LSC-Virgo Meeting
Pasadena, CALTECH
17-20 March, 2008

Current Status of Japanese projects

TAMA/CLIO/LCGT Collaboration
Kazuaki KURODA

Content of this talk

- TAMA
  - Brief history of noise reduction
  - SAS Installation and digital control
  - EMC reduction in SAS
- CLIO
  - Cooling performance
  - Noise hunting and Trial Observation
- LCGT
  - Design and R&D
  - Fund

TAMA

- **TAMA project (1995～)**

Consortium of domestic research organizations

(NAO, Phys.UT, ICRR, KEK, ERI, UEC, Adv.Mater.UT, Tokai U, TEU, NRLM, Kinki U, Kyoto U, Osaka U, Osaka CU, Astron.UT, Niigata U, Tohoku U, Hiroshima U, Hirosaki U, ...)

Construction of TAMA300

R&D for LCGT

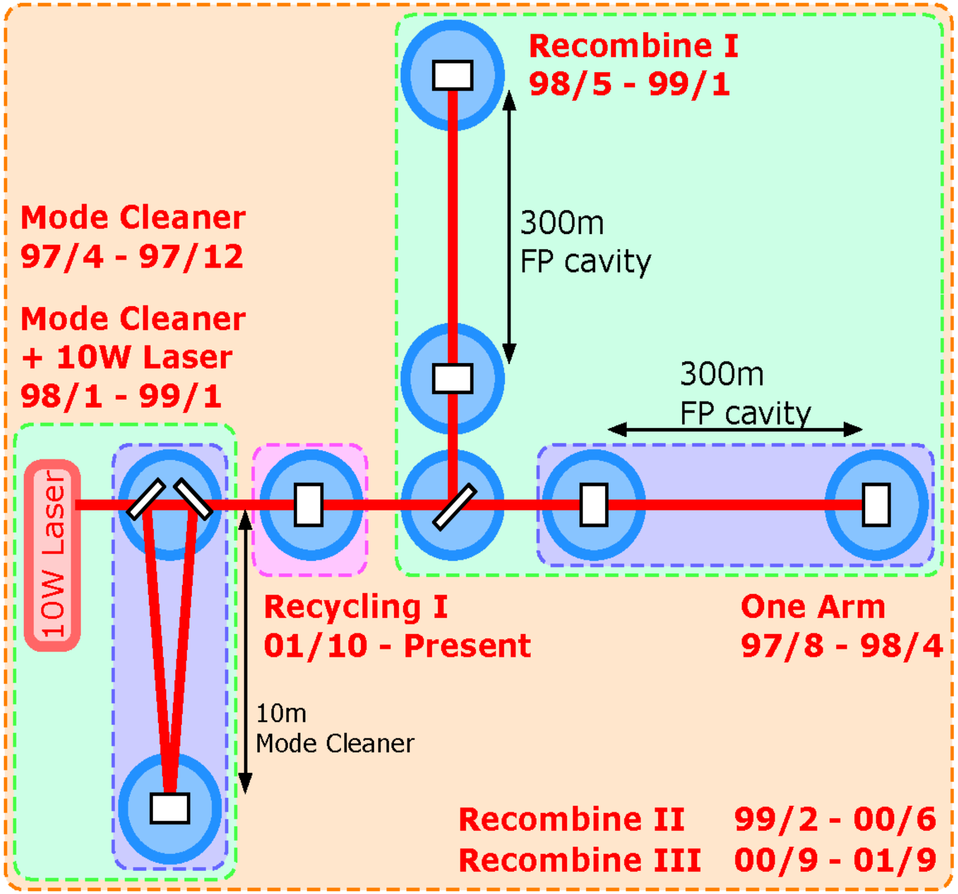
Practical detector
(Observation of our Galaxy)

⇩

Sensitivity to detect
Galaxy events
(World best in 2000-2002)
Earlier observation run
(Obs data more than 2000 hr)

Brief History of TAMA300

1995 Project started
1997 One arm cavity locked
1999 FPMI operation started
DT1(11hr) ,DT2(31hr)
2000 World best sensitivity
h = 5E−21/rHz
DT4(167hr)
2001 DT6(1038hr)
Power Recycled FPMI
2002 First Coincidence Run
with LIGO(S1) and GEO600
2003 DT8(1158hr)
with LIGO(S2)
2003/4 DT9 with LIGO(S3)
and GEO600
Full Automatic Operation
2004— Noise hunting
TAMA-SAS



Observation Summary

TAMA data-taking runs including long-term observations

Run	Term	Year	Live Time (Hour)
DT1	6-Aug → 7-Aug	1999	7
DT2	17-Sept → 20-Sept	1999	31
DT3	20-Apr → 23-Apr	2000	13
DT4	21-Aug → 4-Sept	2000	161
DT5	2-Mar → 8-Mar	2001	111
DT6	15-Aug → 20-Sept	2001	1038
DT7	31-Aug → 2-Sept	2002	25
DT8	14-Feb → 14-Apr	2003	1158
DT9	28-Nov → 10-Jan	2004	558

In 1999, TAMA started to make observations

The world best sensitivity

Continuous observation more than 1000 hr with the highest sensitivity.

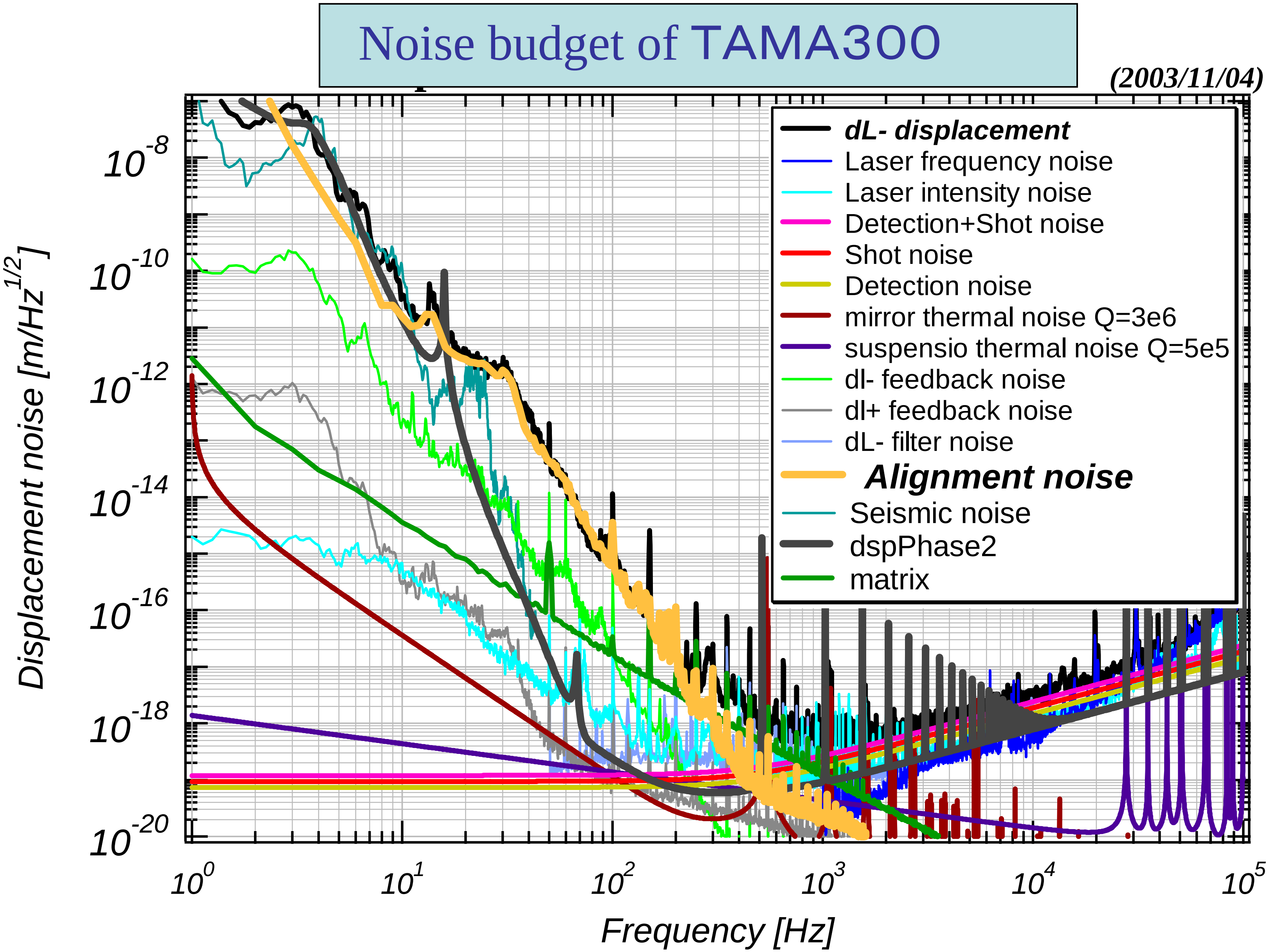
Power recycling

LIGO S1

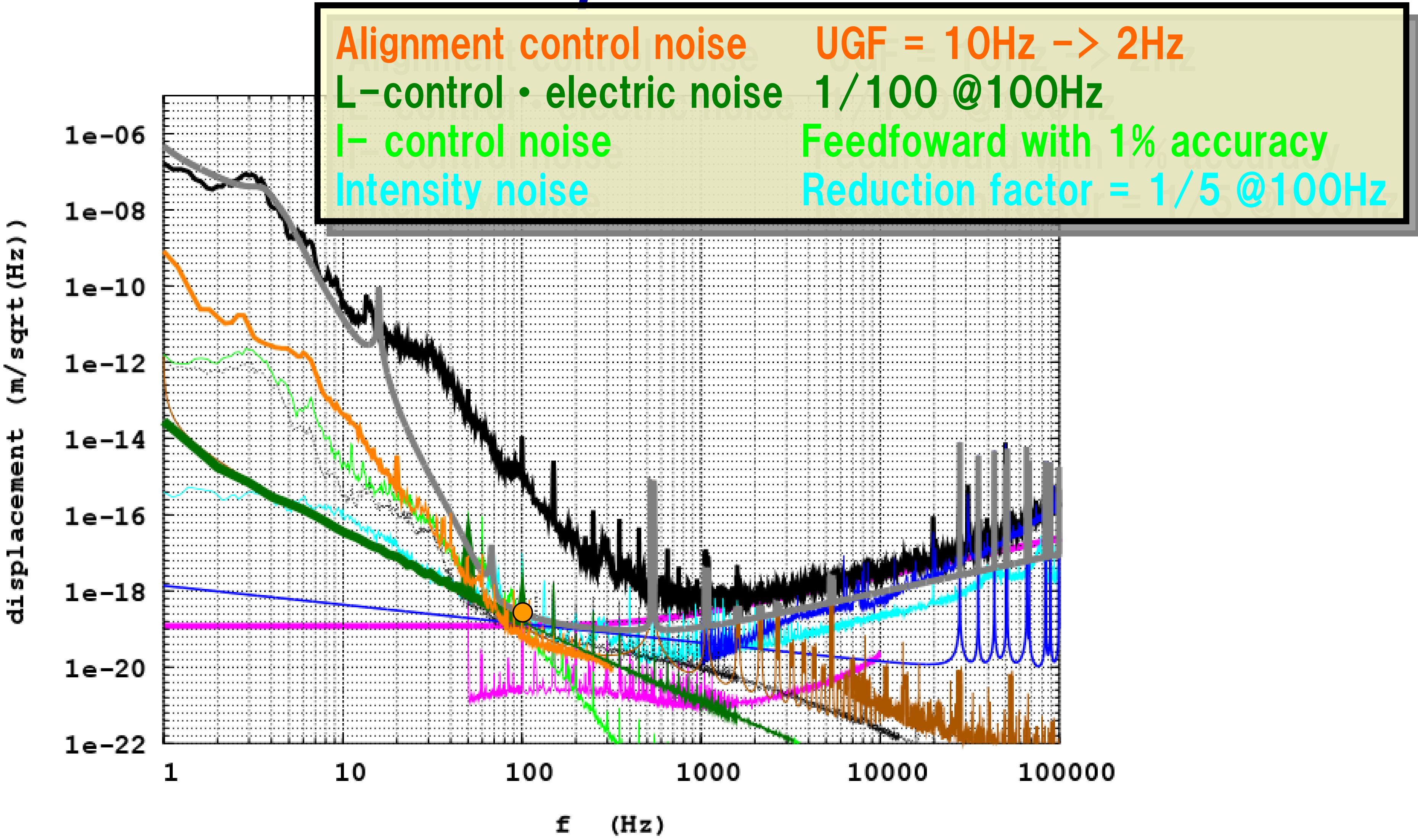
Total 3102 hours data was accumulated.

Some parts of DT7-9 are overlapped with the science runs of LIGO (GEO) and cooperative two papers have been published to limit the event rates of both coalescence and supernova events in our Galaxy.

Improvement(2) Low Frequencies



Higher sensitivity at low frequencies



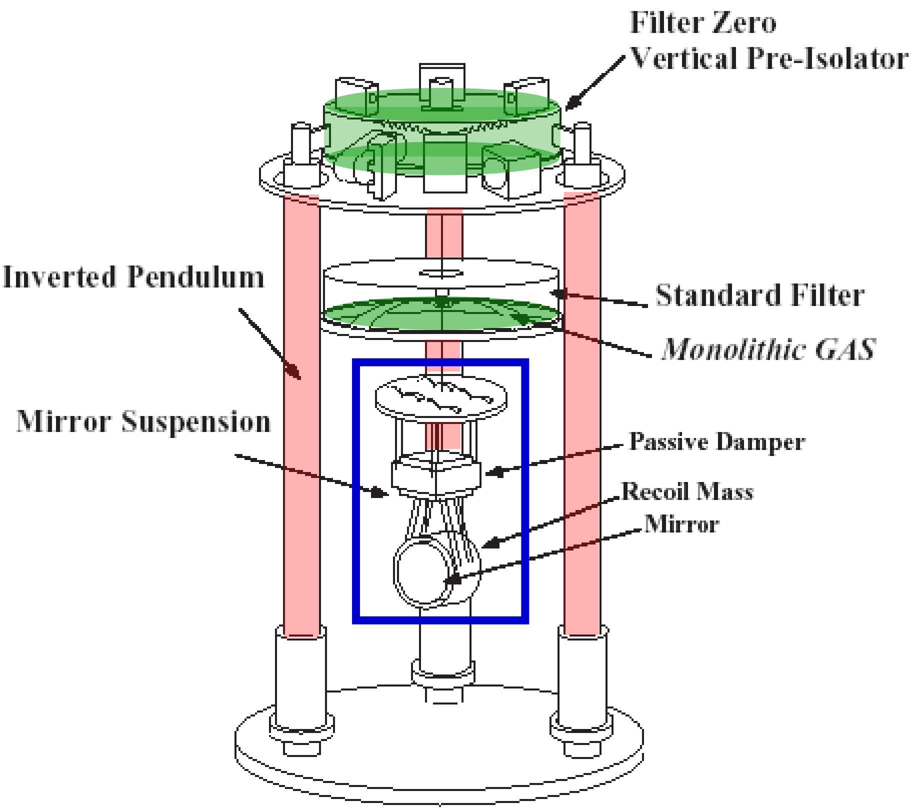
TAMA SAS
(Seismic Attenuation System)

1. Horizontal
   - Inverted Pendulum
   - resonant freq. : 30mHz

2. Vertical
   - Double MGAS Filters
   - Each of 0.5Hz resonance

3. Payload
   - Top mass (Platform)
   - Intermediate mass
   - Mirror - Recoil mass

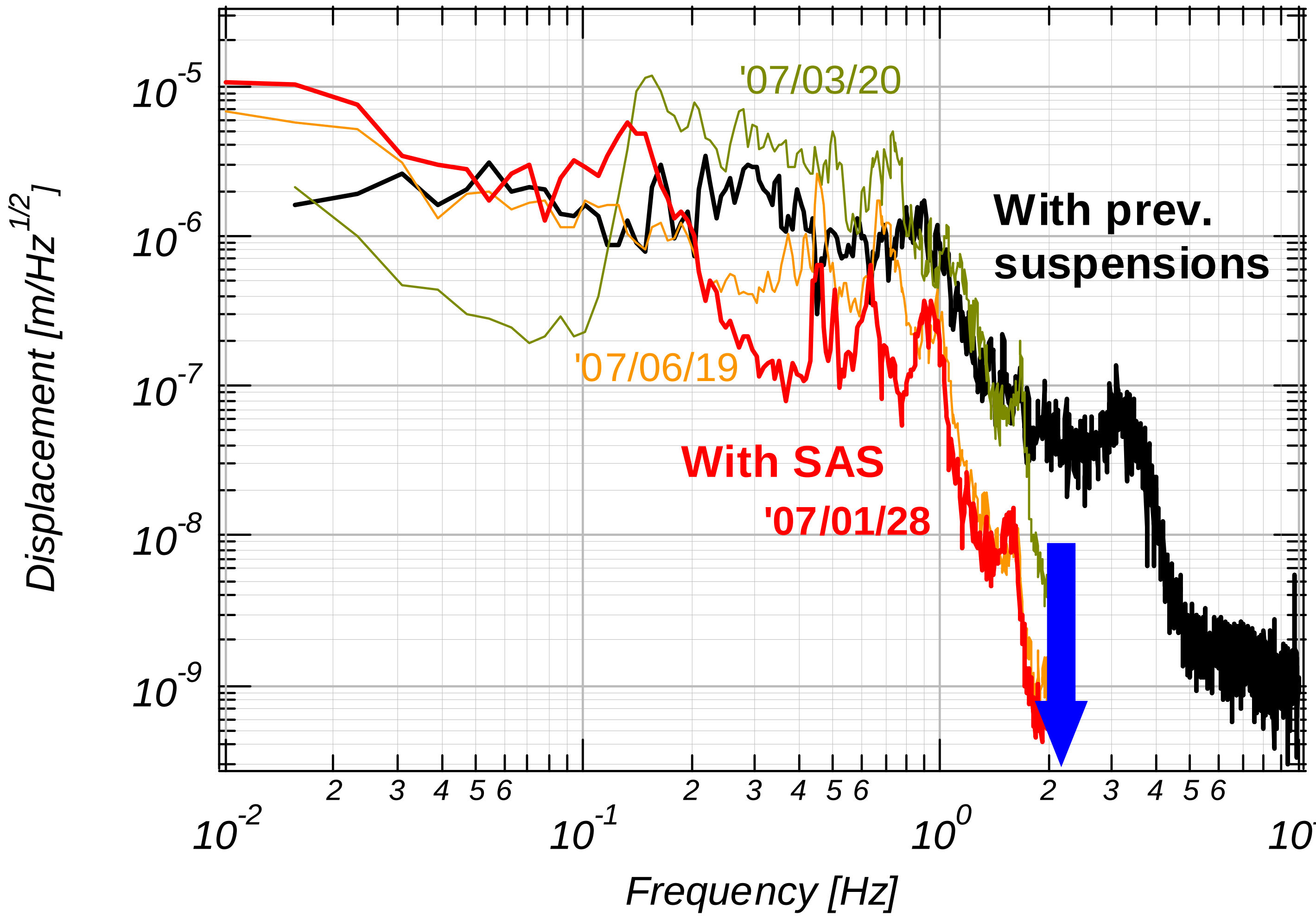
TAMA-SAS
(IP + GASF + Payload)



To reduce the seismic noise, new isolation system is being installed.
This figure shows a schematic view of TAMA SAS.
To isolate horizontal motion, an inverted pendulum is implemented.
For vertical motion, double stage MGAS filters are used.
Finally mirror was suspended by a double pendulum.

Improvement of the inertial damping sevo

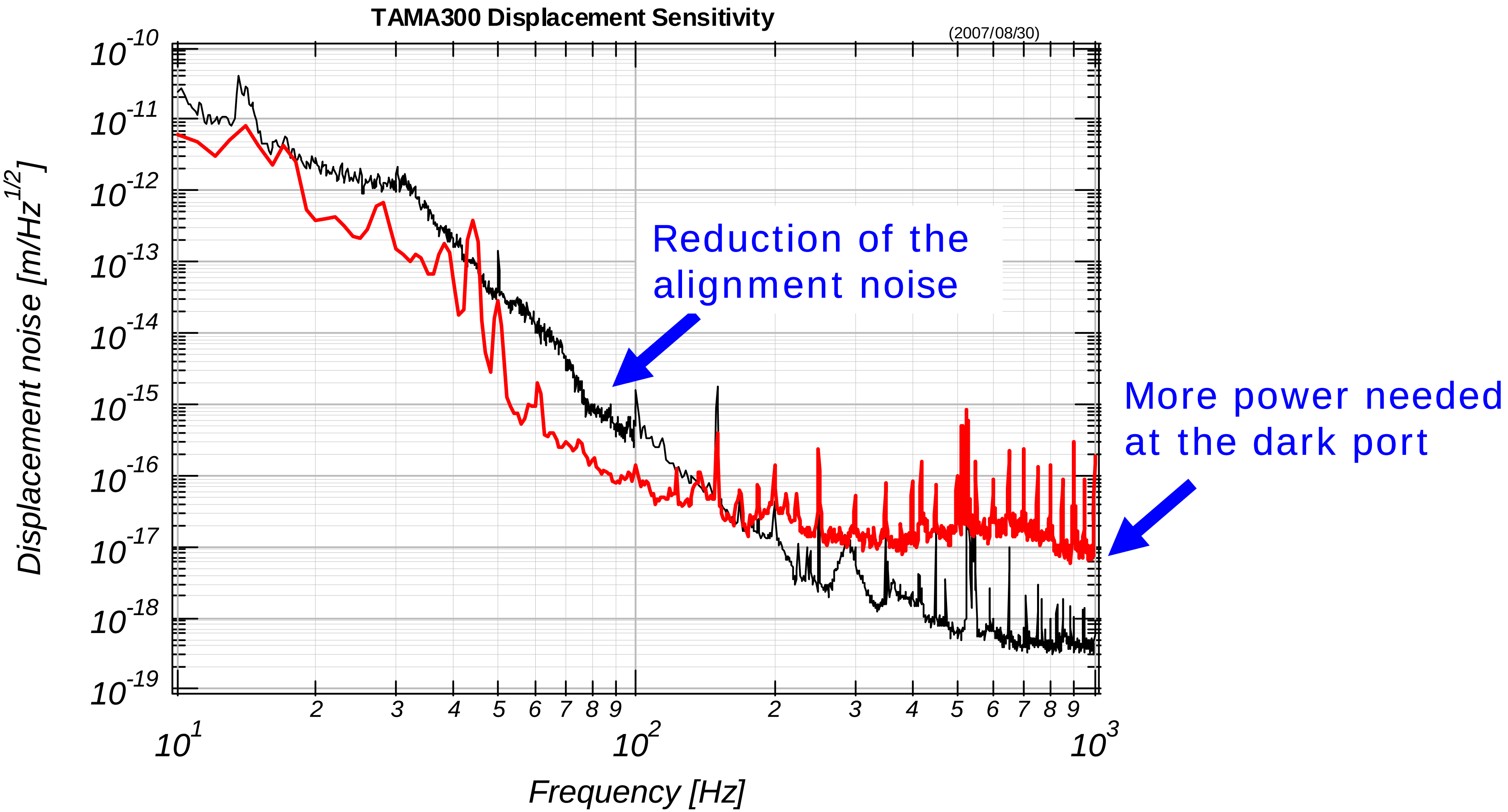
Improvement of the accelerometers/ Servo optimization



> x10 reduction above 0.2Hz from the previous system

Interferometer sensitivity

- Reduction of the alignment control noise
  - Bandwidth 10Hz -> 3Hz

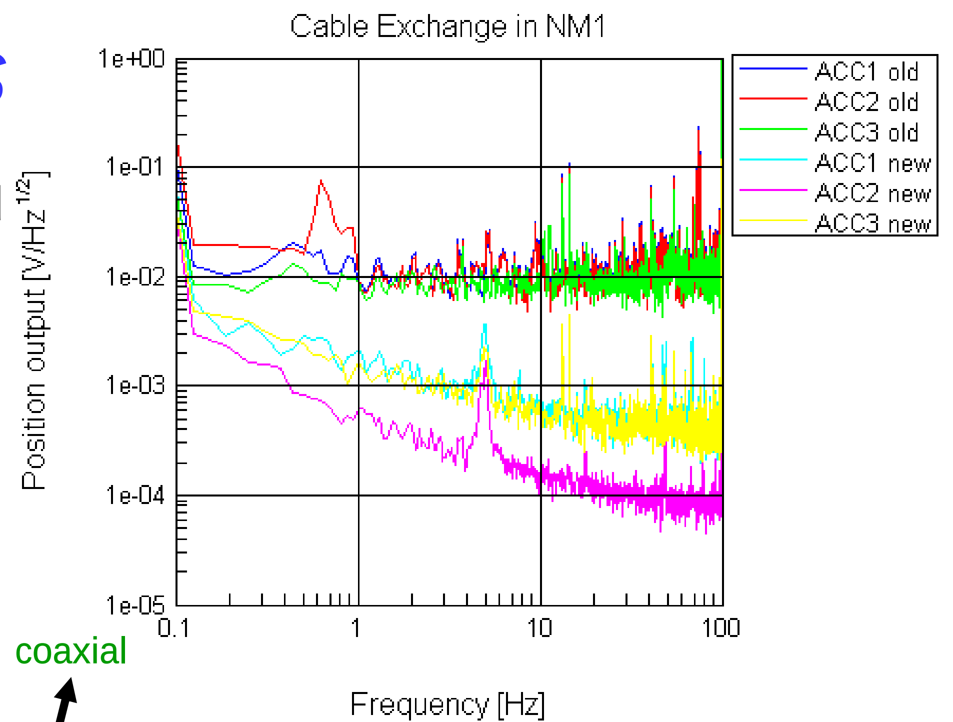


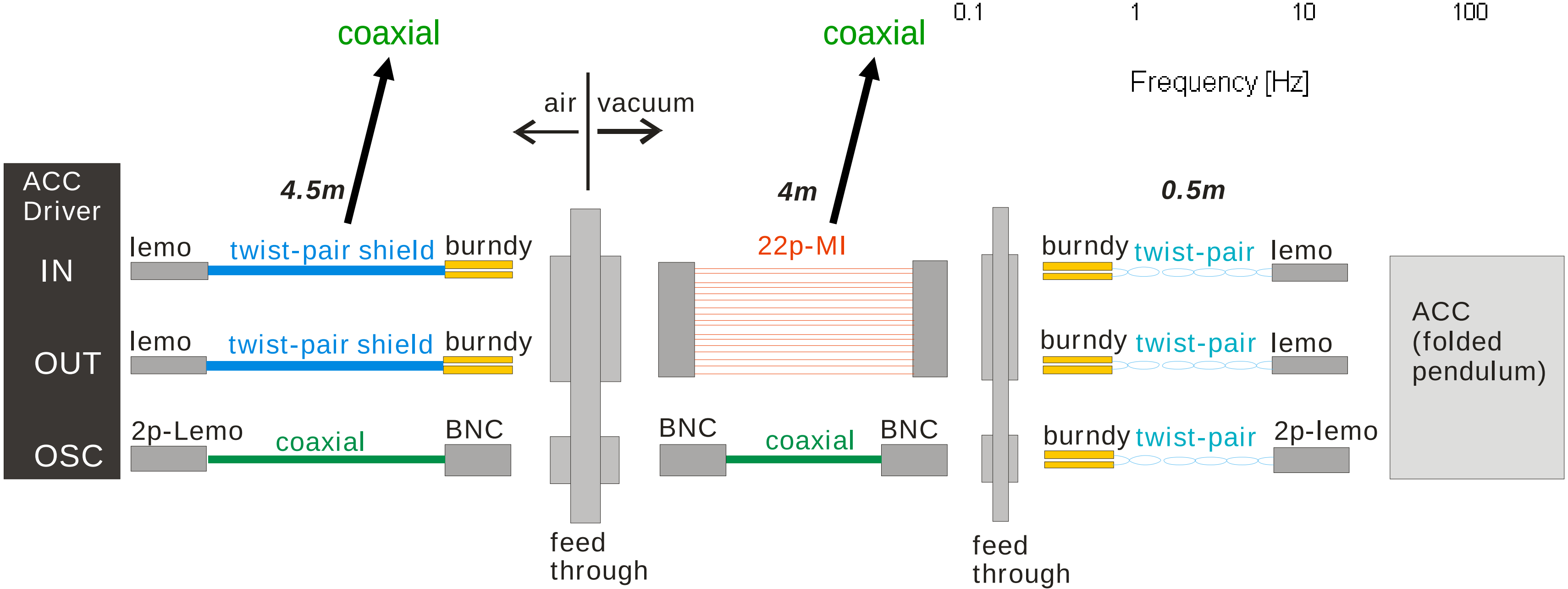
New alignment topology

- Alignment control topology should be renewed
  - Test masses (with SAS): quieter than the other optics
  - Conventional topology to actuate test masses is not a good idea any more
- Alignment control topology
  - Actuate aux. optics like PRM, BS
  - Use of digital control:
    - complicated sensing/actuation matrix
    - low frequency poles and zeros
  - More control BW expected even with lower noise injection
    => allows more power at the dark port
    => better noise level at 1kHz region

EMC problem of accelerometers for SAS

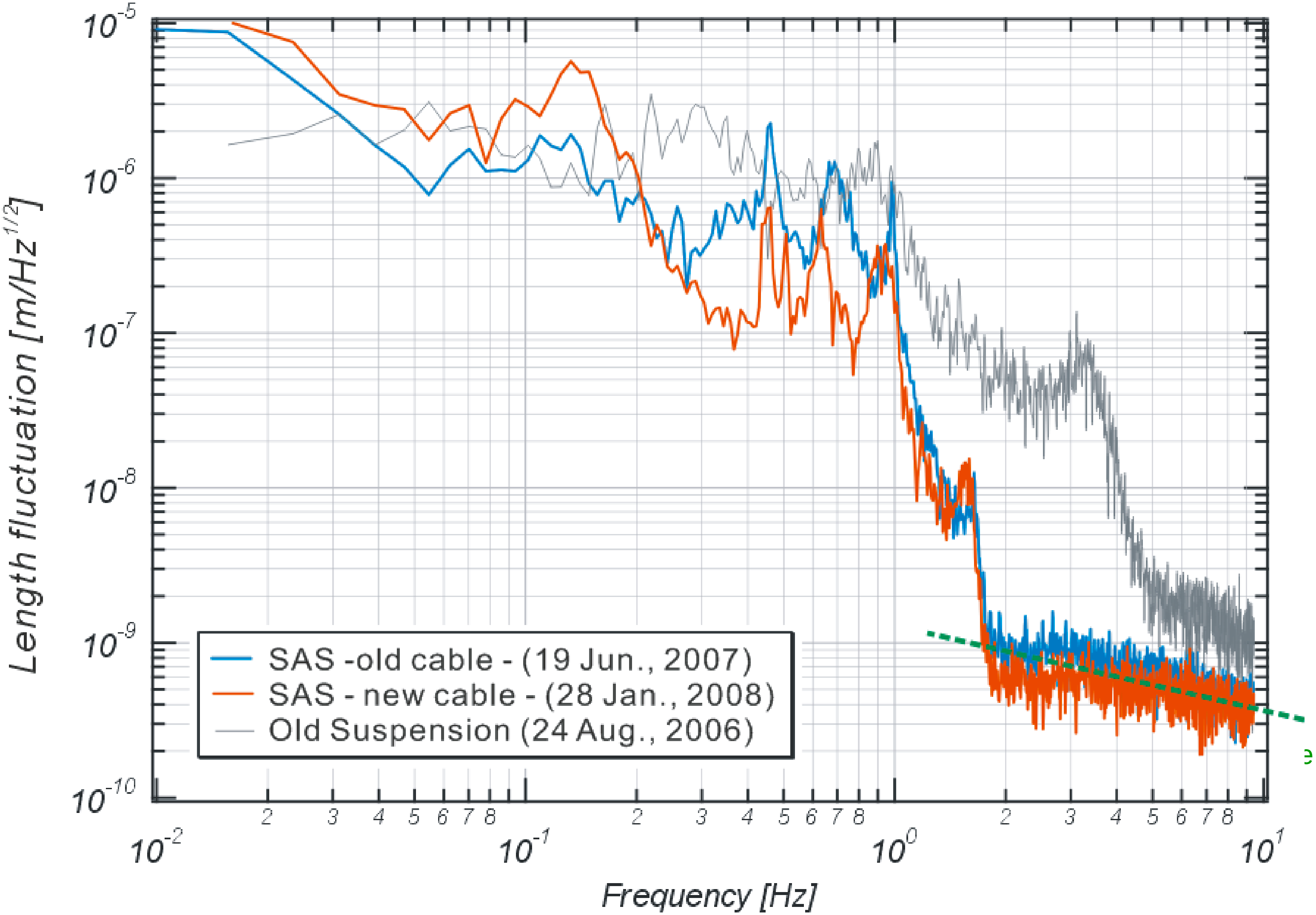
- Sensing signal of ACC is transmitted through the long cable at 100kHz.
- Cables for the position sensor were exchanged from parallel/twist pair cables to coaxial cables.
- The induced noise was reduced by one digit above 1Hz.





Improved length performance

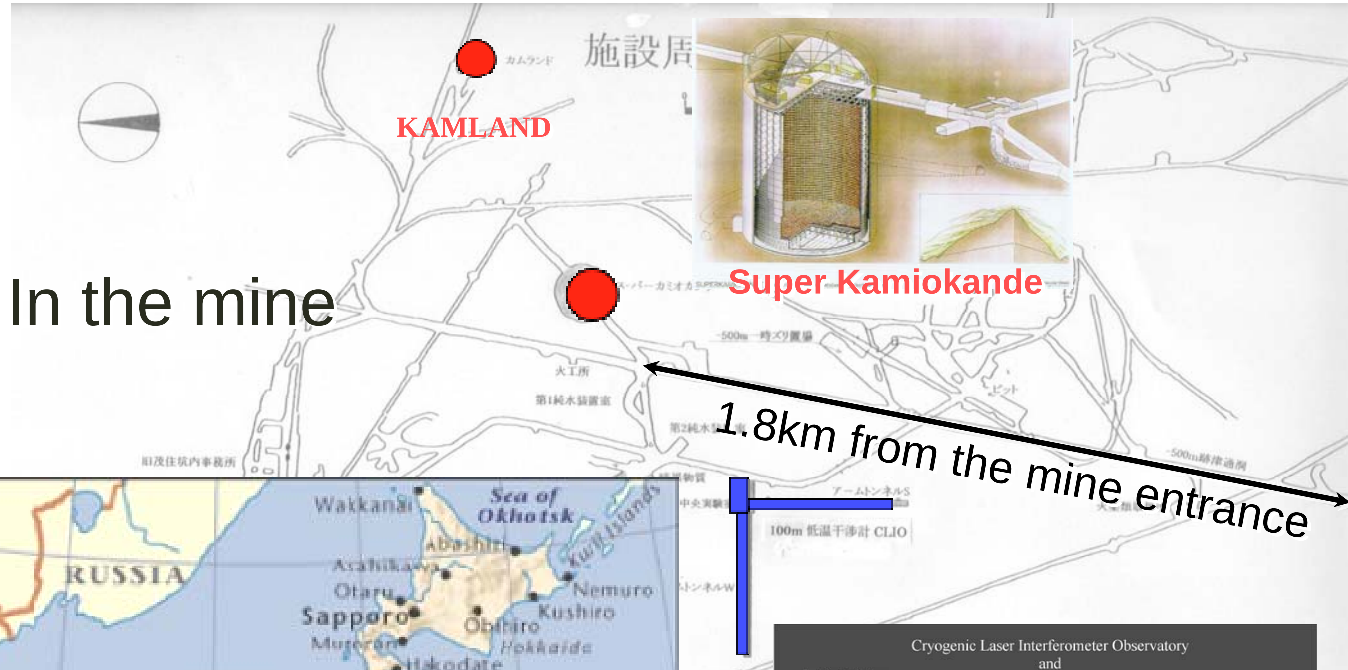
- Sensitivities of ACC were improved by cable exchange.
- Band width for IP control was extended from 2Hz to 4Hz.
- Length performance with SAS was improved at 0.3-1Hz.

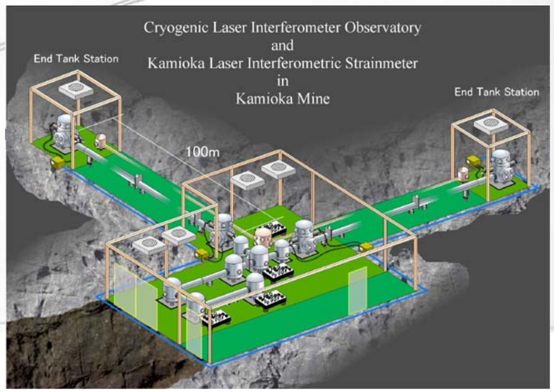


CLIO

CLIO site (Kamioka)

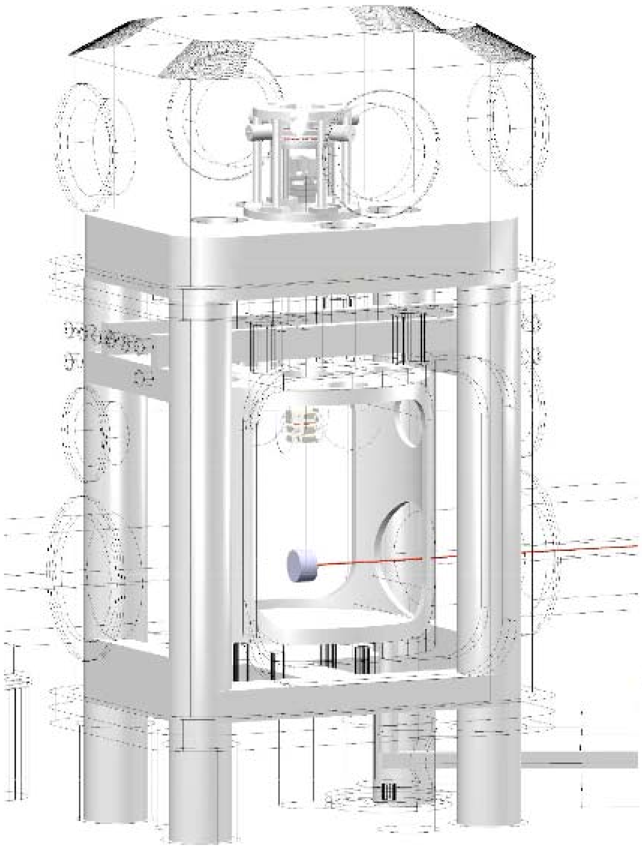
In the mine

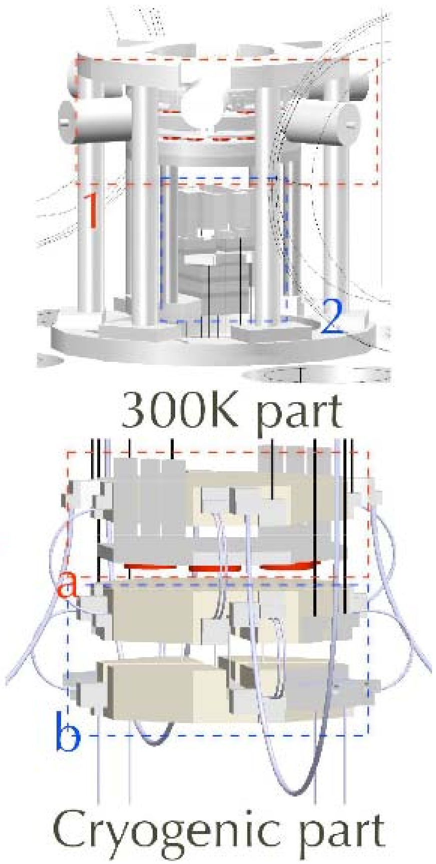




CLIO

Mirror suspension system

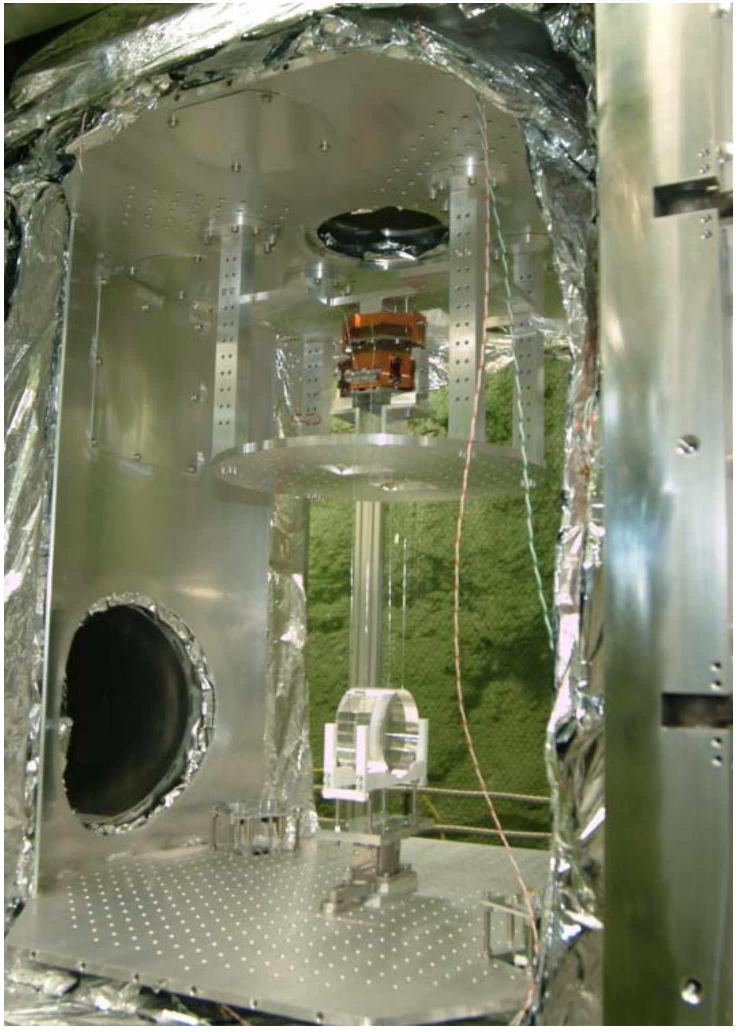




- Sapphire mirror
  - $\Phi 100 \times 60$, 2kg.
- 6 stages vibration isolation.
  - 3 stages in 300K.
  - 3 stages in 10K.

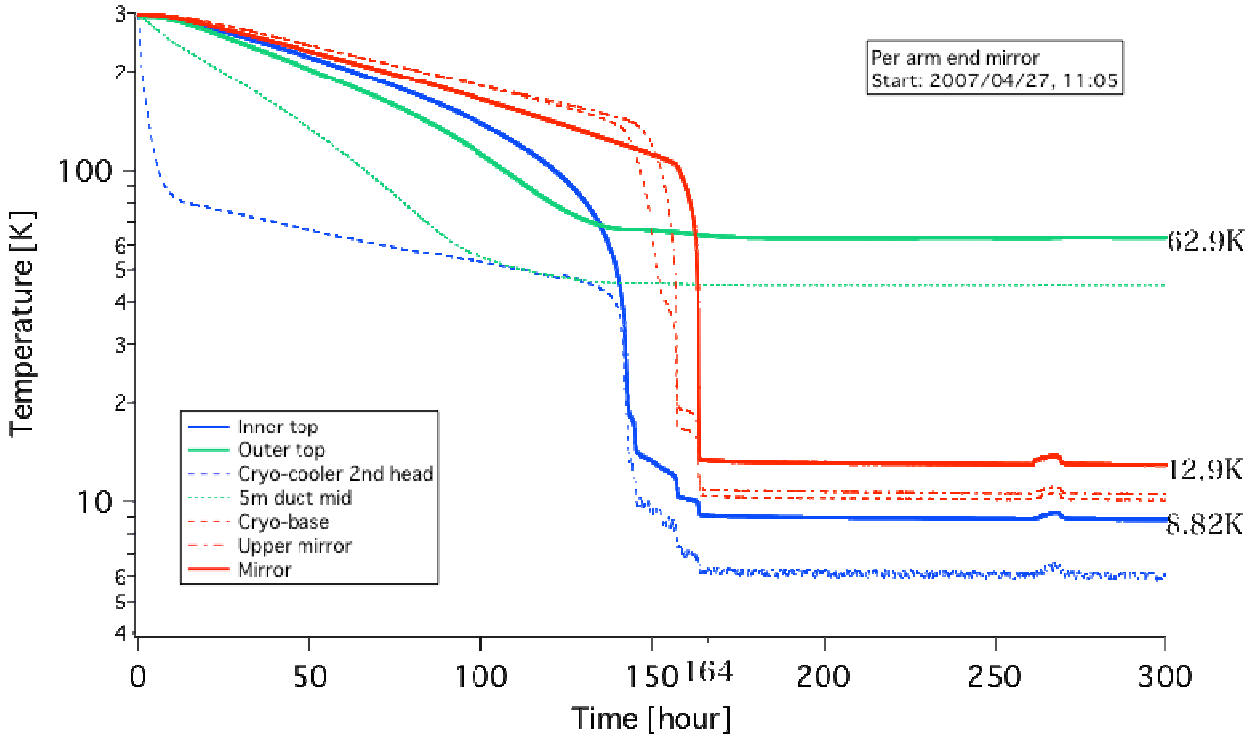
Suspension

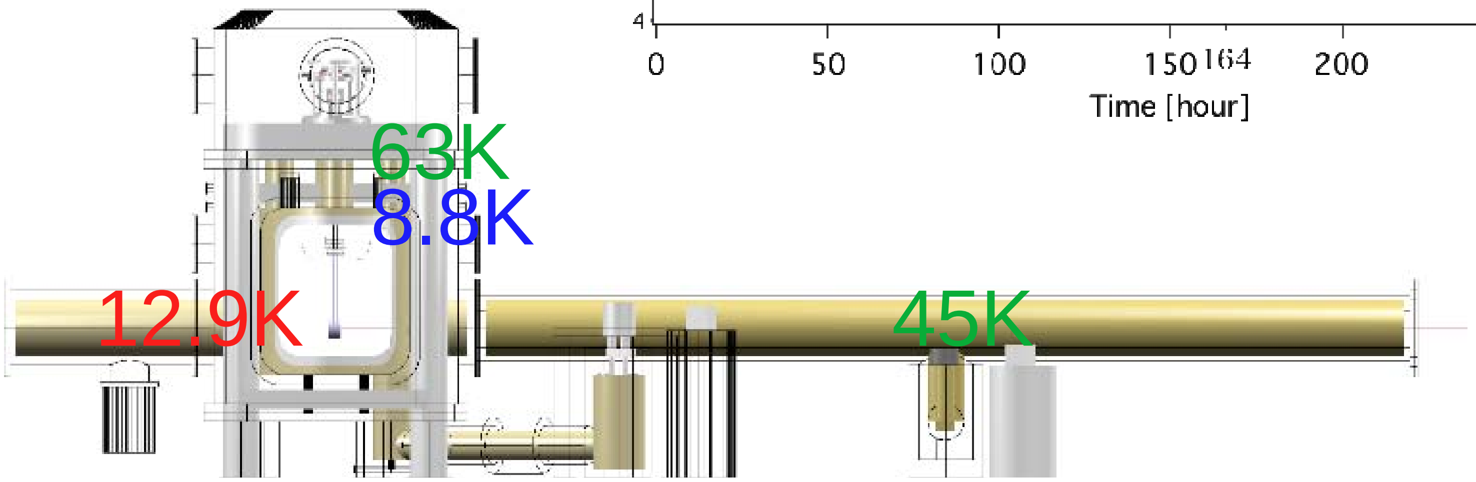
Room temperature room above the cryostat



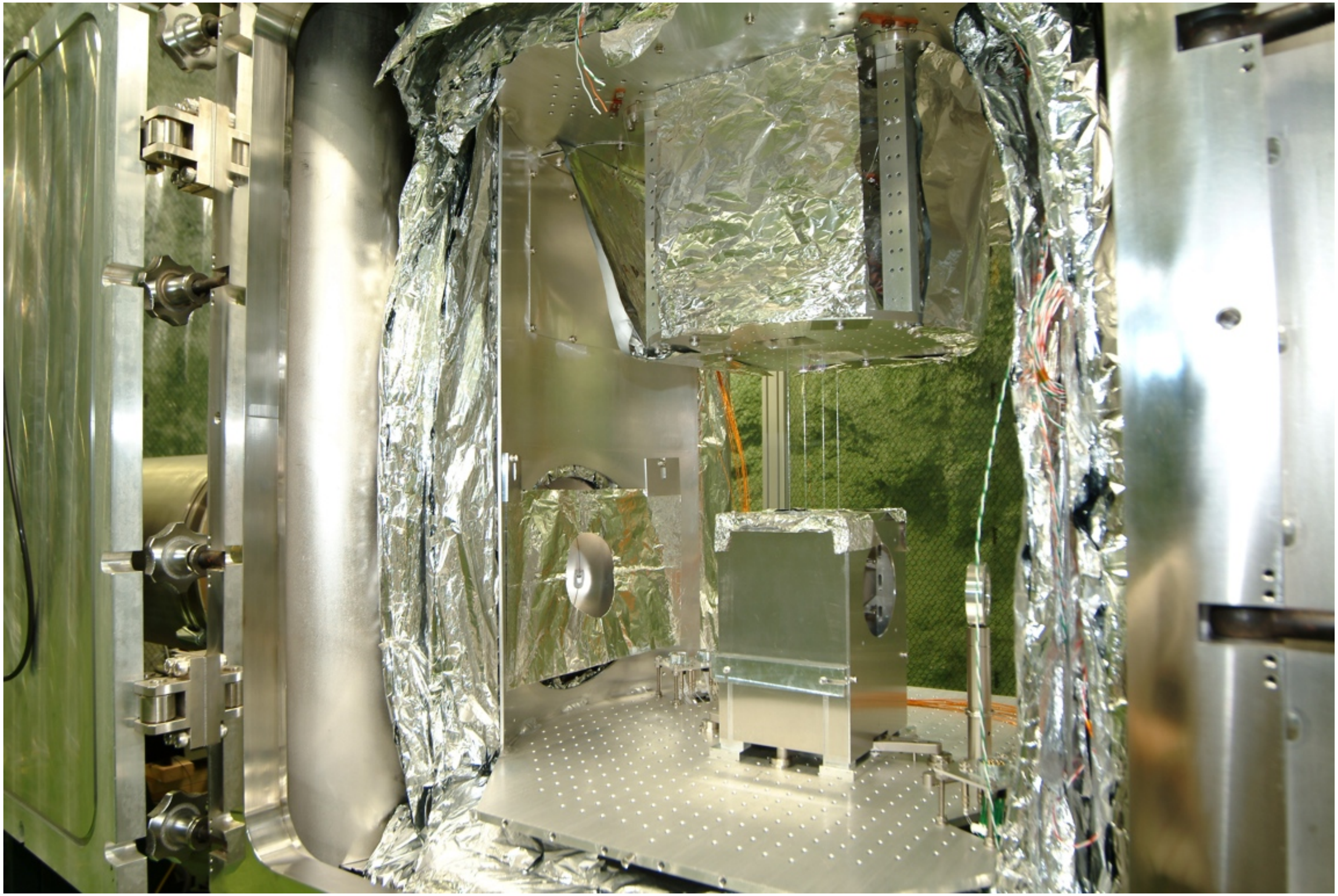
Test mass suspended through two-stages intermediate mass

Cooling test and achieved temperature





For cooling

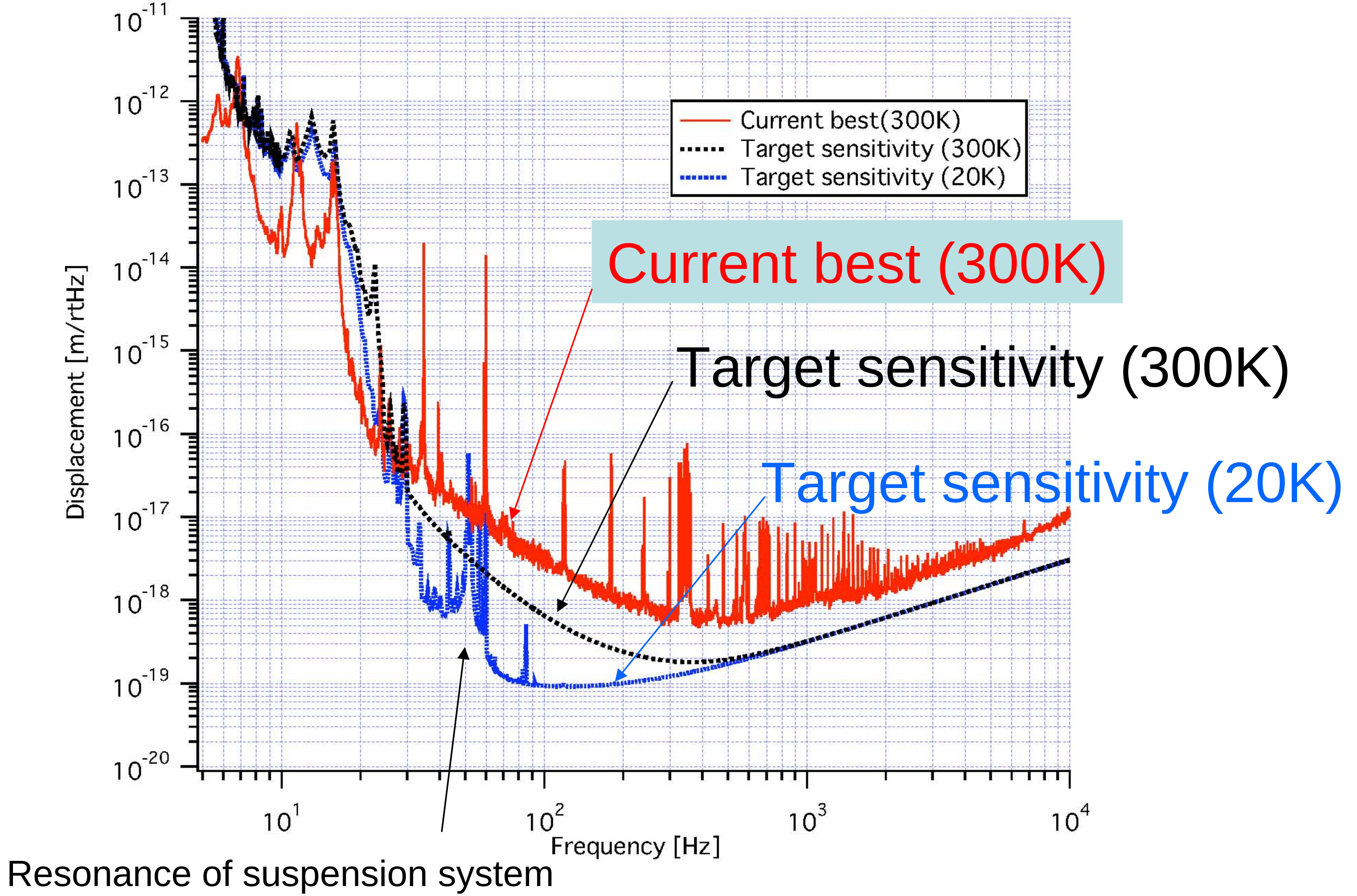


Cooling summary

	Cooling time	Mirror temp	Heat in the suspension	Heat at the 1st cooling 2006/02
Inline end	176hour start 07/06/22,10:00	13.5K	40mW	N/A
Inline near	174hour start 07/06/22,10:00	13.4K	36mW	N/A
Per arm end	164hour start 07/04/27,11:05	12.5K	62mW[#1]	116mW
Per arm near	193hour start 07/08/16,12:30	13.8K	29mW	109mW

#1; No shield for radiation from the outer shield at 63K.

Expected Noise Spectrum at 20K



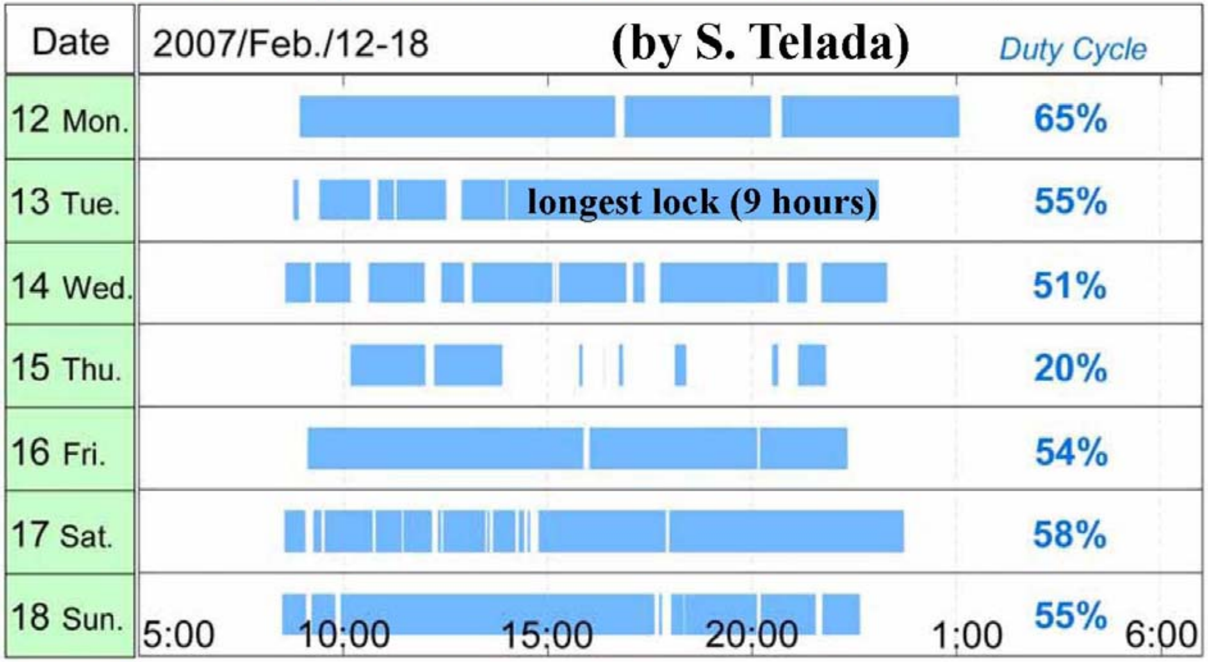
CLIO Trial Observation

2007 Feb.12 – Feb.18 **Observation**

8:00 - 22:00 Operator on Site
22:00 - 8:00 No-Operator

Total 86 hour

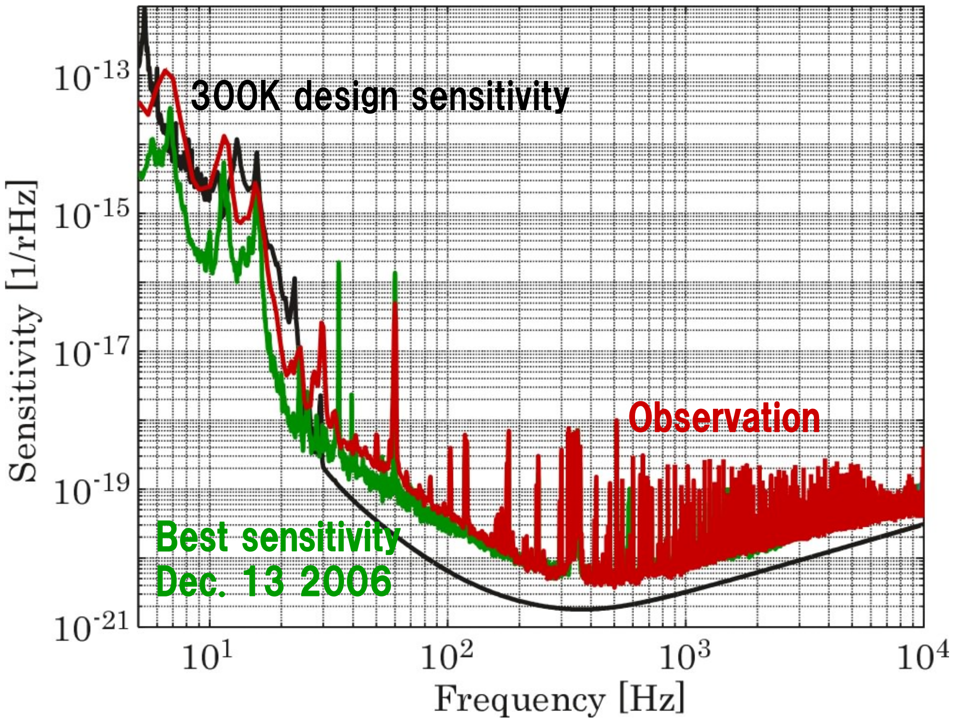
without alignment control and auto lock system



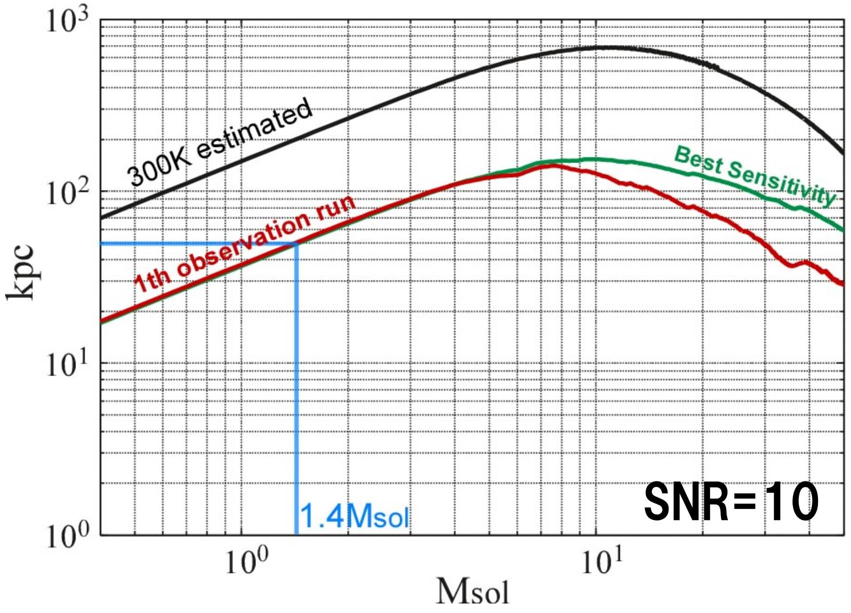
$$h_{\mathrm{U.L.}} = 5.3\times10^{-20}$$

CLIO sensitivity during observation

Sensitivity

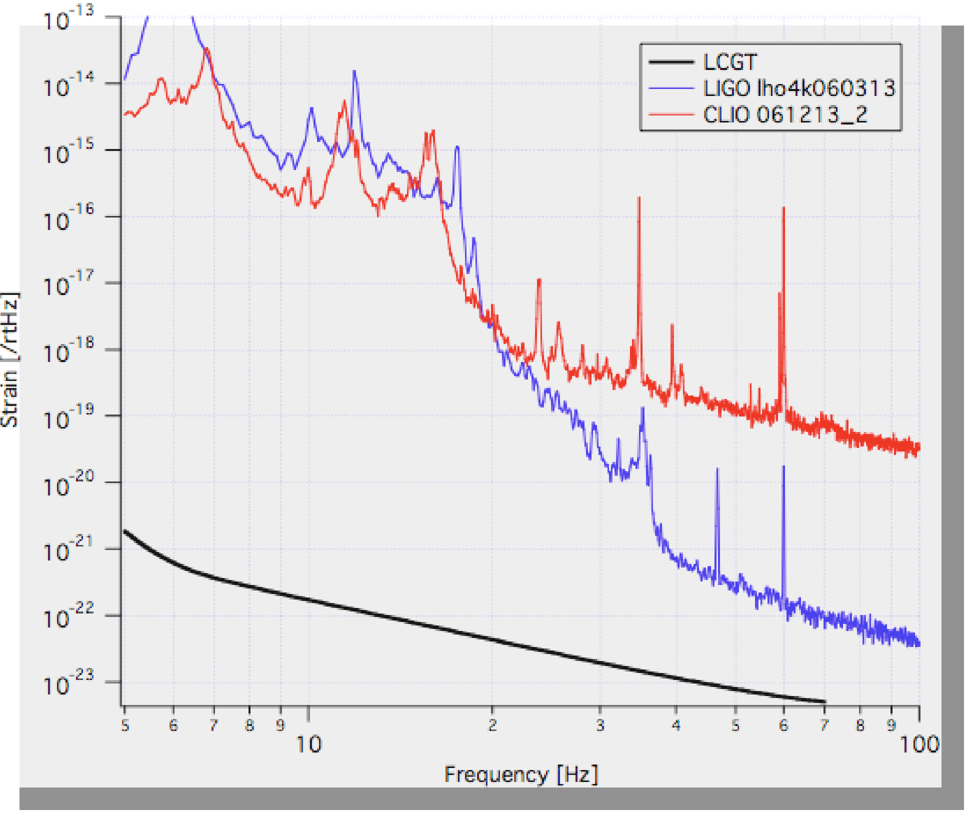


Observable distance for inspiraling compact binaries

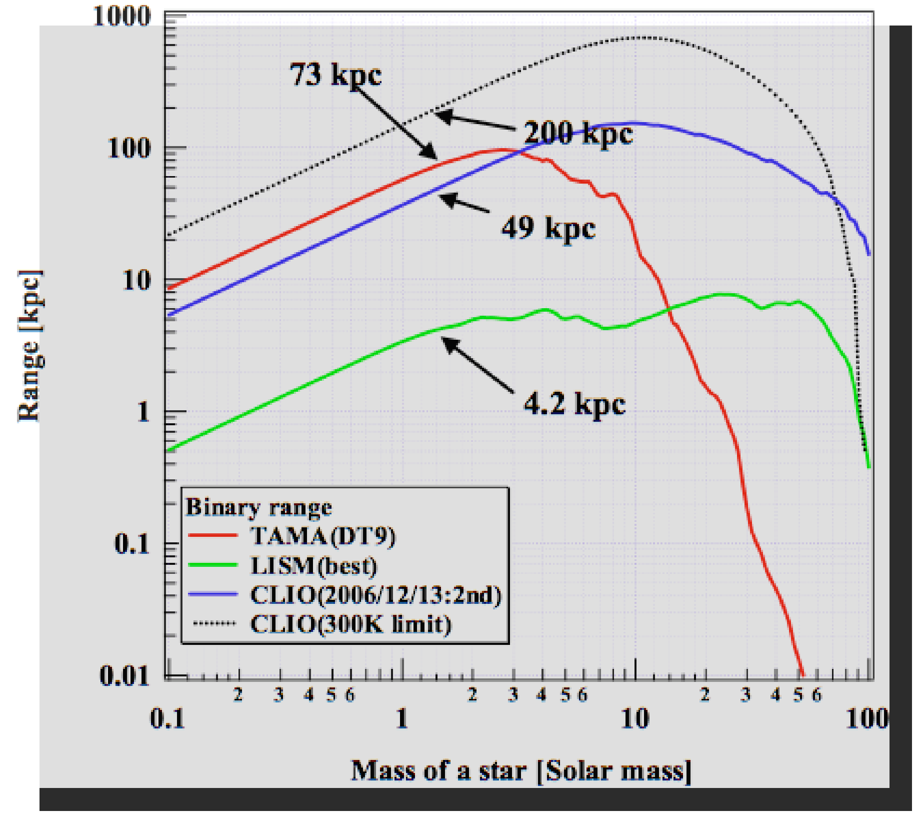


49.5kpc@1.4Msol

GW sensitivity



Strain sensitivity



Dr. K. Yamamoto

Observation range for compact star binary coalescence

Continuous wave analysis

For Vela pulsar $h_{\mathrm{U.L.}} = 5.3 \times 10^{-20}$ (Preliminary)

LCGT

The goal of LCGT

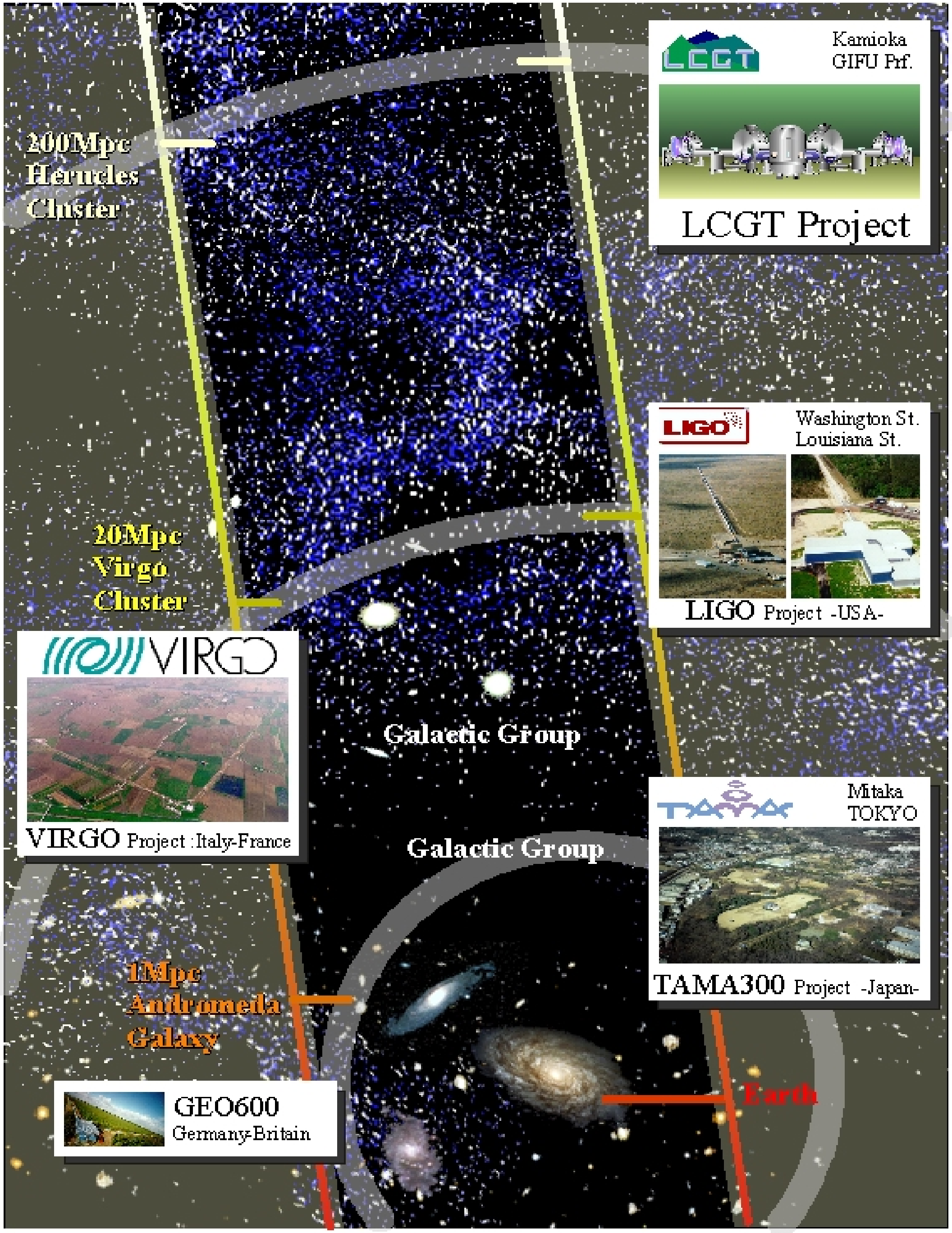
LIGO (USA), VIRGO (French-Italian), GEO (Germany-England), TAMA (Japan) are in operation.

Occurrence of neutron star binary is estimated to be 10^{-5} for matured galaxy per year . There are 0.01 galaxies for 1 cubic Mpc. Present detectors (km-scale) cover up to Virgo cluster（20Mpc). More than several 10 years are needed to detect the event.

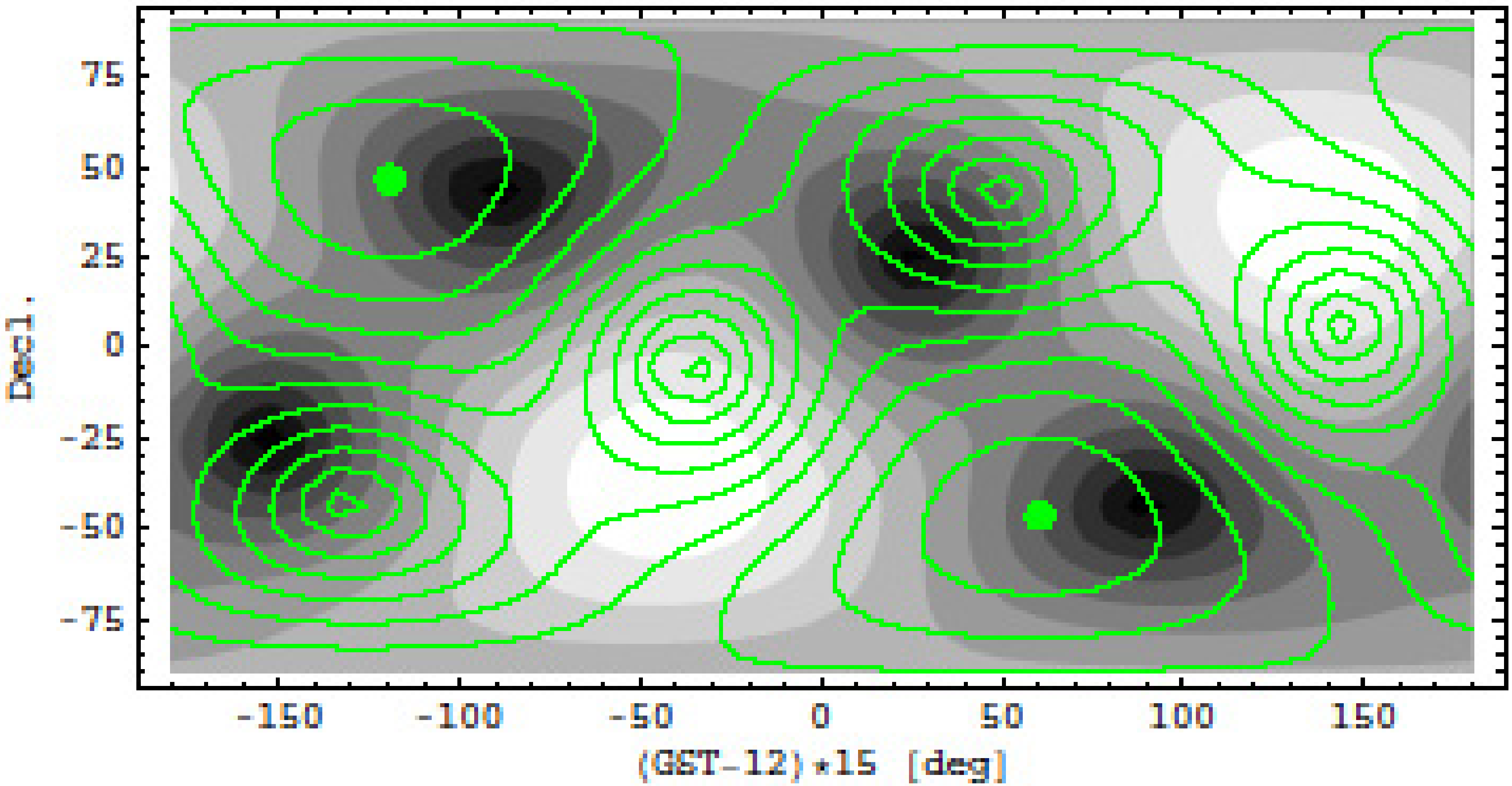
Therefore, we need more sensitive detector. LCGT can detect an event occurring at 260Mpc at maximum and observes events from 1 to 28 in a year.

1pc=3.3light year

View Ranges of Gravitational Wave Detectors



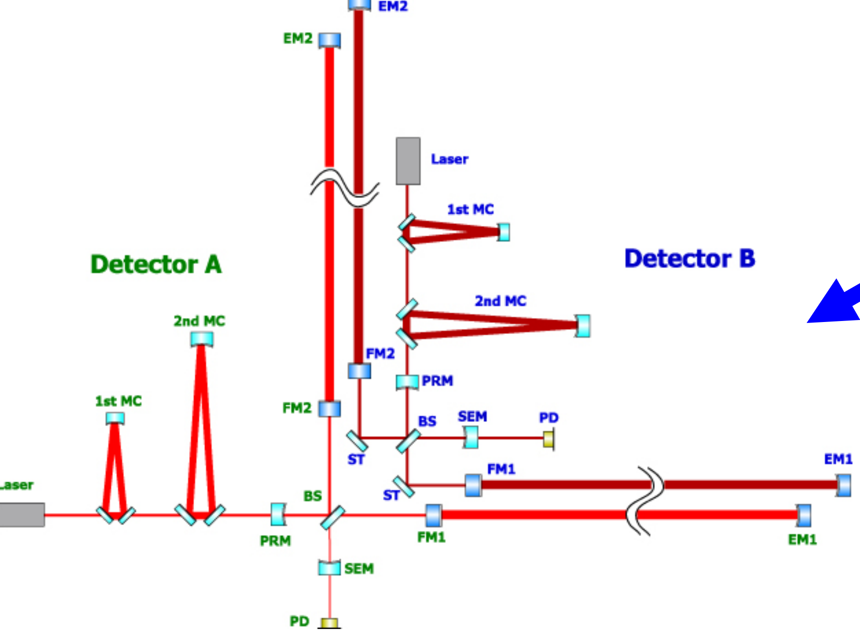
International Network of GW observation



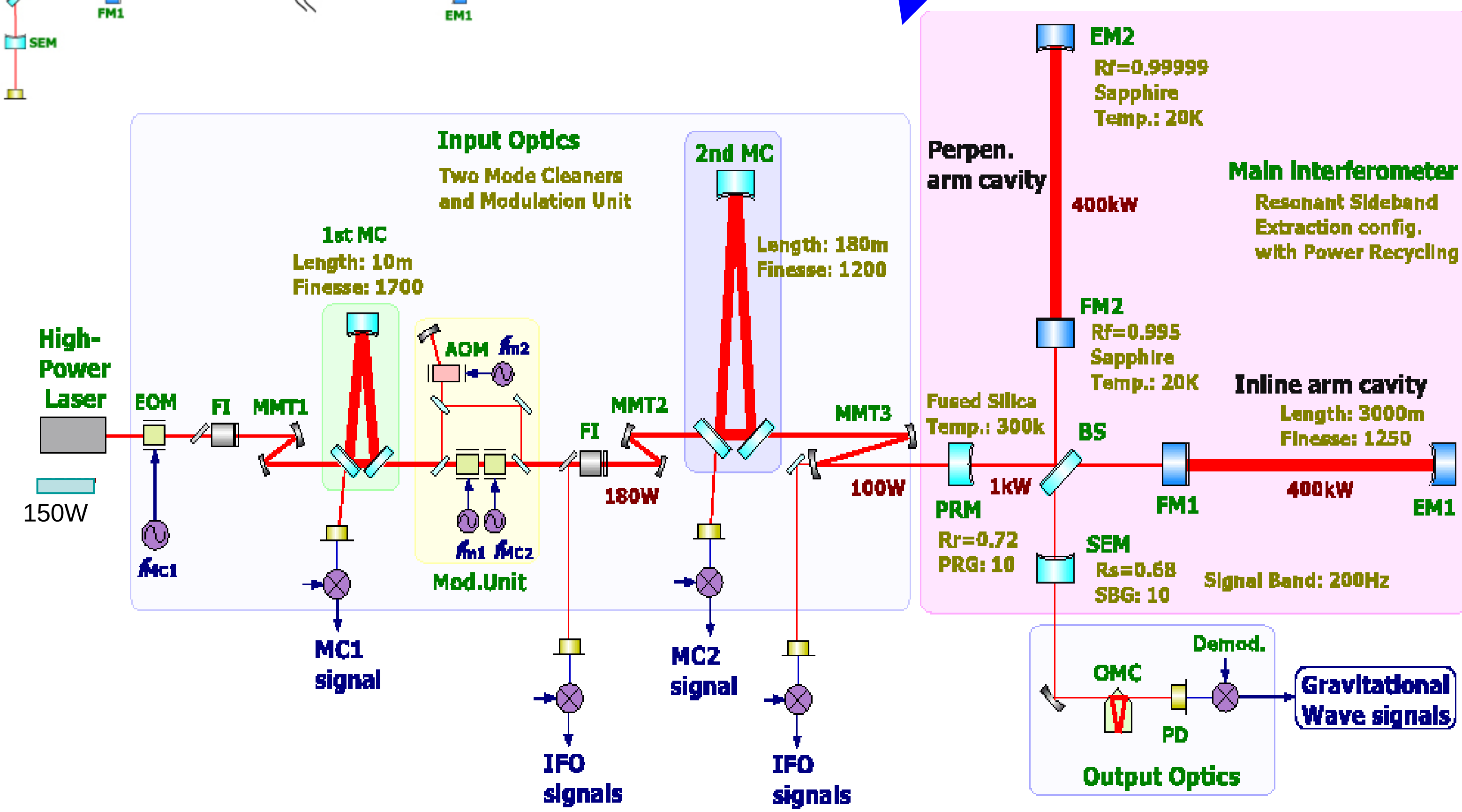
LCGT plays an complementary role with LIGO.
LCGT: grey, LIGO (Hanford): green contour

Optical design of LCGT

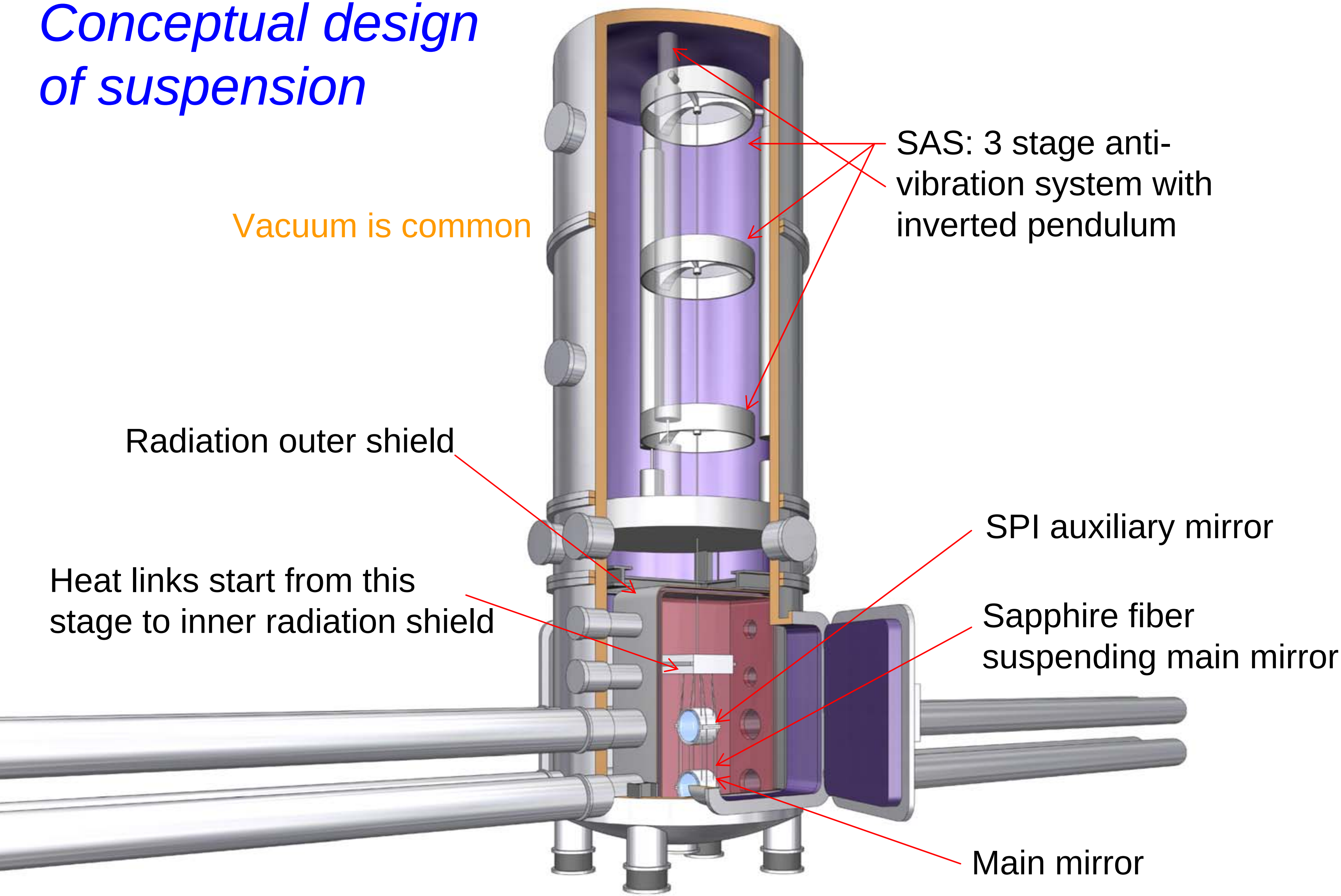
Two interferometers are arranged not to interfere in the same vacuum system.



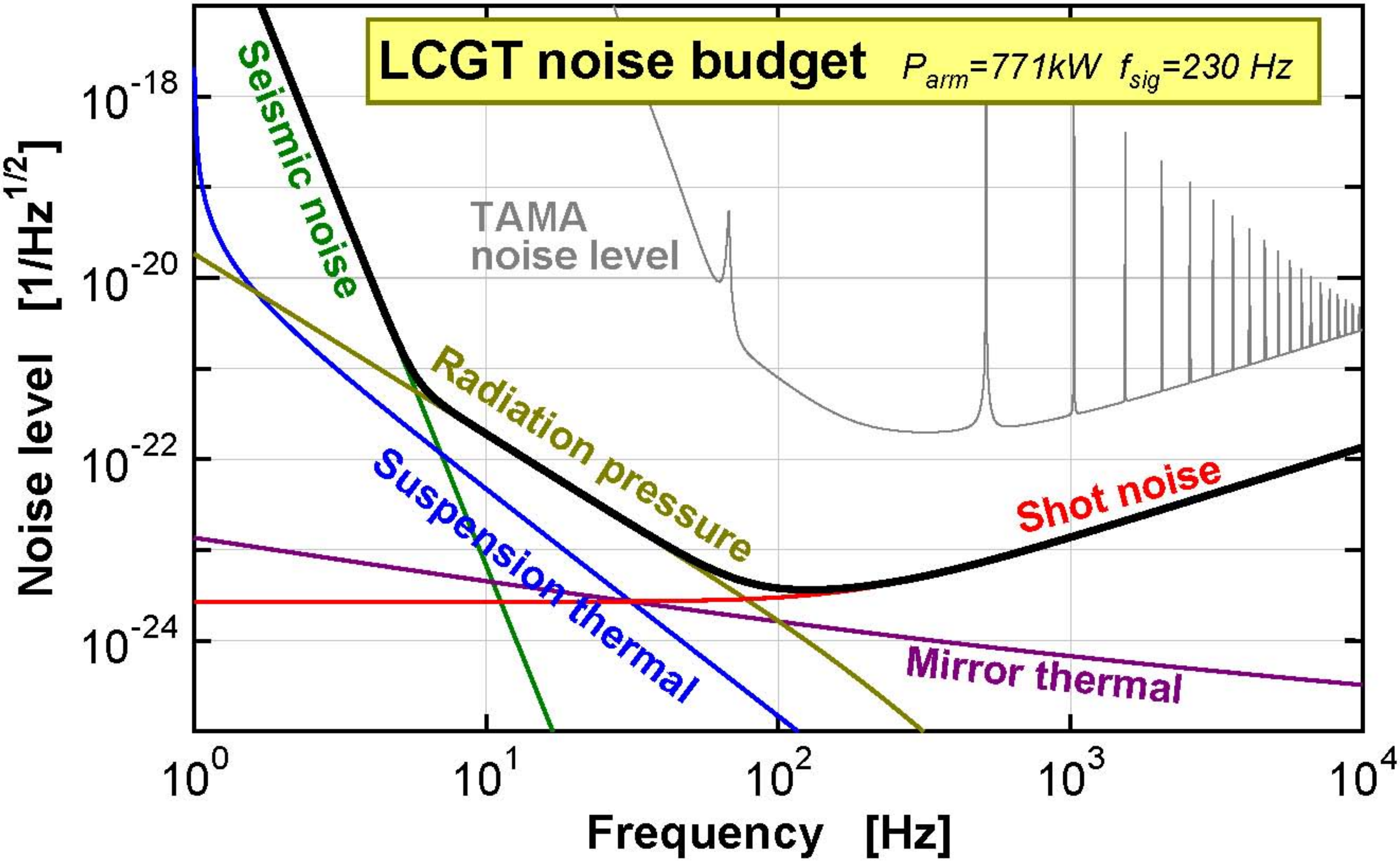
Optical design of the basic interferometer



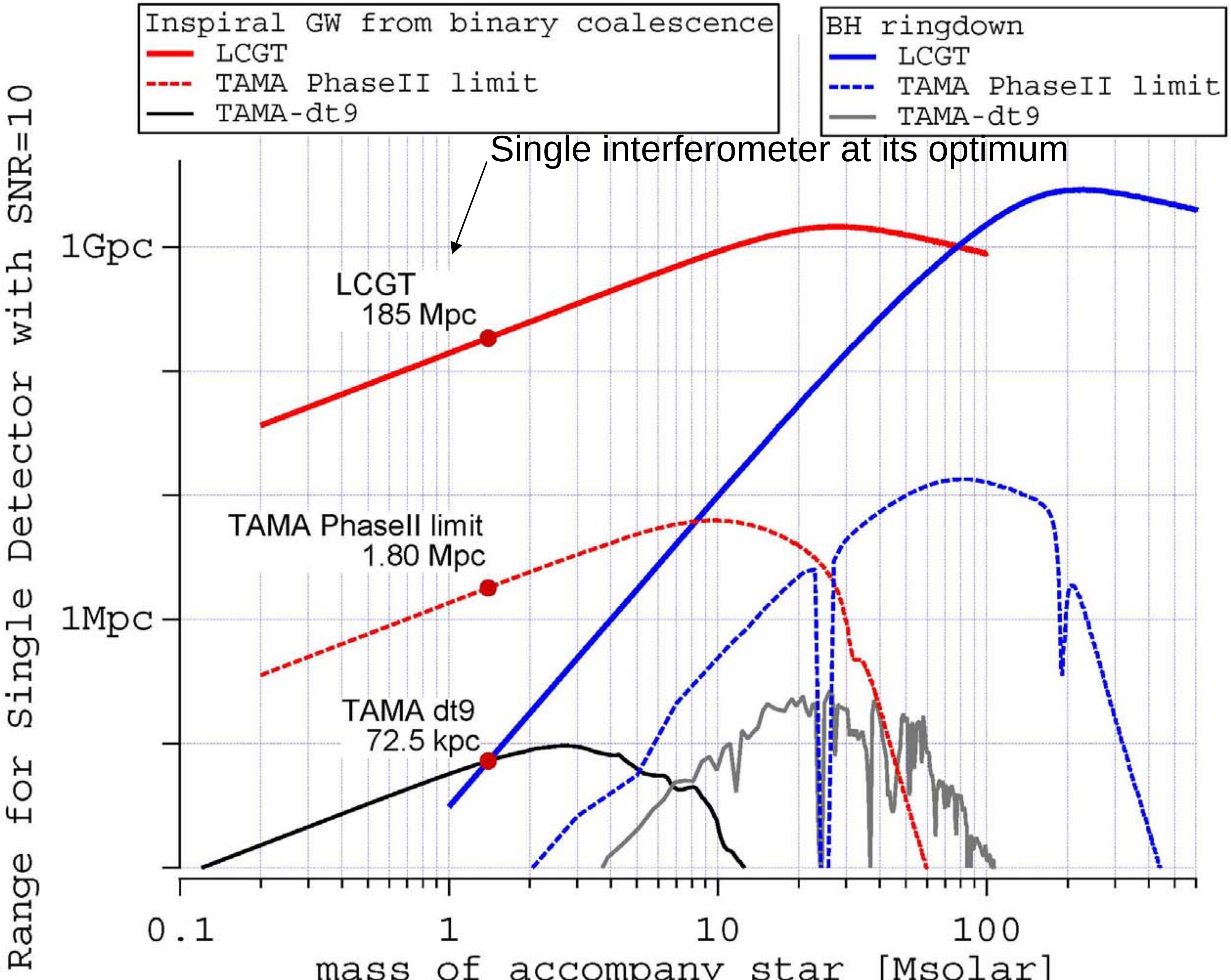
Conceptual design of suspension



Design Sensitivity



Detection Range

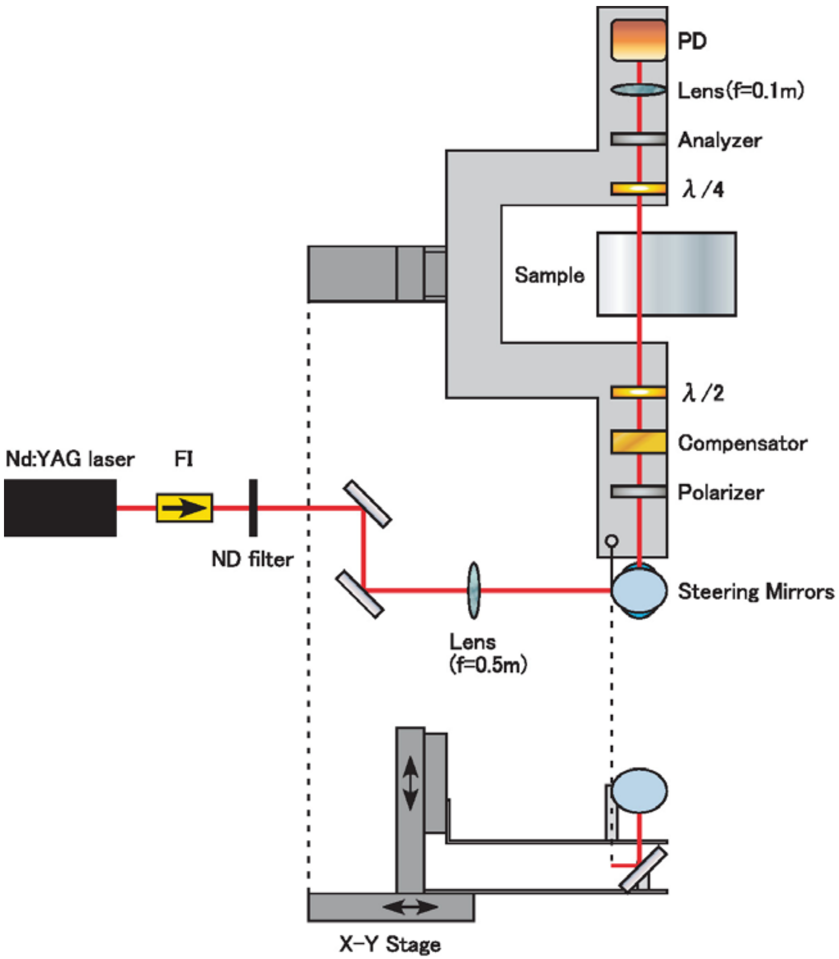


Sapphire cryogenic mirror produces valuable merits

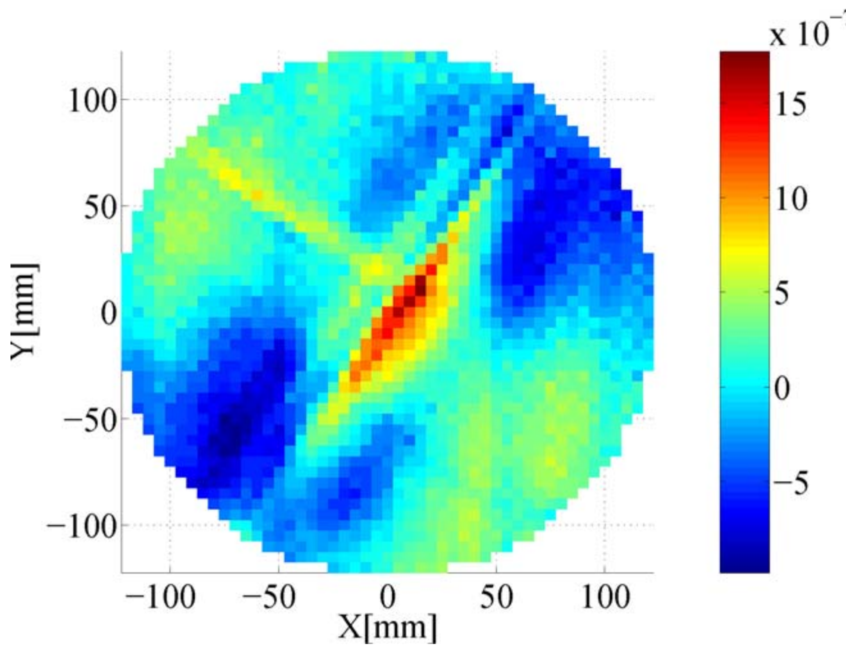
- Less thermal lens effect
  - due to high thermal conductivity and low thermal expansion rate (sapphire)
- Avoidable optical spring parametric instabilities
  - due to higher elastic wave speed (sapphire) and small beam size (cryogenic)
- Free from large optical coating loss
  - due to low temperature

-> K. Yamamoto’S talk

Quality selection of sapphire substrates in collaboration with LIGO team



Auto scanning birefringence device



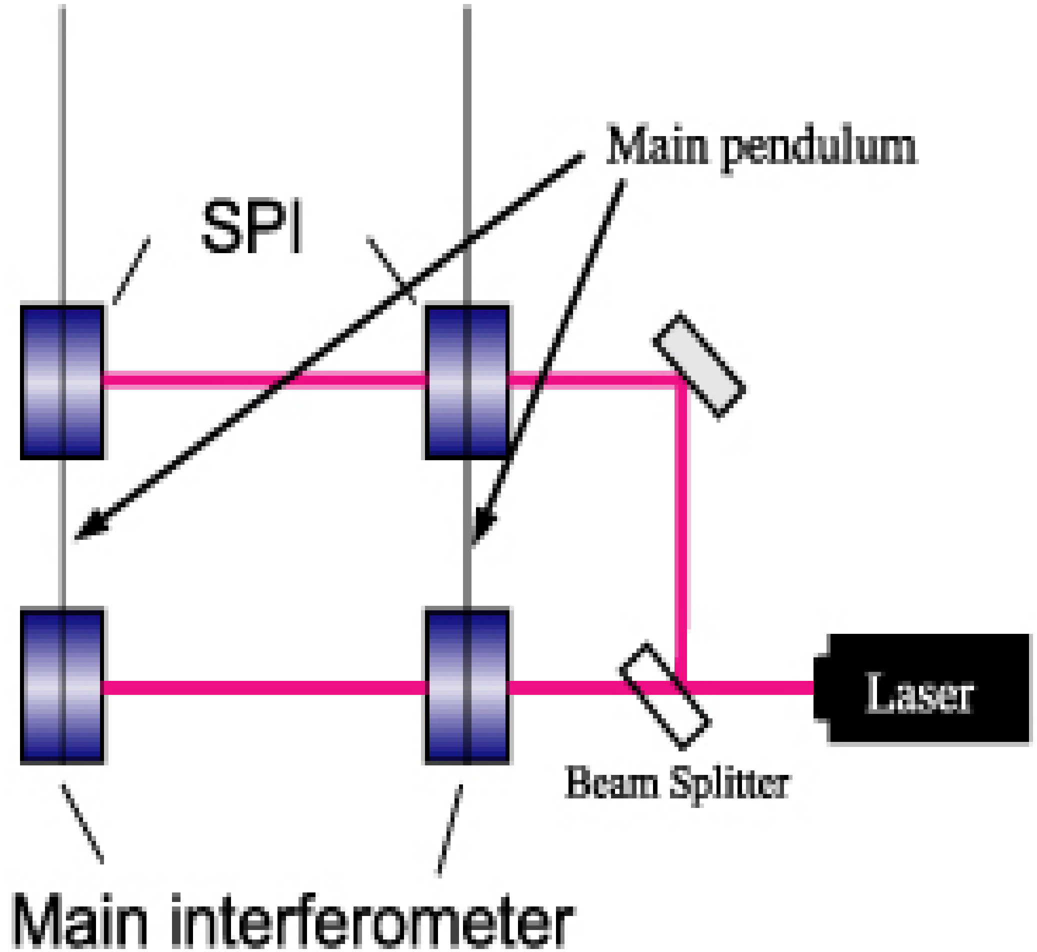
LIGO sapphire sample 250mm in diameter 29kg lent by the courtesy of LIGO.

Large heat production is avoided by RSE

- Broad band RSE (Resonant Side band Extraction method) is applied.
- Power recycling gain is set 11.
- Finesse of the cavity is 1550, which means that observational band becomes to be lower than required.
- RSE keeps the observation frequency band unchanged.

Refrigerator noise is avoided by SPI

Test mass of LCGT is connected to a cooling system by a heat link that possibly introduces mechanical noise. A suspension point interferometer (SPI) is introduced to maintain high attenuation of seismic and mechanical noise without degrading high heat conductivity.



Funding status (March, 2008)

- The LCGT project had a technical review in 2005 by a committee consisting of foreign specialists.
- The project has acquired supports from academic fields necessary for being funded.
- Three organizations (ICRR, NAOJ, KEK) agreed to submit the budget request from ICRR to the government.
- The request has been submitted to the University last December and the University will submit to the Ministry of Education, Sport, Culture, Science and Technology in this June.
- If the Ministry of Education submits to the Ministry of Finance, the possibility of its approval greatly enhances.

Summary

- We have acquired interferometer techniques (power recycling, Fabry-Perot Michelson, control system) by TAMA.
- CLIO proves the feasibility of cryogenic mirror, soon.
- LCGT will detect gravitational wave events.
- We will do the best for funding of FY 2009.