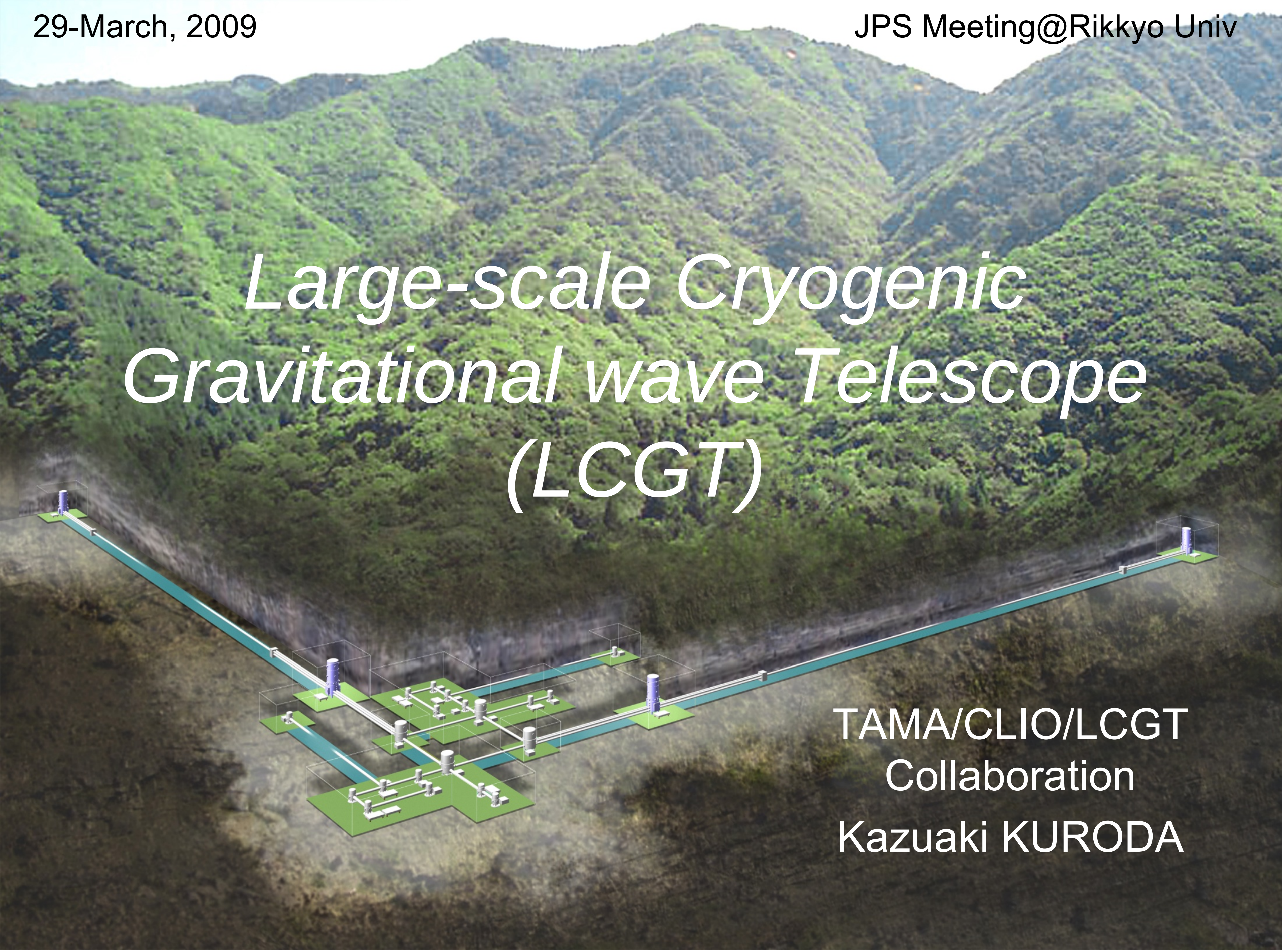
Large-scale Cryogenic Gravitational wave Telescope (LCGT)



TAMA/CLIO/LCGT Collaboration

Kazuaki KURODA

Overview of This talk

- *Science goal of LCGT*
  - First detection of gravitational wave
  - Establishment of gravitational wave astronomy
- *Technical advantage of LCGT*
  - km-scale baseline length
  - Cryogenic mirror originally developed
  - Underground installation
- *Schedule & Cost*
  - Five years construction and 2 years commissioning
  - Construction cost of 1 5.5 B JpnYen and Maintenance cost of 432 M JpnYen
- *Manpower organization*
- *Scientific Impact*

Scientific Goal of LCGT

- First detection of gravitational wave

  --- Experimentally general relativity under strong gravity is tested.

  --- Matter dynamics under extremes of density and pressure is clarified.

- Establishment of gravitational wave astronomy

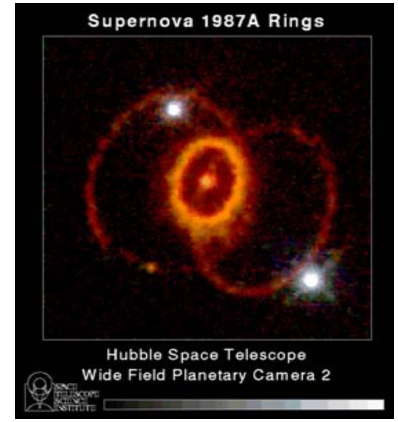
  --- At least three detectors with similar sensitivity are needed to position the source.

  --- LCGT plays a role of Asia-Oceania center among other detectors in US (LIGO) and Europe (Virgo, GEO HF) for GW astronomy.

  --- International collaboration with gamma ray and neutrino observations.

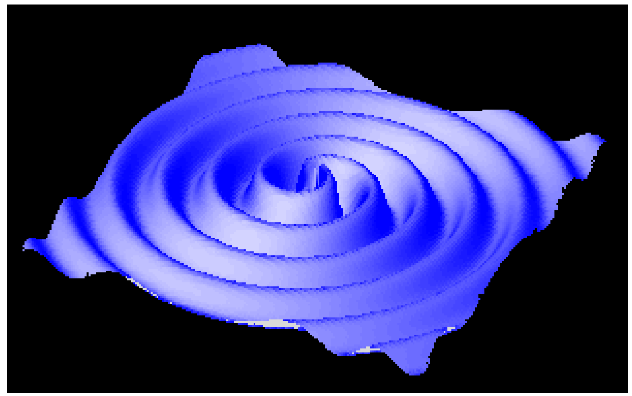
Target GW Sources of LCGT

1. Coalescence of neutron star binaries
2. Coalescence of black hole binaries
3. Core collapse of massive stars
4. ・・・・・



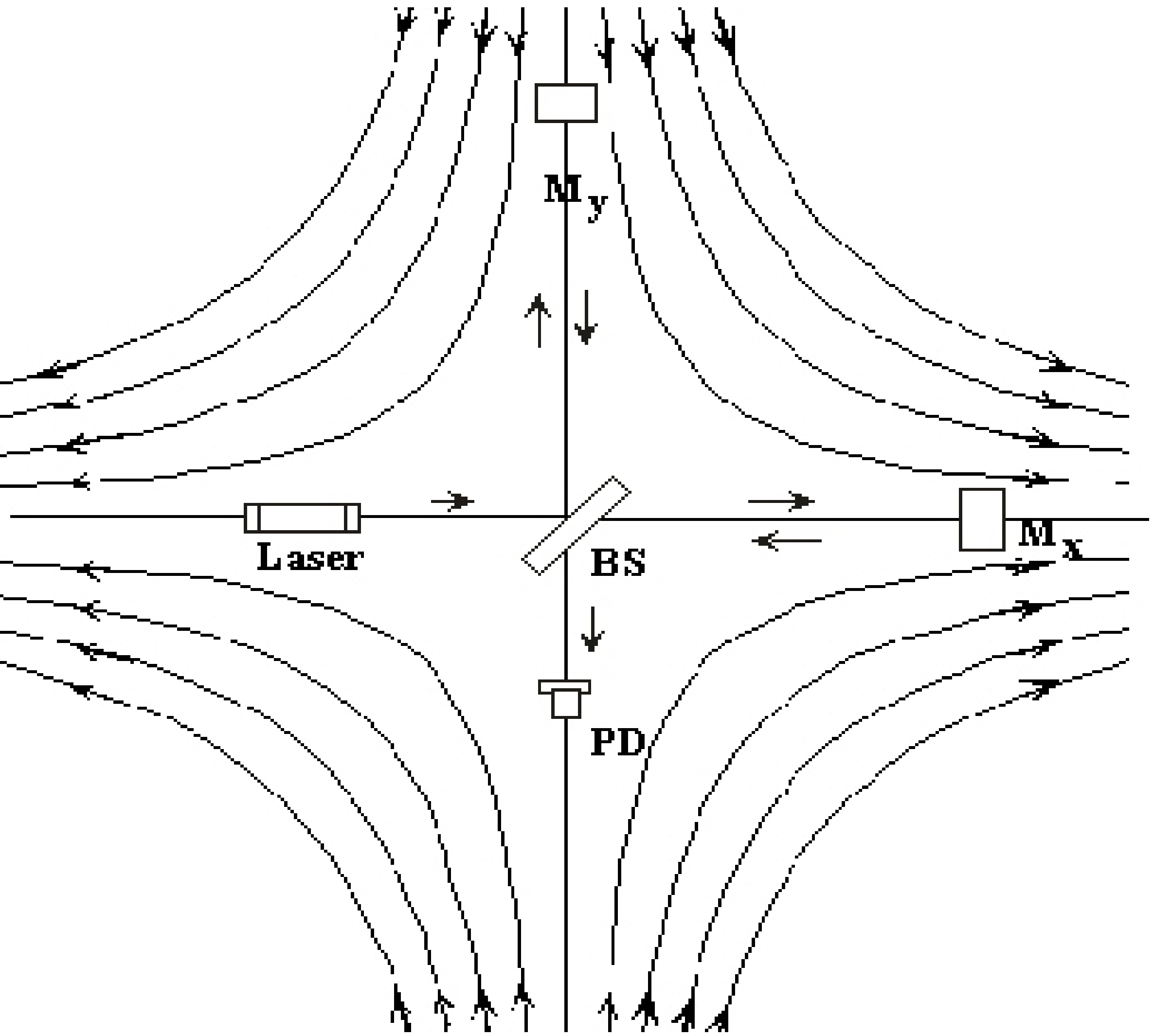
Existing neutron star binaries in our Galaxy

- PSR B1913+16
- PSR B1534+21
- PSR J1141-6545
- PSR J0737-3039
- PSR J1906+0746



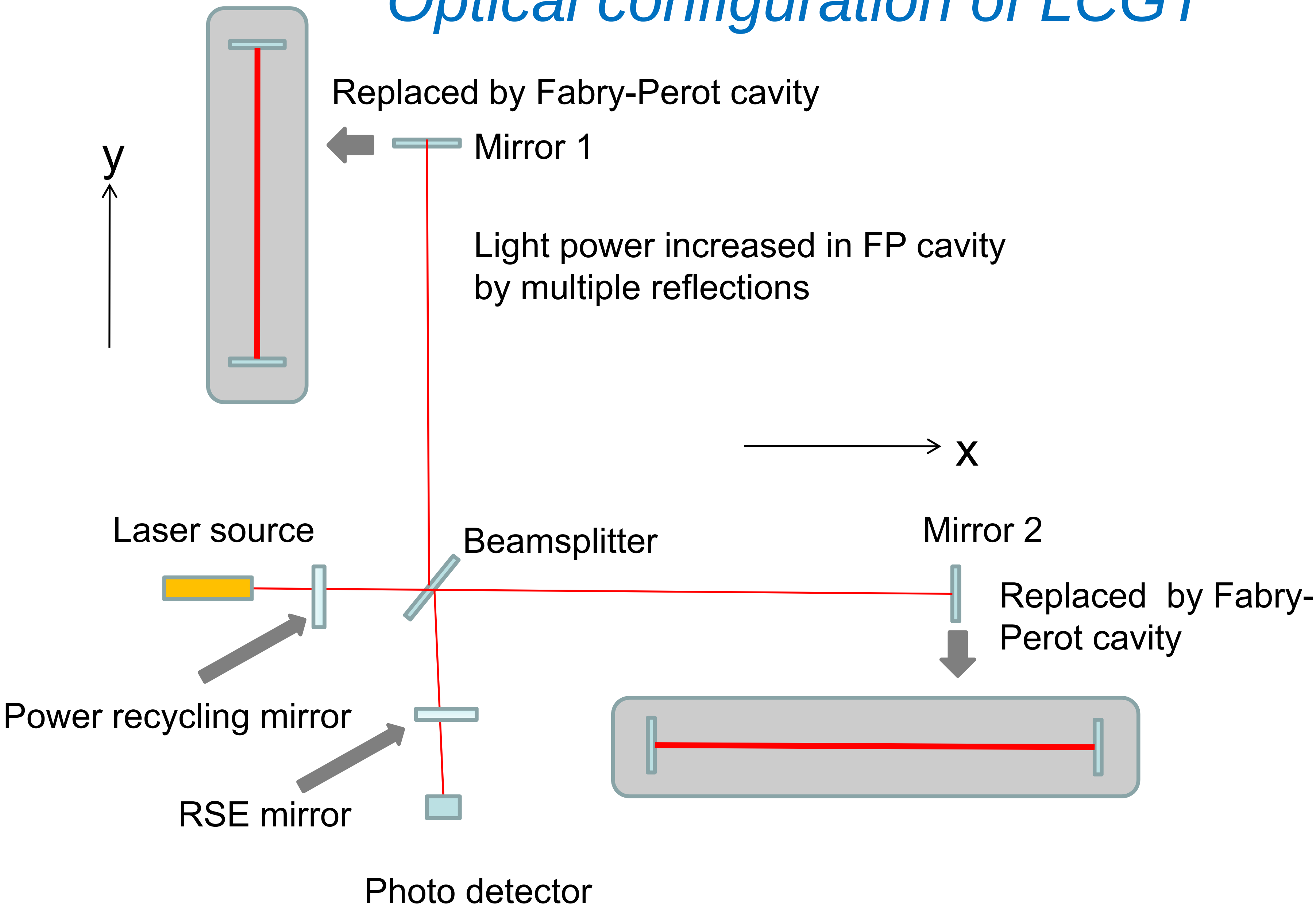
The presently operating detectors such as LIGO (USA), VIRGO (French-Italian), GEO (Germany-England) and TAMA (Japan) have sensitivity to catch GW events occurring at most 20Mpc.Since the occurrence rate of neutron star binary is estimated to be 10^{-5} for matured galaxy per year and there are 0.01 galaxies for 1 cubic Mpc, it takes roughly 300 years to catch one event. LCGT is designed to detect events occurring at 185Mpc at maximum and detects a few events in a year.

Detection of Gravitational wave by Laser interferometer

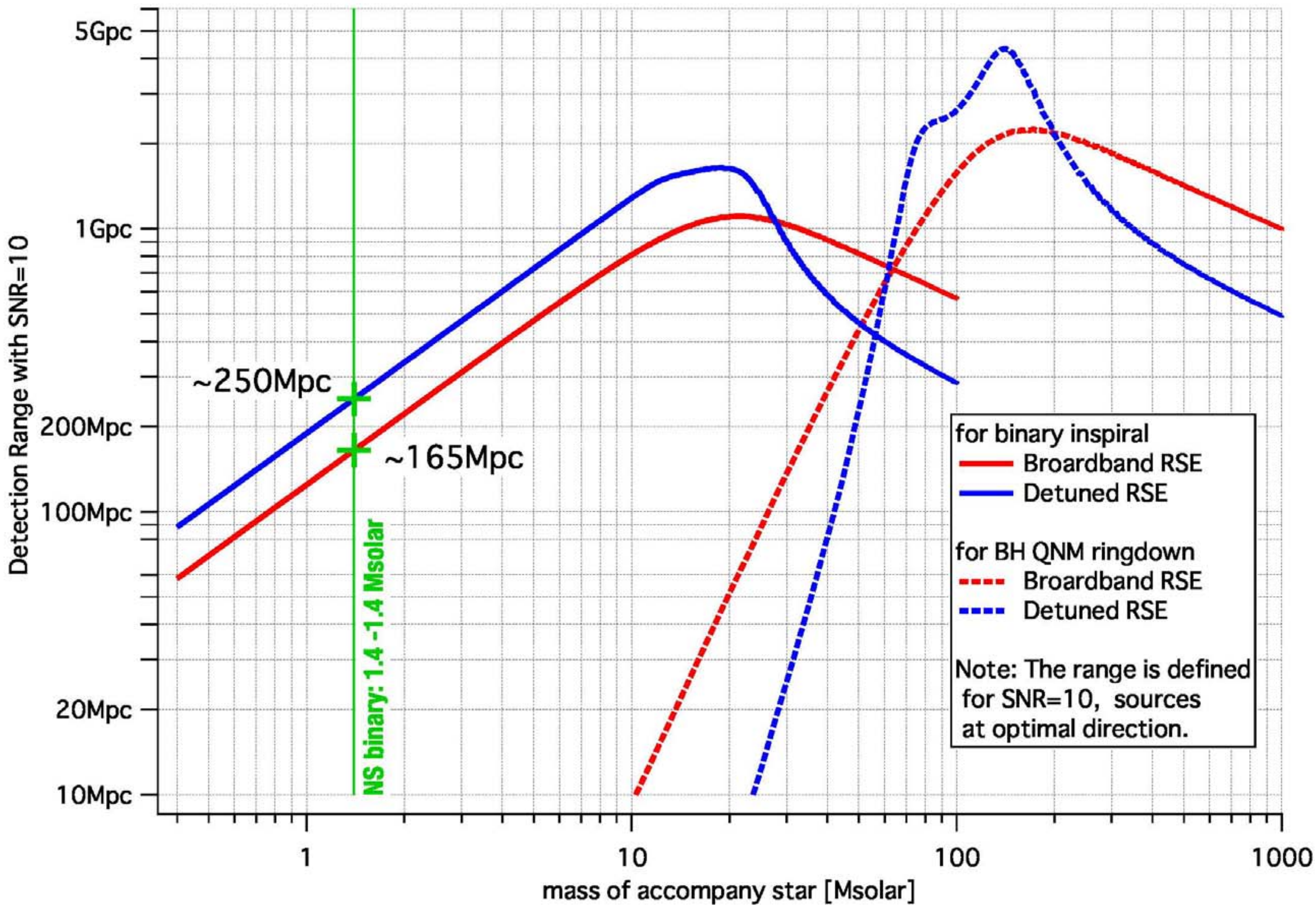


- Suspended mirror (Mx) and suspended beam splitter (BS) behave as test masses for GW
- Michelson Interferometer measures differential displacement between two arms
- Typical magnitude of the event at Virgo cluster is 10^{-14} rad, 10^{-18} m for 1km baseline
- To increase phase sensitivity, optical path is folded many times using Delay-Line, Fabry-Perot, and so on

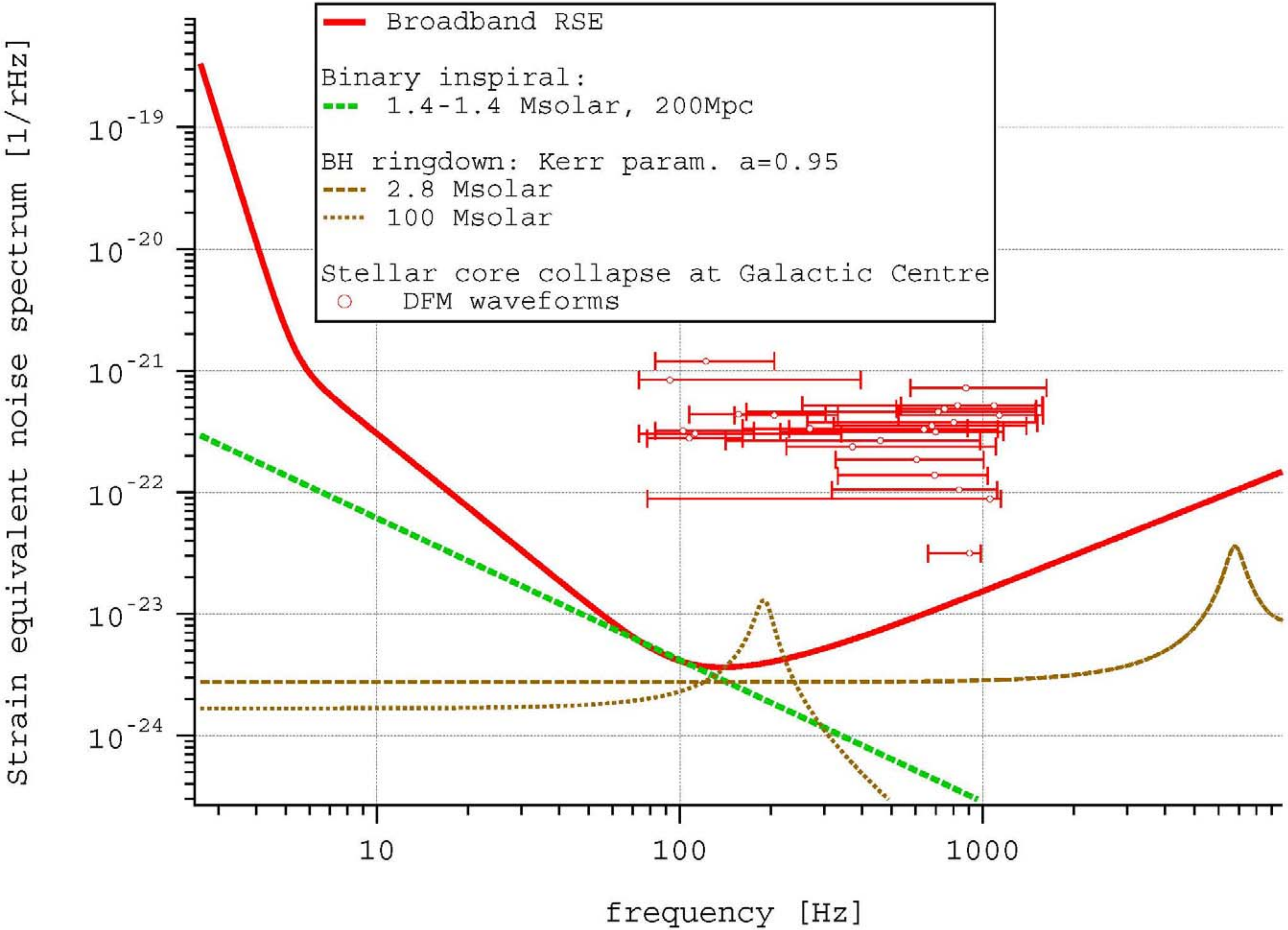
Optical configuration of LCGT



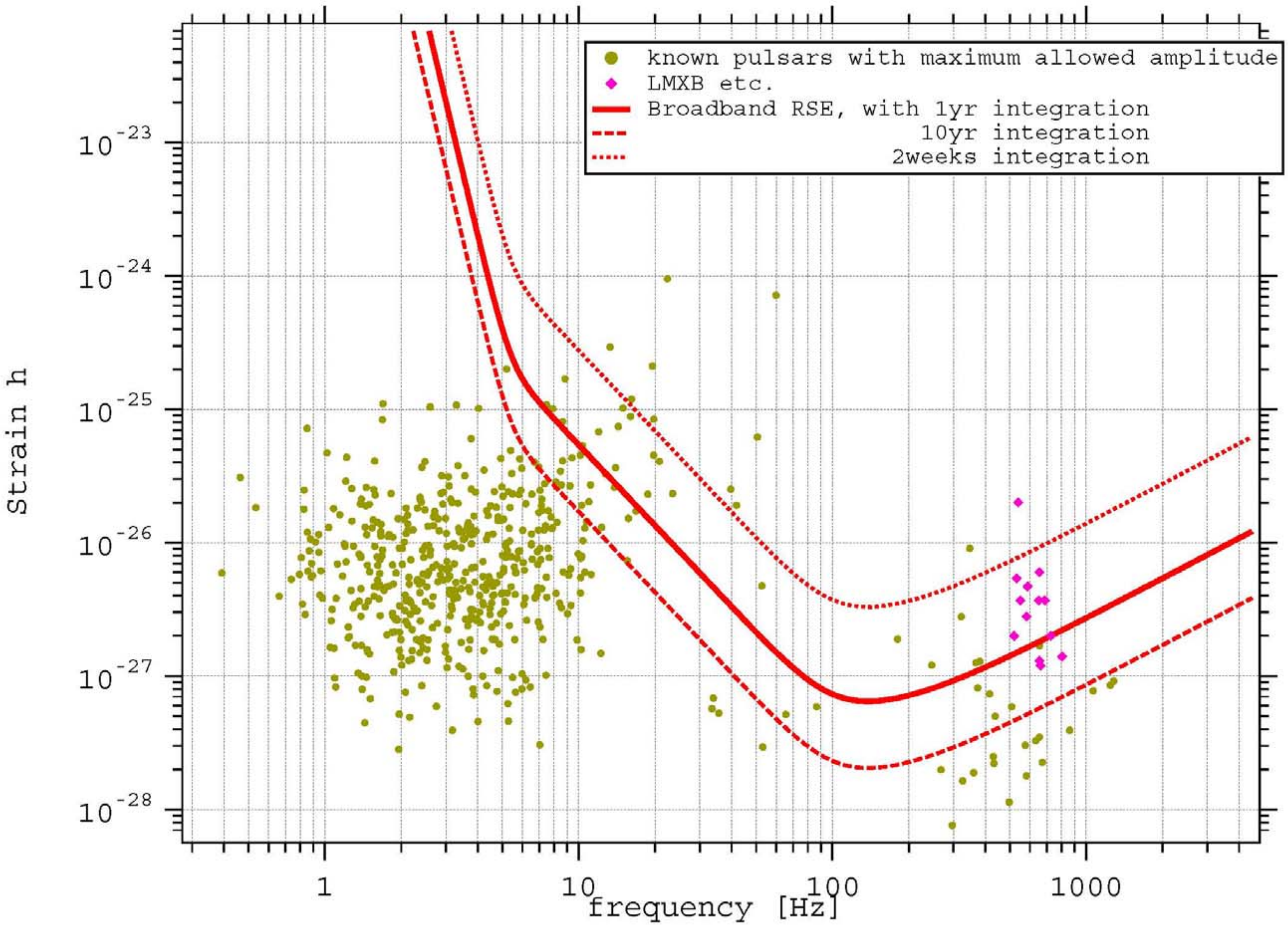
Target sensitivity of LCGT with its advancement



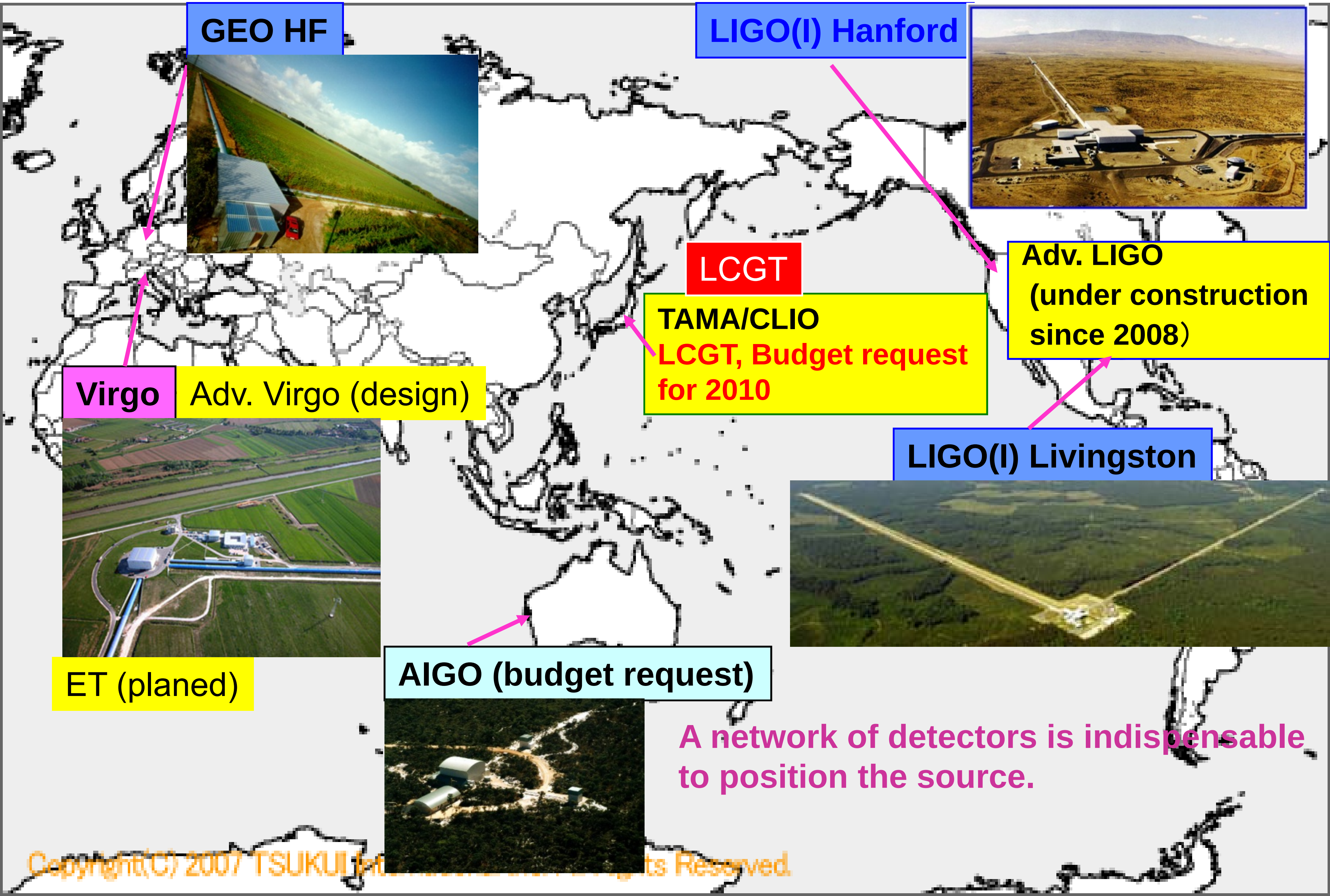
Expected sources of LCGT (1)



Expected sources of LCGT (2)



World wide network for GW astronomy



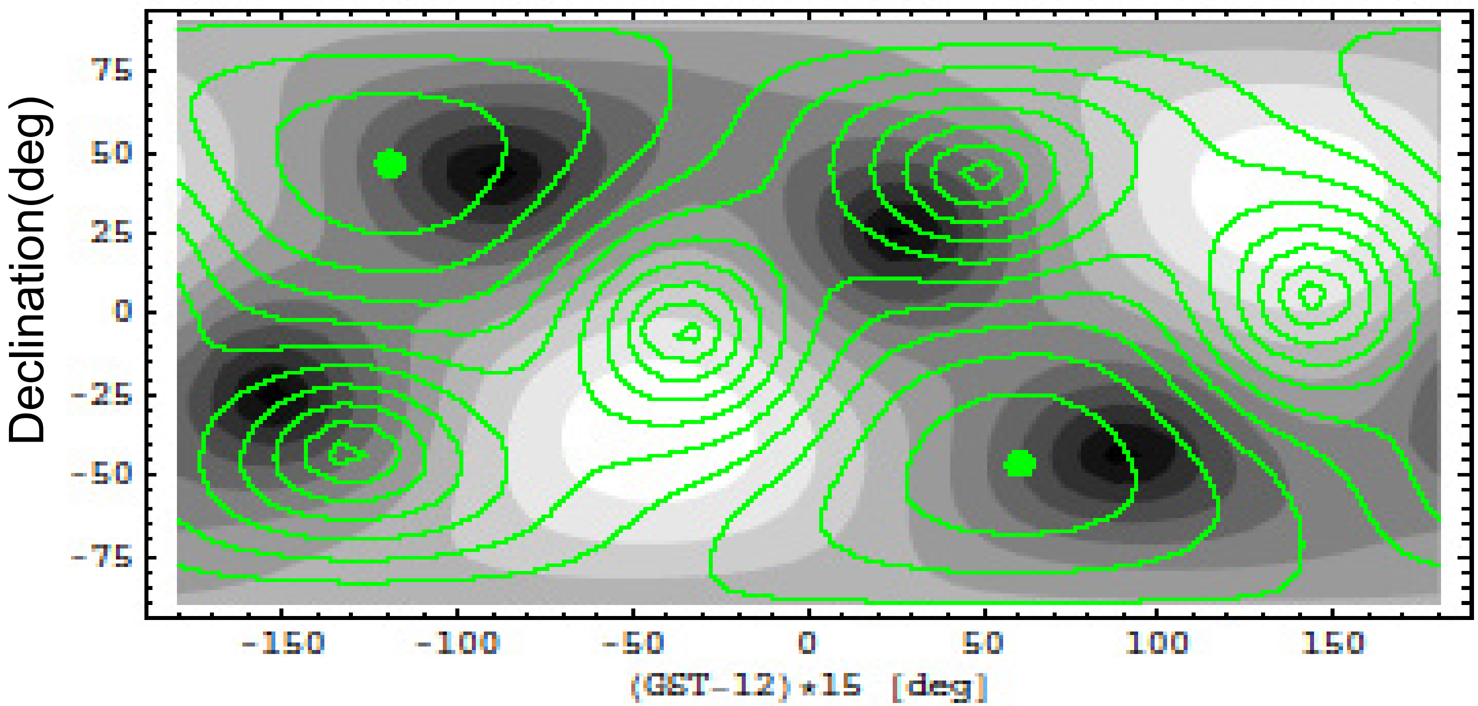
A network of detectors is indispensable to position the source.

Contribution to sky coverage and more precise positioning

Trigonometric determination of sources requires large distances among detectors. Delay times are

LIGO Livingston – LIGO Hanford ~10msec
LIGO Livingston – Virgo ~26msec
LIGO Livingston – LCGT ~32msec

LCGT contributes the international observation by the coverage of a complimentary sky to other detectors: LCGT, grey scale, LIGO (Hanford), green curves.



Sensitivity Limiting factors of laser interferometry

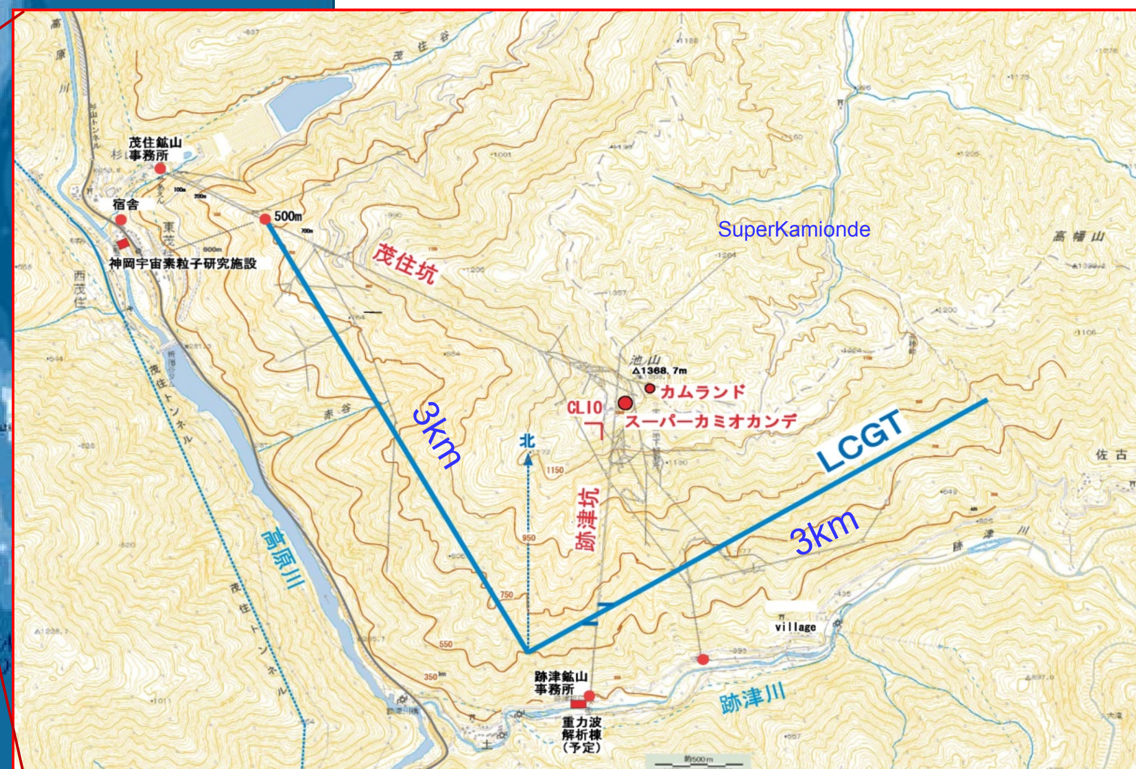
- Mirror motion
  - Thermal noise of mirror bulk oscillation modes
  - Thermal noise of suspension pendulum mode
  - Thermal noise of optical coating
  - Leakage of seismic vibration
- Readout noise
  - Photon shot noise
  - Frequency noise
  - Amplitude noise
- Quantum noise
  - Photon shot noise
  - Radiation pressure noise

Technical advantage of LCGT

- The interferometer of LCGT is placed underground at Kamioka.
  - Seismic measurement shows that the deeper we intrude from the surface, the quieter the noise becomes.
  - Two orders less compared with TAMA site.
- The main mirrors are cooled down to 20 K by refrigerators.
  - Thermal noise is reduced by direct cooling of the mirrors.

Location of LCGT

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

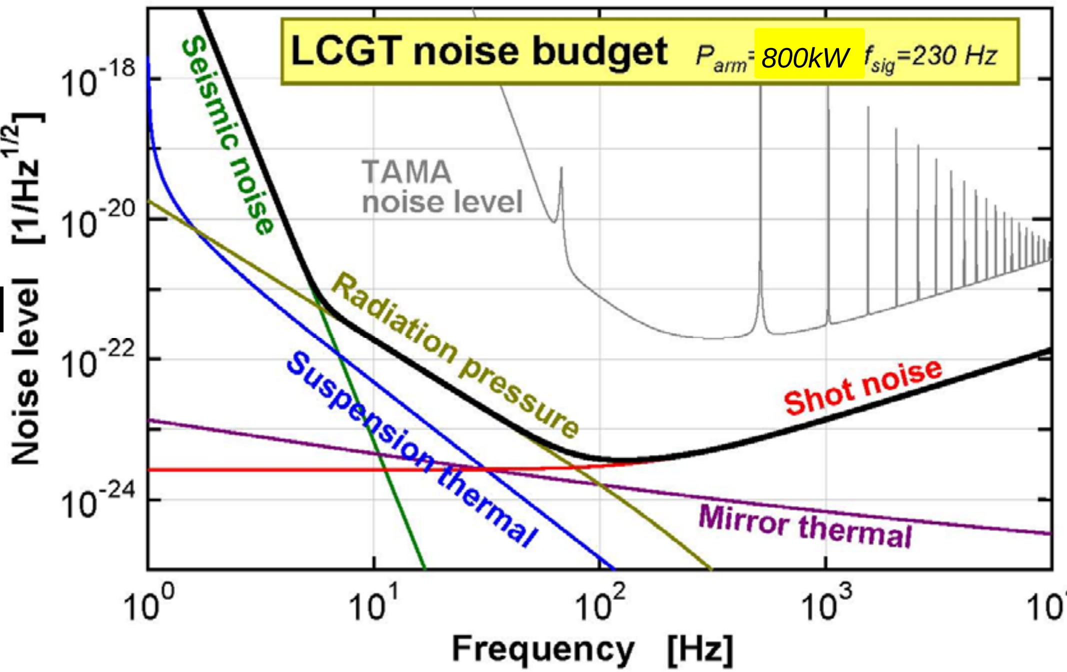


Design Sensitivity in detail

In order to attain the sensitivity to catch the event at ~200Mpc, we need to reduce shot noise determined by 800kW optical power.

Thermal noise of the mirror, coating of the mirror, and suspension need to be suppressed by cryogenic temperature, 20K. Mechanical losses of these parts are required to satisfy this thermal noise limit; they are 10^{-8}, 4×10^{-4}, 10^{-8}

Final sensitivity is limited by quantum noises in the observation frequency band, 230Hz. Radiation pressure noise is determined both by the optical power and mass, 30kg.



Merit and Demerit of Sapphire cryogenic mirror

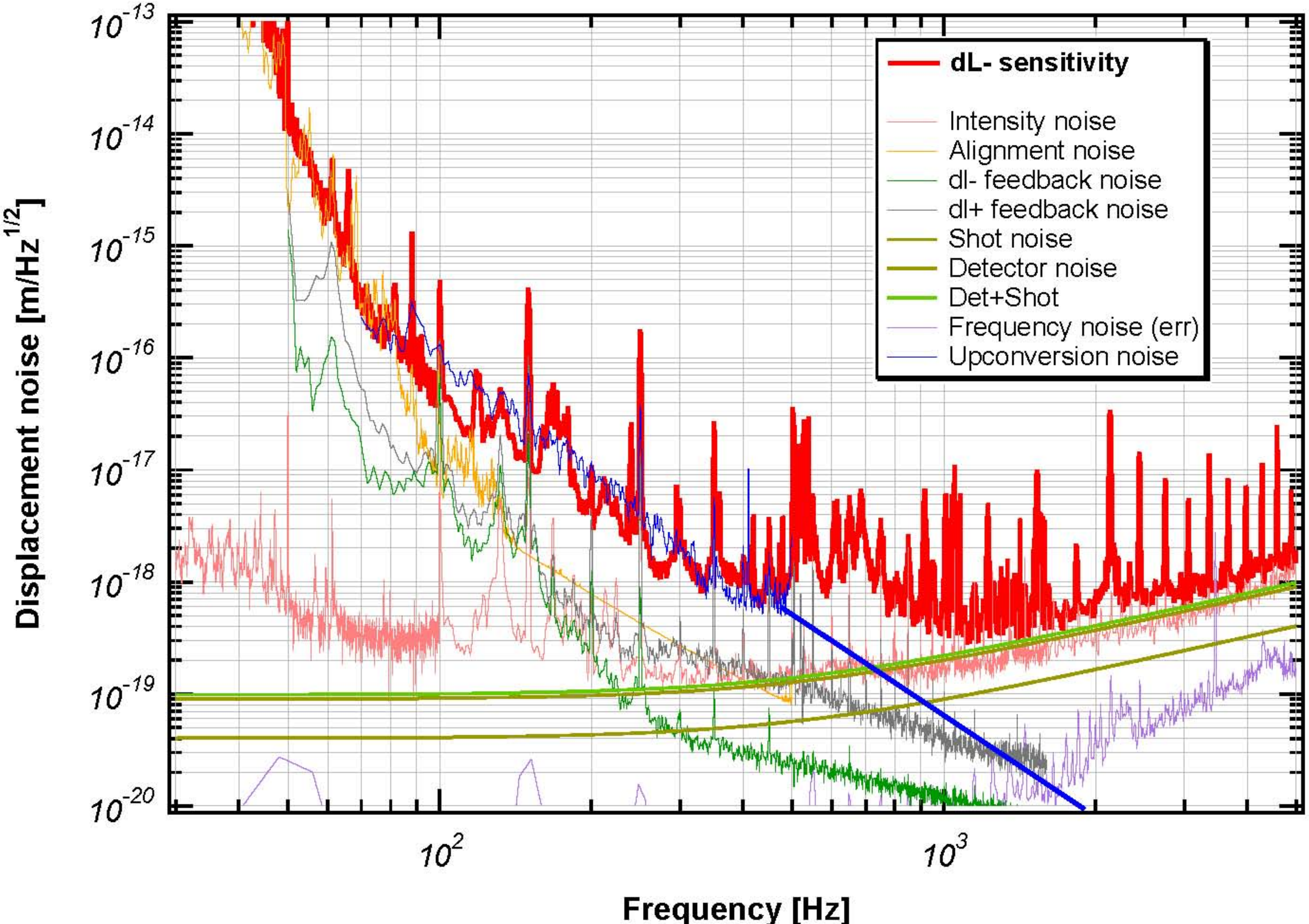
- Suppressed power recycling gain
  - considering large optical loss of sapphire substrate, the power passing through NM is reduced while finesse increased to keep the required sensitivity
- Less thermal lens effect
  - due to high thermal conductivity and low thermal change of coefficient of refractive index (sapphire)
- Avoidable optical spring parametric instabilities
  - due to higher elastic wave speed (sapphire) and small beam size (cryogenic)
- Free from large optical coating loss
  - due to direct cooling (low temperature)

Technical base for LCGT


1975	Resonant Antenna (Physics Dept, UT)
1980	Cryogenic antenna (KEK)
	TENKO-10 (ISAS)
	Grant-in-Aid for Scientific Research of MEXT
1990	TENKO-100 (ISAS)
	NAO 20m (NAO, Mitaka)
	Grant-in-Aid for Creative Basic Research of MEXT
2000	TAMA 300 (Mitaka) LISM (Kamioka) └*establishment of optical interferometer*
	Grant-in-Aid for Scientific Researches
	CLIO 100 (Kamioka) └*establishment of cryogenic technique*
2010	*LCGT*

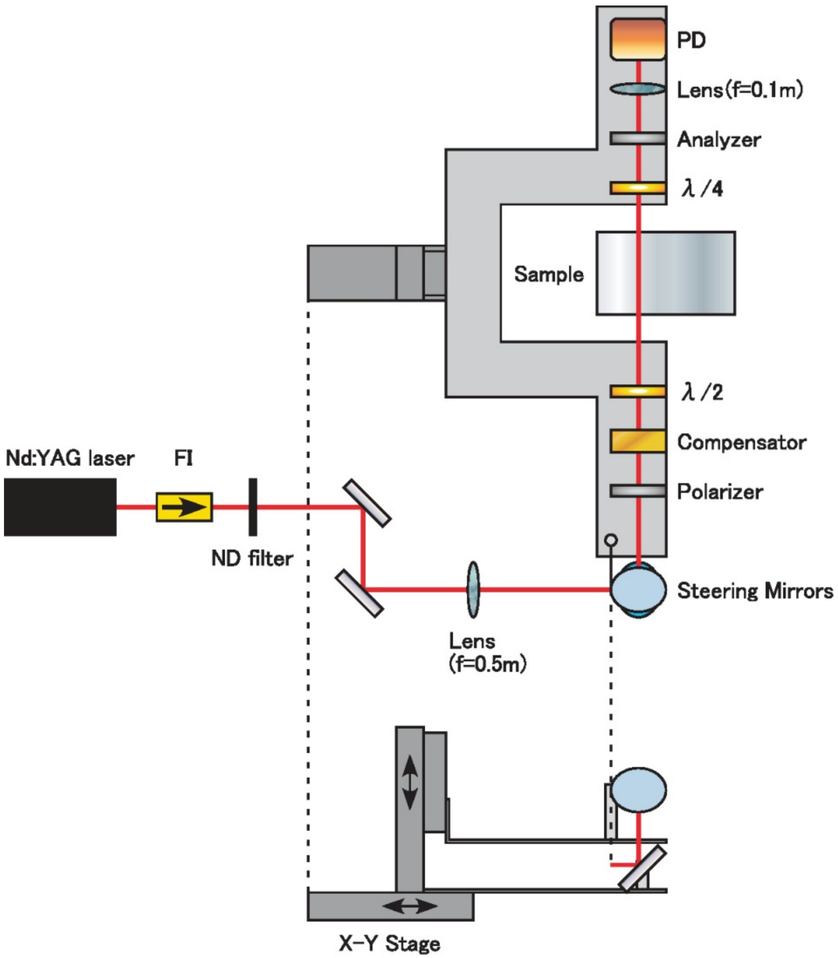

Achieved sensitivity by TAMA

- Almost all noise sources that limit TAMA sensitivity have been recognized.
- Low frequency region of TAMA sensitivity is limited by up-conversion noise

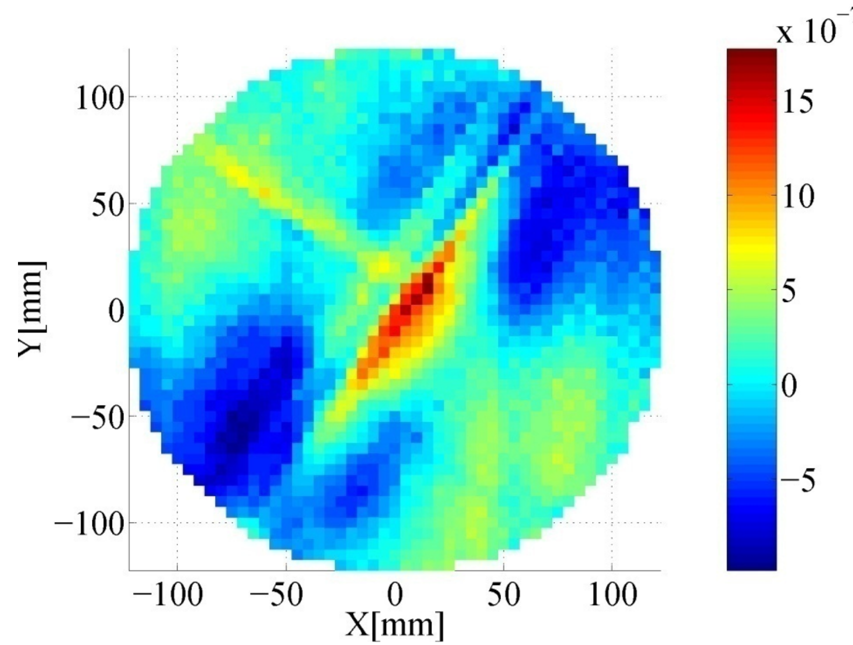


Quality selection machine of sapphire substrate

In order to cope with large optical loss of sapphire substrate, quality selection of sapphire pieces has been developed.



Auto scanning birefringence device



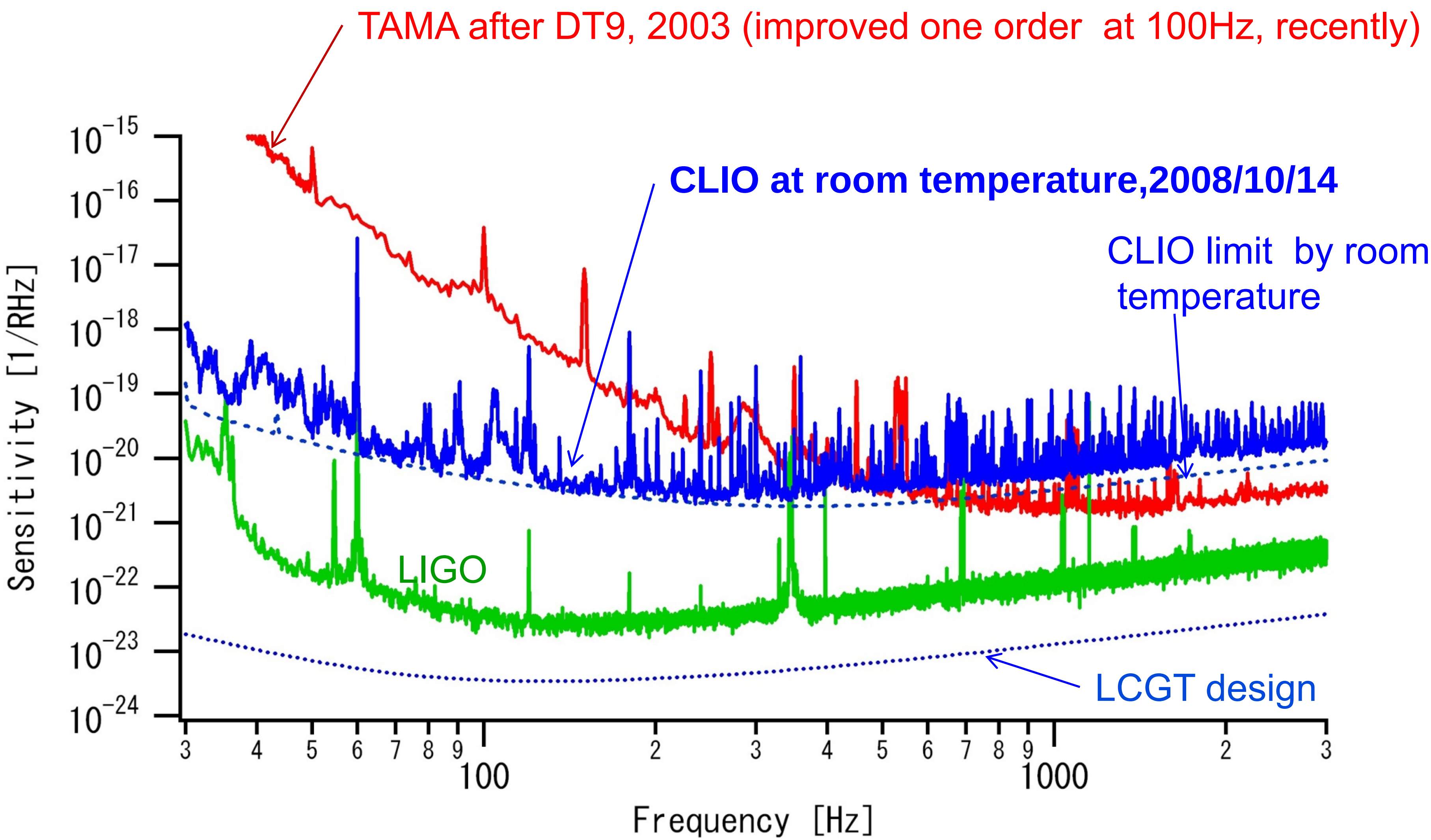
LIGO sapphire sample 250mm in diameter
29kg lent by the courtesy of LIGO.

Other R&D items (other than TAMA&CLIO)

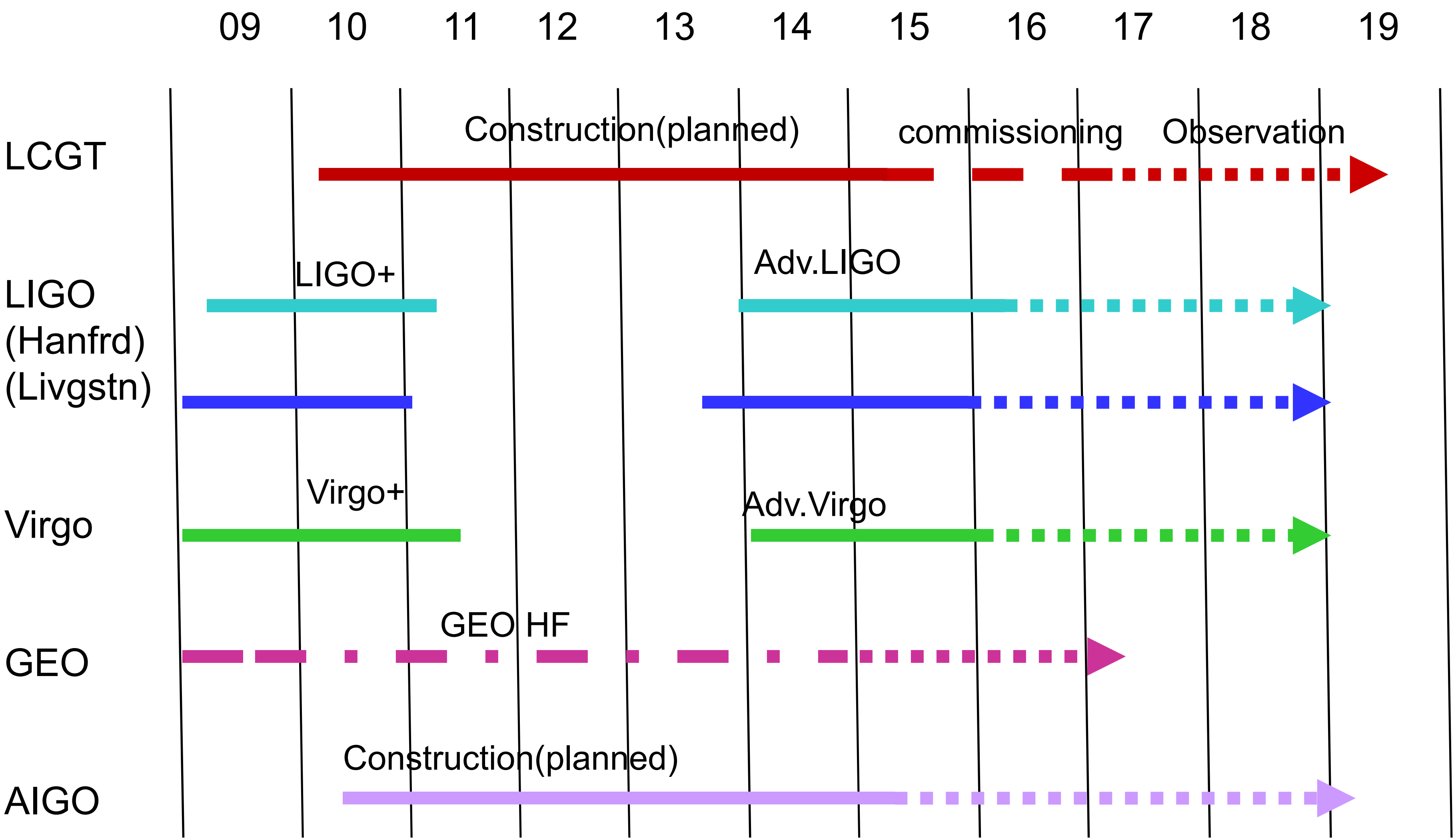
- RSE control scheme NAOJ
  - Broadband RSE control scheme analysis
  - Well defined parameters
- Suspension fiber development KEK
  - Sapphire rod deformation
  - Thermal conductivity measurement
- High power laser system

  (Department of Advanced Materials Science, UT)

Summary of Sensitivity improvement



LCGT Schedule with other ground projects



Cost estimation of LCGT

1. Construction (15.5 B JpnYen + R&D 300 M for 5 years)

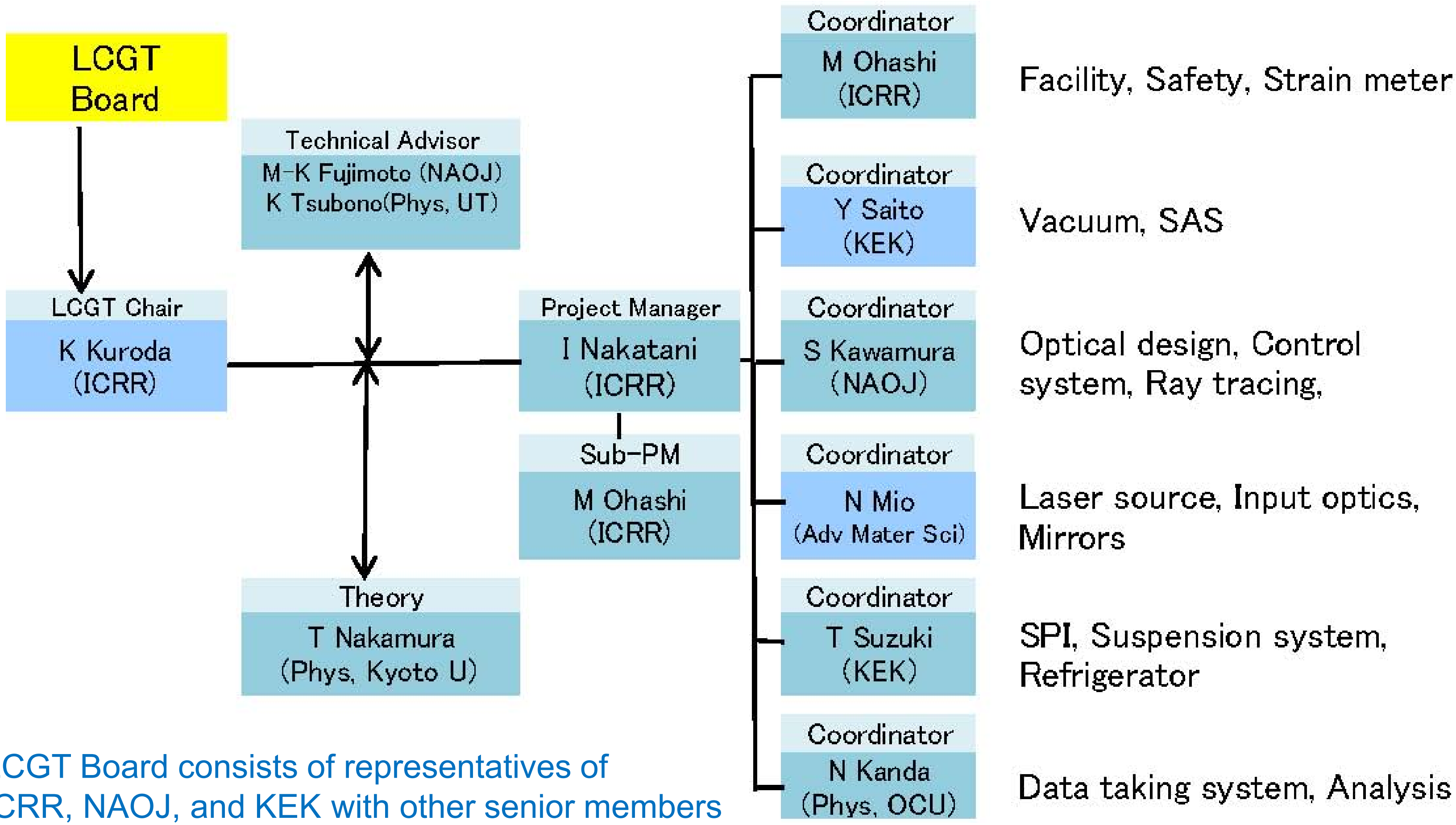
Item	Financial Year					Sub total (1000 Yen)
	2010	2011	2012	2013	2014	
Tunnel construction						3,586,000
Optical system						847,640
Vacuum system						6,655,280
Laser source system						450,500
Suspension/Cryo system						2,222,650
Anti Vibration system						242,000
Length compensator						980,000
Digital Control System						315,000
Research Building						210,000
Sub total in FY year	1,225,100	3,909,570	3,873,690	3,386,330	3,114,380	15,509,070

2. Commissioning and Observation (432 M JpnYen / Year)

Two years commissioning for 2015-2016 and start observation in 2017.

Man power Organization

LCGT is hosted by ICRR under MOU with NAOJ and KEK.
Its organization consists of 92 domestic researchers belonging to 17 universities or research institutes and 26 oversea members belonging to 14 universities or research institutes (118 researchers in total).



LCGT Board consists of representatives of ICRR, NAOJ, and KEK with other senior members

Support by GWIC for early construction of LCGT

GWIC: http://gwic.gravity.psu.edu

GWIC Statement on the Importance of the LCGT Interferometer Detector

April 3, 2008

Gravitational wave observations hold the potential to revolutionize our understanding of the universe. What we know of the cosmos today arises almost exclusively from observations made in the electromagnetic spectrum. However, some of the most important phenomena of fundamental physics – e.g., the catastrophic transformation of spacetime when two black holes coalesce – have no electromagnetic signature and can only be observed in gravitational waves. Additionally, some of the most energetic cosmic phenomena – e.g., the violent formation of a black hole which may drive a gamma-ray burst, or the collapse and bounce of a stellar core leading to a supernova explosion – are difficult or impossible to observe electromagnetically, but leave clearly visible gravitational wave signatures. Gravitational wave observations will permit us to pierce the veil that shrouds these phenomena from our understanding.

Significance and impact by detecting gravitational waves

Advanced interferometric gravitational wave detectors are being developed in the USA (Advanced LIGO) and in Europe (Advanced Virgo and GEO HF) which will have the sensitivity required to observe a variety of gravitational wave signals. However, there is an urgent scientific need for another detector of comparable sensitivity located in the other longitudinal hemisphere to come into operation simultaneously or soon after the US and European detectors (approximately 2015). Full exploitation of the information contained in the gravitational waves requires a network of detectors operating in coincidence with the intercontinental baselines to localize the sources. The addition of another detector to the network will also greatly increase the reliability of gravitational wave observations, since the false alarm rate drops dramatically as the number of detectors in the network increases.

A world wide network is indispensable to fully exploit of the information contained in GW by adding new one in Asia/Oceania

The Gravitational-Wave International Committee (GWIC) fully endorses the development of the Large-scale Cryogenic Gravitational wave Telescope in the Kamioka mine in Japan. This would significantly enhance the directional sensitivity of the array of detectors and provide a truly global observatory. The Japanese gravitational wave group has made fundamental and fruitful contributions to global interferometer research with the development and operation of the TAMA detector and with the studies of an underground cryogenic interferometer prototype. Thus this Committee strongly supports the funding of LCGT to be operational by 2015 or shortly thereafter.

GWIC endorses the operation of LCGT by 2015 or shortly after, which significantly enhances the directional sensitivity of the array of detectors and provides a truly global observatory

Domestic support by research communities and Review

- 1993: Gravitational wave telescope was nominated as one of future projects by the report of subcommittee of ICRR.
- 1994: Early realization of Gravity wave detectors were described in the Astronomical subcommittee of Science Council of Japan.
- 1994: MOU promoting GW research among directors of NAOJ, KEK, and ICRR, being renewed every two years hereafter.
- 2000: Space Science subcommittee of the academic council of MEXT nominated LCGT as one of projects in a fund waiting list with recommending the reinforcement of R&D.
- 2005: Special report of the Astronomical subcommittee of Science Council of Japan strongly requested the prompt funding of LCGT on behalf of the whole astronomical community.
- 2005: External technical review panel of ICRR concluded the soundness of the LCGT design.
- 2007: ICRR was nominated as the host institute for LCGT under revised MOU originally exchanged in 1994.
- 2007: Future research plan committee of ICRR exclusively pushed LCGT.
- 2008: GWIC under IUPAP･PaNAGIC strongly supported the funding of LCGT that made the beginning of observation in 2015 possible.
- 2008: Astronomy & Astrophysics subcommittee of Science Council of Japan raised the resolution to promote early LCGT funding.

Scientific Impact of LCGT

- Pioneering work for GW Astronomy
- Experimental test of general relativity under strong gravity
- Matter dynamics under extremes of density and pressure
- Strong motive force to accelerate space interferometers
- International collaboration stronger than any other else
- Advanced technologies of seeds for future industry

Summary

- Interferometer techniques (power recycling, Fabry-Perot Michelson, control system) by TAMA and the feasibility of cryogenic mirror proven by CLIO are the technical foundation of LCGT.
- If LCGT is funded soon, we reliably detect GW at the first time or at least early time.
- We initiate GW astronomy by leading the world-wide network formed by LCGT, adv. LIGO, adv. Virgo and GEO HF.