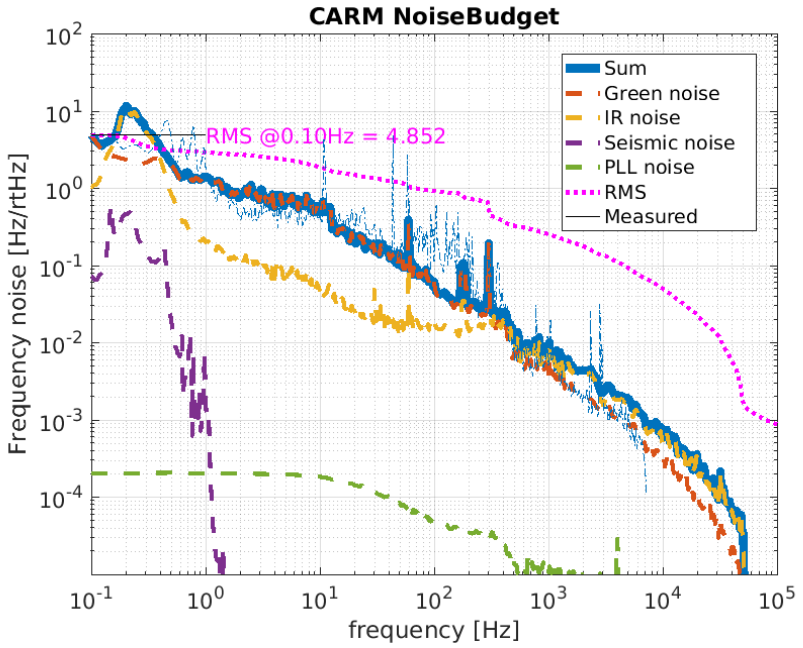
Sensitivity ~ 3×10^{-17} $Hz^{-1/2}$ at 100Hz

We improved it by one order from iKAGRA

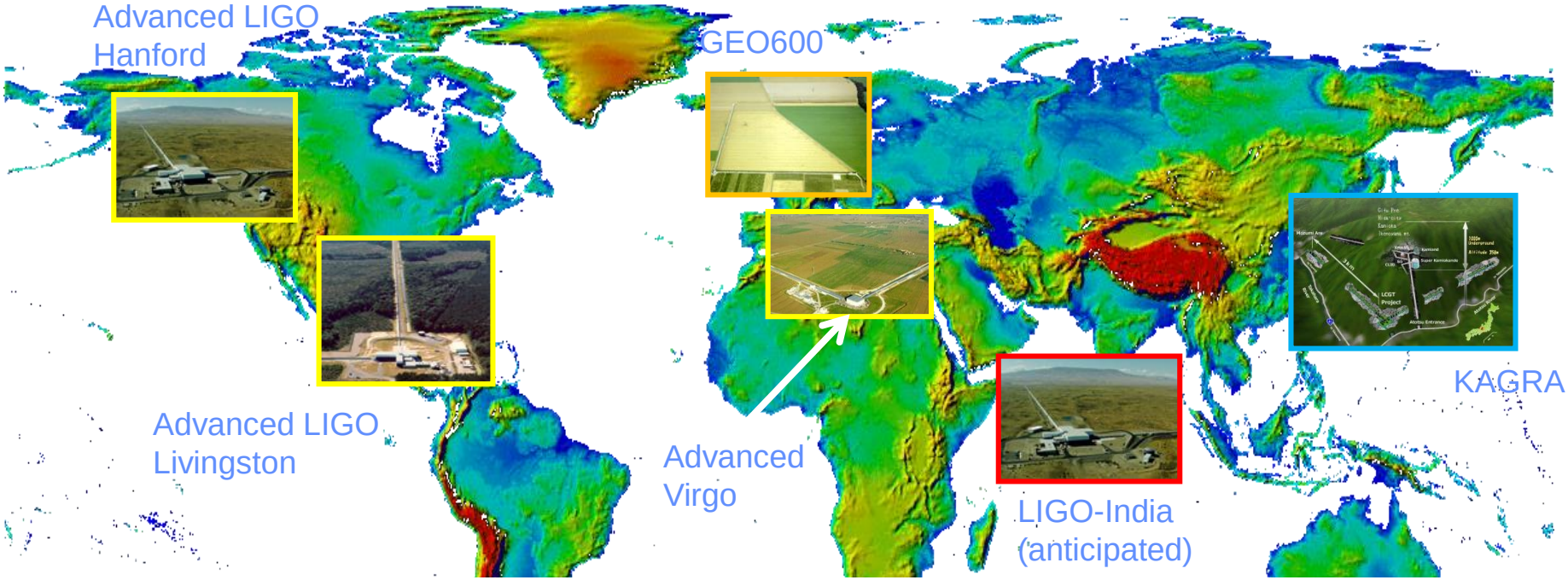
X-arm (3km Fabry-Perot Cavity) Test

- X-arm test has completed
  - X-arm locked with the axillary (green) laser, then successfully handed off to the IR laser
  - Noise budget

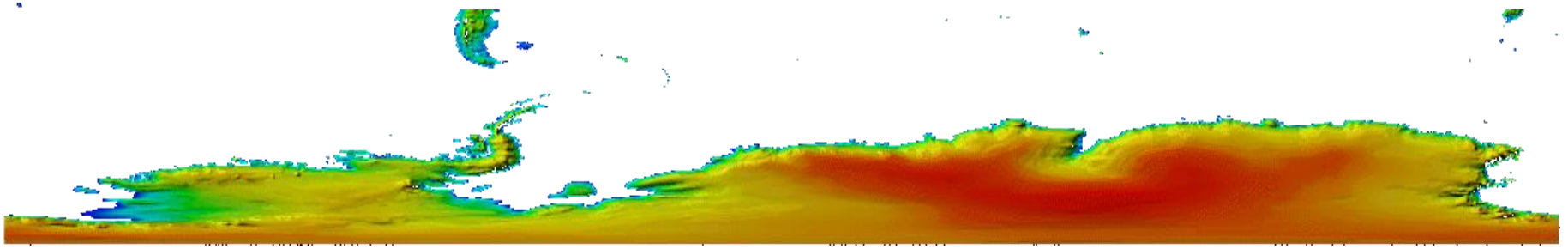




International Network for GW Observation

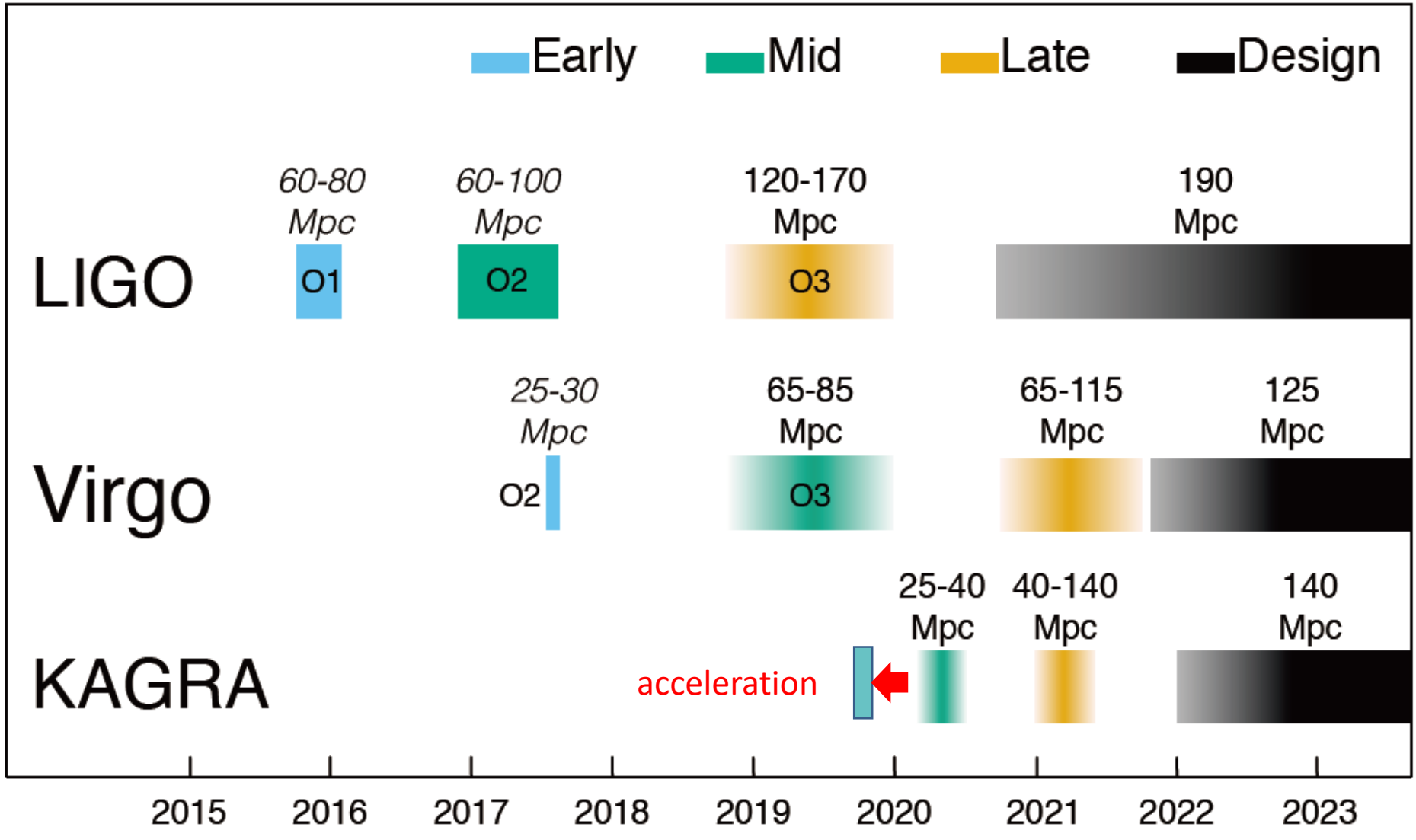


It is necessary to determine the direction of GW sources.



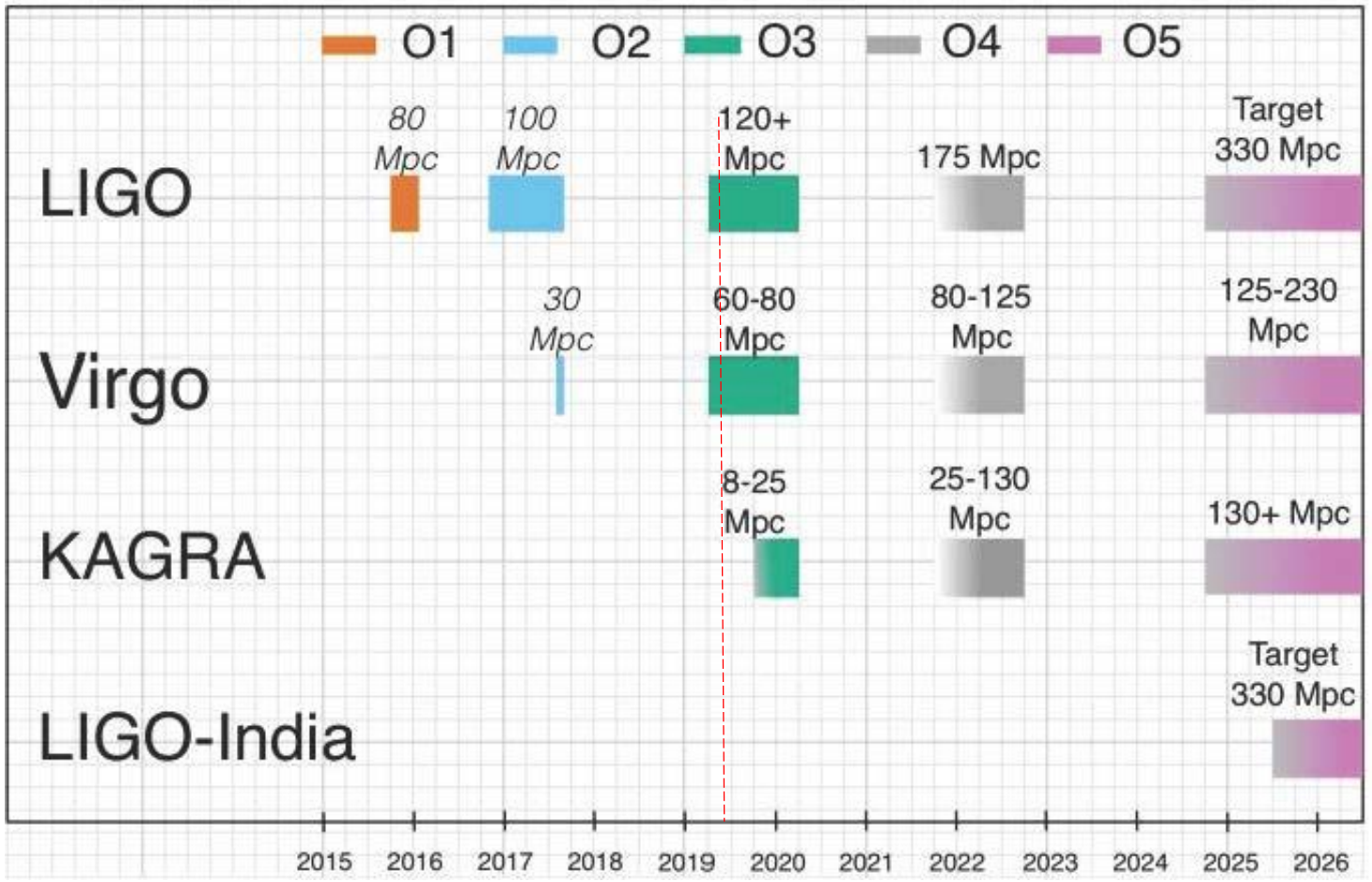
Toward joining O3

- We have decided to accelerate KAGRA schedule to join O3.

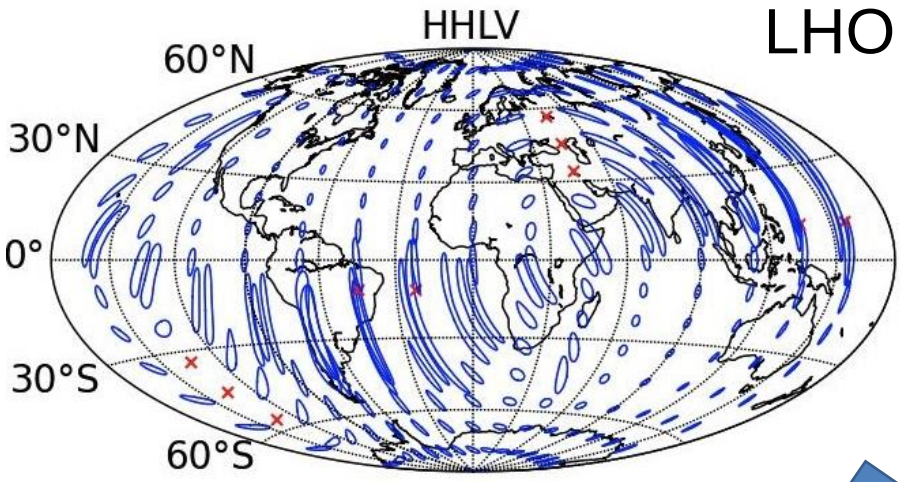


Joint Run Planning with LIGO and Virgo

KAGRA plans to join O3 in the fall of 2019.



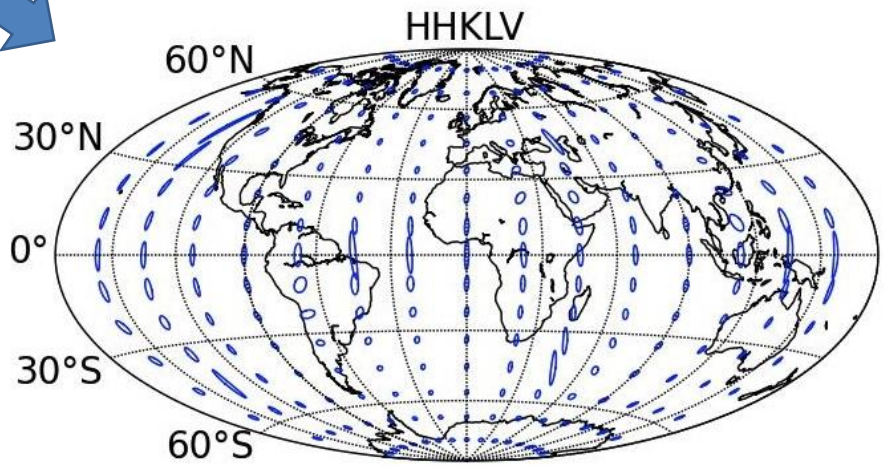
Current GW network + KAGRA



LHO + LLO + Virgo

KAGRA improves the accuracy of the direction of the GW sources.

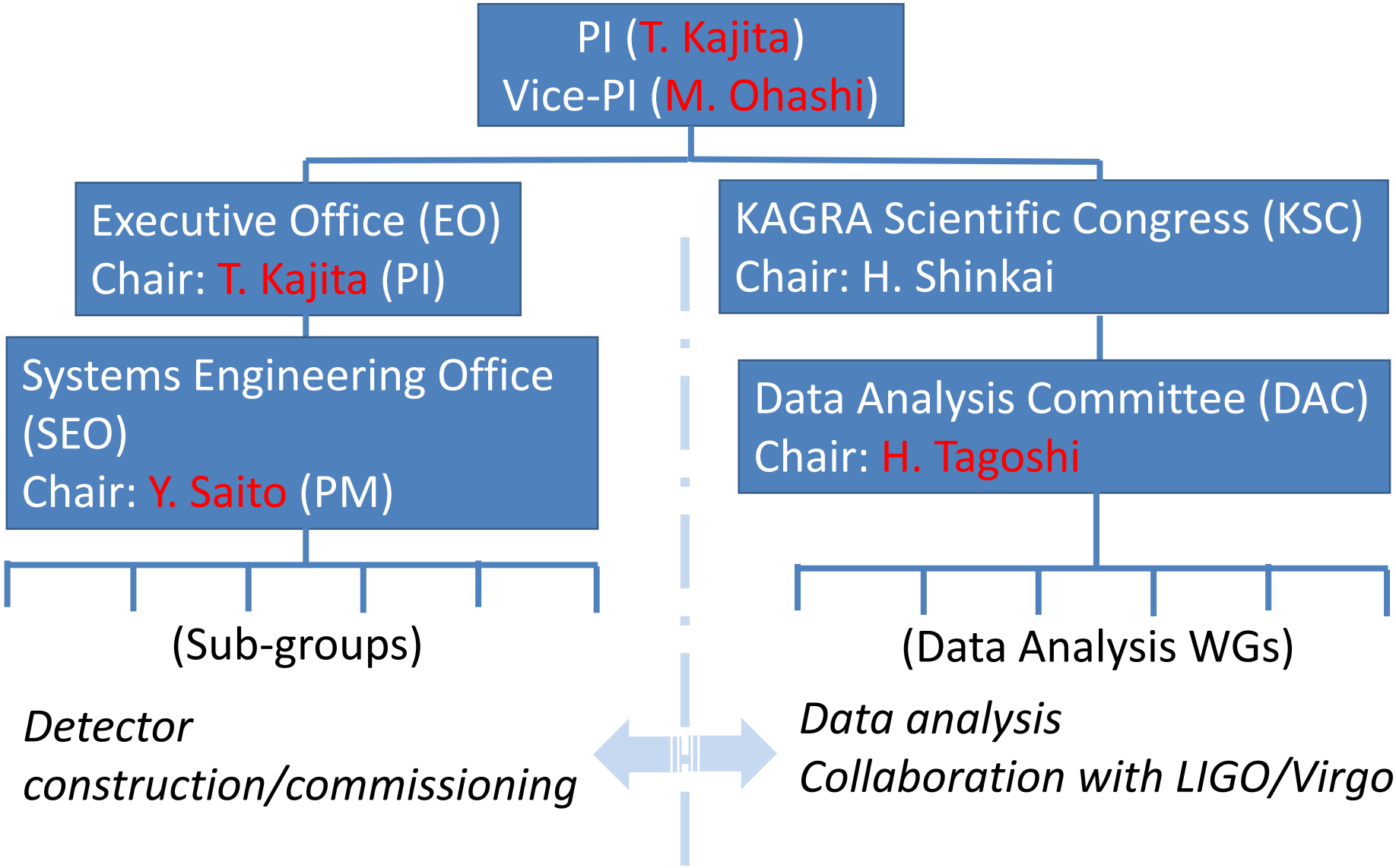
LHO + LLO + Virgo + KAGRA



x denotes blind spots

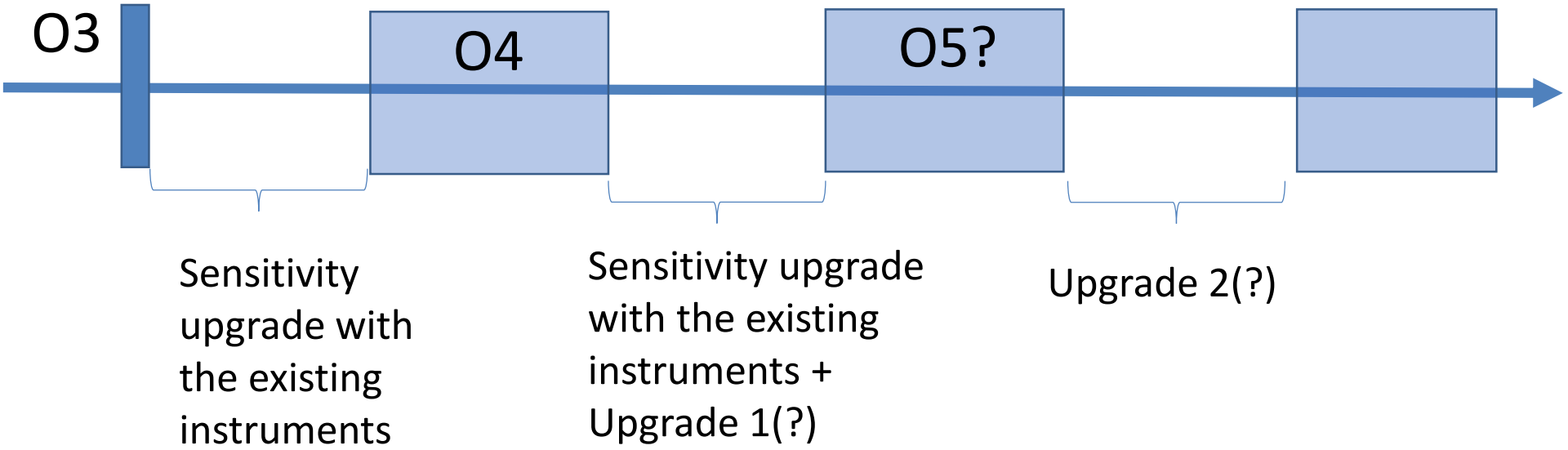
S. Fairhurst, "*Improved source localization with LIGO India*", *J. Phys.: Conf. Ser.* 484 012007

KAGRA management structure



KAGRA upgrade

- It is almost the time to think about the future of KAGRA.
- For discussing the KAGRA upgrade, KAGRA has formed the Future Planning Committee (FPC) under KSC.
- Following the recommendation of the FPC, SEO will decide the plan to install the upgrade into the KAGRA interferometer.
- As a guideline, the research group which plans the upgrade should have the responsibility to install the upgrade into KAGRA including the responsibility on the budget. (KAGRA needs the upgrade money from another countries.)



KAGRA Observatory as an International research center

Summary

- In the spring of 2019, we completed the construction phase and move on to the commissioning phase. KAGRA plans to join O3 in the fall of 2019.