LCGT Bandwidth Study

~ Consideration of low-frequency configurations ~

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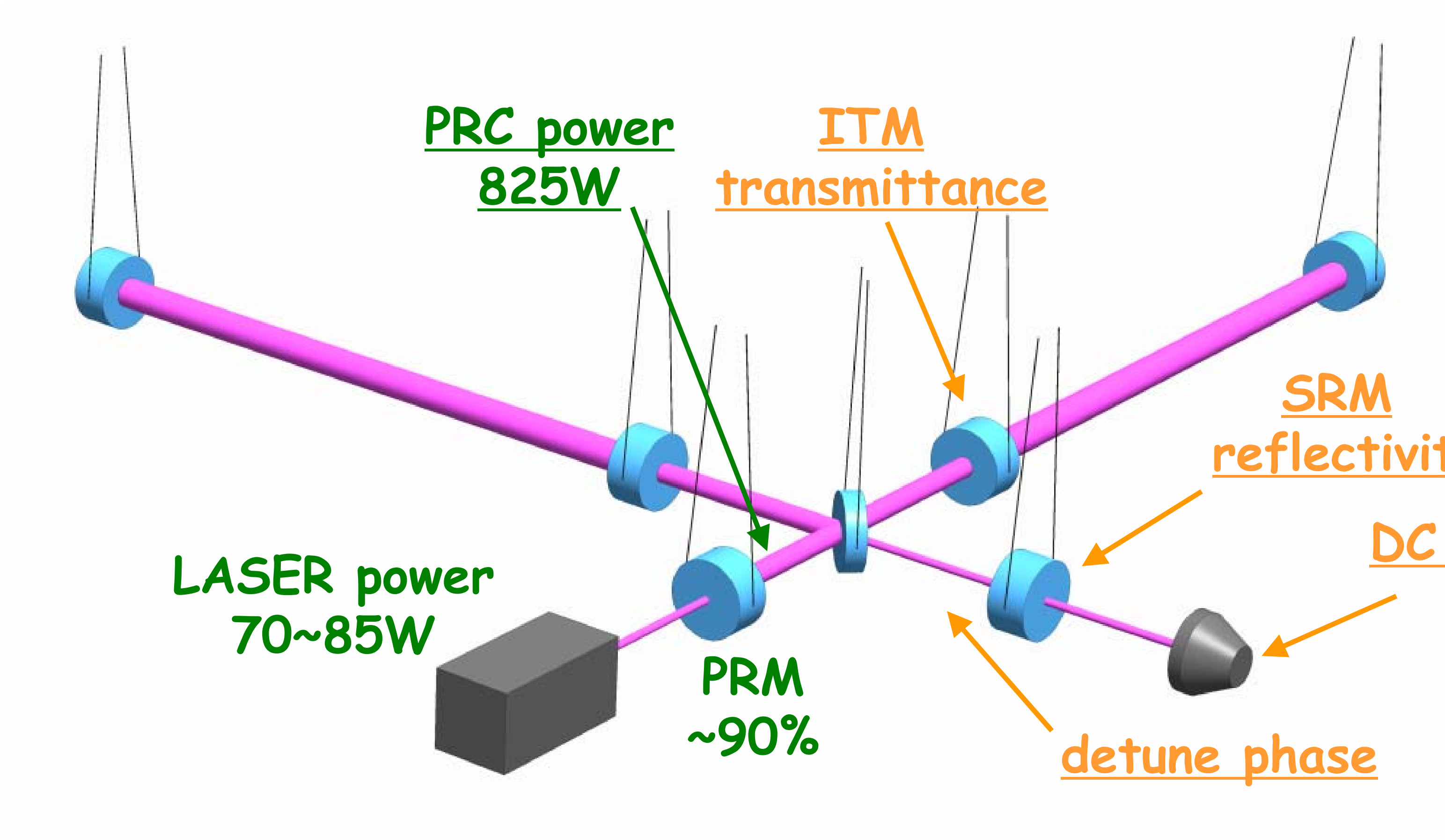
Tokyo Inst of Technology
Kentaro Somiya

on behalf of
LCGT-LF Special WG

K.Somiya

LCGT configuration

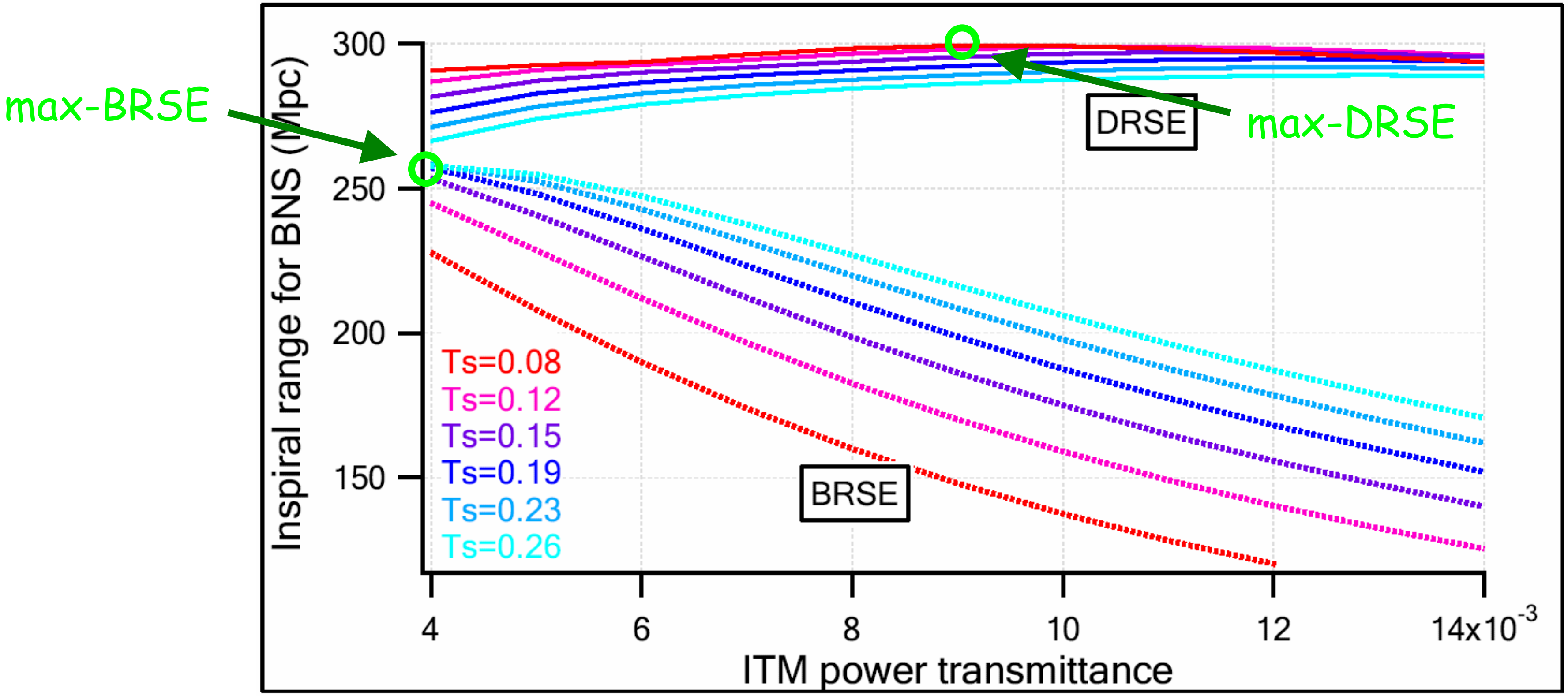
[Figure: courtesy by Aso]



- Input power is limited by the cooling capability
- There are 4 parameters to be tuned

Setups for the highest IR [BW study 2009]

Detune phase and DC readout phase are chosen to maximize IR at each point

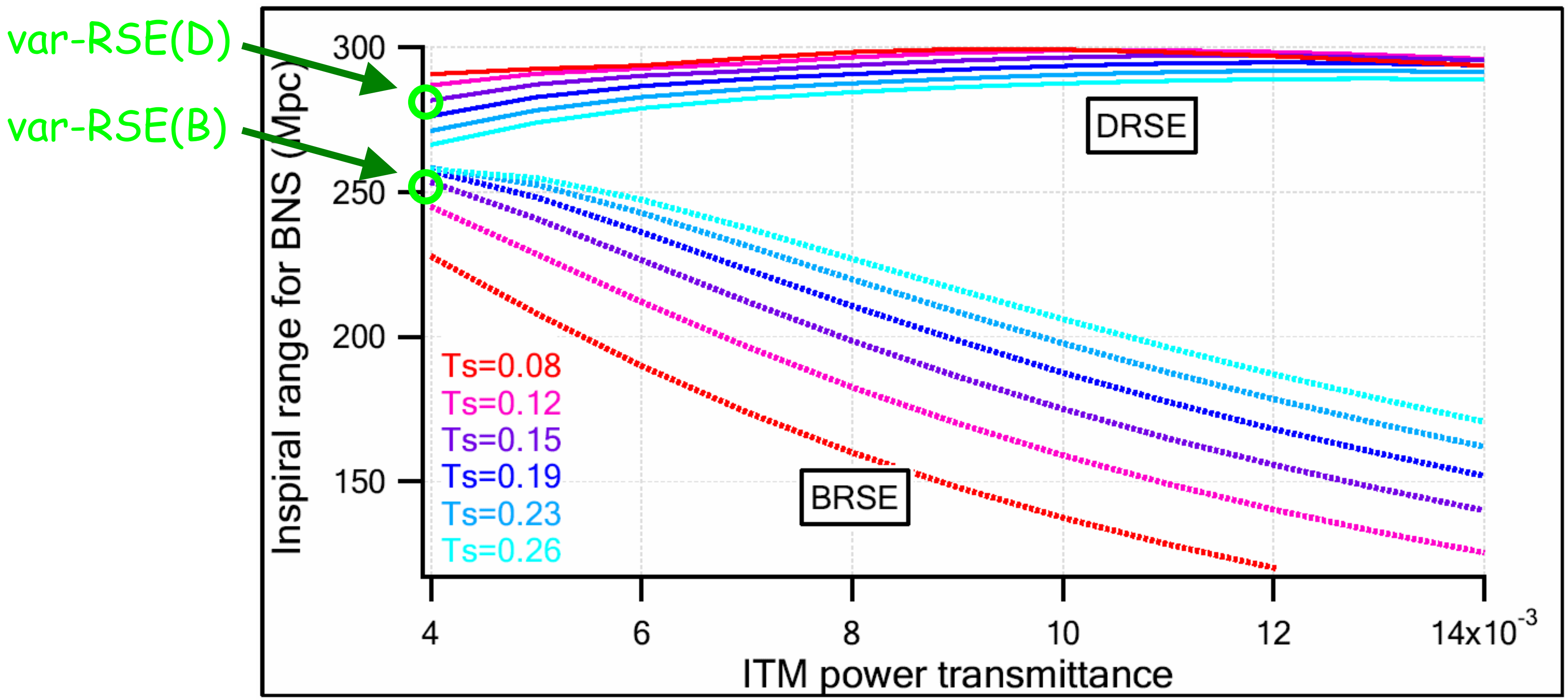


- **Max-BRSE and Max-DRSE are not compatible**
- **Max-DRSE spectrum is quite narrow-band**
- **High-IR DRSE with decent-IR BRSE is desirable**

Compatibility

[BW study 2009]

Detune phase and DC readout phase are chosen to maximize IR at each point

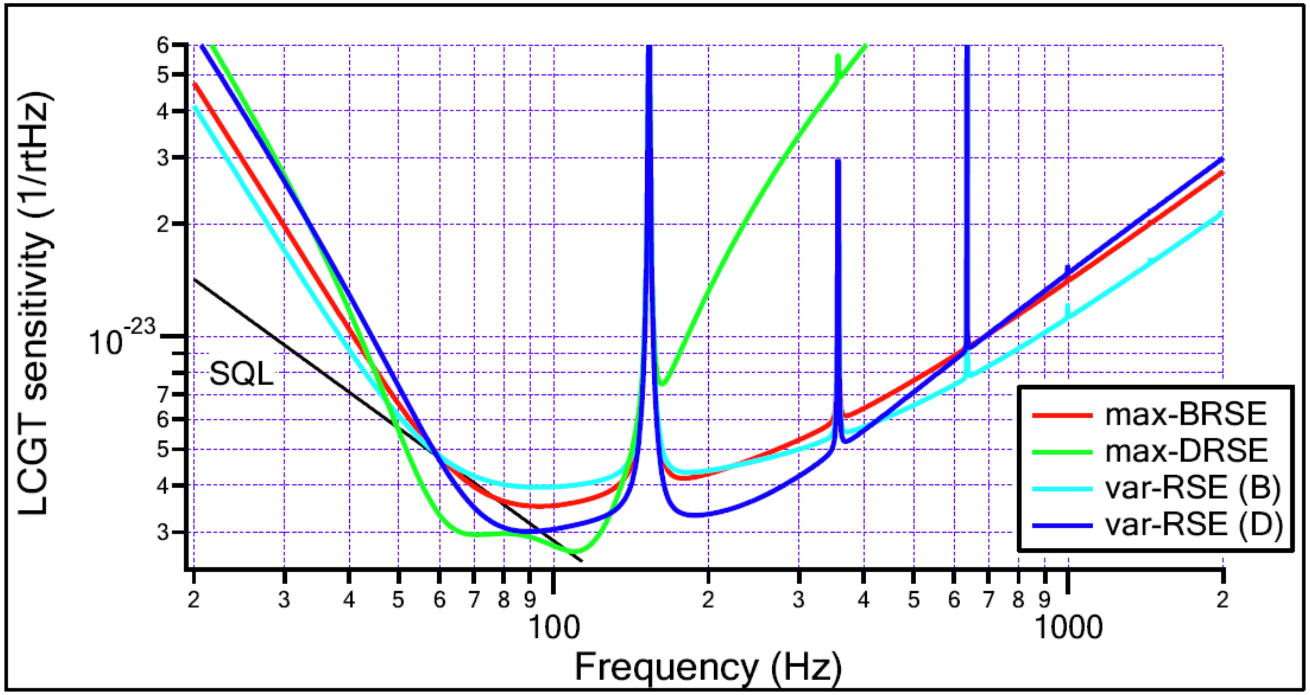


Variable-RSE with an intermediate optical setup

⇒ **bLCGT configuration**

Sensitivity spectra

[BW study 2009]

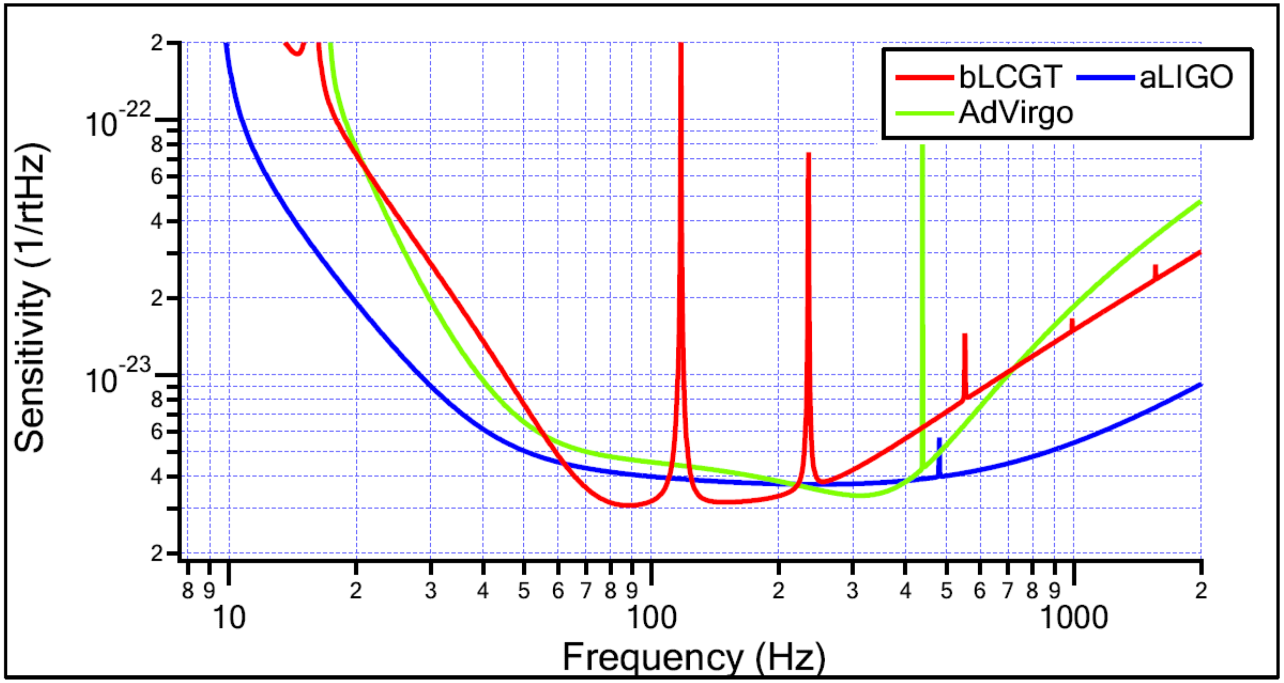


	T_{ITM}	T_S	ϕ	ζ	IR(SN8)
mB	0.4%	23%	90deg	128deg	259Mpc
mD	0.9%	8%	75deg	104deg	299Mpc
vB	0.4%	15%	90deg	122deg	255Mpc
vD	0.4%	15%	87deg	135deg	**281Mpc**

We decided to start with the var-DRSE configuration.

Changeable to the var-BRSE in the future.

Comparison with other detectors



*LCGT noise curves have been updated

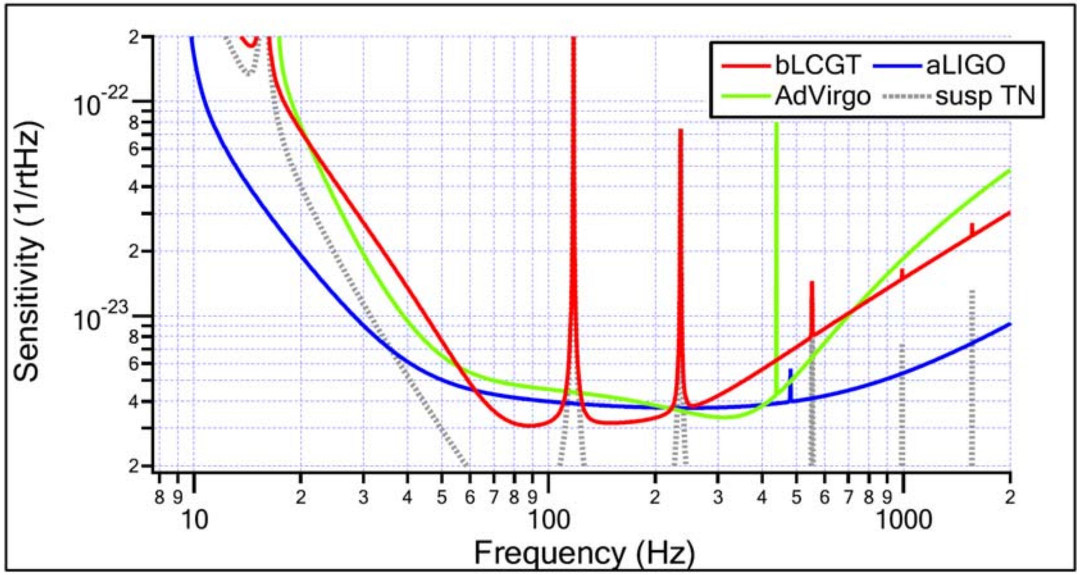
IR=309Mpc (aLIGO), 242Mpc (AdVirgo), 273Mpc (LCGT)

[309Mpc × $\frac{3}{4}$ =231Mpc]

LCGT strategy — cryogenics → low Mirror TN → deep spectrum

aLIGO strategy — 4km → already high IR → broad spectrum

Significance in GW network



IR=309Mpc (aLIGO), 242Mpc (AdVirgo), 273Mpc (LCGT)
*Without suspension TN, IR of LCGT would be 301Mpc.

- Optimization so far was for LCGT as a single detector

⇒ LCGT could put more significance to GWIC by going low frequencies

- Optimization so far was with the highest power (400kW in arm)

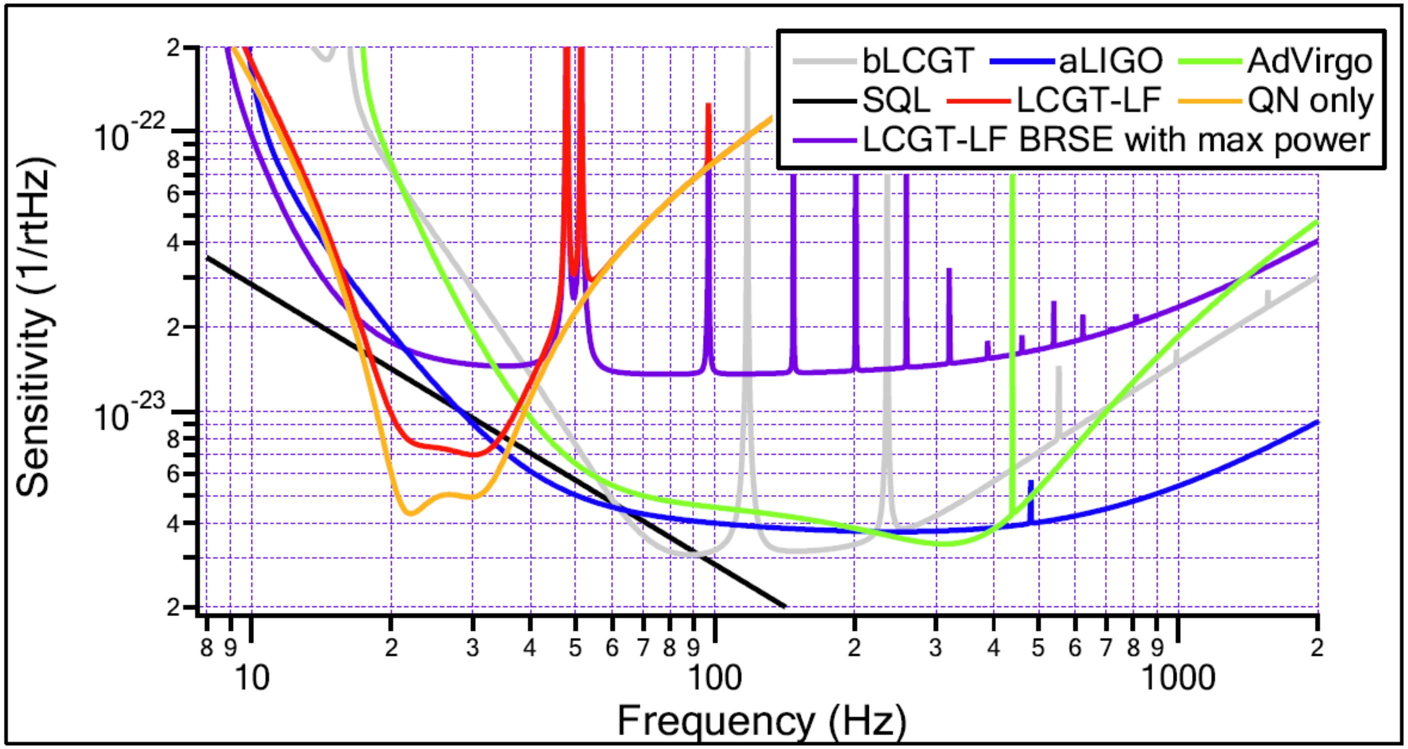
⇒ Suspension TN could be reduced by low-power operation

⇒ **LCGT-LF study** (WG member: Agatsuma, Aso, Hayama, Kanda, Kuroda, Takahashi, K.Yamamoto, me + collaboraton)

- Possible LF configuration
- LF/HF GW sources
- Technical feasibility ... etc.

[Ref: JGW-T1000446-v2]

LCGT-LF



- Input power 1.5~12W
- T_S 15% -> 12%
- T_{ITM} 0.4 -> 0.6%
- Fiber length 30cm -> 120cm
- Fiber thickness 1.6mm -> 1.4mm
- Max 170mW cooling

(for BNS)
IR=309Mpc (aLIGO)
IR=242Mpc (AdVirgo)
IR=273 (bLCGT)

IR for BNS = 196Mpc
IR for 100Ms BBH = 4.17Gpc
[IR w/o TN: 282Mpc/6.88Gpc]

(for 100Ms BBH)
IR=3.45Gpc (aLIGO)
IR=3.98Gpc (aLIGO BBH)

Inspiral End Freq = 44Hz

(1) How much do we gain at low freq?

(2) Is there any technical benefit?

Discussion (1) GW at low freq

- **BH-BH inspirals**

  ~ High-end of 50-50Ms BBH inspiral is 44Hz
  Mass ratio etc. are not given by ring-downs but by inspirals

- **Vela pulsar**

  ~ 22Hz

- **NS-NS inspirals**

  ~ LCGT-LF's IR is as high as 196Mpc
  Observation at unique frequencies
  Lower accuracy in parameter estimates

Discussion (2) GW at high freq

- **NS-NS merger**
  - ~ Merger signals would appear at 2~8 kHz
- **LMXB**
  - ~ Most of them are outside the range but ScoX-1 is possible
- **Supernova**
  - ~ Event rate is not high but we cannot miss an event in our galaxy
  - ~ Possibility of multi-channel observation

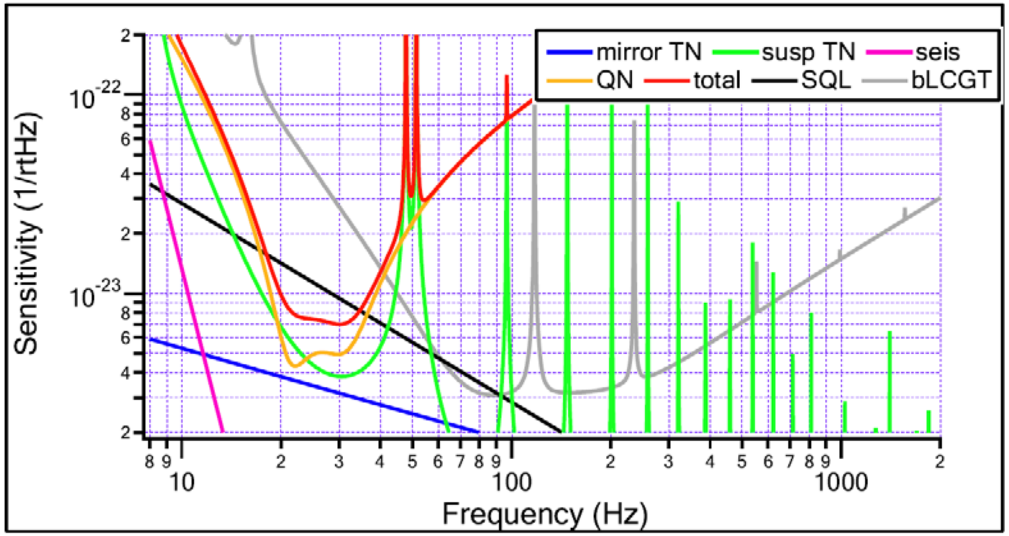
Discussion (3) narrow-banding

- As was studied in 2009, even if the IR is same, the accuracy of parameter estimates for binary inspirals decreases by narrow-banding

- For cosmic GW background, cross-correlation with multiple detectors is necessary and having a unique spectrum will become a disadvantage

- Xylophone would work if 2 detectors are on a same site like ET, but it is different with LCGT and AdVirgo that have different antenna patterns

Discussion (4) technical points



- Low RMS motion would result in the reduction of various technical noise sources
- We can avoid the absorption issues of Sapphire that we rely on companies

bLCGT

☺seismic
☹absorption

Risk balance

LCGT-LF

☹seismic
☺absorption

However...

[Miyoki, yesterday]

Toss the Table (TДT)

① Original targeted sapphire mirror diameter is 25 cm for bLCGT.
② Recently, not 25cm but 22cm mirror substrate preparation was decided.
③ 22cm substrate cannot be used for the present bLCGT design, because the beam diameter on ETM is larger ETM diameter and we will get a lot of optical loss.

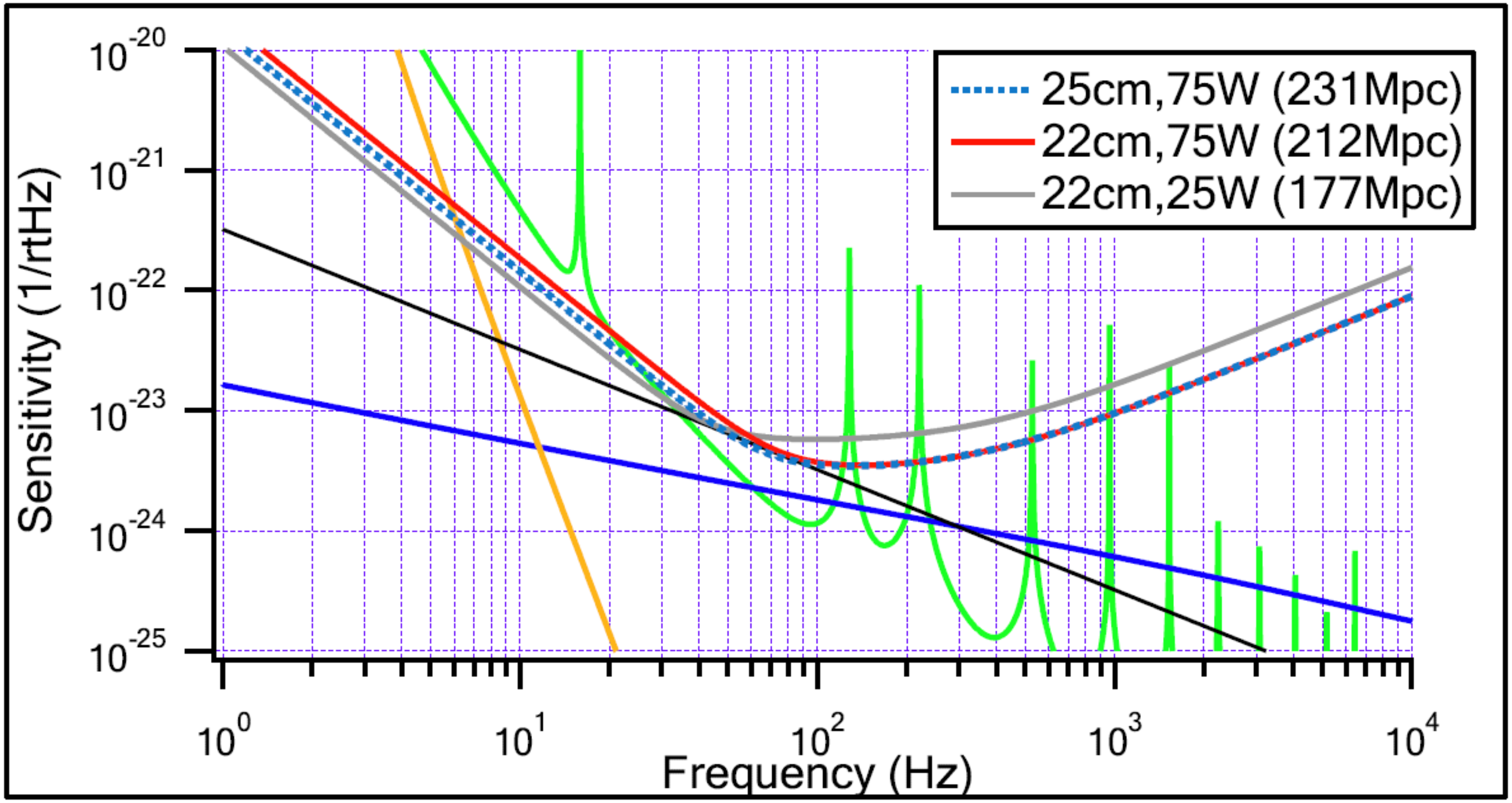
buy mirrors now ⇒
- low mass
- high absorption
- high loss

⇒
- RP noise ↗
- shot noise ↗
- susp TN ↗

Yesterday, I said the inspiral range will decrease by a large factor, but it seems we can recover the range by detuning.

BRSE with 22cm mass

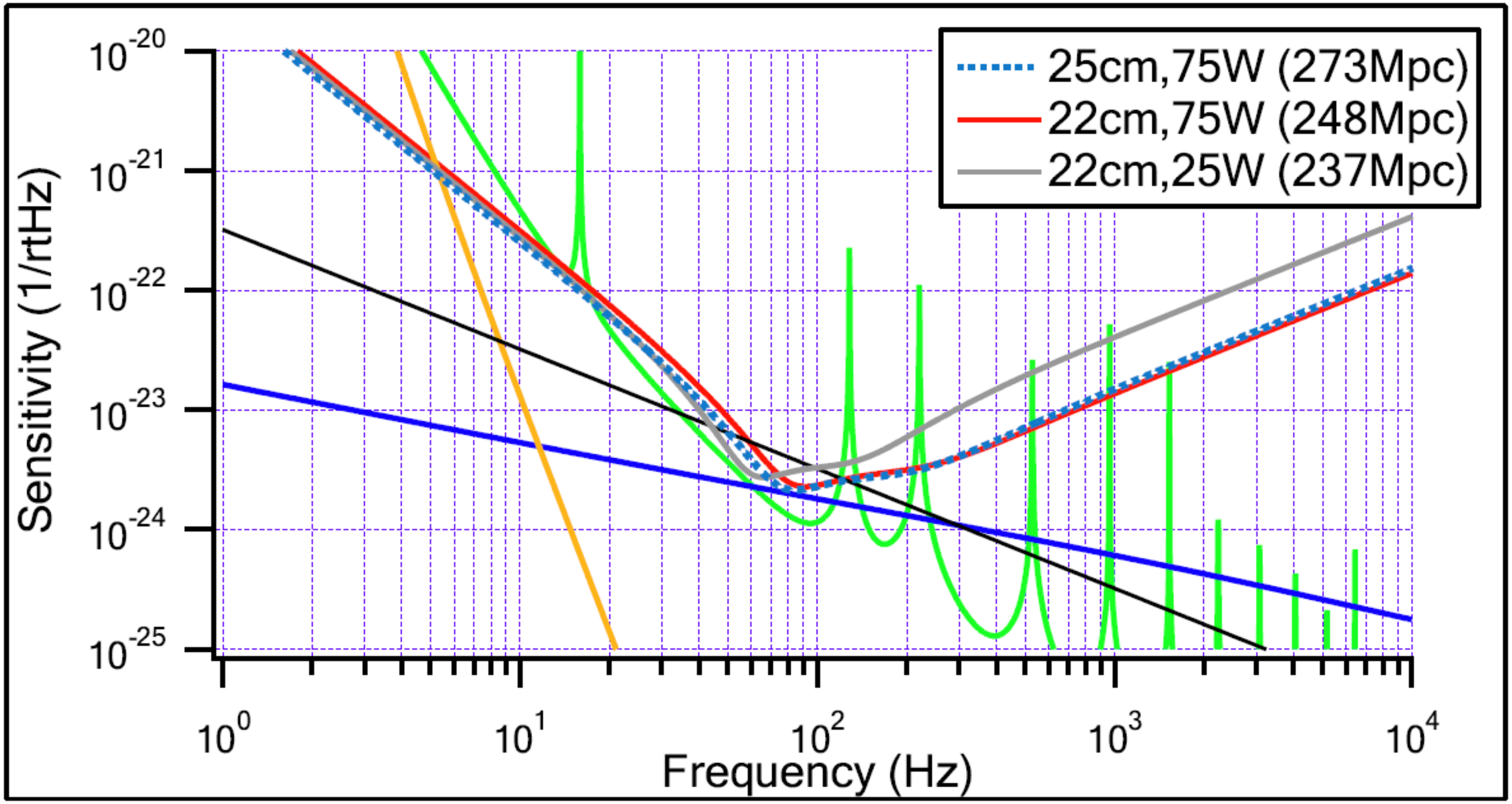
w=4cm/4cm



- Absorption being x3, we should reduce the power by 1/3
- IR may decrease by 23% compared with BRSE (25cm,75W)
- IR should be 200+Mpc for 1 event/year w/90% probability

DRSE with 22cm mass

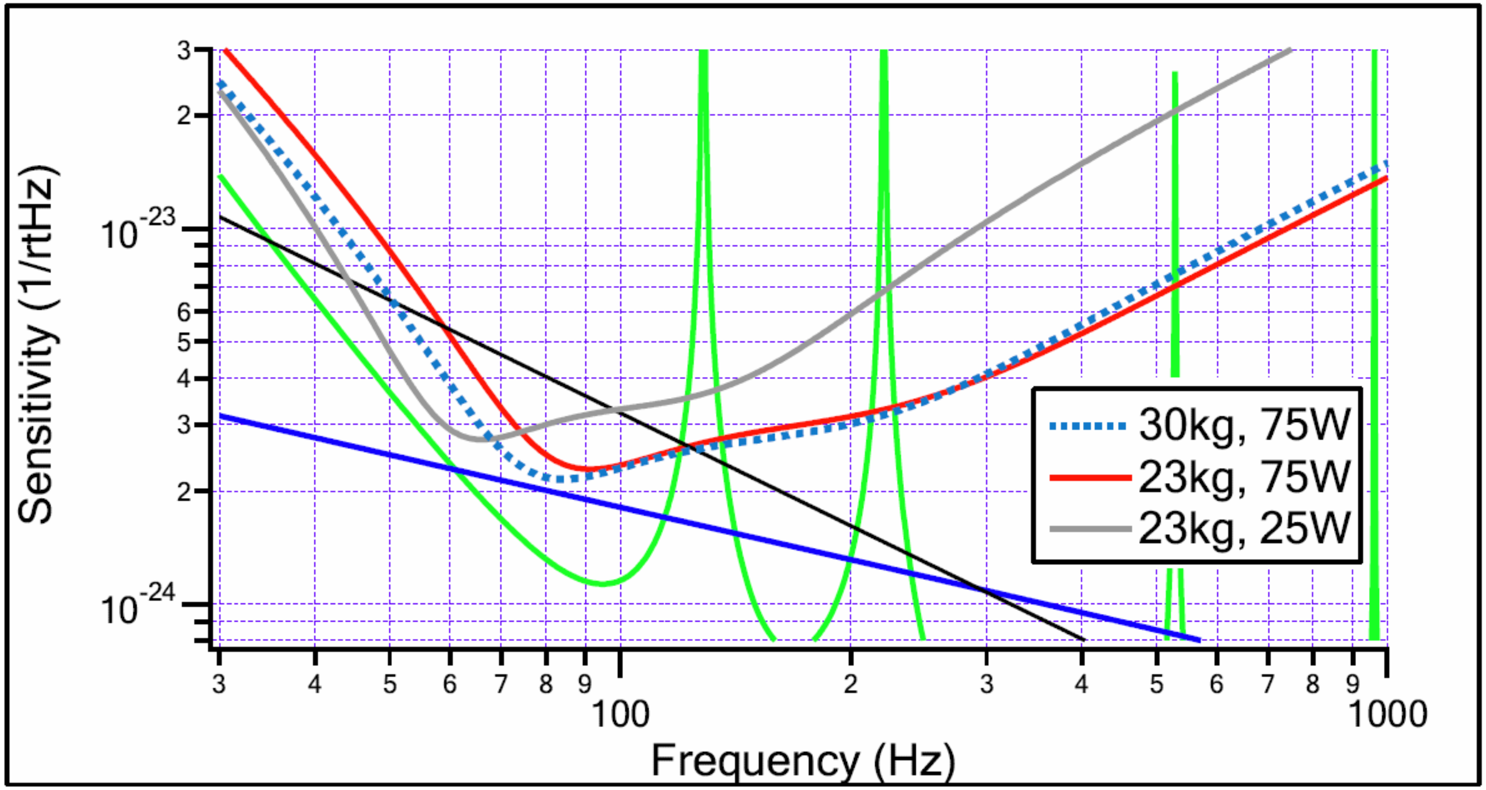
w=4cm/4cm



- IR reduction can be recovered by bandwidth reduction
- HF sensitivity is worse by ~4
- Detuning is as large as 6.0 degrees (~3.5 deg for 25cm)

DRSE with 22cm mass

w=4cm/4cm



- We can recover the bandwidth as we improve the mirror quality, i.e. absorption (20~70ppm/cm)
- Similar to AdVirgo strategy
- Control scheme may have to be changed

Summary

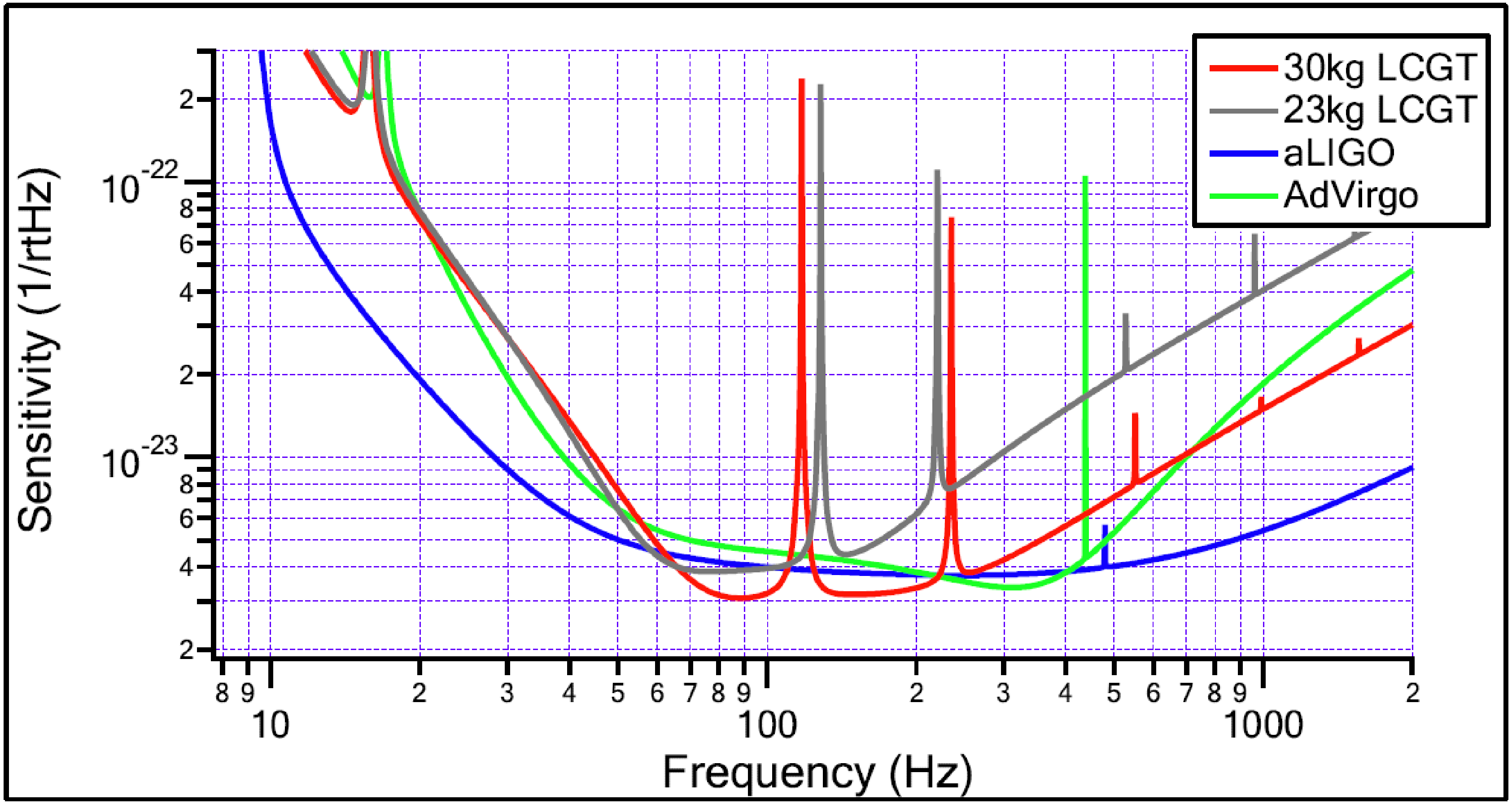
- Cryogenic detector can go deeper in the spectrum
- Trade-off of bandwidth and good sensitivity
- Narrow-band operation is not good
- Low-power low-frequency operation is not good

- Table was tossed
- Maybe we should sacrifice the bandwidth now
- Maybe we should re-optimize the setup parameters
- Maybe we should go for silicon

[In my opinion, it is certainly necessary to purchase the 22cm Sapphire mirrors, but it's just to improve the mirror quality; we don't use the mirrors but wait for better and bigger mirrors.]

Supplementary slides

Comparison with other detectors

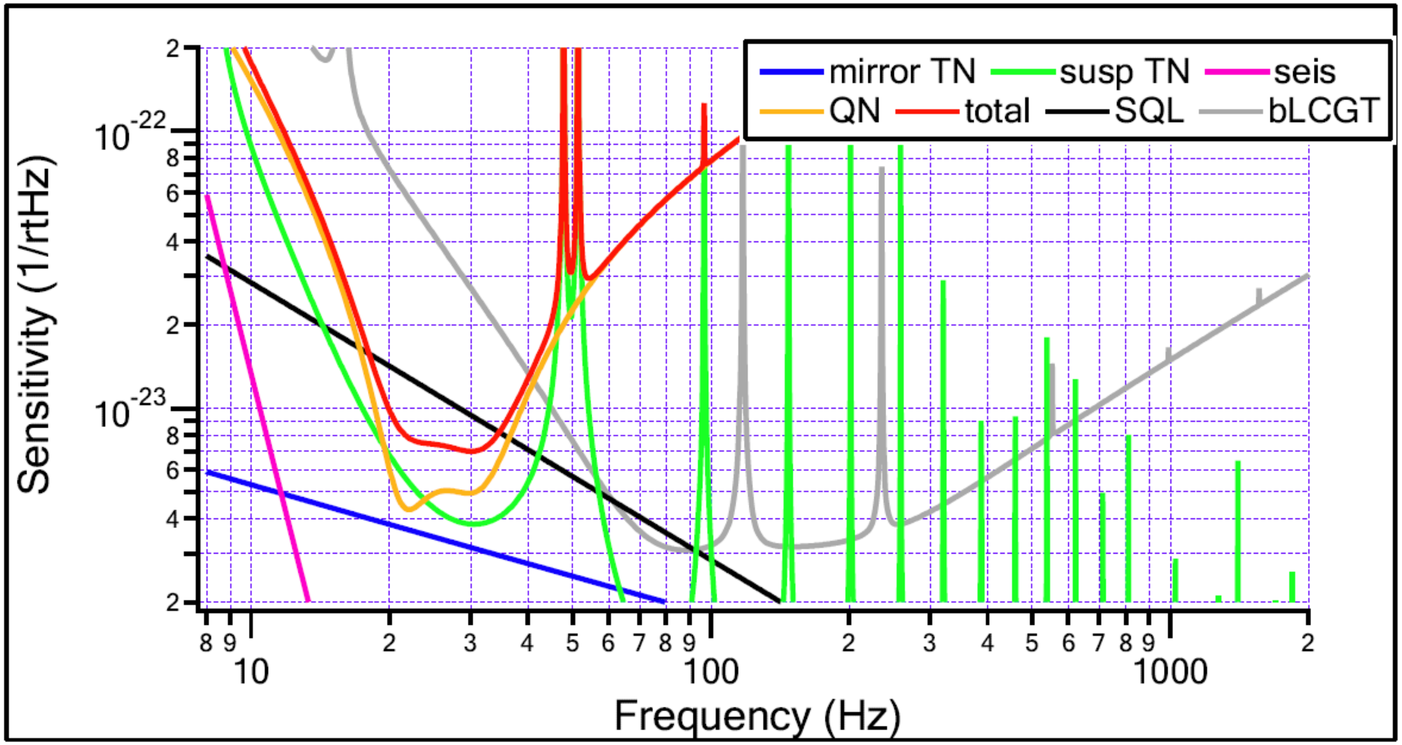


[parameters]

25cmLCGT: m=30kg, w=3.5/4.5cm, I=75W, Tm=20K

22cmLCGT: m=22.8kg, w=4.0/4.0cm, I=25W, Tm=20K

Noise Budget of LCGT-LF



- Input power 1.5~12W
- PRG=11, Rsr=88%
- Finesse 1050
- Fiber length 120cm
- Fiber thickness 1.4mm
- Max 170mW cooling

- Vertical resonance and 1st violin overlapped at 50Hz
- Broadband operation at these frequencies is challenging
- T(=20K) could be 12.4K (IM Temperature is set 10K)