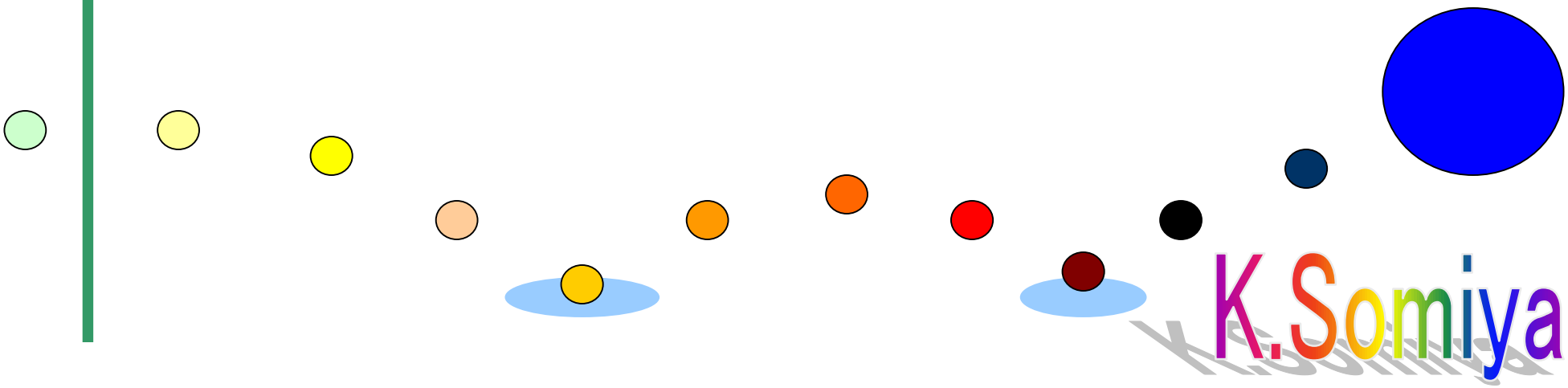
Advanced Configurations for a High-Frequency GW Measurement

KIW8
July 2021

K.Somiya

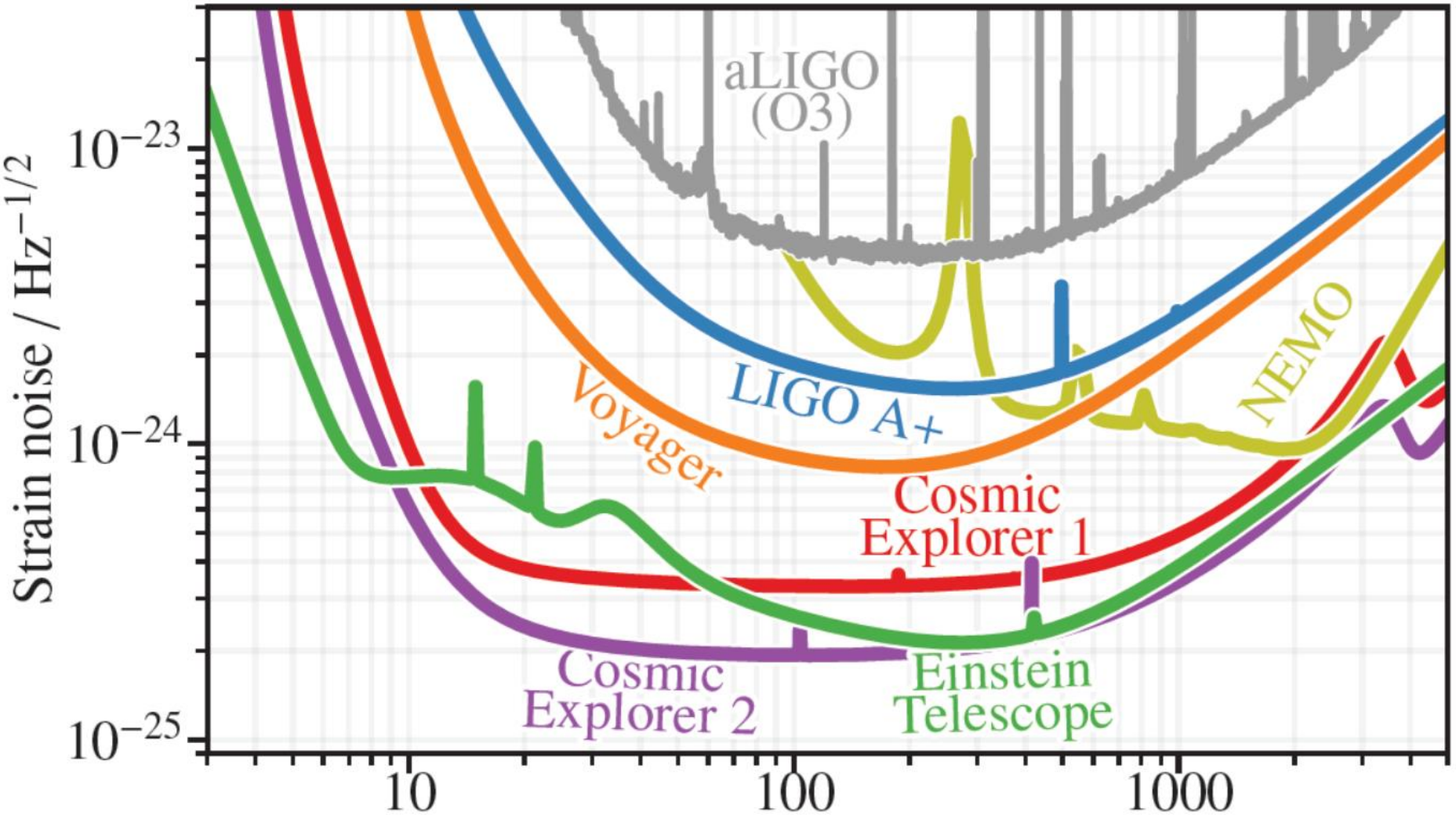


Contents

- Overview of KAGRA+ and 3Gs
- Possible improvement of KAGRA+
- Other advanced techniques
- Summary

Sensitivity curves of 2-3Gs

CE-G2100017

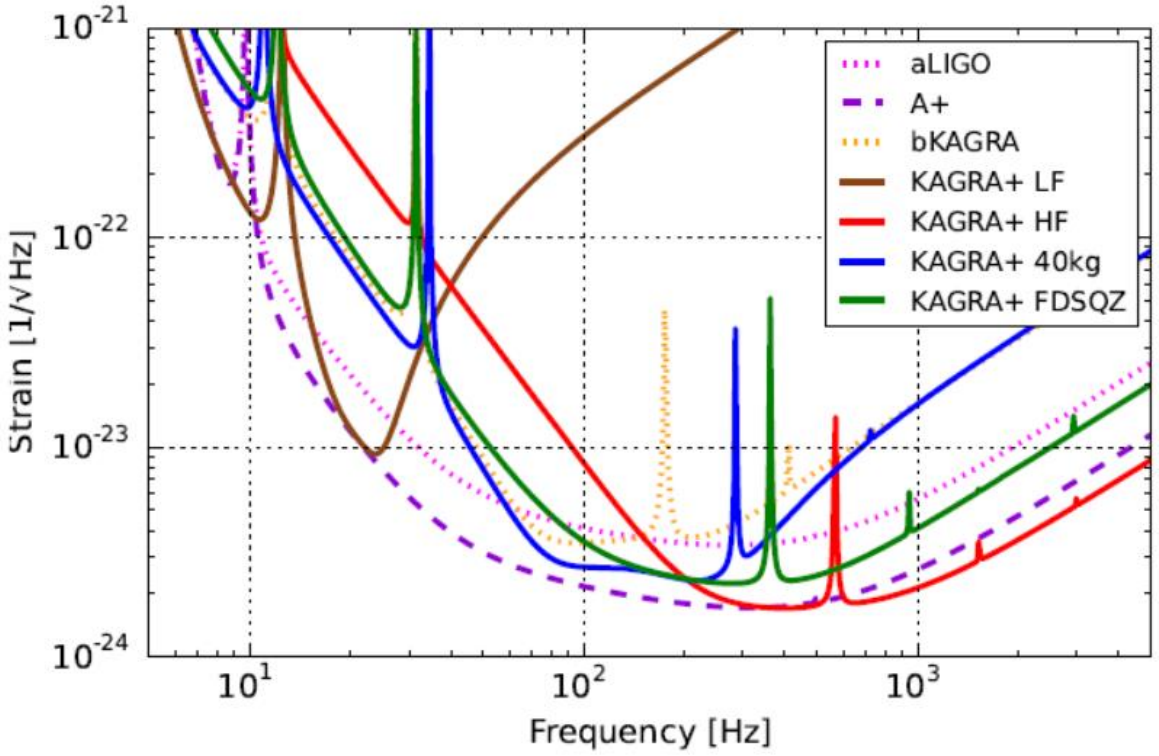


Design comparison

*1 Adya et al
*2 CE-G2100017
*3 Hild CQG 2010
*4 Robie APS 2020
*5 McCuller PRL 2020
*6 Acernese PRL 2019
*7 Jones 2020

	aLIGO	AdVirgo	KAGRA	NEMO[*1]	Voyager[*4]	CE1[*2]	CE2[*2]	ET-LF[*3]	ET-HF[*3]
Location Length	US 4km	IT 3km	Japan 3km	AUS 2-4km	US 4km	US 40km	US 40km	EU 10km triangle	
Wave-length	1064nm	1064nm	1064nm	2um	2um	2um	2um	1550nm	1064nm
Mirror	Silica 300K	Silica 300K	Sapphire 23K	Silicon 123/150K	Silicon 123K	Silica 300K	Silicon 123K	Silicon 10K	Silica 300K
Mass	40kg	42kg	23kg	74kg	200kg	320kg	320kg	211kg	200kg
Arm power	0.8MW	0.6MW?	0.4MW	4.5MW	3MW	1MW?	~3MW	18kW	3MW
SRC	short BB	short BB	short detune	LSRC BB	short BB	short BB	short BB	short detune	short BB
Squeeze	4.4dB[*5]	3.2dB[*6]	none	7dB	10dB	6dB?	10dB	10dB	10dB
Filter cavity	16m[*5]	300m (AdV+)	none	none	300m	4km?	4km	10km? (1km[*7])	10km? (300m[*7])

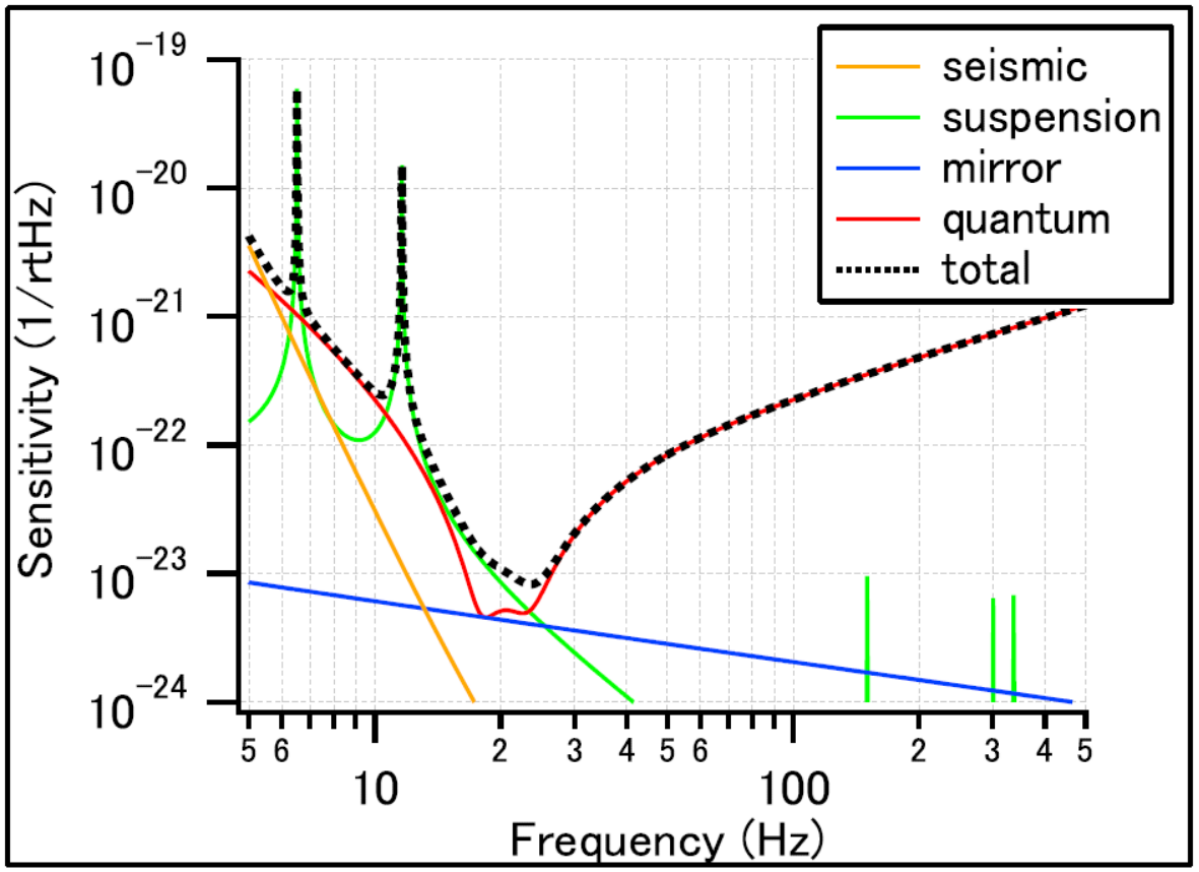
KAGRA+ (White Paper)



	bKAGRA	LF	HF	40kg	FDsq
SRM	85%	95%	91%	92%	83%
detune	3.5°	28.5°	none	3.5°	none
fiber(l)	35cn	1m	20cm	29cm	23cm
fiber(d)	1.6mm	0.5mm	2.5mm	2.2mm	1.9mm
mass	23kg	23kg	23kg	40kg	23kg
I_{BS}[W]	670	4.5	3440	1500	1500
temperature	22K	24K	21K	21K	21K
SQ	0	0	6dB	0	5dB

- **4 senarios toward the final combined configuration.**
- **No recommendation was given; to be discussed in FSC.**
- **We keep updating the spectra with new ideas.**

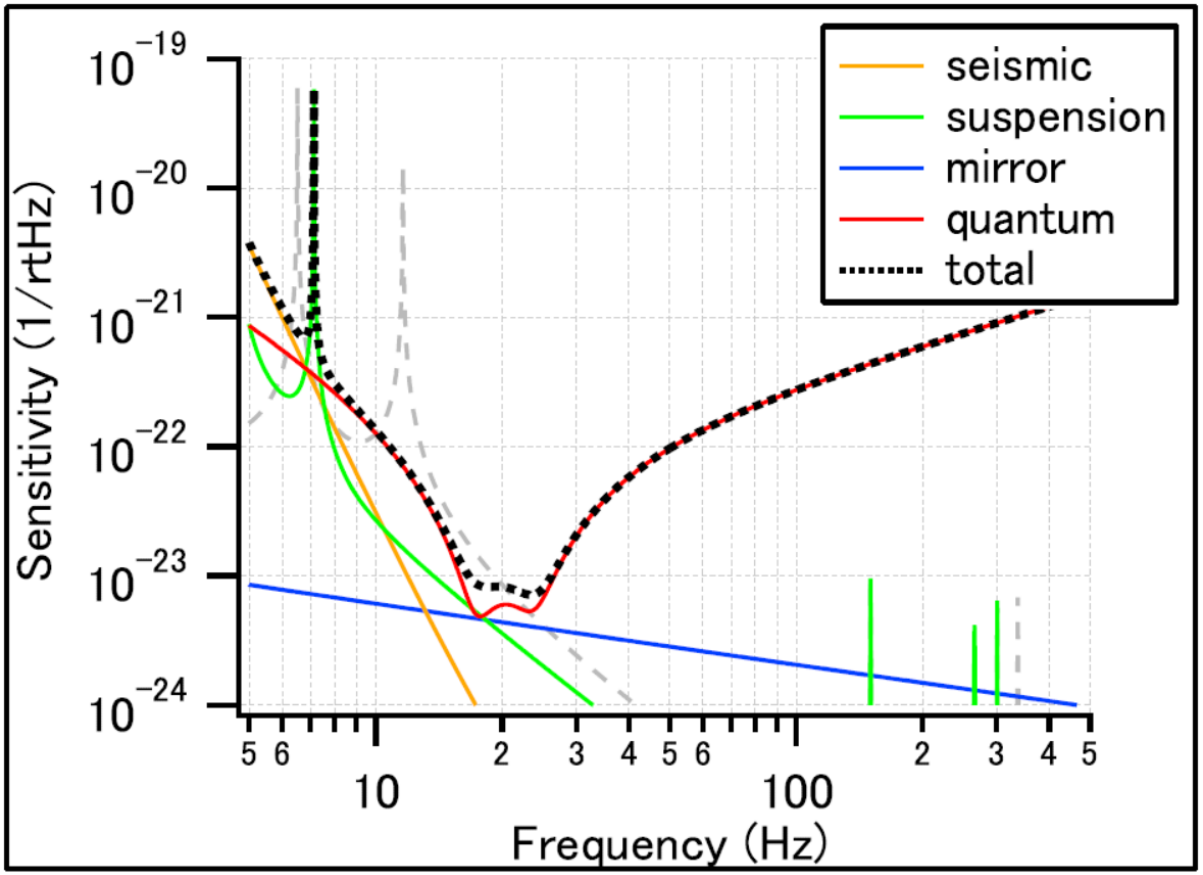
Possible improvement of LF



	bKA GRA	LF	
SRM	85%	95%	
detune	3.5°	28.5°	
fiber(l)	35cn	1m	
fiber(d)	1.6mm	0.5mm	
mass	23kg	23kg	
IM	21kg	300kg	
blade	14Hz	14Hz	
IBS[W]	670	4.5	
temperature	22K	24K	
SQ	0	0	

- **Susp TN limits the sensitivity below 20Hz**
- **We found that susp TN can be reduced if the blade spring frequency is lower.**

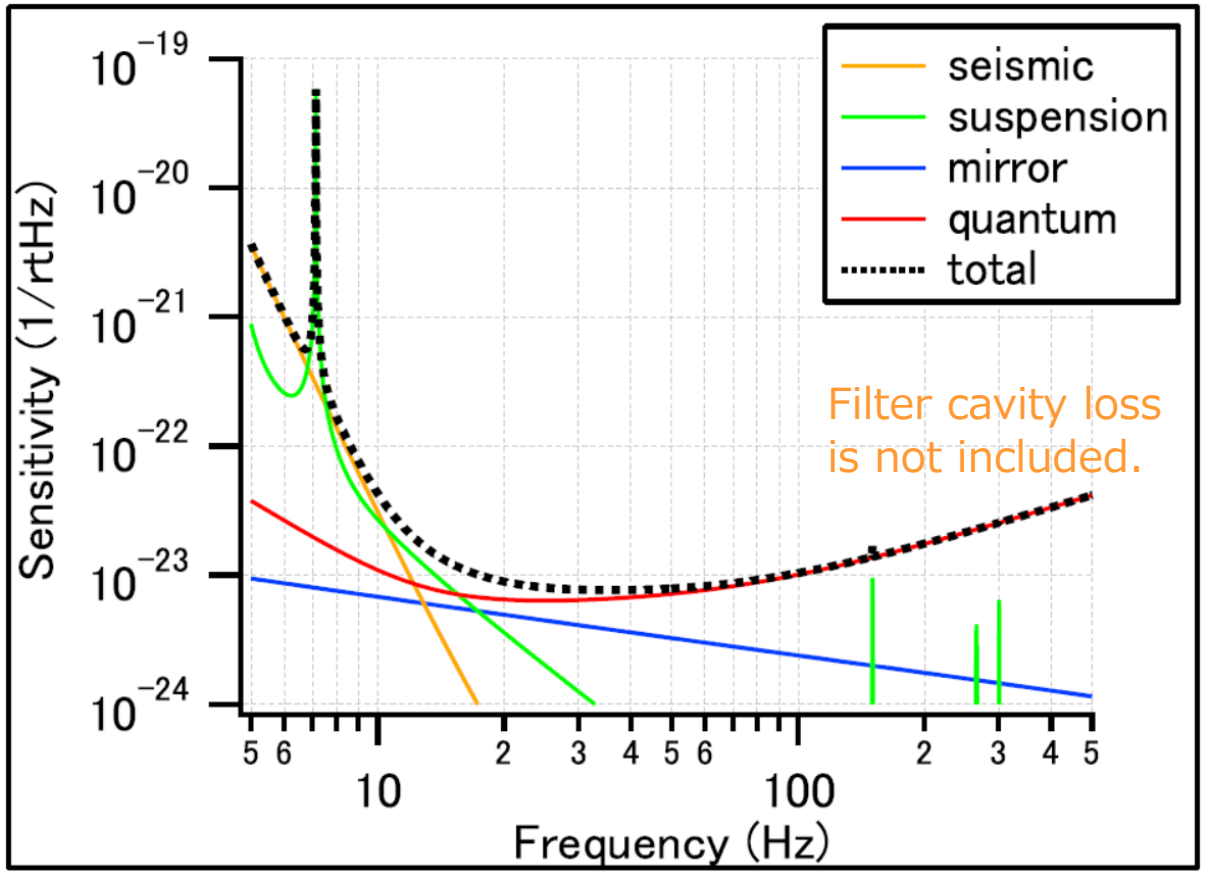
Possible improvement of LF



	bKA GRA	LF	LF2
SRM	85%	95%	95%
detune	3.5°	28.5°	35.6°
fiber(l)	35cn	1m	1m
fiber(d)	1.6mm	0.5mm	0.5mm
mass	23kg	23kg	23kg
IM	21kg	300kg	300kg
blade	14Hz	14Hz	5Hz
IBS[W]	670	4.5	4.5
temperature	22K	24K	24K
SQ	0	0	0

- **Susp TN is not limiting the sensitivity**
- **QN can be improved with a heavier mass**
- **Or we can try a broadband FD squeezing.**

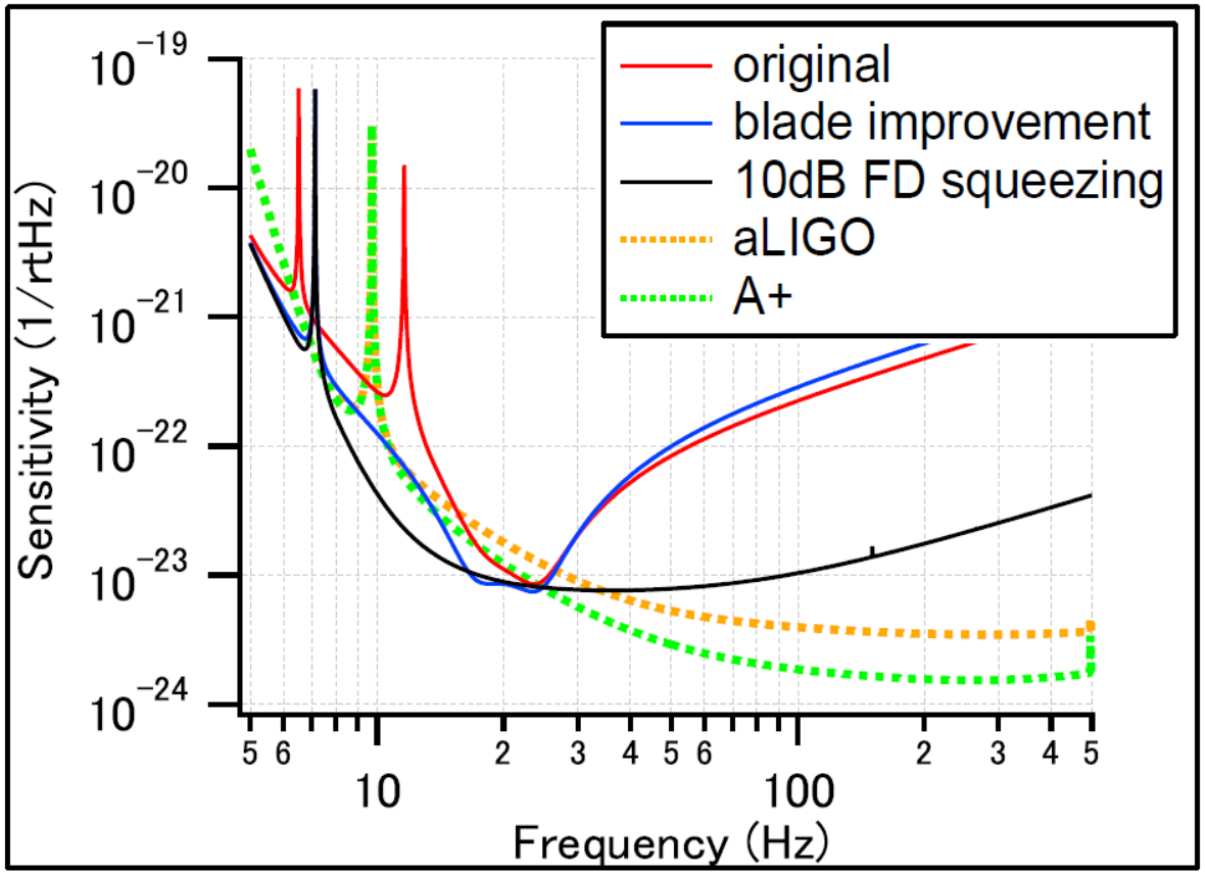
Possible improvement of LF



	bKA GRA	LF	LF2	LF3
SRM	85%	95%	95%	40%
detune	3.5°	28.5°	35.6°	0
fiber(l)	35cn	1m	1m	1m
fiber(d)	1.6mm	0.5mm	0.5mm	0.5mm
mass	23kg	23kg	23kg	23kg
IM	21kg	300kg	300kg	300kg
blade	14Hz	14Hz	5Hz	5Hz
I_{BS}[W]	670	4.5	4.5	4.5
temperature	22K	24K	24K	24K
SQ	0	0	0	10dB

- **Broader sensitivity with FD squeezing.**
- **A room for further improvement with higher power.**
- **The LF filter cavity might be challenging.**

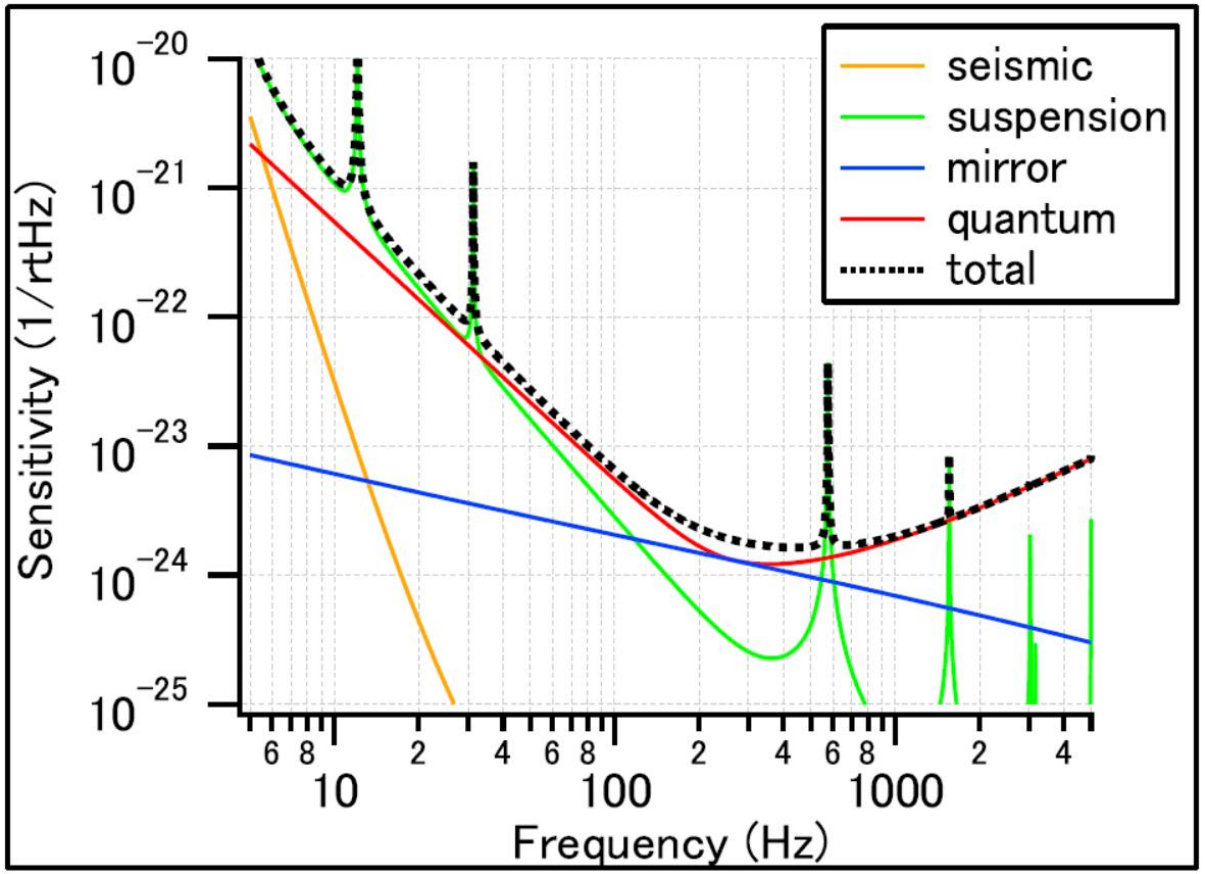
Possible improvement of LF



	bKA GRA	LF	LF2	LF3
SRM	85%	95%	95%	40%
detune	3.5°	28.5°	35.6°	0
fiber(l)	35cn	1m	1m	1m
fiber(d)	1.6mm	0.5mm	0.5mm	0.5mm
mass	23kg	23kg	23kg	23kg
IM	21kg	300kg	300kg	300kg
blade	14Hz	14Hz	5Hz	5Hz
IBS[W]	670	4.5	4.5	4.5
temperature	22K	24K	24K	24K
SQ	0	0	0	10dB

- **Sensitivity can be better than A+ below 20Hz.**
- **We can make the most of use of building the telescope underground.**

Possible improvement of HF

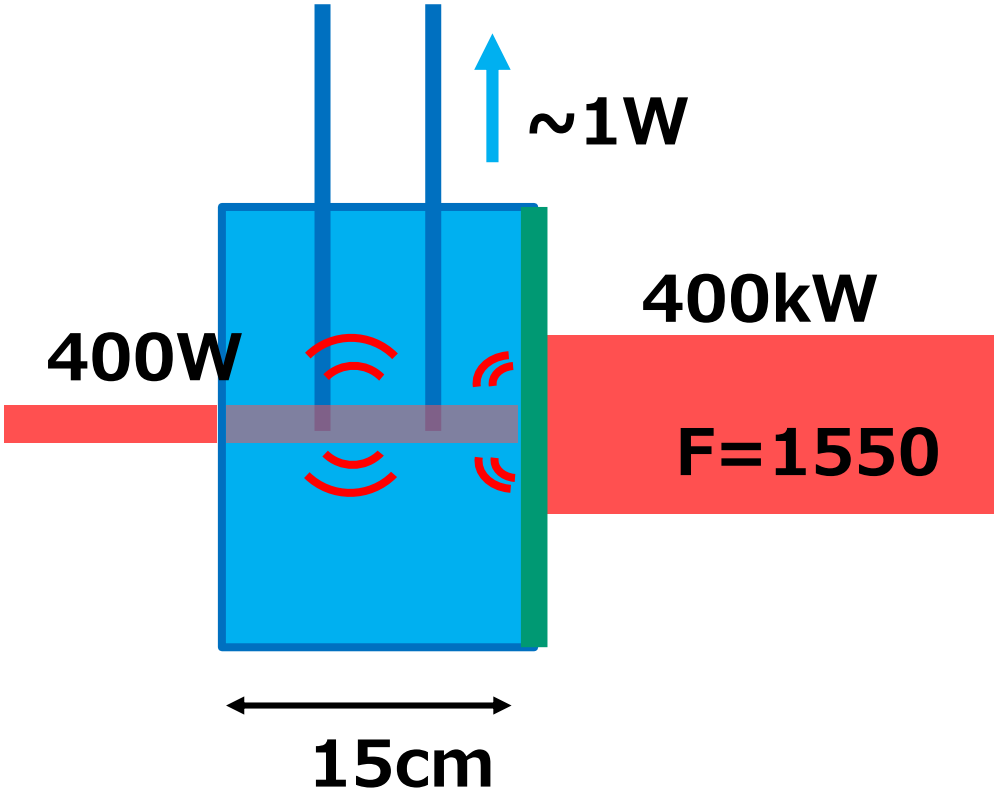


	bKA GRA	HF	
SRM	85%	91%	
finesse	1550	1550	
detune	3.5°	none	
fiber(l)	35cn	20cm	
fiber(d)	1.6mm	2.5mm	
mass	23kg	23kg	
I_{BS}[W]	670	3440	
temperature	22K	21K	
SQ	0	6dB	

No filter cavity.

- **If we aim at a clear observation of a NS merger, a better sensitivity at 2-4kHz is needed.**
- **OzGrav people say “1e-24 is required.”**

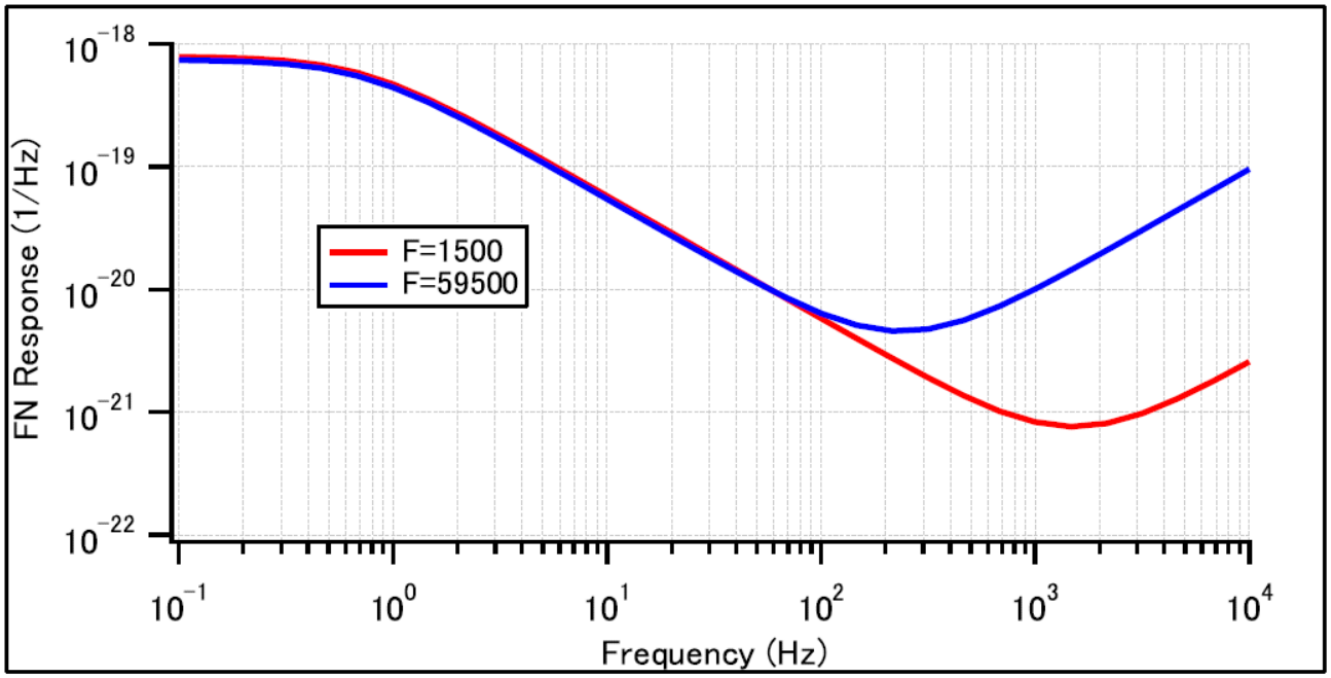
Let us consider ERSE and LSRC



- Absorption in substrate = 50ppm/cm → 0.6W
- Absorption in coatings = 1.0ppm → 0.4W
- Cooling capability = 1W

- Increasing the finesse by x6, we can keep the TM temperature even with a x2 power in the arms.
- Further increasing the finesse, we can omit PR to make if Extreme RSE (ERSE).

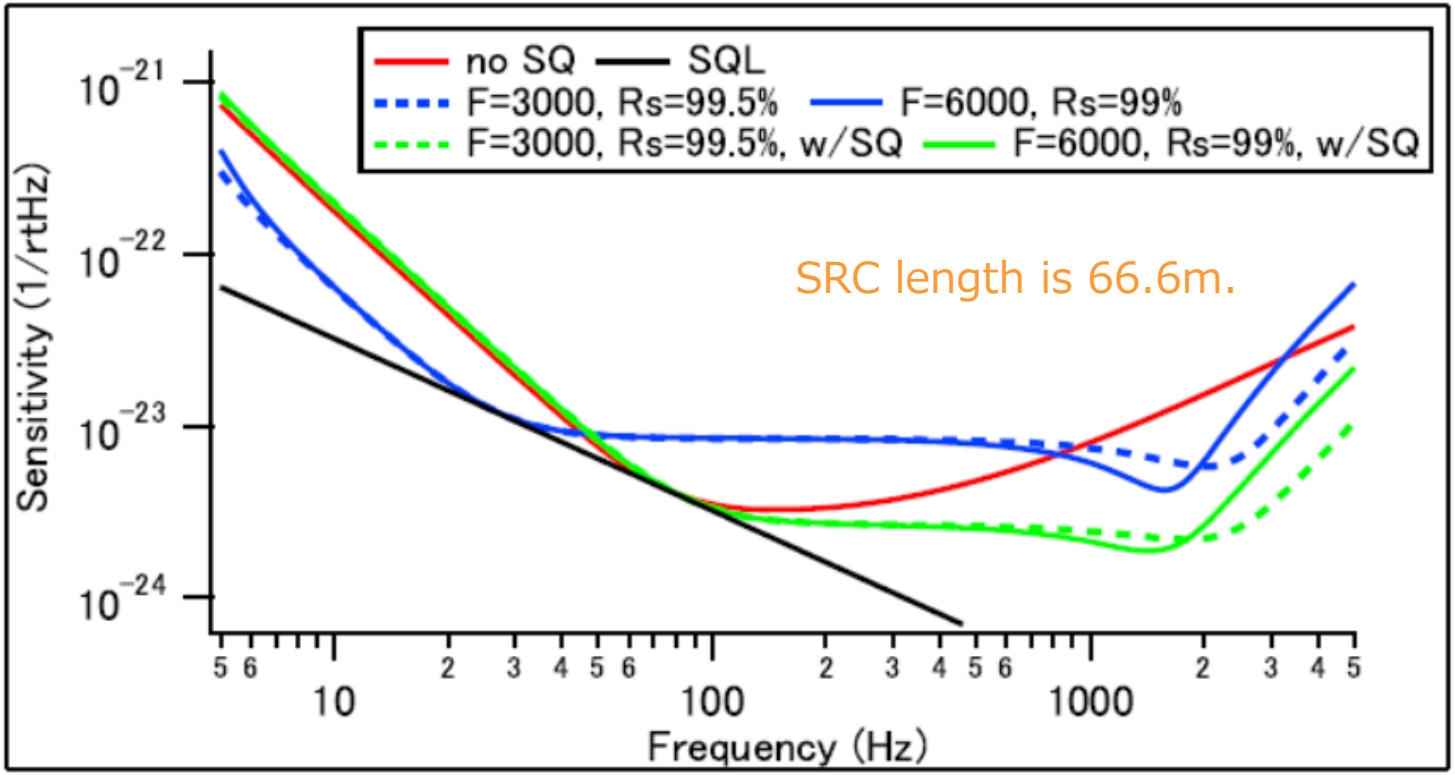
Laser noise coupling



The laser noise coupling increases with the finesse as the filtering effect at the power recycling is reduced. Further study is needed.

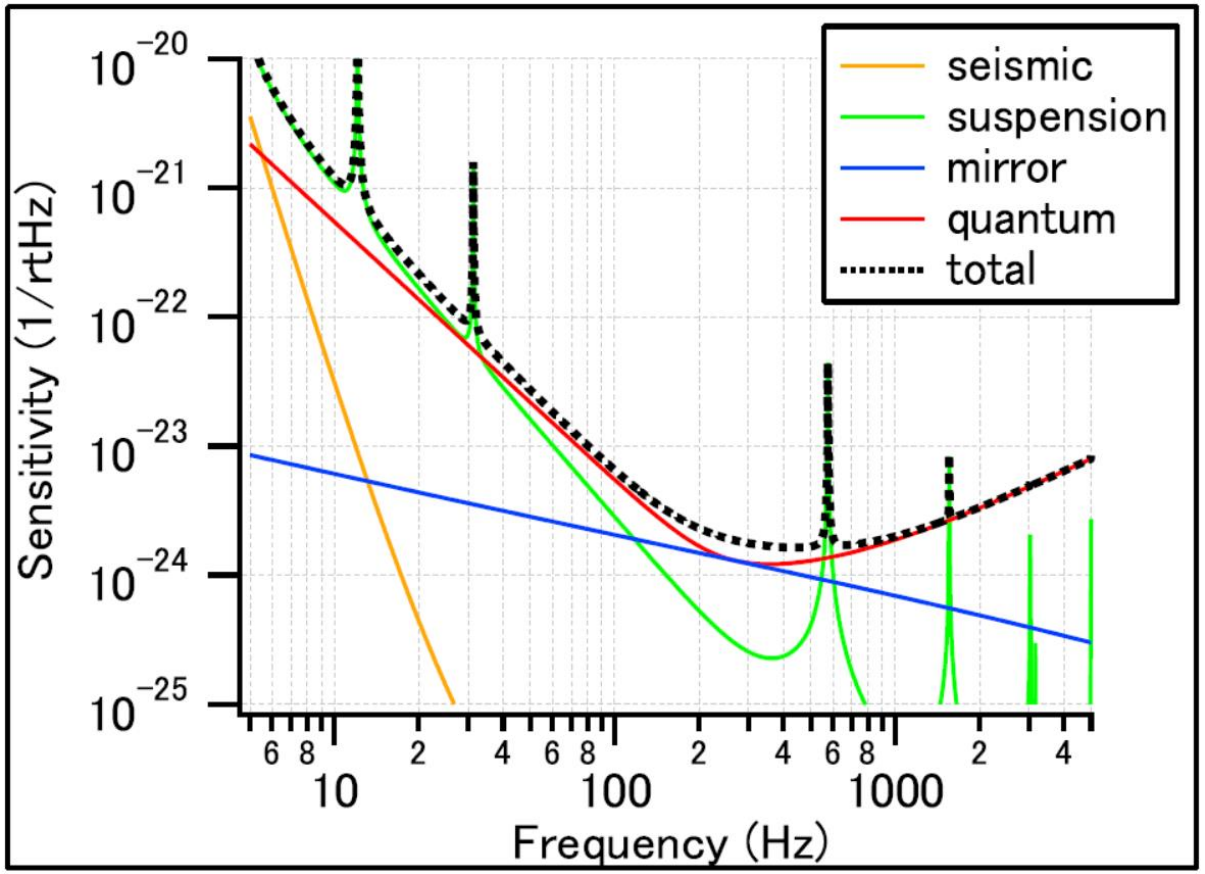
Long SRC effect

[Miao 2014]
[Martynov 2019]
[Somiya 2020]



- **Increasing the finesse, we will see a dip in a kHz band; Long Signal Recycling Cavity (LSRC) effect.**
- **Unlike a detuned SR, a frequency-independent SQ is ok to improve the sensitivity around the dip.**

Possible improvement of HF



	bKA GRA	HF	
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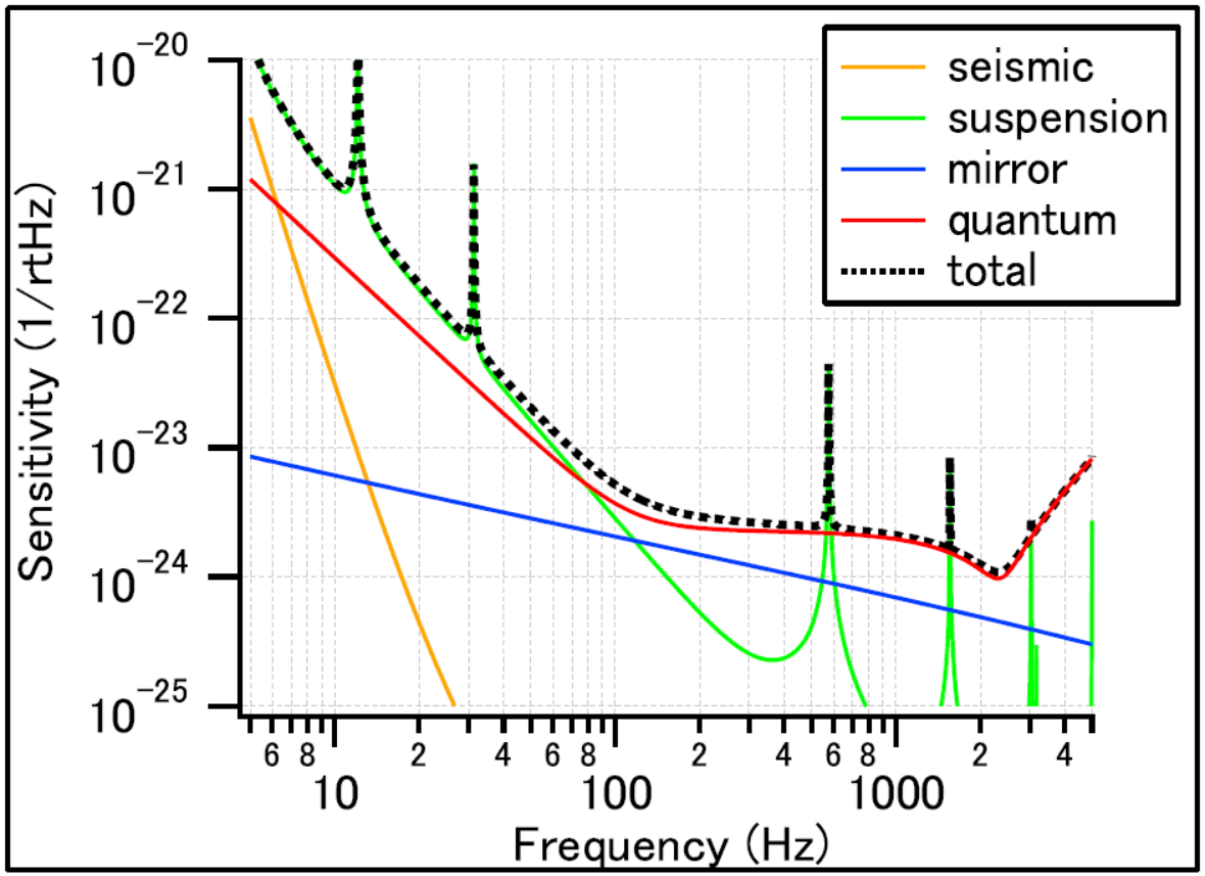
No filter cavity.

- **If we aim at a clear observation of a NS merger, a better sensitivity at 2-4kHz is needed.**
- **OzGrav people say “1e-24 is required.”**

Possible improvement of HF

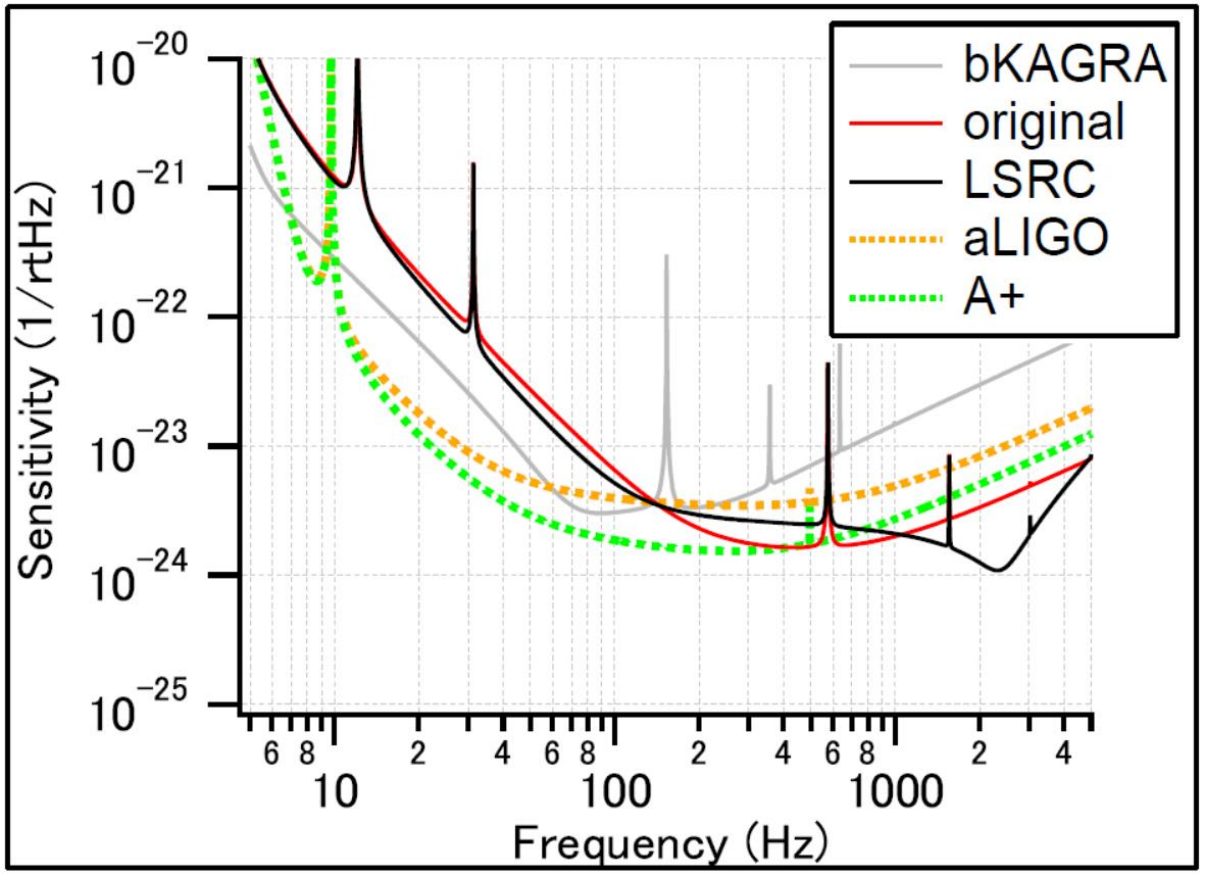


	bKA GRA	HF	HF2
SRM	85%	91%	99.5%
finesse	1550	1550	3100
detune	3.5°	none	none
fiber(l)	35cn	20cm	20cm
fiber(d)	1.6mm	2.5mm	2.5mm
mass	23kg	23kg	23kg
I_{BS}[W]	670	3440	3440 (860)
temperature	22K	21K	22K
SQ	0	6dB	6dB (10dB)

No filter cavity.

- **The requirement is almost satisfied.**
- **Parameters can be relaxed if we could extend the SRC length.**

Possible improvement of HF



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SRM	85%	91%	99.5%
finesse	1550	1550	3100
detune	3.5°	none	none
fiber(l)	35cn	20cm	20cm
fiber(d)	1.6mm	2.5mm	2.5mm
mass	23kg	23kg	23kg
I_{BS}[W]	670	3440	3440 (860)
temperature	22K	21K	22K
SQ	0	6dB	6dB (10dB)

No filter cavity.

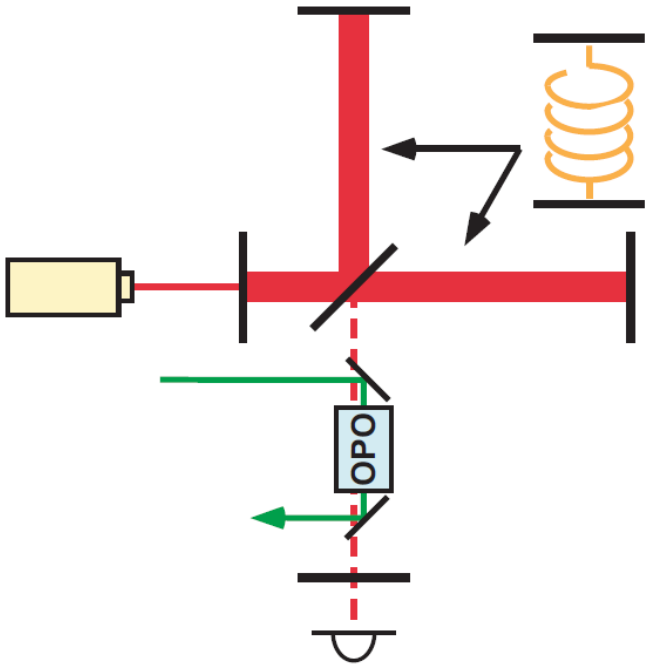
- **Sensitivity can be better than A+ above 1kHz.**
- **Comparable to ET/CE1, close to CE2/NEMO.**
- **Extremely high SRC gain may be challenging.**

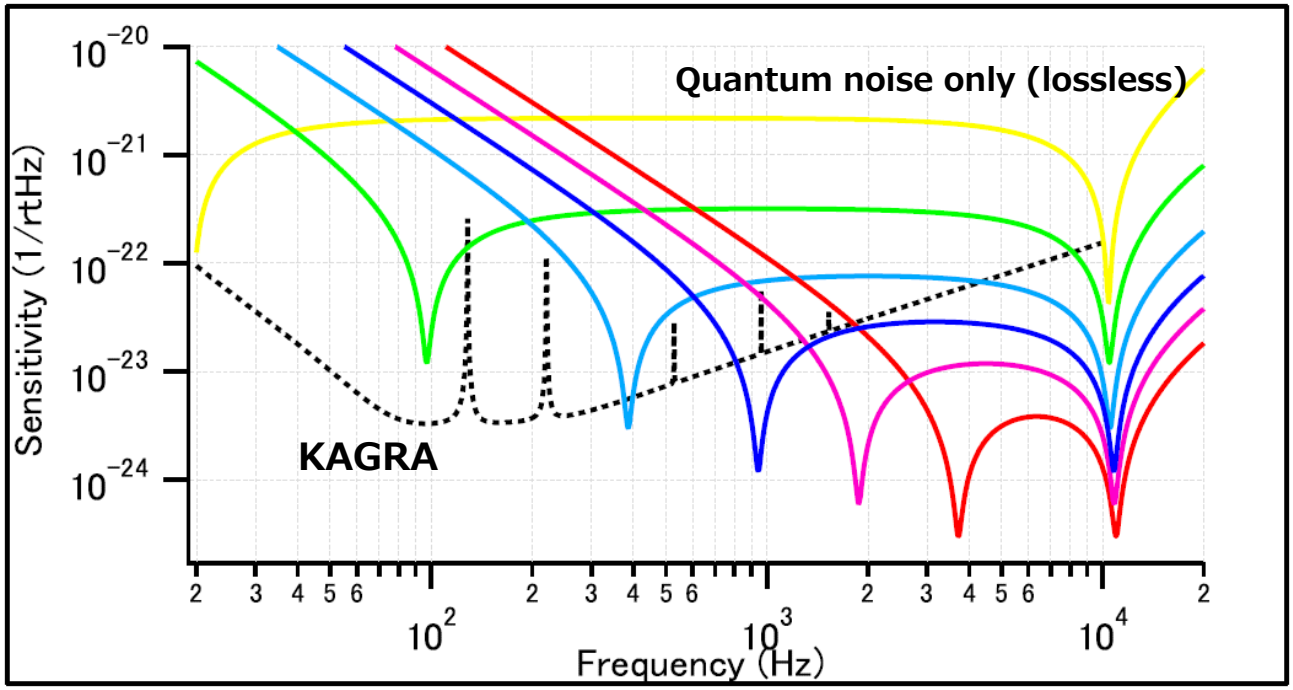
Other advanced techniques

- Parametric amplification
- Quantum expander
- White light cavity
- Sloshing Sagnac

Parametric signal amplification

[Somiya 2014]

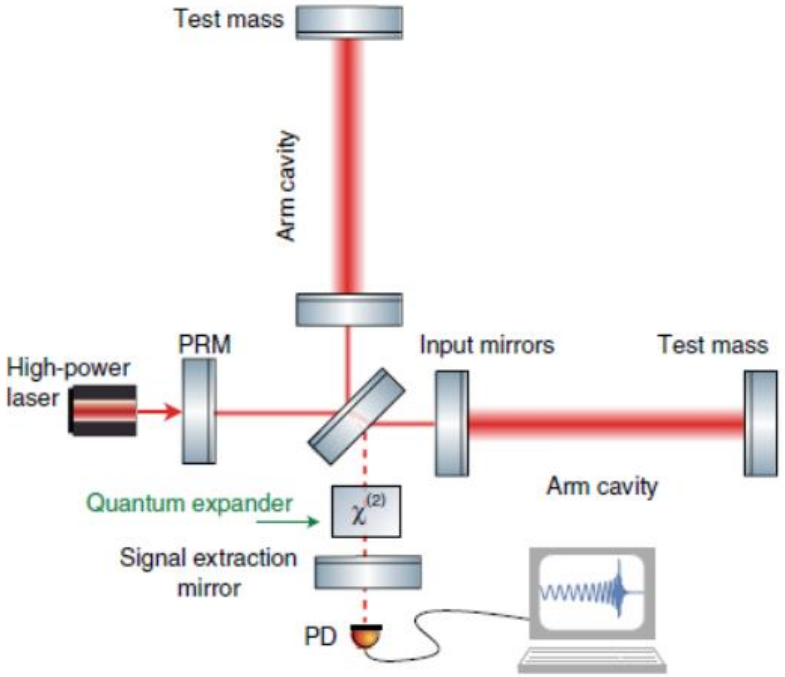


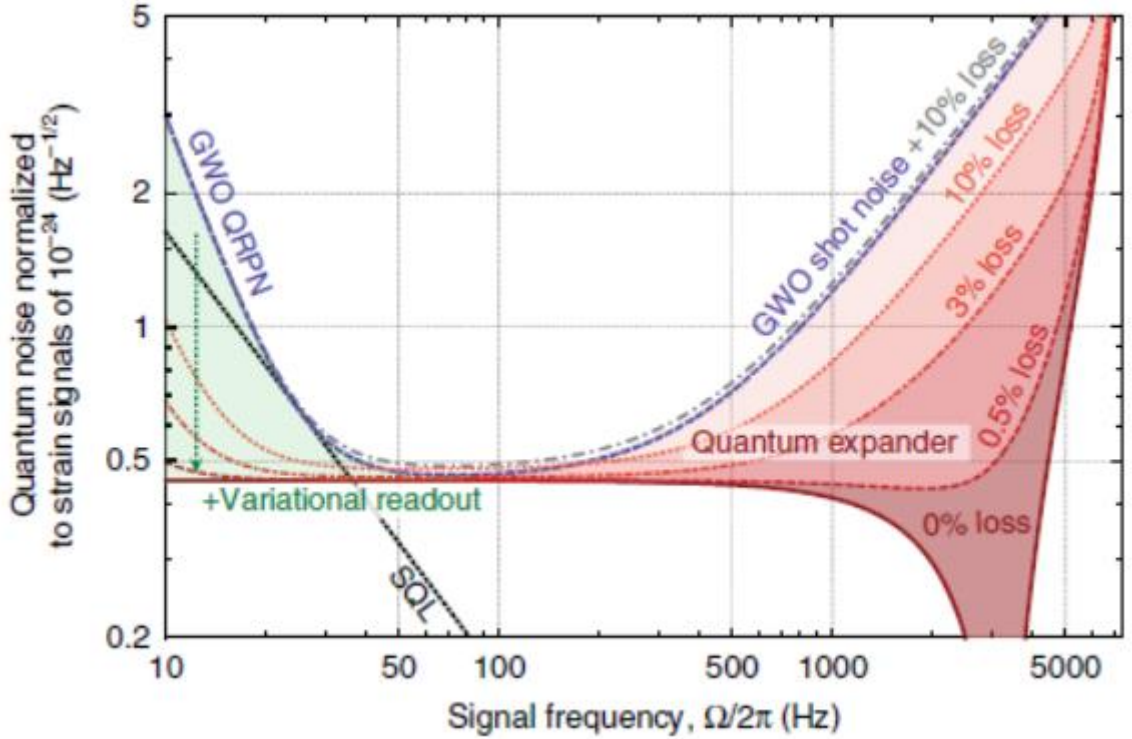


- **Signal is amplified via OPA in a detuned SRC**
- **Optical spring can be as stiff as resonating at a kHz.**

Quantum expander

[Koroboko 2019]

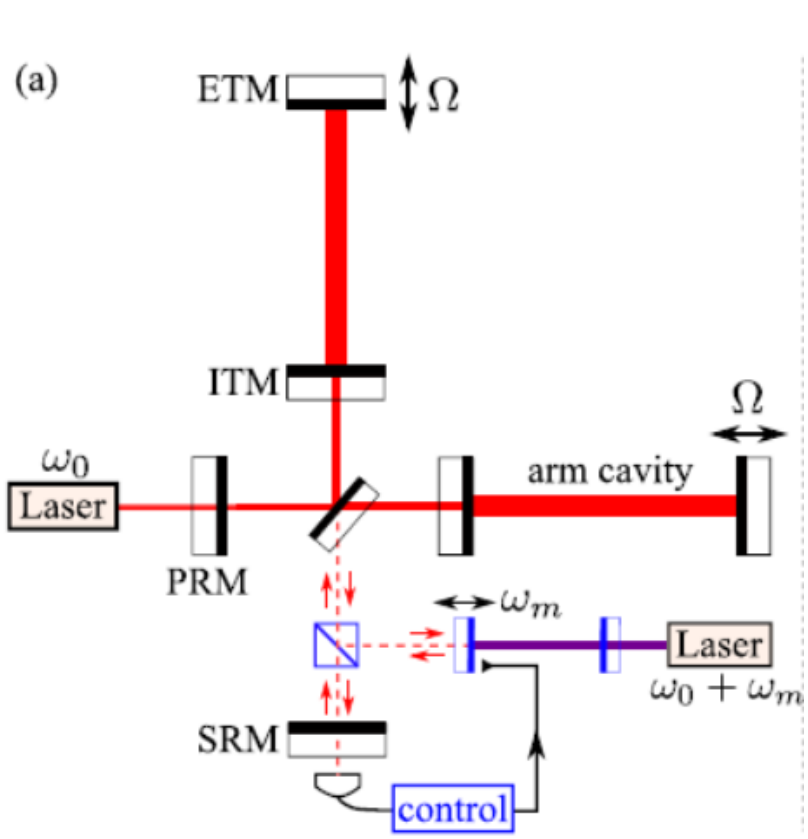


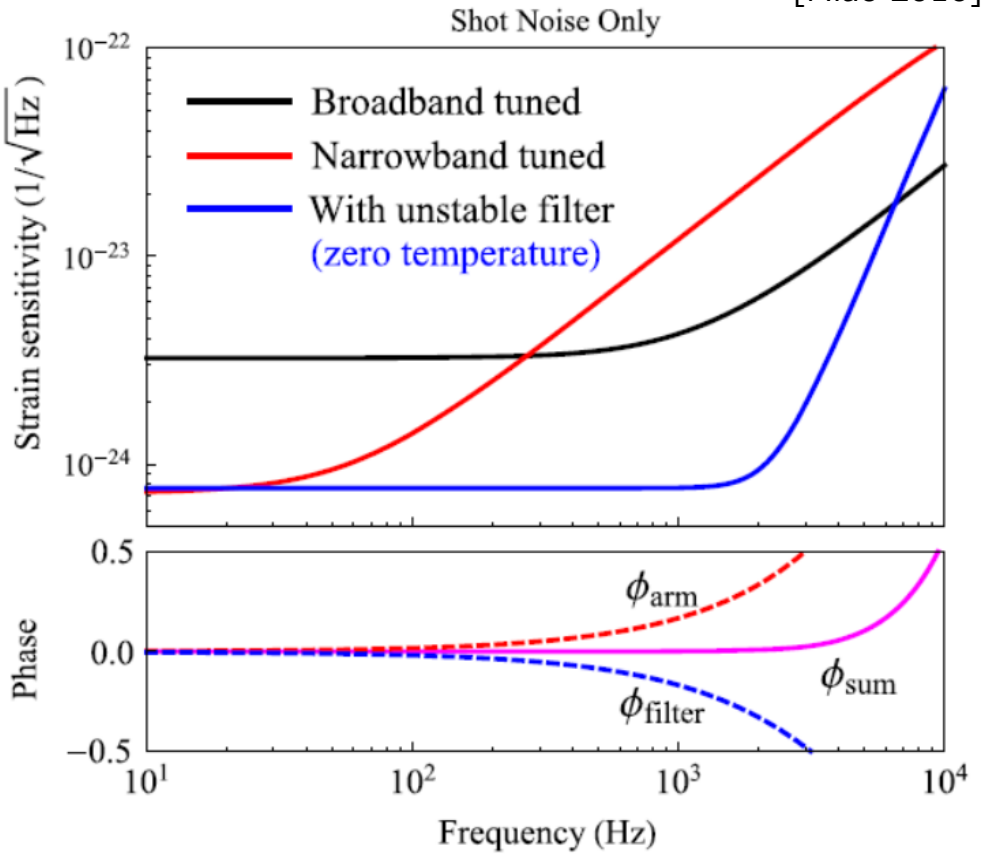


- **Signal is amplified via OPA in a non-detuned RSE.**
- **Long SRC effect improves the sensitivity at a kHz.**

White light cavity

[Miao 2016]

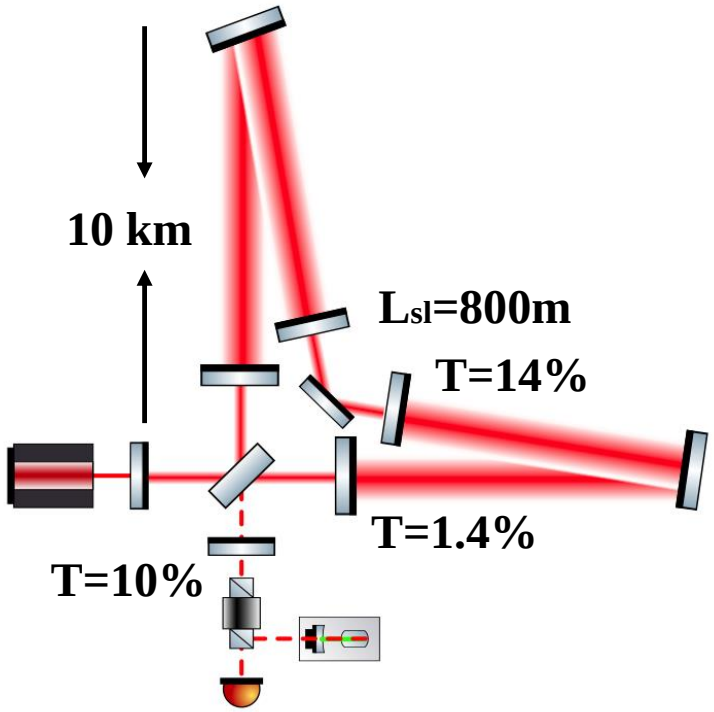


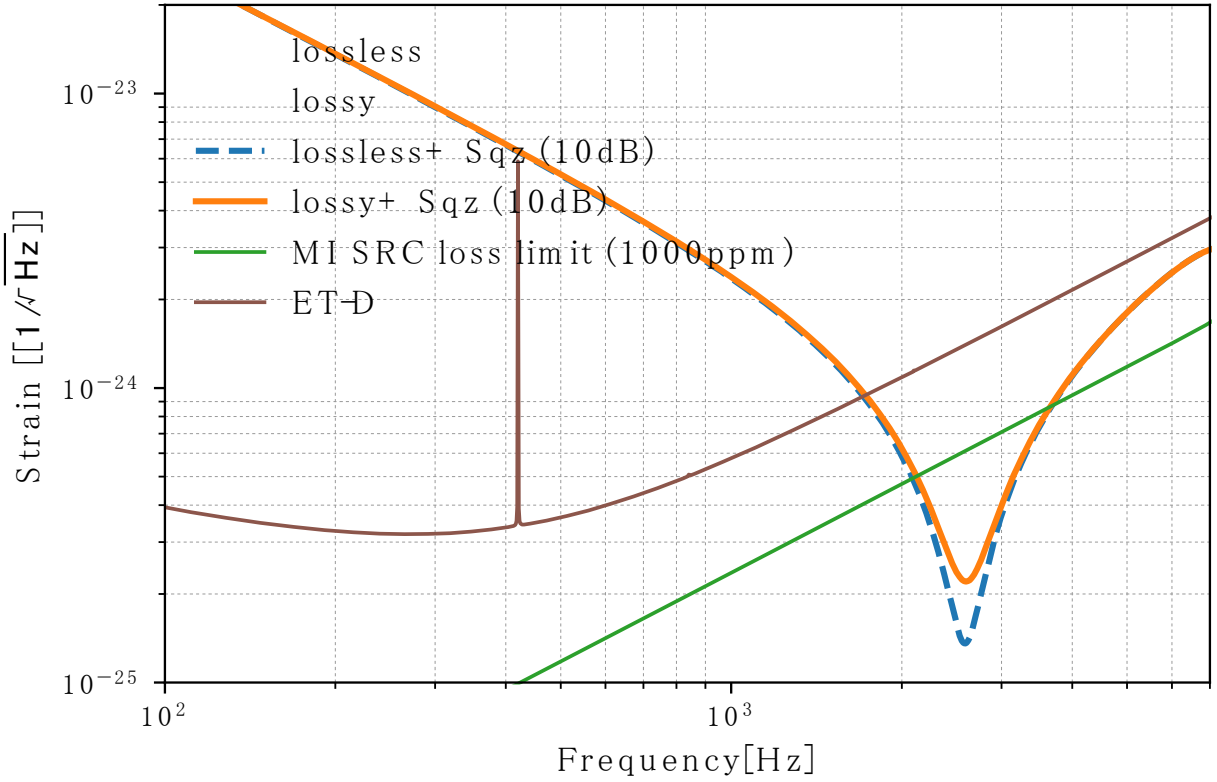


- **An opto-mechanical filter compensates the phase delay of the arm cavity.**
- **Cavity pole is removed and HF sensitivity improves.**

Sloshing Sagnac

[Zhang, GWADW2021]





- **SRC loss that can limit the sensitivity in MI can be removed at a kHz.**
- **Sloshing cavity loss is introduced by can be less if we choose a right parameter set.**

Summary

- KAGRA+(LF) sensitivity can be improved with a softer blade spring and FD squeezing.
- KAGRA+(HF) can also be better with increasing the arm cavity finesse and utilizing LSRC effect.
- We introduced some other advanced techniques for a high-freq GW observation.
- We shall discuss it more in the Future Strategy Working Group (FSWG) open meeting in Nov.