JGW-T2011662

May 12, 2020

Summary of Sensitivity Estimate for O4 in Various Interferometer Configurations

Yuta Michimura Kentaro Somiya Kazuhiro Yamamoto



Where Are We? 10-14

- ~1 Mpc at best
- PRFPMI with 70% SRM tilted, 3-5 W to PRM, ~250 K, DC readout
- O1 excess x400
- Almost shot noise limited at high freq. (klog <u>#13475</u>)

O4 target on Obs. Scenario Paper 25-130 Mpc by ~2021



O3 best and O4 Target

	Mirror temp.	Power at BS	SRM reflectivity	Detuning angle	Homodyne angle	Excess noise
O3 best	~250 K	30-50 W	70% tilted	~90 deg (PRFPMI)	~90 deg (conventional)	O1 x 400
O3 low	22 K	10 W	0 %	90 deg (PRFPMI)	90 deg (conventional)	O1 x 20
O3-15Mpc	22 K	10 W	70 %	90 deg	90 deg	O1 x12
O3 high / O4 low	22 K	33 W	70 %	90 deg (BRSE)	90 deg (conventional)	O1 x 8
O4 80Mpc	22 K	404 W	85 %	90 deg	90 deg	O1 x 2
O4 high	22 K	673 W	85 %	90 deg (BRSE)	90 deg (conventional)	no excess
Design	22 K	673 W	85 %	86.5 deg	135.1 deg	no excess

For details, see <u>JGW-T1809078</u>

Noise Budget (for 0.6 Mpc 20200309)

• Some excess noises at mid freq, shot noise at high freq



Assumptions for Estimation

- IFO configuration: PRFPMI with 0% SRM or DRFPMI with 70% SRM, upto 300 W at BS (no shot noise coupling considered)
- Temperature: 22 K to 300 K (heat extraction capability not considered); see <u>JGW-P2011614</u>
- Frequency and intensity noise: current level or estimated noise using Optickle (see, also, <u>JGW-</u> <u>T1910352</u>)

- Assume ITMs are not replaced (see <u>JGW-</u> <u>G2011541</u>)

 Actuator noise: Not significant for O4 if we do it right, with whitening filters (see <u>JGW-T2011661</u>)

Excess Noise

Excess noise should be reduced by at least ~1/20



Various Thermal Noise

• 120 K thermal is comparable to x8 O1



Various Quantum Noise (DR)

• At least 30 W at BS is necessary if DR



Various Quantum Noise (PR)

• DR necessary if excess noise is more than x8 O1



Laser Noises (Frequency + Intensity)

• Hard to predict; see "Details" attached for details



Inspiral Range vs Power (x0 O1)

• Power change not so significant with other noises



Inspiral Range vs Power (x8 O1)

• Power change not so significant with other noises



O4 "Minimum" Example

• x8 O1, 100 K, 50 W at BS, DR, 1/3 laser noise



O4 "Low Frequency" Example

• x1 O1, 22 K, 30 W at BS, PR, same laser noise



O4 "High Frequency" Example

• x12 O1, 100 K, 300 W at BS, DR, 1/10 laser noise





Conclusions So Far

- Should be below ~100 K (achieving O4 target above 120 K) is not possible)
- Low-mid frequency noise should be reduced at least by a factor of ~ 20 (more at low frequencies)
- DR necessary if excess noise is more than x8 O1
- Higher power is better, but not so important especially when other noises are high (~30 W at BS could be enough)
- Laser noise should be reduced (by subtraction, better alignment, further stabilization etc.)
- As we have been keep saying, investigations on current noises and noise coupling mechanisms are very important (low frequency noise; laser intensity and frequency noise) for estimating the sensitivity in O4

Details

Various Thermal Noise

• All temperatures



Various Quantum Noise (DR)

• All powers



Various Quantum Noise (PR)

• All powers



How to Realize 100 K ?

• Possible cooling process?

- First cool the test mass with four cryocooler

- When reached below ~100 K, turn off two cryocoolers for cryopayload (shields have to be kept cooled); as we have done in July 2019, we can keep the temperature at ~100 K (klog <u>#10033</u>)

- Turn on two cryocoolers occasionally to keep the temperature ~100 K

• Maximum input power?

- Thermal lensing: At 100 K, thermal lensing is smaller by 1/100~1/300 than 300 K, but larger by 4 orders of magnitude than 20 K. Thermal lensing would be OK below ~130 K (See <u>JPCS 32, 062 (2006)</u>).

- Cooling power (with 4 cryocoolers): 67 K can be achievable with 0.8 W heat load to the test mass, with current thermal resistance of 70 K/W (according to <u>JGW-G1910569</u>). <300 W at BS would be OK.

- Cooling power (with 2 cryocoolers): According to the cooling curve from bKAGRA Phase 1 (7 K/day at around 100 K), 0.2 W heat load makes the mirror temperature at steady state (around 100 K, thermal conductivity of sapphire fibers are low). Absorption from light will be ~0.001*P_{BS} where P_{BS} is the power at BS. Therefore, P_{BS}=200 W is good to keep ~100 K.

Frosting of the Test Mass

 Finesse drop observed when one of the test mass temperature is below ~30 K

klog <u>#10033</u>



date in IST

Laser Intensity Noise Coupling

Measured to be larger than Optickle model



Laser Intensity Noise

• RIN of 3e-8 /rtHz achieved. 1e-8 /rtHz possible in O4?



Laser Frequency Noise Coupling

Measured to be larger than various models



Laser Frequency Noise

Close to CARM shot noise limit from Optickle



Laser Noise Projections

Close to CARM shot noise limit from Optickle



Guessing Laser Noise in O4

- Pessimistic case: same as current level
- Optimistic case: RIN of 1e-8 /rtHz x Optickle coupling and CARM shot noise limited x measured coupling

