Downselection of observation bandwidth for KAGRA

MG13, Stockholm

Jul. 2012

K.Somiya, K.Agatsuma, M.Ando, Y.Aso, K.Hayama,
N.Kanda, K.Kuroda, H.Tagoshi, R.Takahashi, K.Yamamoto,
and the KAGRA collaboration

Outline

1. Brief review and current status of KAGRA
   (previously known as LCGT)

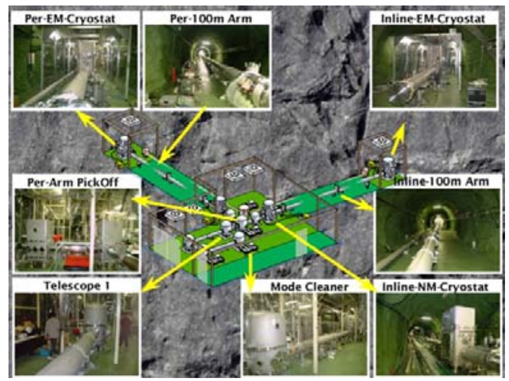
2. Downselection of observation band for KAGRA

GW detectors in Japan

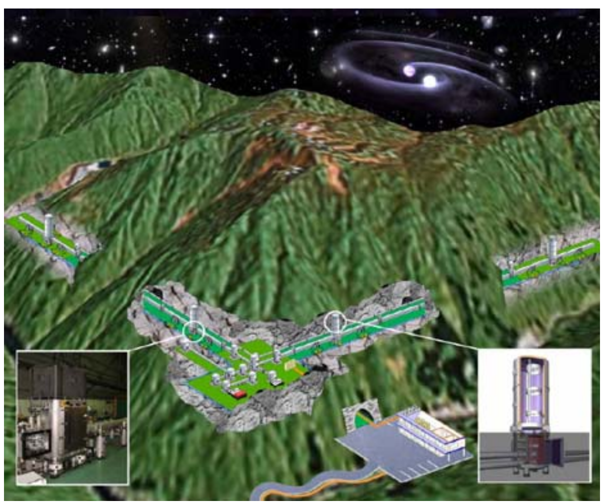
Tokyo

Kamioka (Gifu)

TAMA ('95~)
- observation runs from '99
- 300m baseline



CLIO ('03~)
- cryogenic operation
- thermal noise reduced
- 100m baseline
- Miyoki's talk today

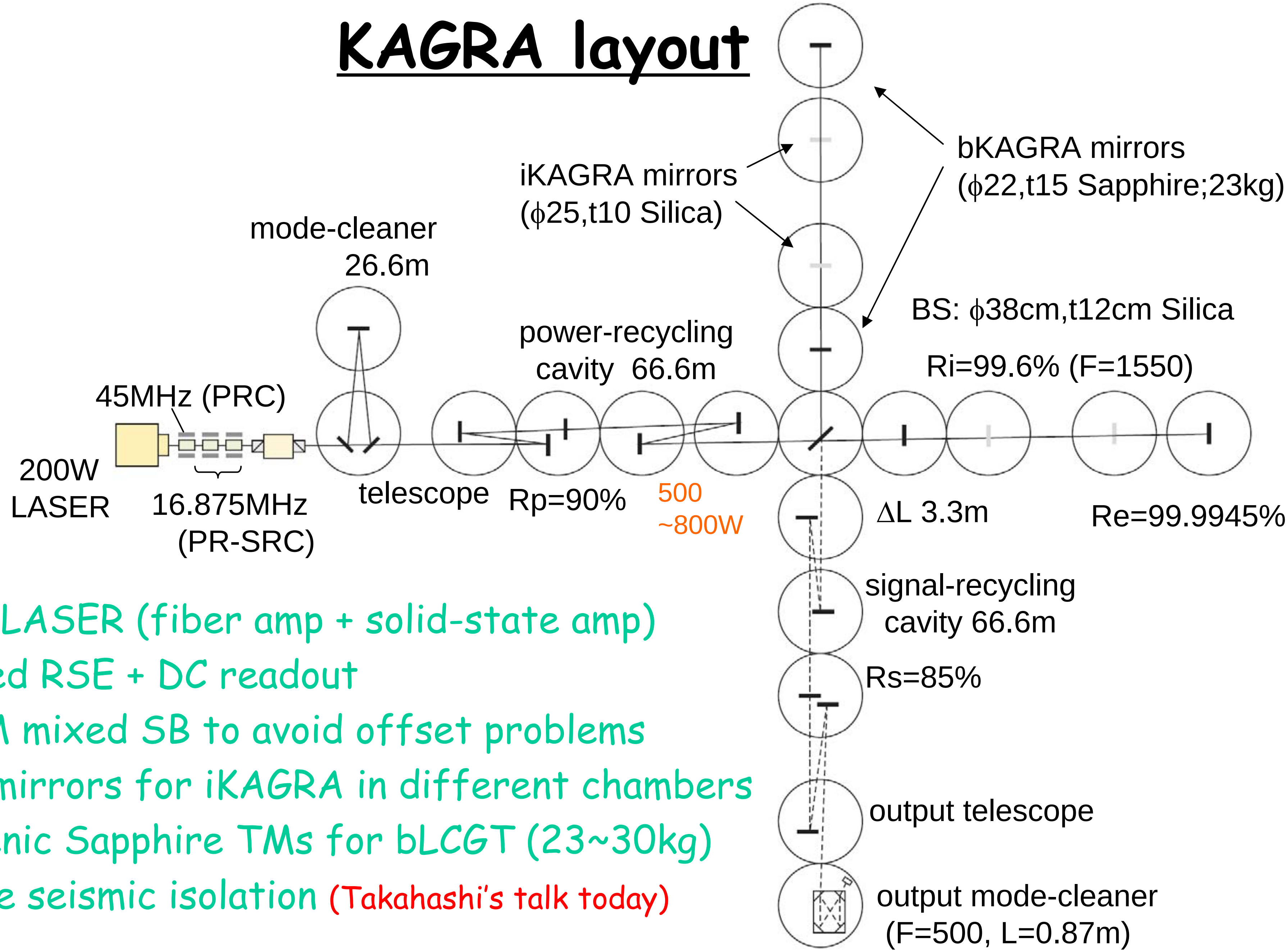


KAGRA ('11~)
- $200M project approved in 2010 (w/~15% deduction)
- construction started in 2011
- first science run at 300K planned in 2015 (iKAGRA)
- full-scale cryogenic operation will start in 2017~18 (bKAGRA)

International collaboration/support

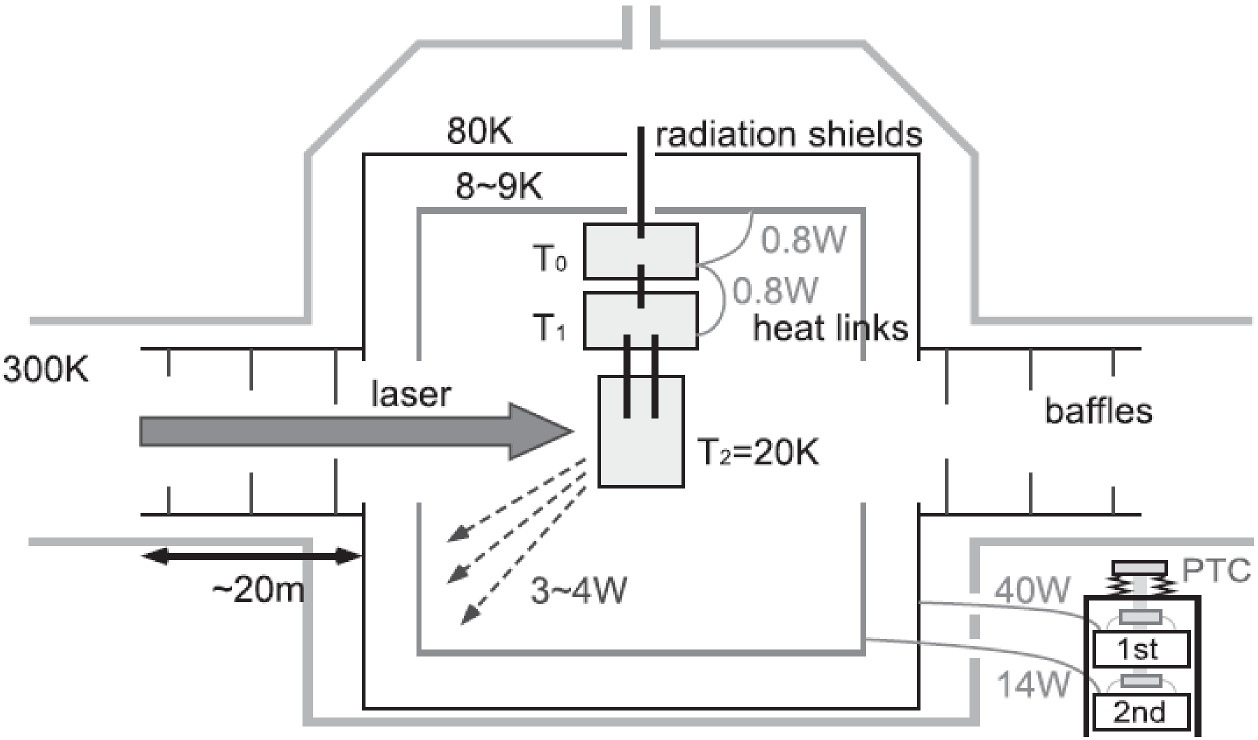
- Many supports from LIGO/Virgo/GEO
- Collaboration with other Asian countries
- people-to-people cooperation
- ET-KAGRA collaboration (ELiTES)
- JSPS postdoc opportunities for oversea researchers

KAGRA layout

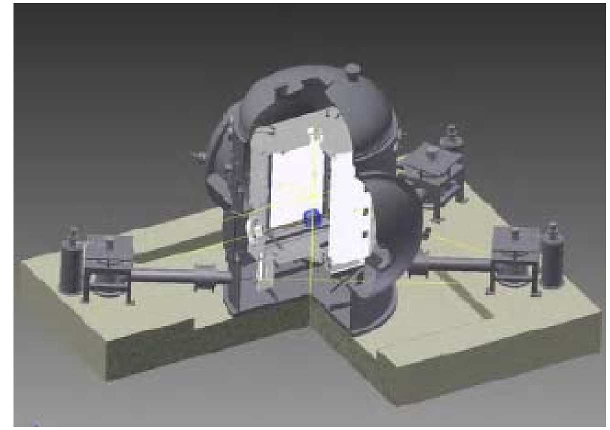


- 200W LASER (fiber amp + solid-state amp)
- Detuned RSE + DC readout
- PM-AM mixed SB to avoid offset problems
- Silica mirrors for iKAGRA in different chambers
- Cryogenic Sapphire TMs for bLCGT (23~30kg)
- 7-stage seismic isolation (Takahashi's talk today)

Cryogenic system

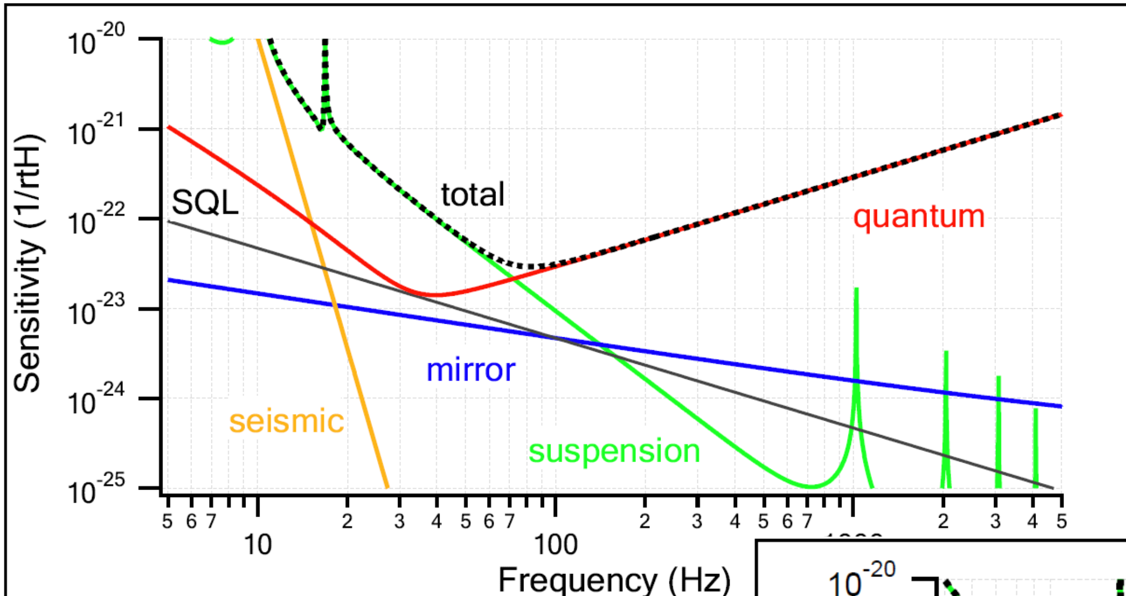


- <1ppm absorption in coatings
- <50ppm/cm absorption in Sapphire substrate
- radiation from 300K
- heat from scattered light
- DLC coated radiation shield
- 30/15days to cool/heat mirrors



top: cryostat schematic
mid: $\frac{1}{4}$ cryo-cooler prototype
bot: sample sapphire fiber

KAGRA sensitivity



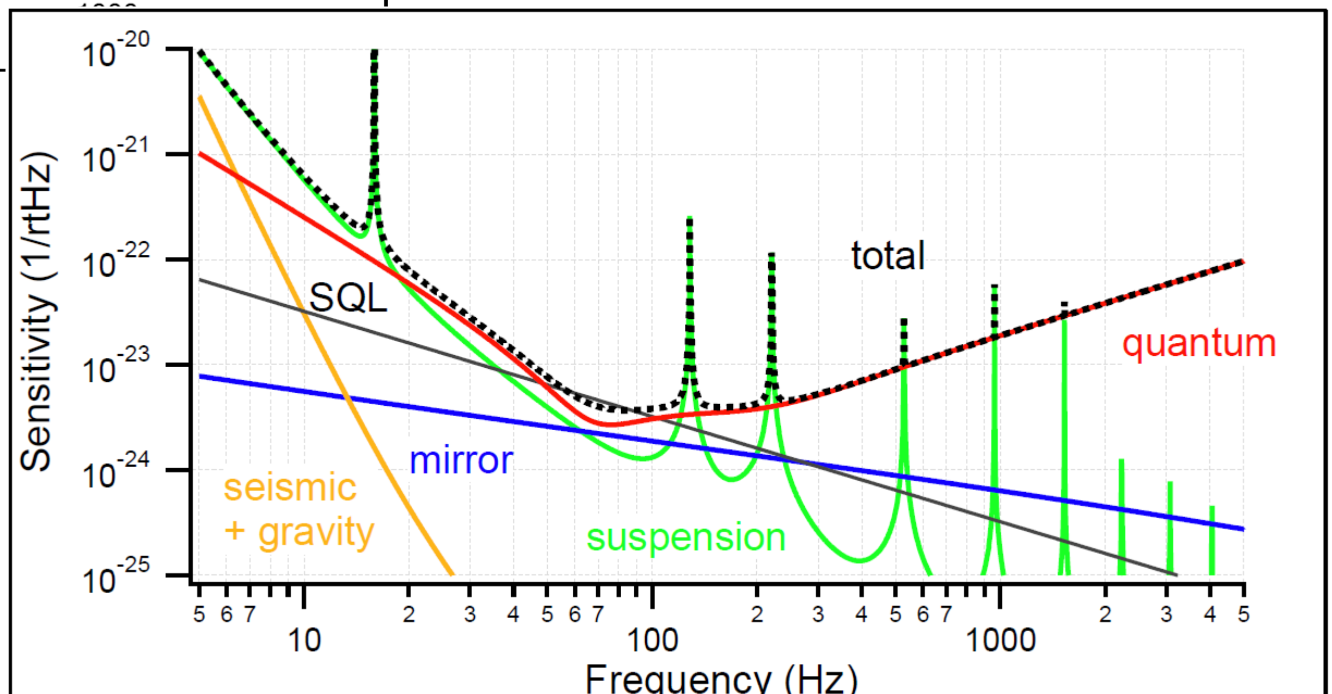
* Most recent designed sensitivities
(subject to be updated)

iKAGRA sensitivity

- operation in 2015
- simple configuration at 300K
- important milestone toward bKAGRA

bKAGRA sensitivity

- operation in 2017~18
- 23kg Sapphire mirror at 20K
- 240Mpc (optimal direction)
  (140Mpc w/sky-average)



Downselection of observation band

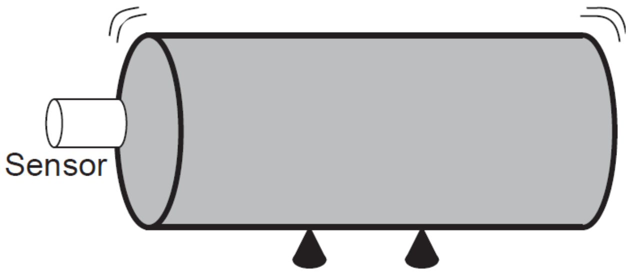
KAGRA facts

- low classical noise
- a bit lower power
- a bit behind in schedule

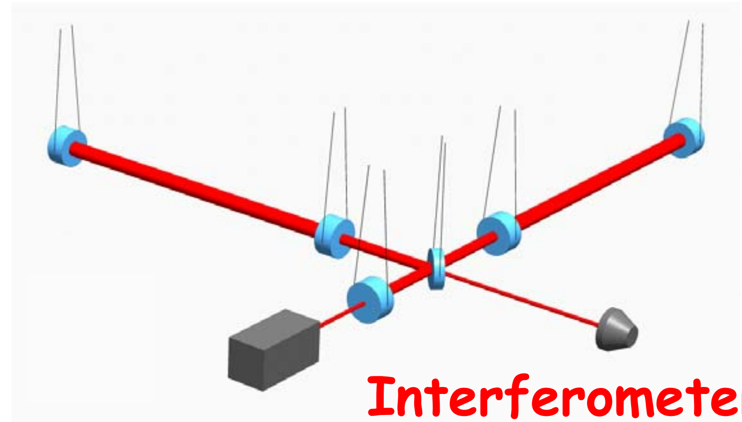
Strategic choice of the observation band is important

~ broadband?
~ narrow-band?
~ low-freq tuned?

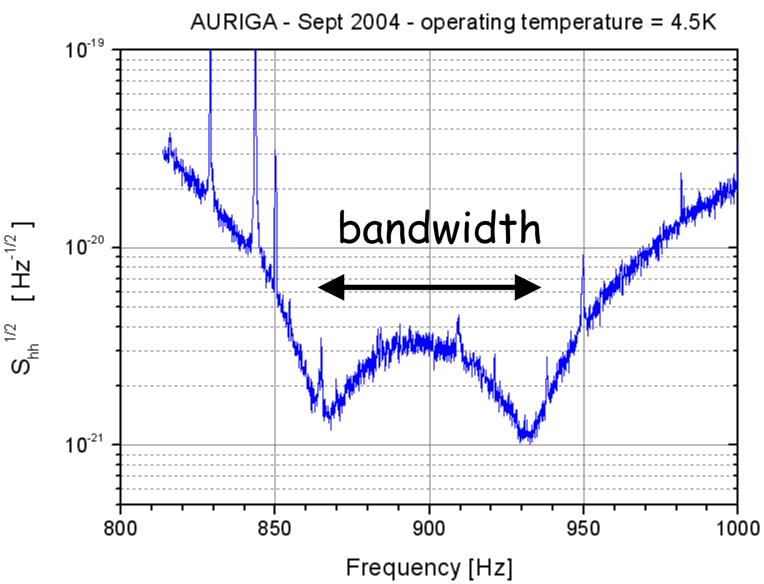
Bandwidth of GW detectors

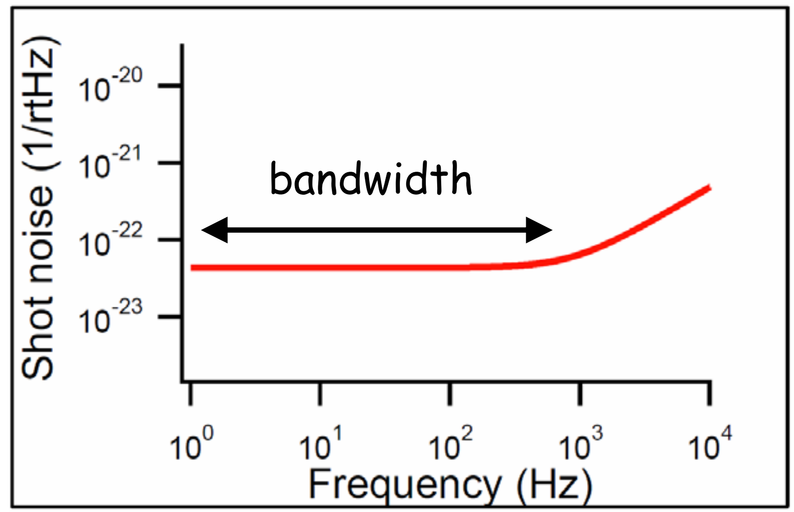


Resonant bar



Interferometer



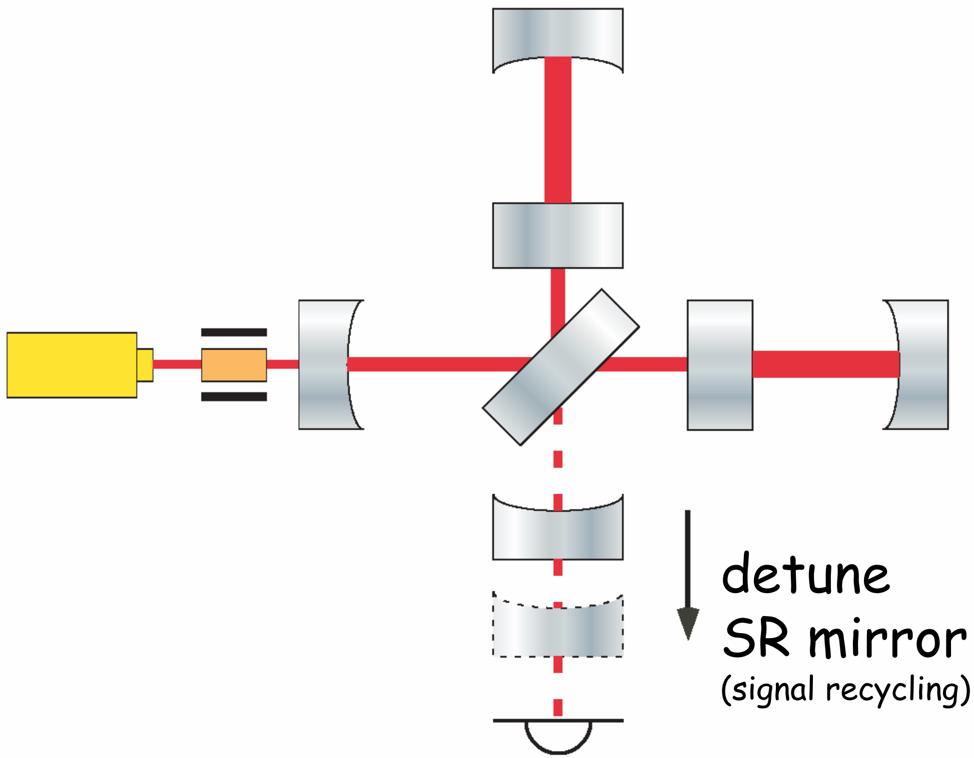


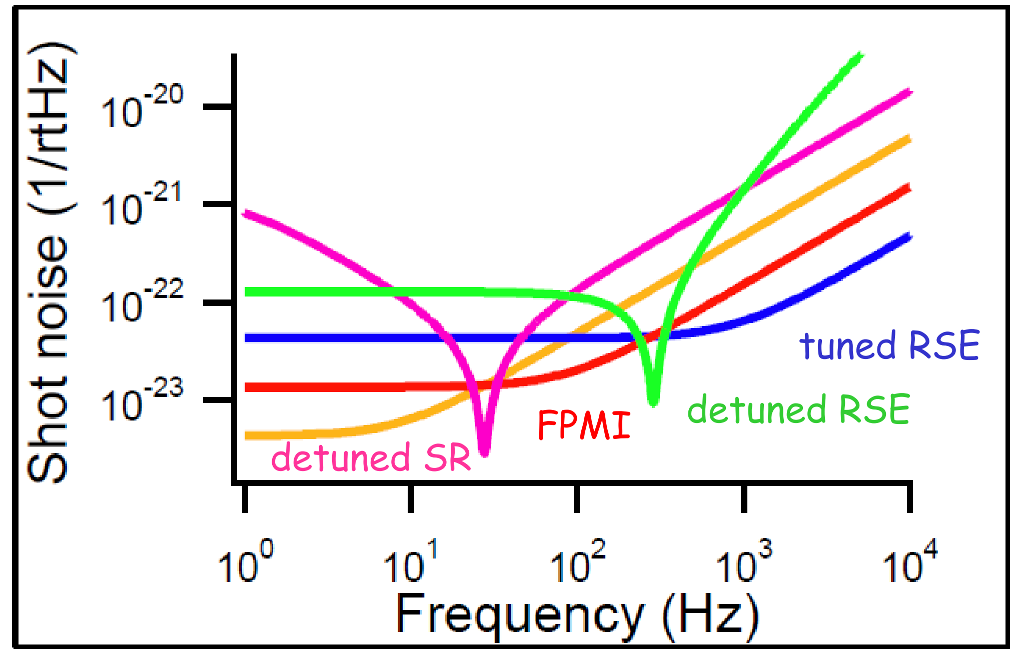
* The bandwidth and floor level are determined by mirror reflectivity.

Narrowband

Broadband

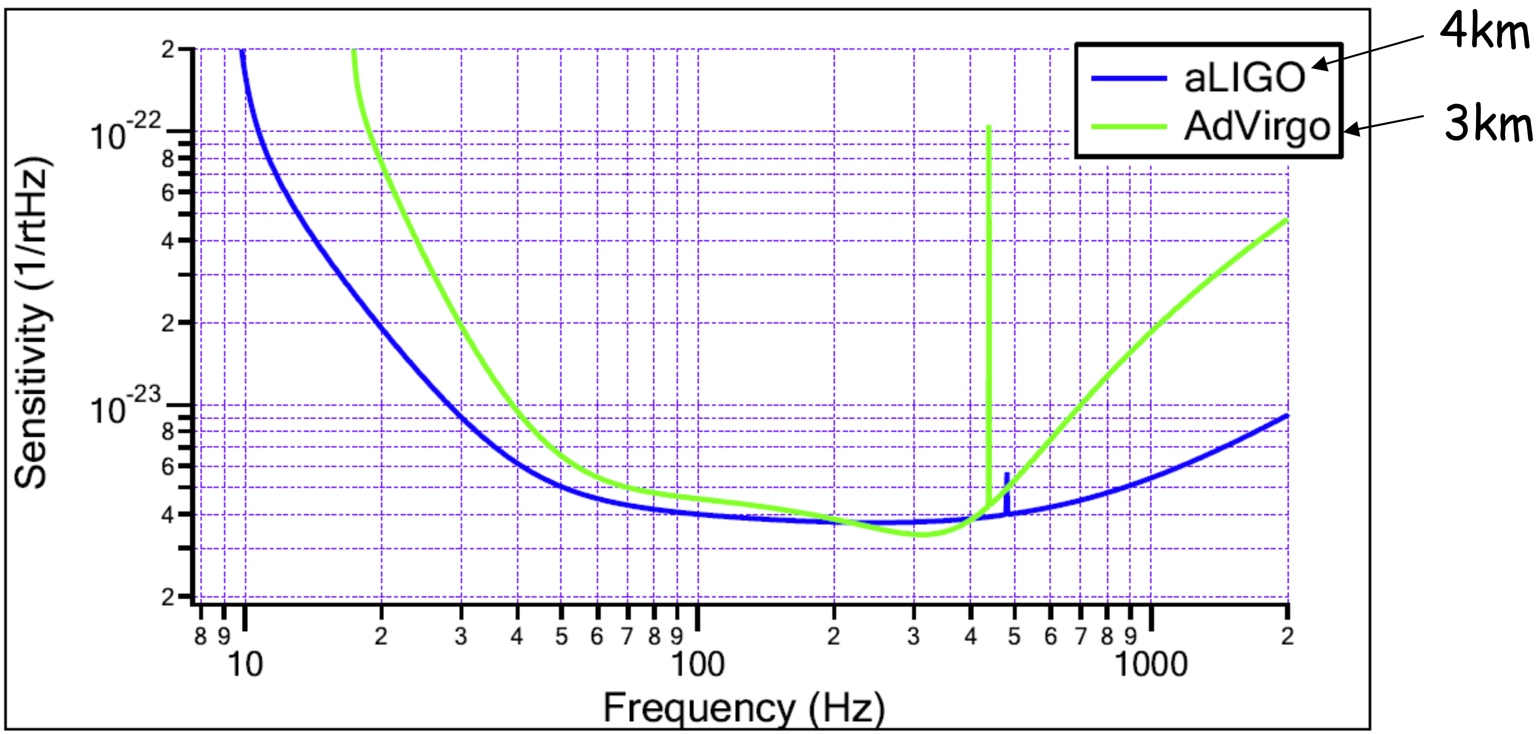
Bandwidth of advanced detectors





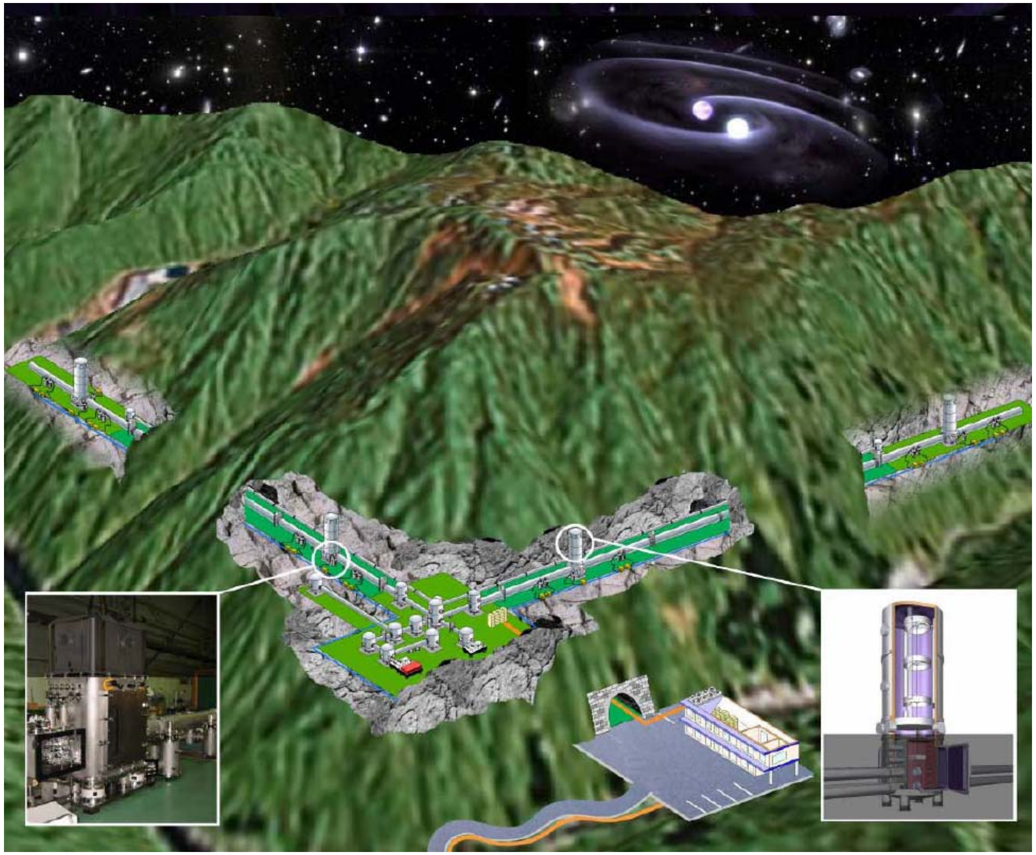
- Off-resonant SRM makes the bandwidth narrower
- Event rate can be higher for some GW sources

Bandwidth of aLIGO and AdVirgo



- aLIGO=tuned RSE: balanced choice for various sources, less technical difficulties
- AdVirgo=slightly detuned RSE: high event rate for NS binaries

KAGRA



- 3km detector in Japan
- construction started in 2011
- underground
- cryogenic

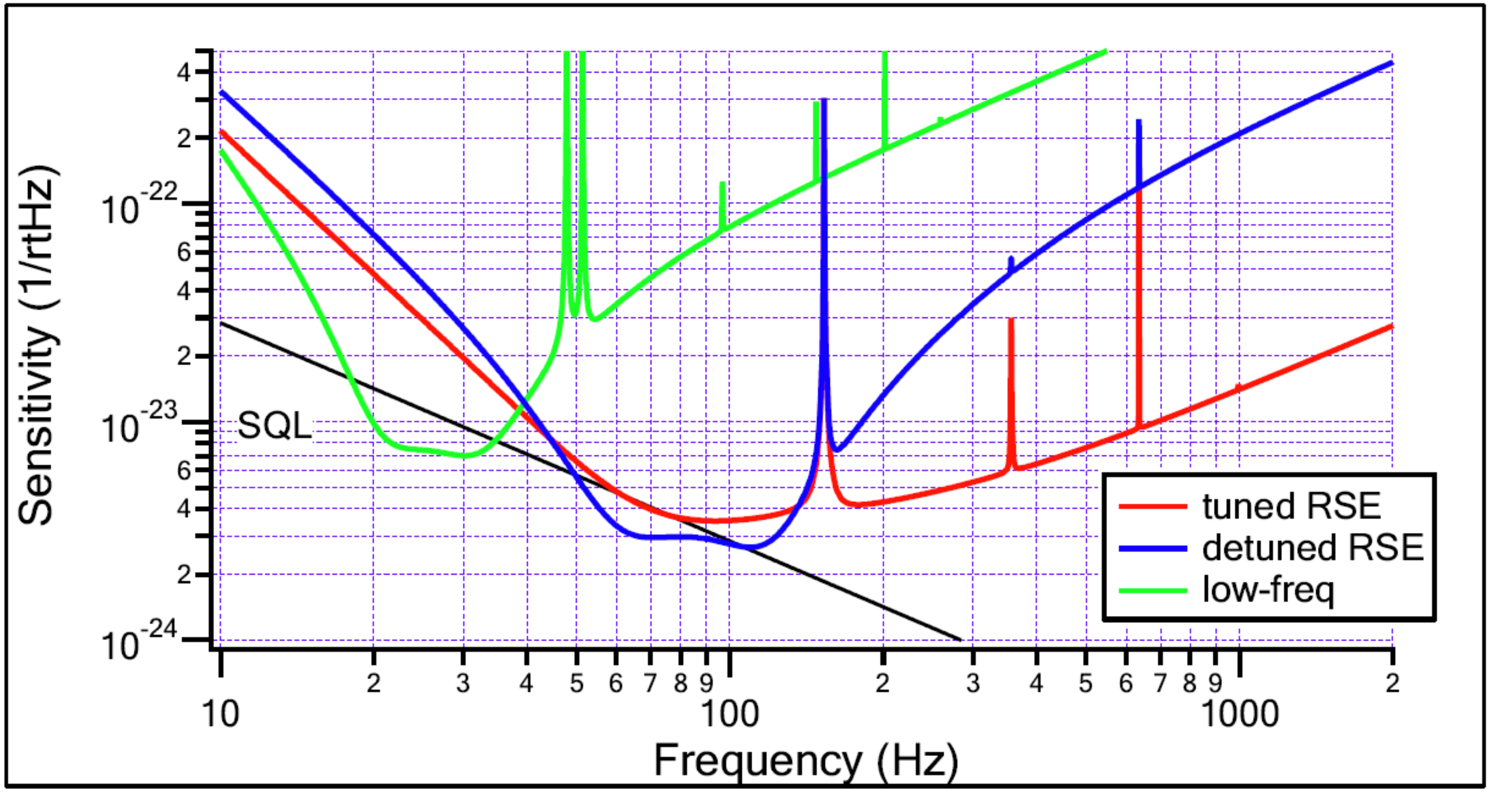
Sensitivity is mostly limited by quantum noise

~ Should we go deep and narrow?

~ Can we shift it to lower-freq?

Bandwidth selection is more essential for KAGRA

Candidate sensitivity curves



tuned/detuned RSE: parameters chosen to maximize the BNS inspiral range (260/300Mpc)

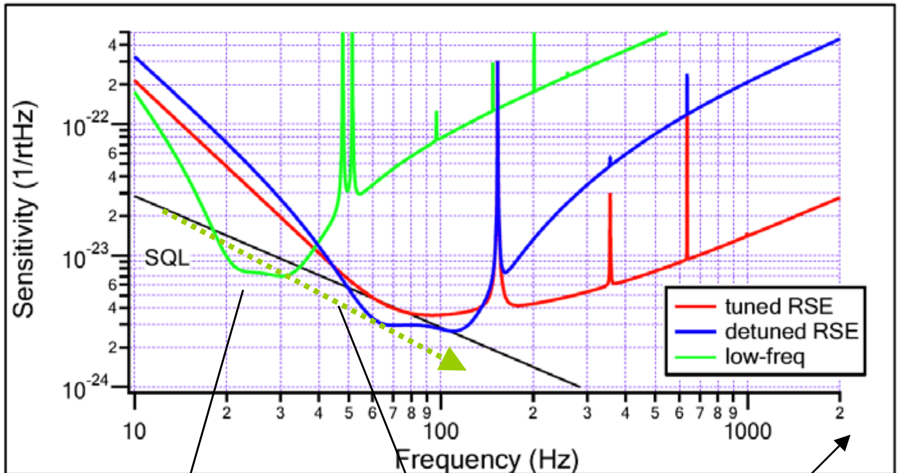
low freq: low-power operation (BNS IR=200Mpc)

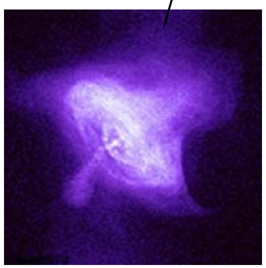
* Inspiral range calculated for GWs from the optimal direction
* Some parameters used here have been changed

Discussion points

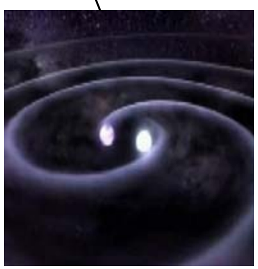
- GW sources at high/low frequencies
- Estimation accuracy of source parameters
- Variable RSE
- Xylophone with other detectors
- Technical point of view

GW sources at high/low frequencies

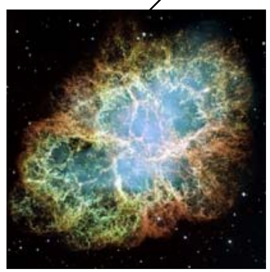




Pulsars
(Vela at 22Hz)



BNS inspiral
up to 1.57kHz



Supernovae

- **BH-BH binaries**
  ~ 100Ms BBH inspiral ends at 44Hz and some info unavailable from the ring-down
- **NS-NS binaries**
  ~ Inspiral range of low-freq config is as high as 200Mpc but we'll miss the merger
- **Supernovae**
  ~ used to be our primary target and cannot be missed
- **Pulsars** ~ good and bad
- **Stochastic** ~ cross correlation analysis

- **There are too many to lose at high freq**
- **It depends on how significant KAGRA can be at low freq**

Estimation accuracy of source parameters

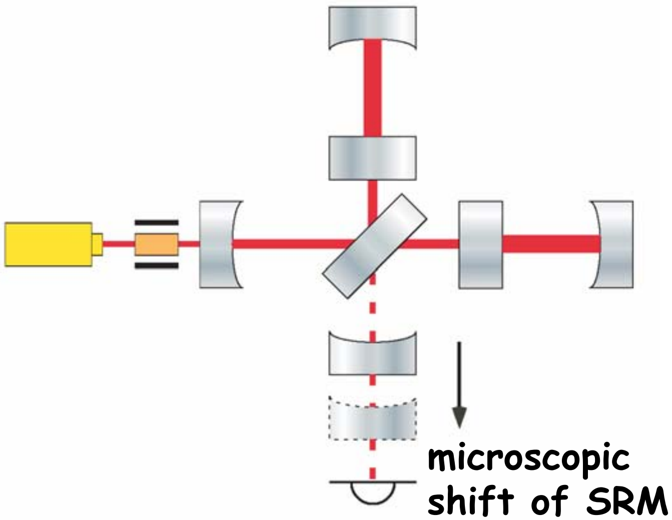
~ calculation by Tagoshi

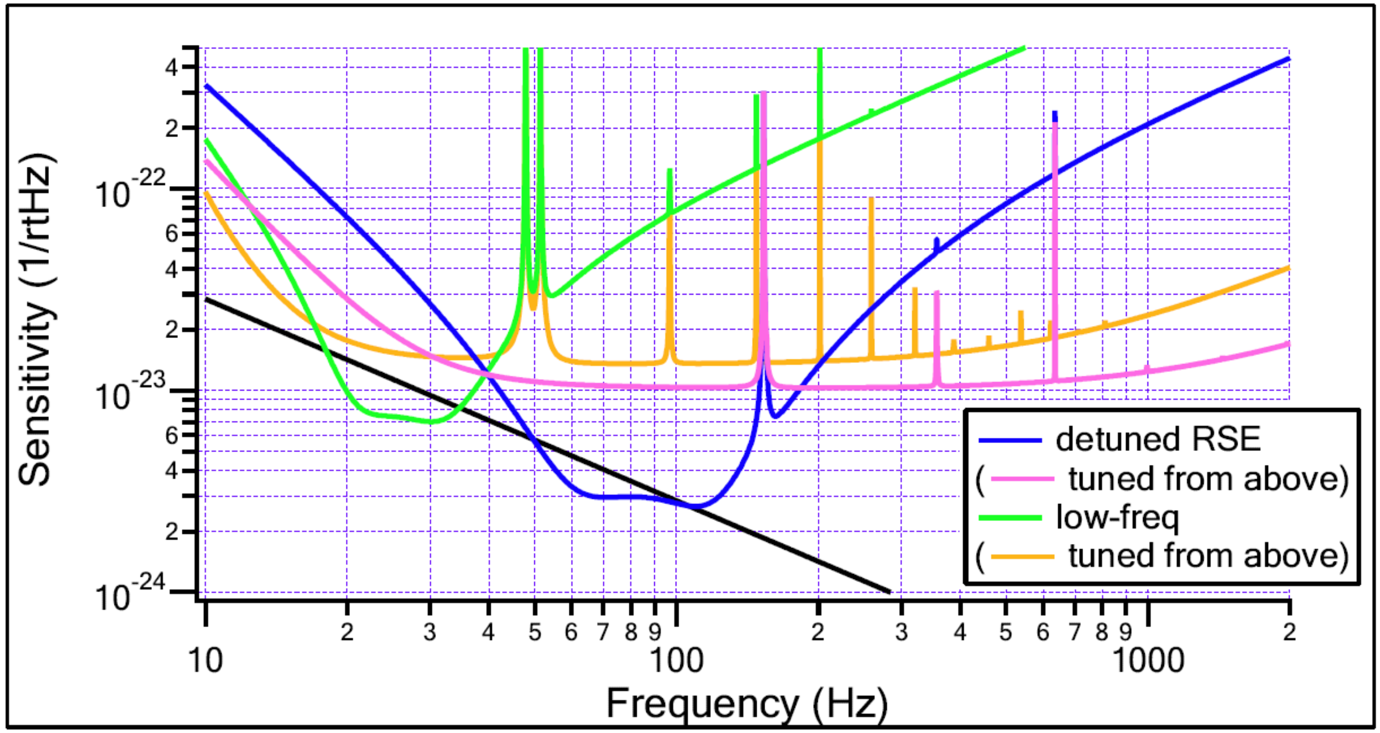
	tuned RSE	detuned RSE
BNS range	260Mpc	300Mpc
10Ms BBH range	570Mpc	680Mpc
event rate (1/yr)	5.4 (1.1~19.1)	8.2 (1.7~28.8)
arrival time error	0.25msec	1.08msec
chirp mass error	2.3e-5	3.7e-5

The narrower the bandwidth,
the less accurate the estimation.

Variable RSE

* Rana's idea in 2006



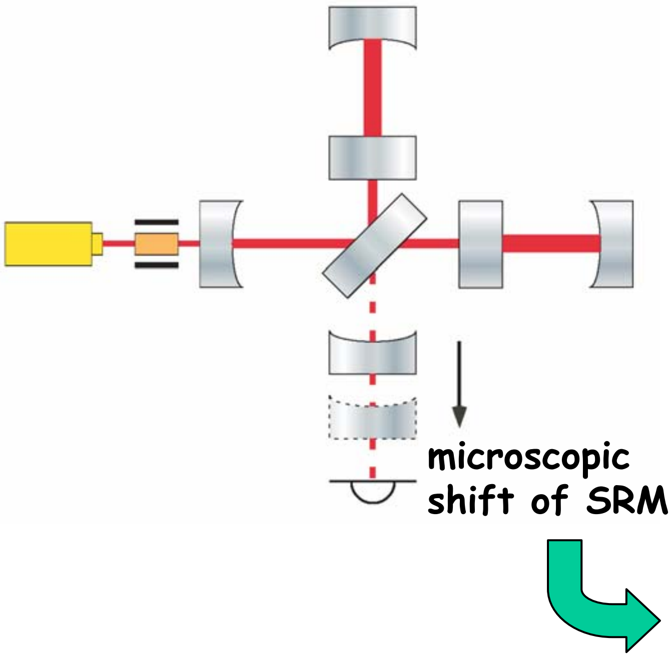


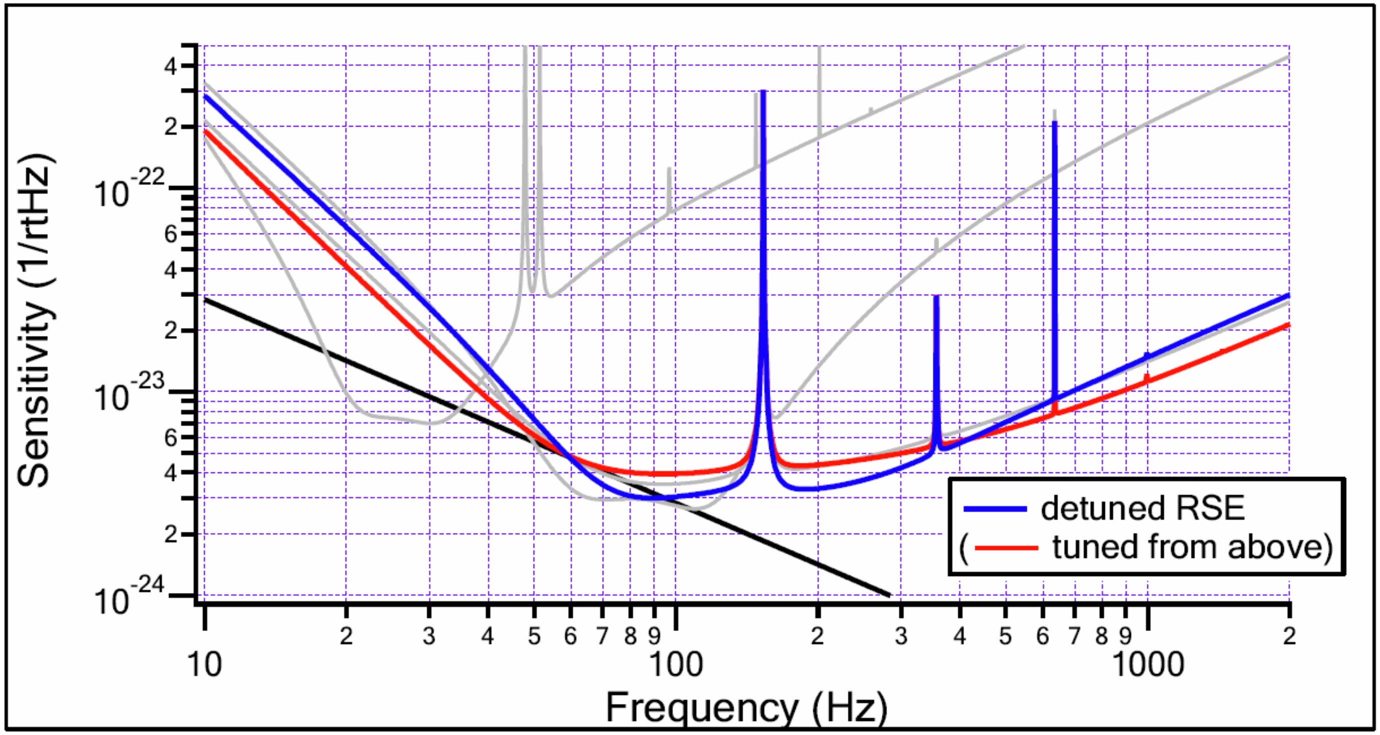
* This can be done by adding an offset on the ctrl signal

- **Mirrors are same; power and detune phase are different**
- **Tuned RSE sensitivities are too shallow with those setups**

* Transformation within 30 sec would be required to see the merger after observing inspirals at 20Hz.

Variable RSE (2)



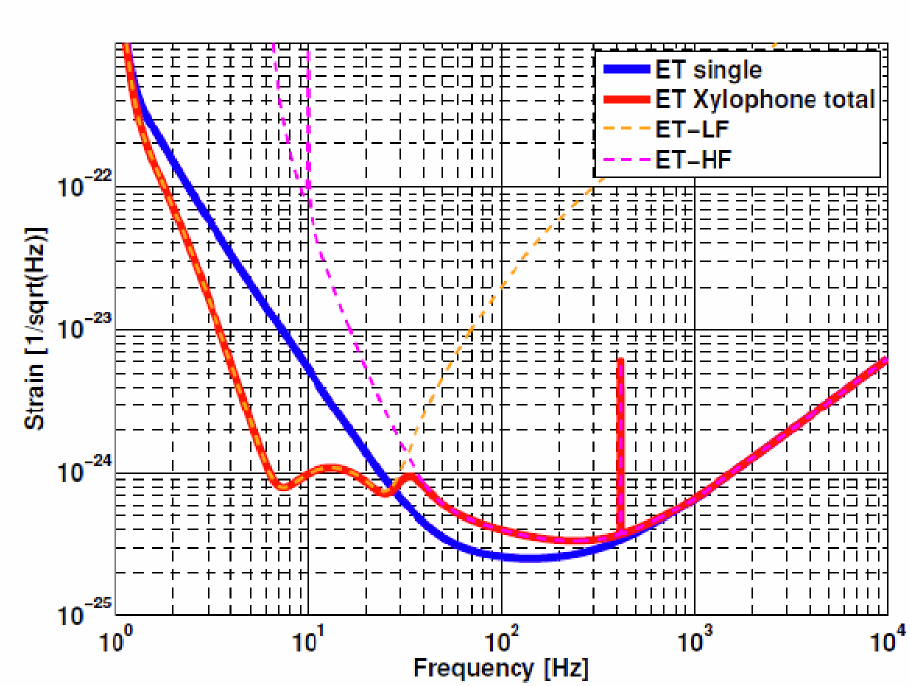


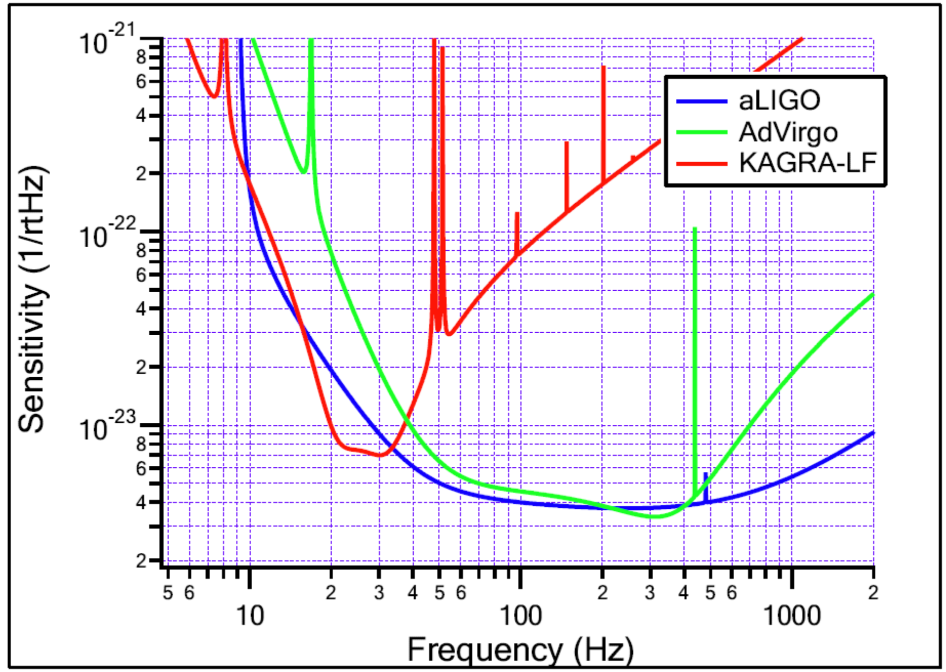
* This can be done by adding an offset on the ctrl signal

- **The best pair of the variable RSE configuration**

	tuned (max)	detuned (max)	tuned (opt)	detuned (opt)
range	260Mpc	300Mpc	250Mpc	280Mpc
arr.time error	0.25msec	1.08msec	0.22msec	0.25msec

Xylophone

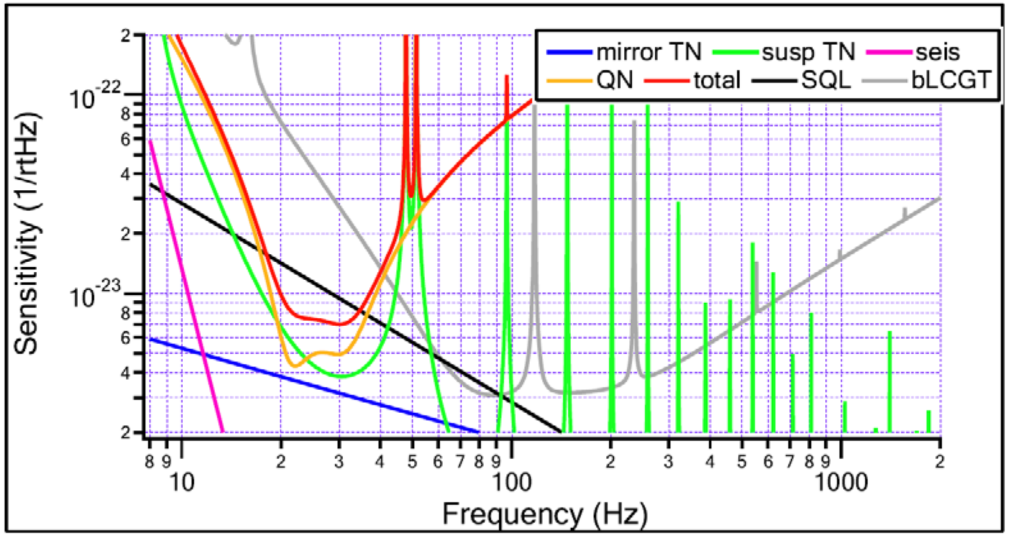




- Can we do the same as ET Xylophone with AdVirgo to compensate low-freq sensitivity?
- It may give more significance to the global GW community

→ This won't work like ET as KAGRA and Virgo are geographically separated...

Technical point of view



- Input power 1.5~12W
- T_S 15% -> 12%
- T_{ITM} 0.4 -> 0.6%
- Fiber length 120cm
- Fiber thickness 1.4mm
- Max 170mW cooling

- Low RMS motion gives better performance at low frequencies
- Heat issues can be avoided

bKAGRA

☺seismic
☹cooling

Risk balance

KAGRA-LF

☹seismic
☺cooling

Comparison with 3G detectors

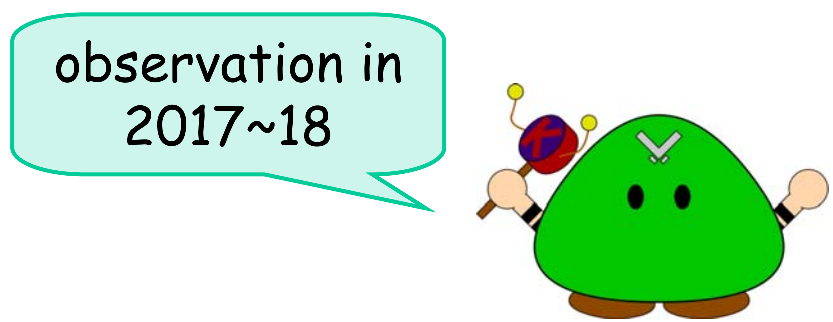
	aLIGO/AdVirgo	KAGRA	ET/LIGO3
underground	X	O	O
cryogenic	X	O	O
heavy mass	X	XX	O

These three are the important factors to realize a good sensitivity at low frequencies.

Unfortunately one of them is missing in KAGRA.
We've been working on to find a way to resolve this.

Conclusion of the bandwidth study

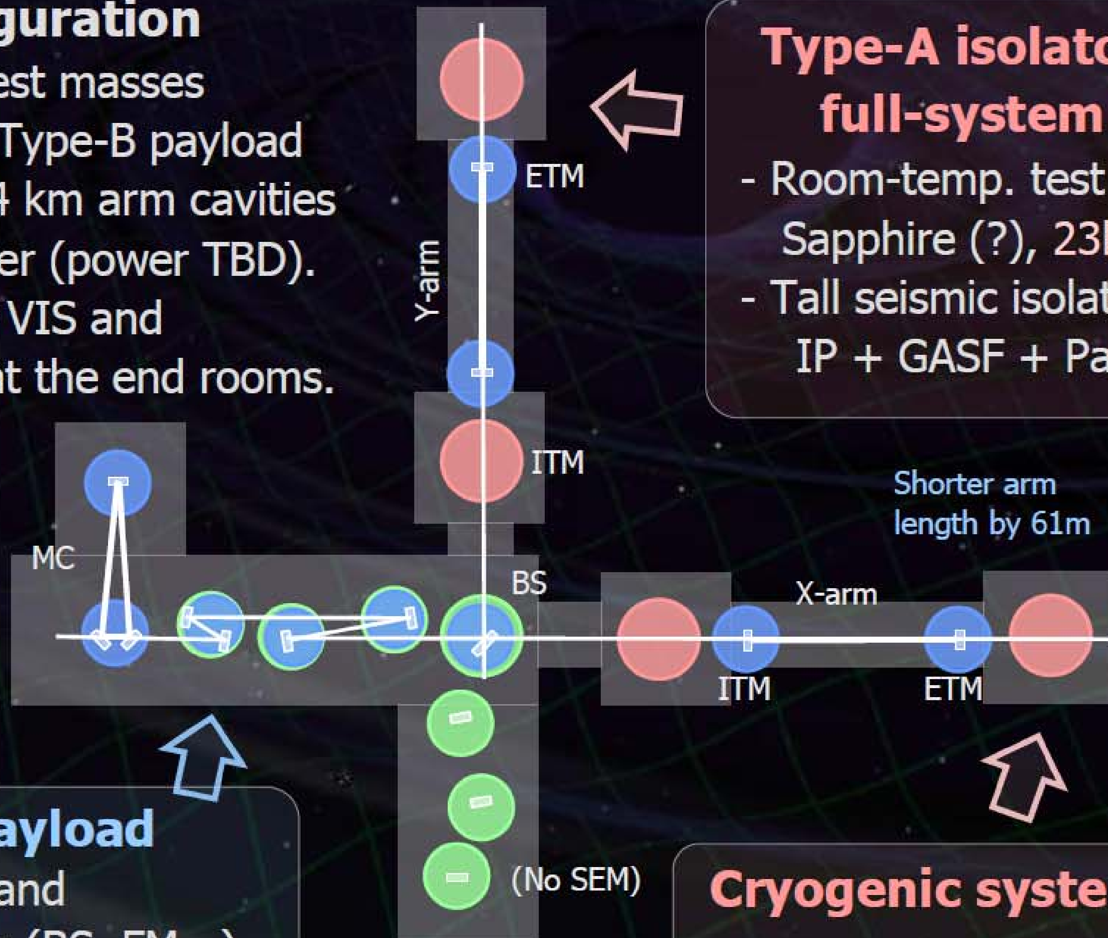
- We chose slightly detuned RSE compatible with broadband RSE as the KAGRA baseline design (bKAGRA)
- KAGRA-LF is reasonable as it avoids the risk of heat absorption and make the most use of low seismic motion, but there are many scientific disadvantages and the Xylophone option doesn't work well for us
- Therefore, KAGRA goes with bKAGRA configuration



iKAGRA commissioning (- 2015.12)

iKAGRA configuration

- Room-temp. test masses suspended by Type-B payload
- FPMI with 2.94 km arm cavities
- Low laser power (power TBD).
- On-site test of VIS and Cryo-system at the end rooms.

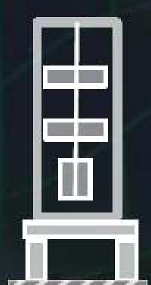


Type-A isolator full-system test

- Room-temp. test
  Sapphire (?), 23kg, 290K
- Tall seismic isolator
  IP + GASF + Payload

iLCGT obs. run
in Dec. 2015
~1 month

Type-B payload



- Test mass and
  Core optics (BS, FM,..)
  Silica, 10kg, 290K
- Seismic isolator
  Table + Type-B Payload
  or Fixed Type-B

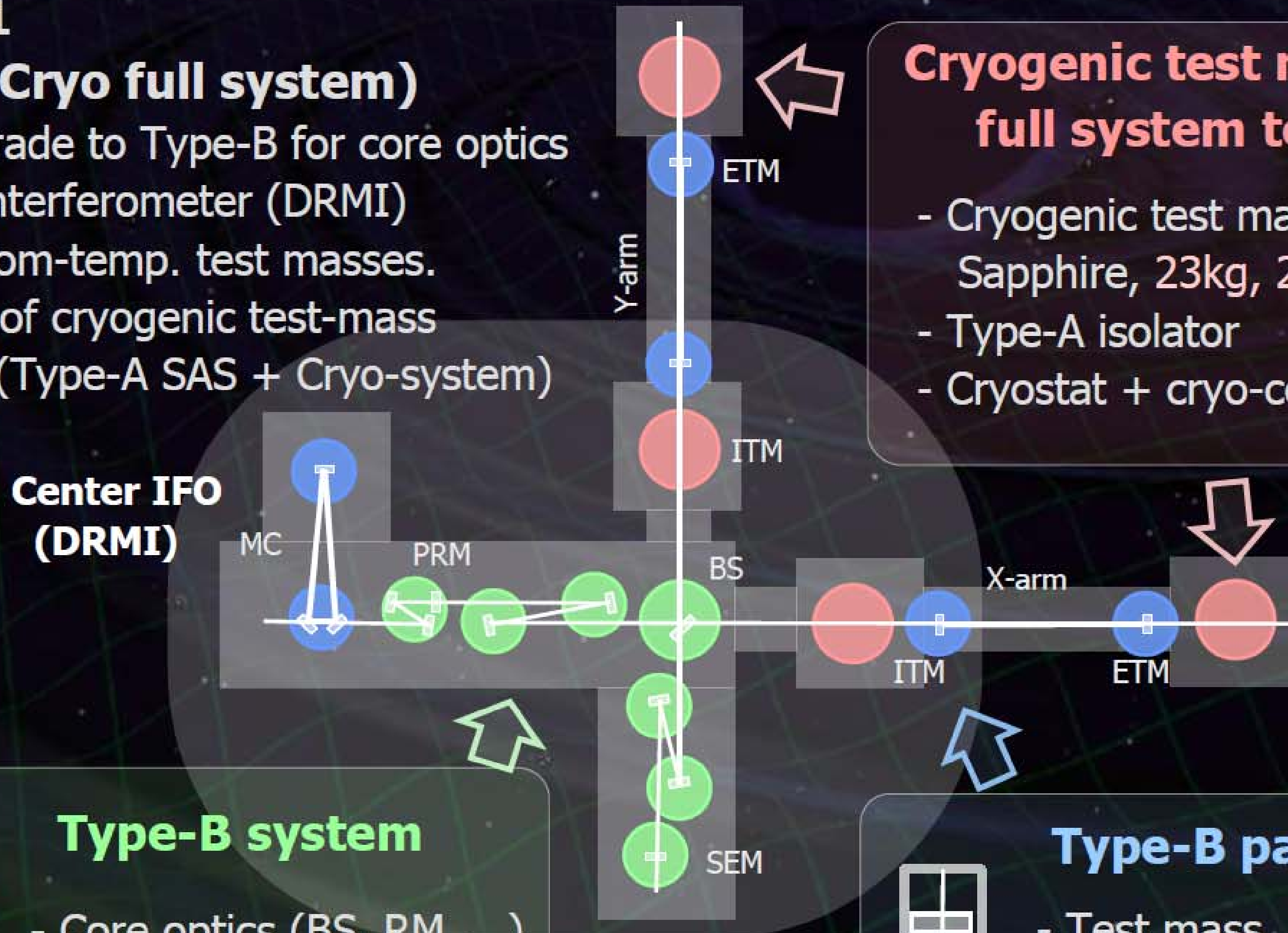
Cryogenic system test

- Cryostat + Rad. shield duct
- Cryo-cooler
- Cryogenic payload
- Fixed Type-ASAS

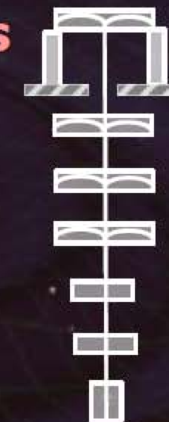
bKAGRA commissioning 1 (- 2016.9)

bKAGRA1
(DRMI, Cryo full system)

- VIS upgrade to Type-B for core optics
- Center interferometer (DRMI) with room-temp. test masses.
- Full test of cryogenic test-mass system (Type-A SAS + Cryo-system)



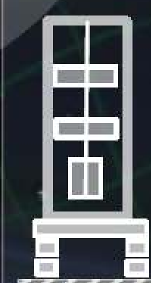
Cryogenic test mass full system test



- Cryogenic test mass
  Sapphire, 23kg, 20K
- Type-A isolator
- Cryostat + cryo-cooler

Type-B system

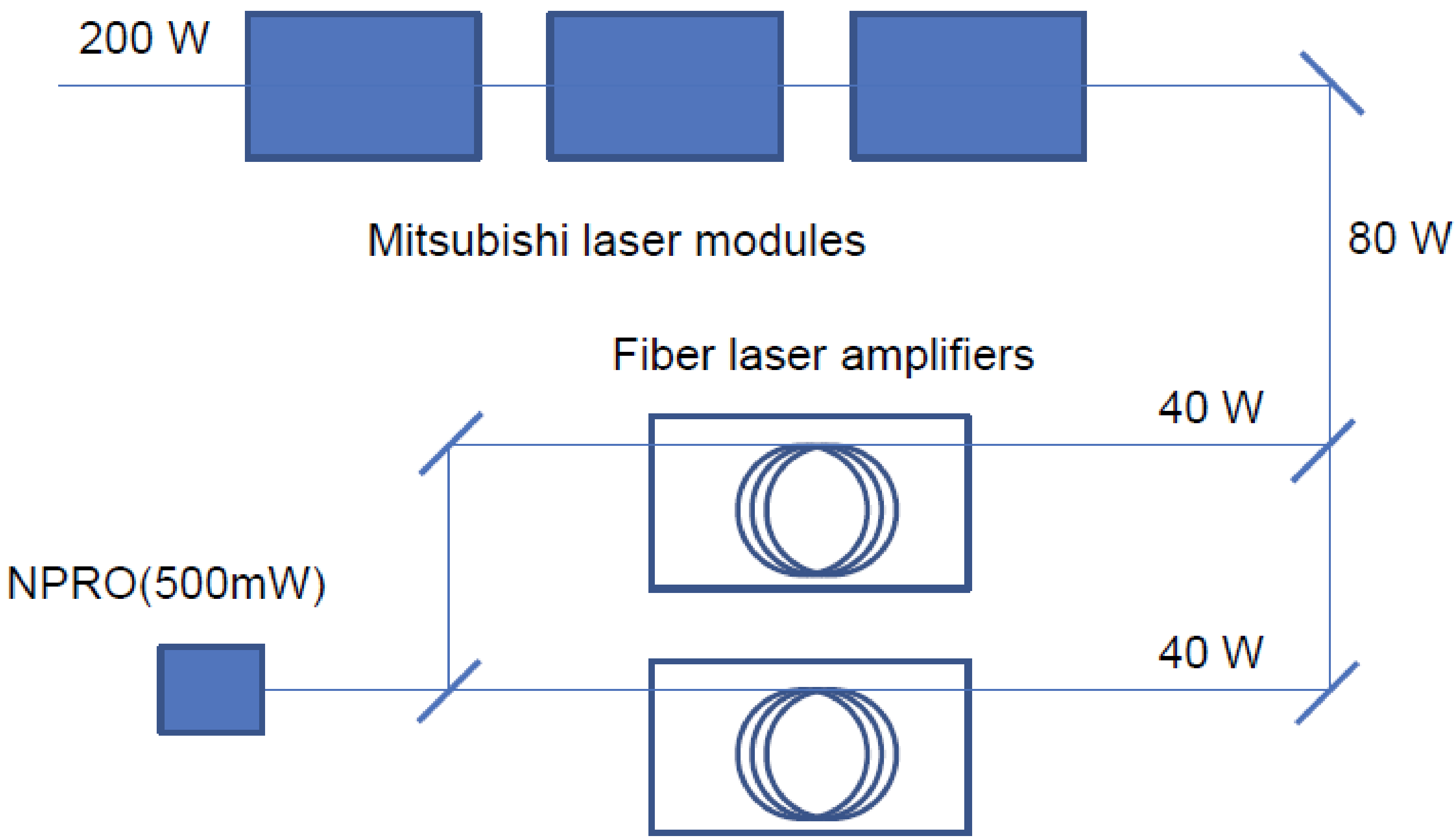
- Core optics (BS, RM ,…)
  Silica, 10kg, 290K
- IP + GASF + Payload
- Stack for aux. optics



Type-B payload

- Test mass
  Silica, 10kg, 290K
- Seismic isolator
  Table + Type-B Payload

LASER



NPRO + fiber amplifier + solid-state amplifier