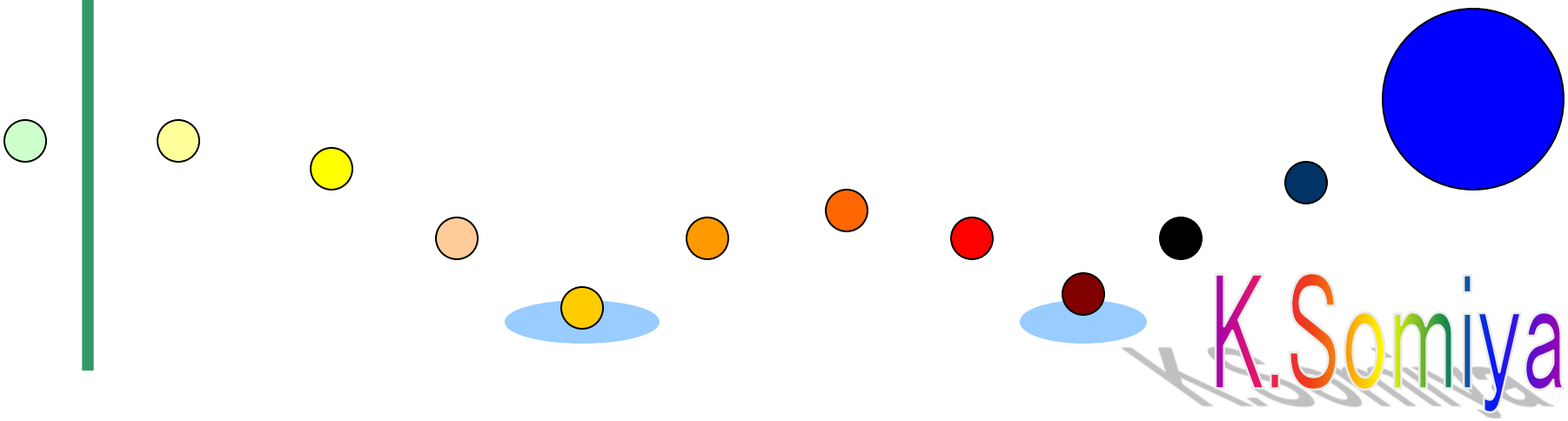
OMC for KAGRA

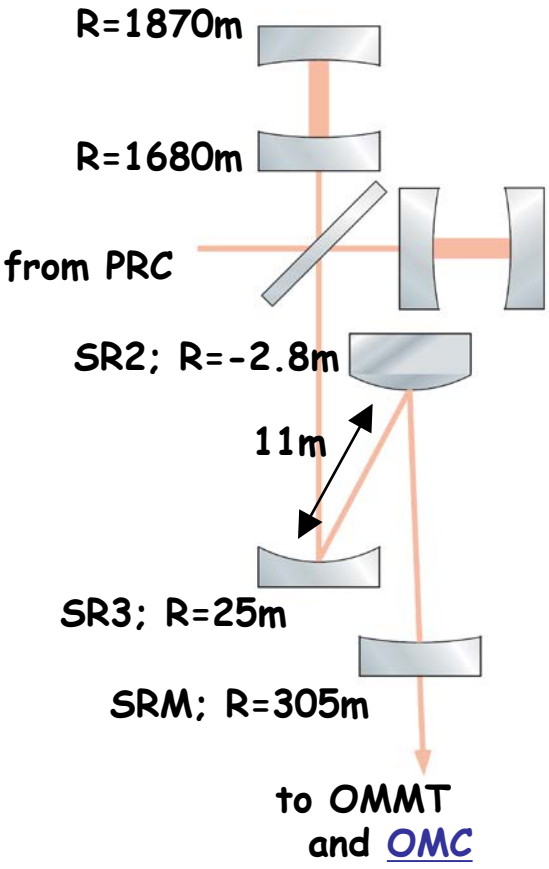
Feb. 2013

KAGRA f2f meeting

Kentaro Somiya

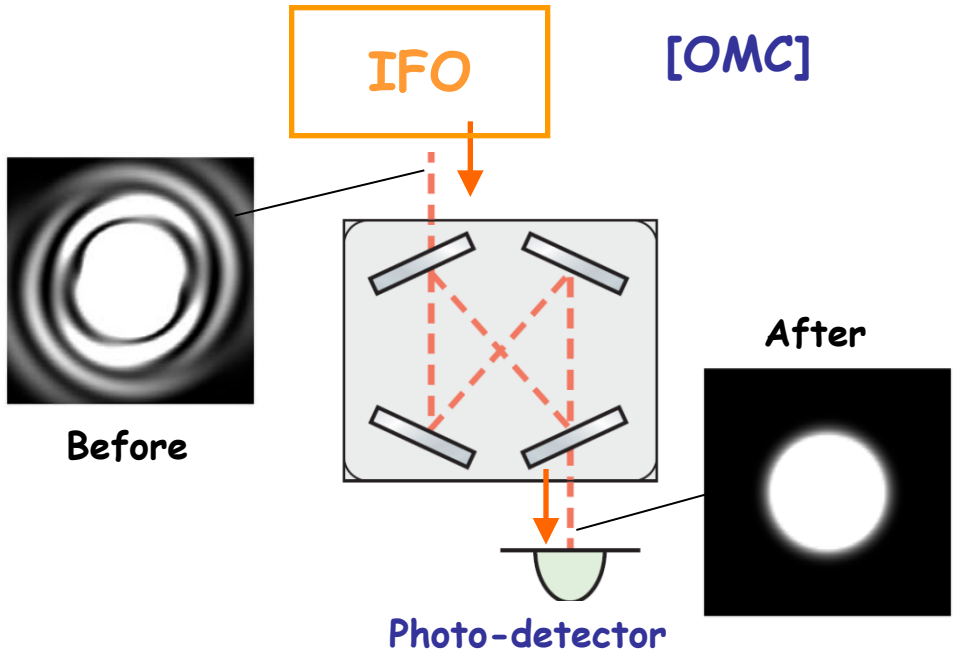


Output mode-cleaner



[KAGRA output optics]

(wSRM=4.0mm, wSR2=4.0mcm,
wSR3=36mm, wITM=35mm, ηSRC=20deg)

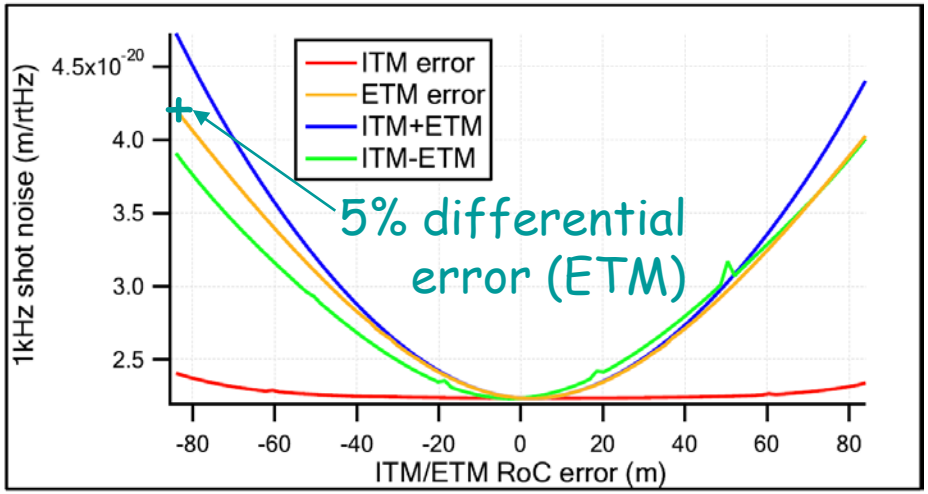


OMC's role

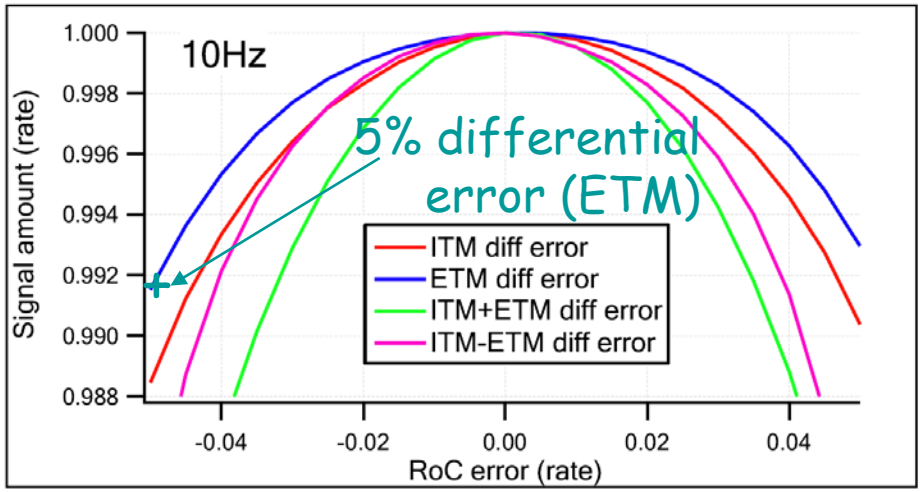
(i) Removal of junk light

(ii) Removal of 16.875MHz SB

TM curvature error



Shot noise increase for junk light



Signal reduction for mode-mismatch

Shot noise increases for...

(i) SRC mode-mismatch (common)

- fixable by SR2-SR3 telescope (1% error -> 13cm adjustment)

(ii) Junk light increase

- partially removable by OMC

(iii) Signal decrease (differential)

- unfixable, but small

With 1% error

* 1% diff error on ETM
* TM loss: 41ppm/49ppm
* Finesse difference 0.5%

RF						DC					
TEM00	TEM20	TEM02	TEM40	TEM04	TEM22	TEM00	TEM20	TEM02	TEM40	TEM04	TEM22
85mW	0.1mW	0.1mW	4uW	4uW	3uW	1.0mW	8.9mW	8.9mW	30uW	30uW	20uW

Requirement to OMC

(i) Signal reduction for optical loss < ~2% <- 2% degrade
-> finesse < 1000 (30ppm/mirror)

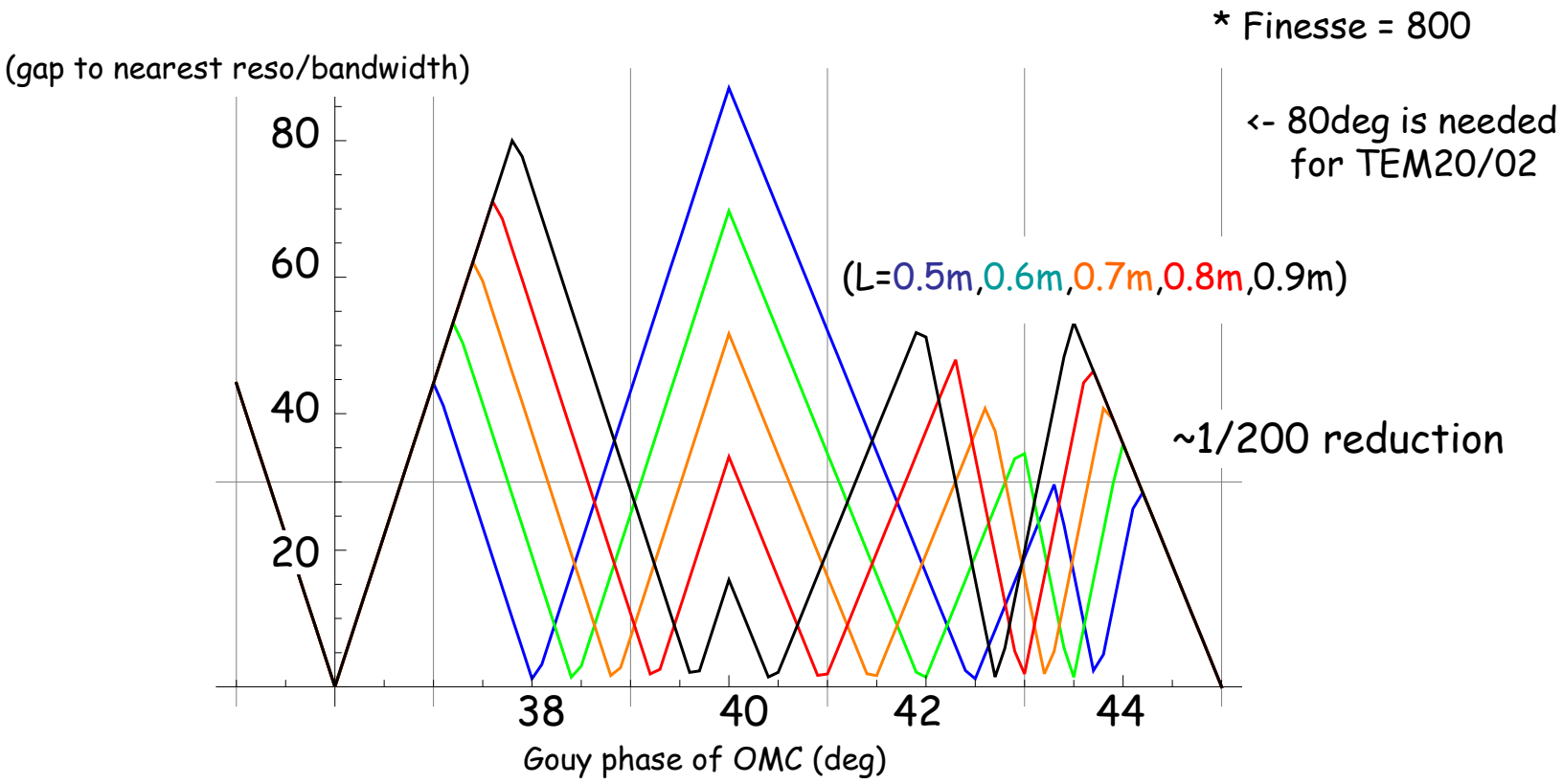
(ii) RF SB should be less than 10uW (x1/8500) <- 2% degrade
-> Lomc > 90cm

(iii) TEM20/02 should be less than 2.5uW (x1/3600) <- 0.5% degrade
-> Gouy phase = 7~83 deg (finesse=800)

(iv) Other HOM should be less than 0.5uW (x1/200~) <- 0.5% degrade
-> Less solution with longer OMC; astigmatism issue

* The requirement depends on the loss imbalance

Gouy phase selection



Considering up to the 8th order, 19, 38, 80, 99 degs are candidates

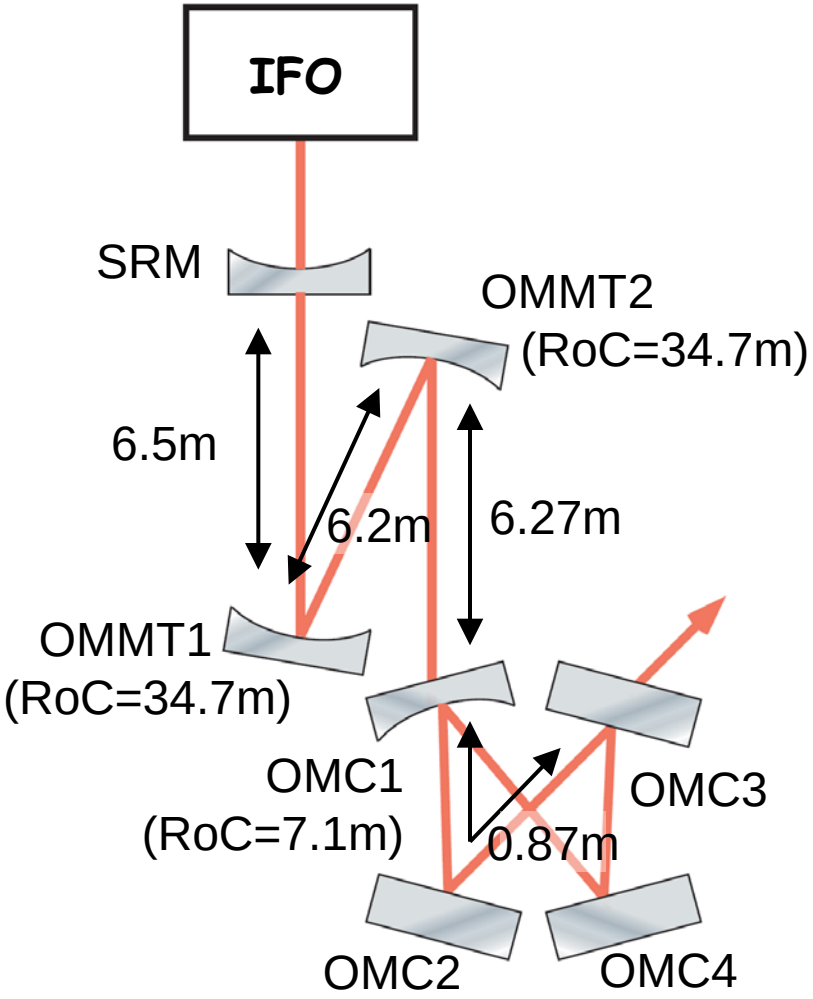
-> 19 and 38 are good with the 2nd order modes

-> OMMT length will be 10m+ for 19 deg

-> L=87cm is the best, 2nd HOM of RFSB taken into account

* Astigmatism makes Gouy phase shifted by 0.5~1 def btw V/H

OMC design



before OMC

RF	DC					
total	TEM00	TEM20	TEM02	TEM40	TEM04	TEM22
85mW	1.0mW	8.9mW	8.9mW	30uW	30uW	20uW

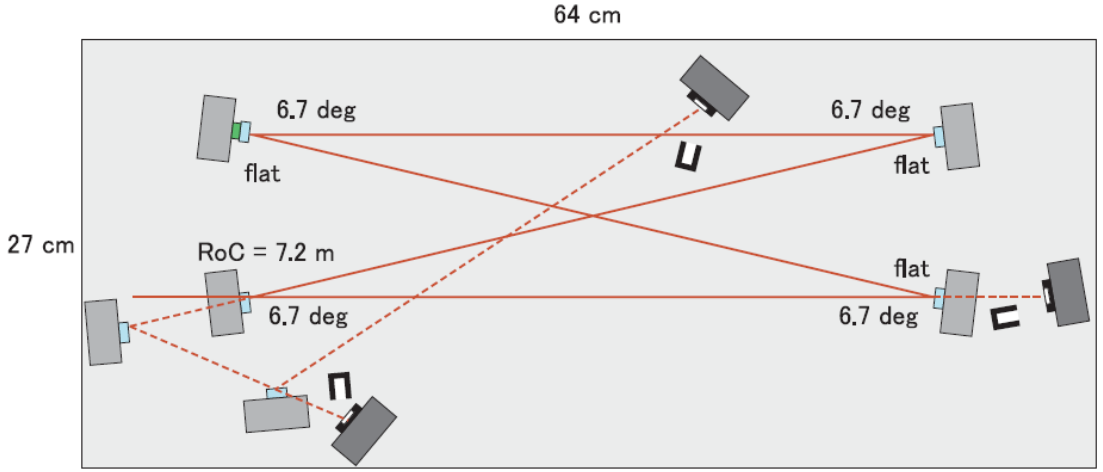
after OMC

RF	DC					
total	TEM00	TEM20	TEM02	TEM40	TEM04	TEM22
4uW	980uW	0.1uW	0.1uW	0.1nW	0.2nW	0.1nW

Reflectivity of OMC1/3 is 99.6%

Preliminary design

item	value
SRM-OMMT1 length	6.5 m
OMMT1-OMMT2 length	6.2 m
OMMT2-OMC1 length	6.266 m
OMC roundtrip length	1.74 m
OMMT1 RoC	34.7 m
OMMT2 RoC	34.7 m
OMMT1 incident angle	1.9 deg
OMMT2 incident angle	1.9 deg
OMC mirrors incident angle	6.7 deg
OMC1 RoC	7.2 m
OMC2-4 RoC	flat
beam radius on OMMT1	4.1 mm
beam radius on OMMT2	4.3 mm
beam radius on OMC1	0.95 mm
power reflectivity of OMC1	99.6 %
power reflectivity of OMC3	99.6 %
OMC suspension	Type-C
OMC material	Alminum



- The 1st mirror is curved
- Same incident angle for every mirror
- Breadboard is quite large

OMC section in MIF document

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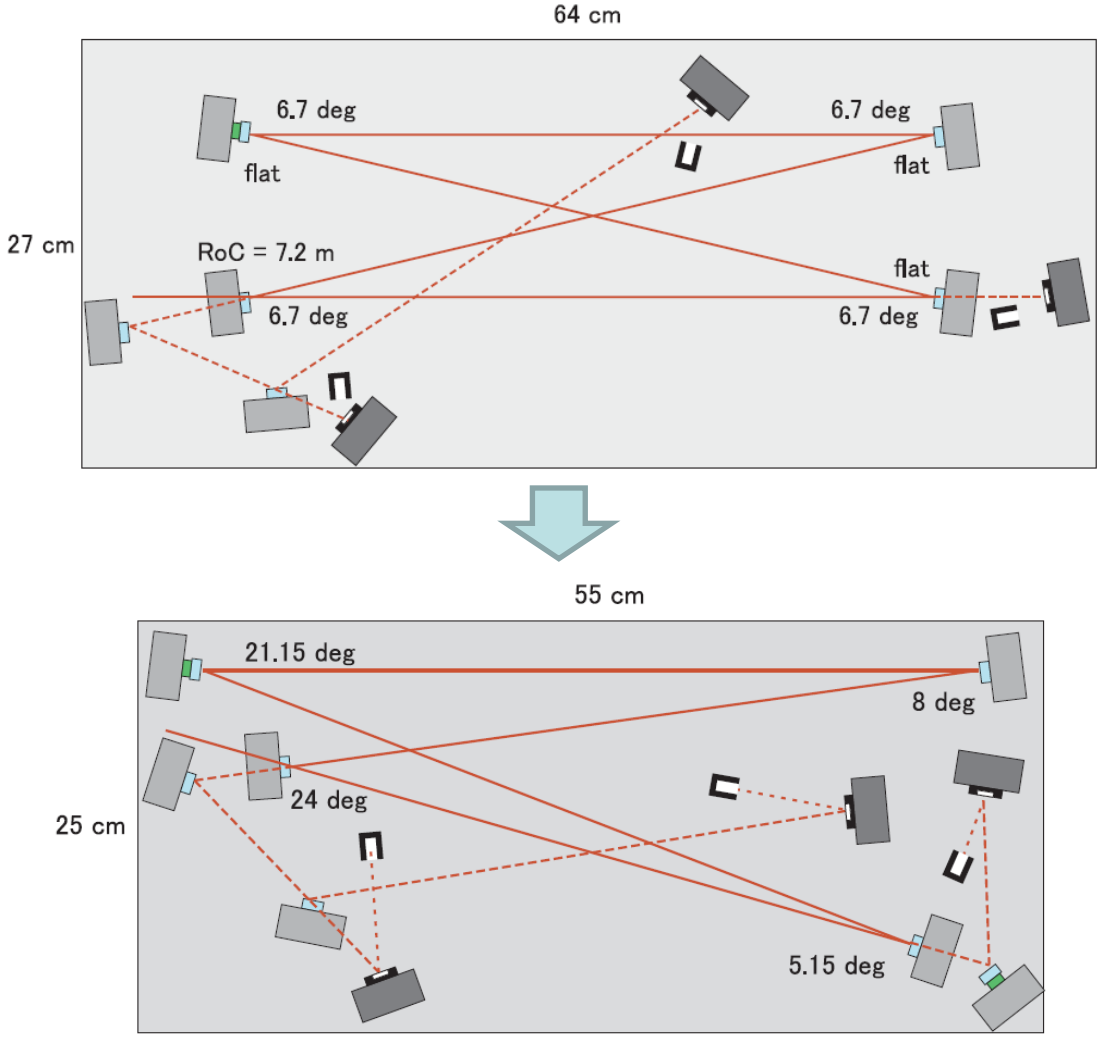
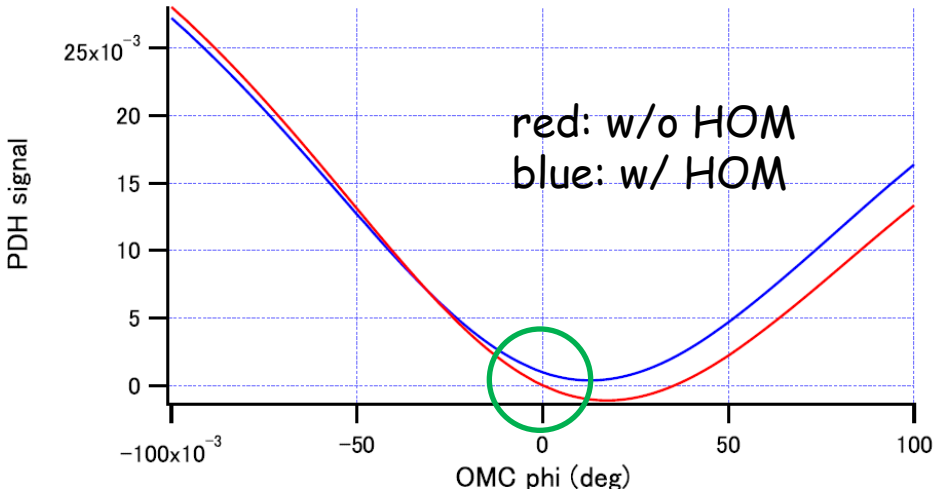
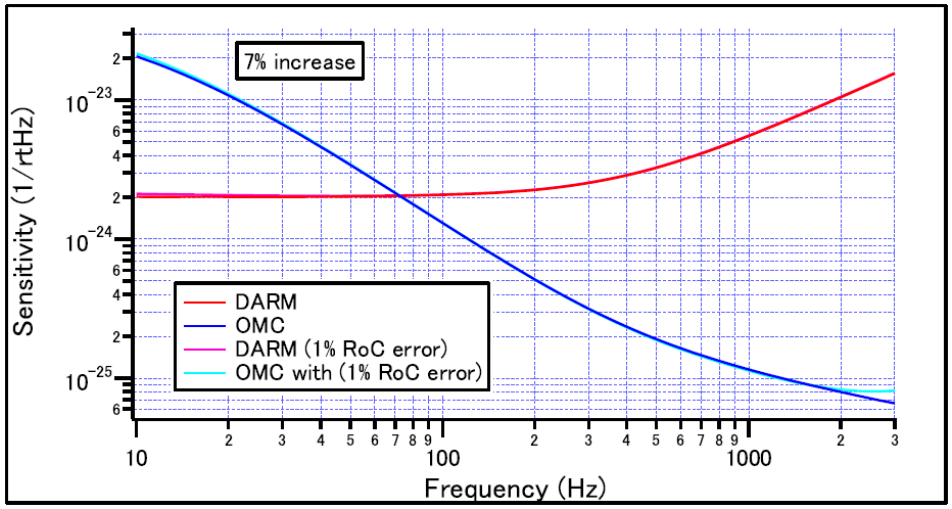
OMC section in MIF document



- Small angle of the curved 2nd mirror
- Compact design

OMC shot noise on DARM





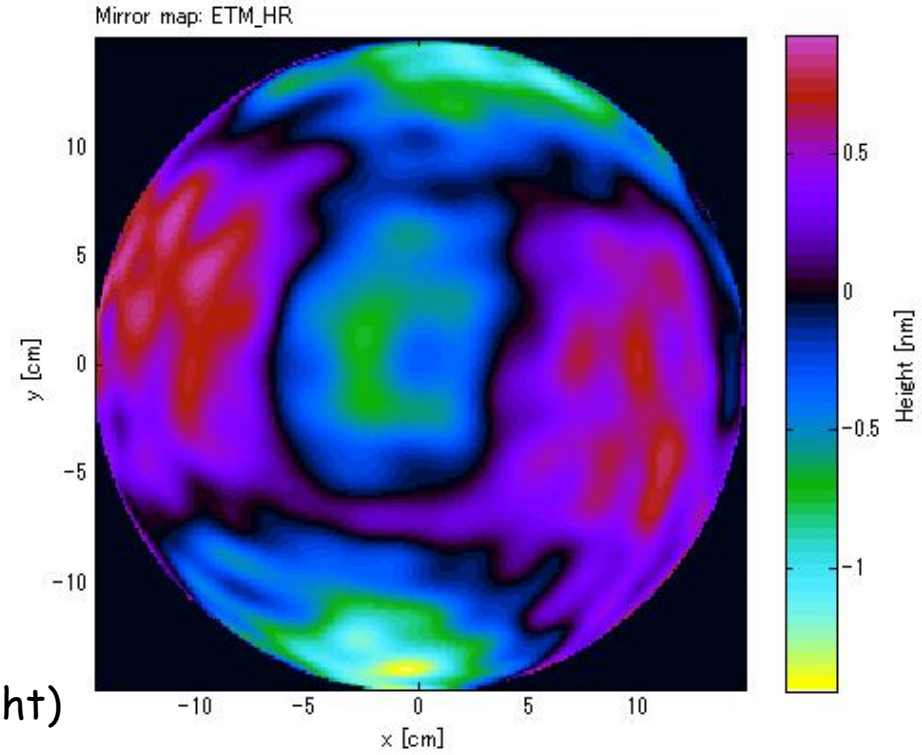
- FINESSE simulation with and without the higher order modes
- OMC length signal is obtained by PDH (DC + detuned SB)
- With 1% error of TM RoC, the OMC shot noise increases by 7%
- To be cross-checked with the Optickle result for no-HOM case

More realistic simulation necessary

Parameters	Requirement	Loss
Radius of curvature	1.9km (±0.5%)	N/A
Roughness (λ < 1mm)	rms = 0.16nm	5ppm
Figure (λ > 1mm)	rms < 0.5nm @ d < 140mm rms < 2nm @ d > 140mm	30ppm
Defects	2e4 [μm2] @ d < 100mm 3e5 [μm2] @ d > 100mm	1ppm
Point scattering	-	9ppm
Absorption (coating)	-	1ppm

KAGRA mirror requirement (Left)

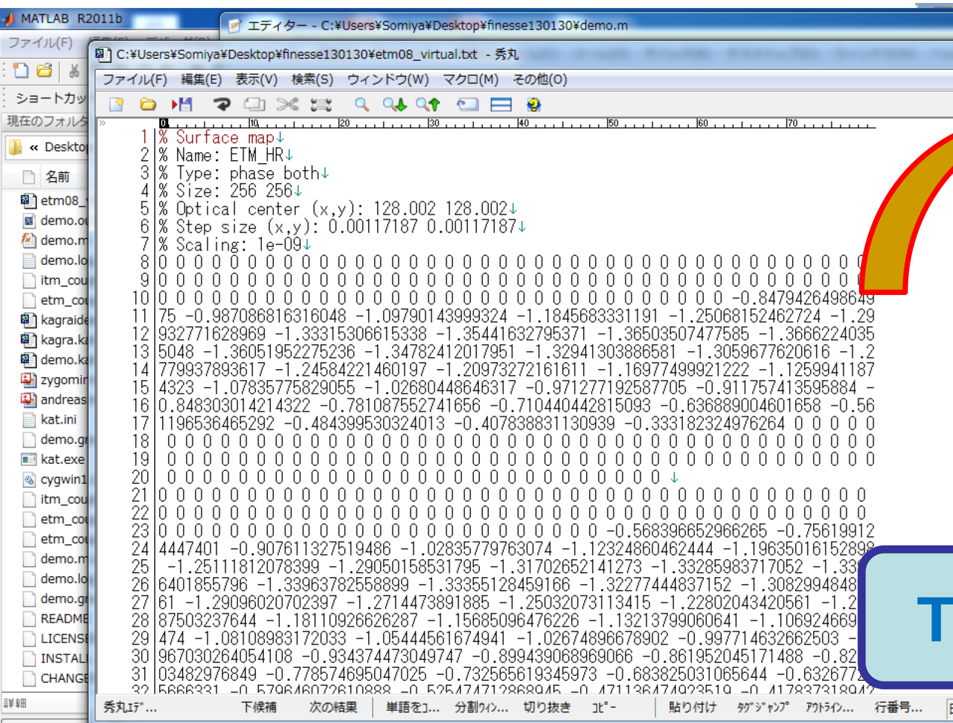
Fake mirror map provided by Andreas (Right)



- FINESSE can calculate the sensitivity with an actual mirror map (expansion up to the ~10th mode is necessary)

- The surface accuracy of the fake map above is similar to the KAGRA mirror to be delivered (~0.5nm)

More realistic simulation necessary



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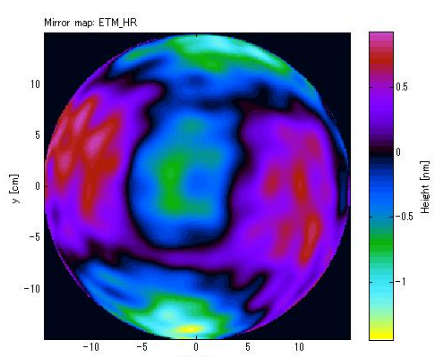
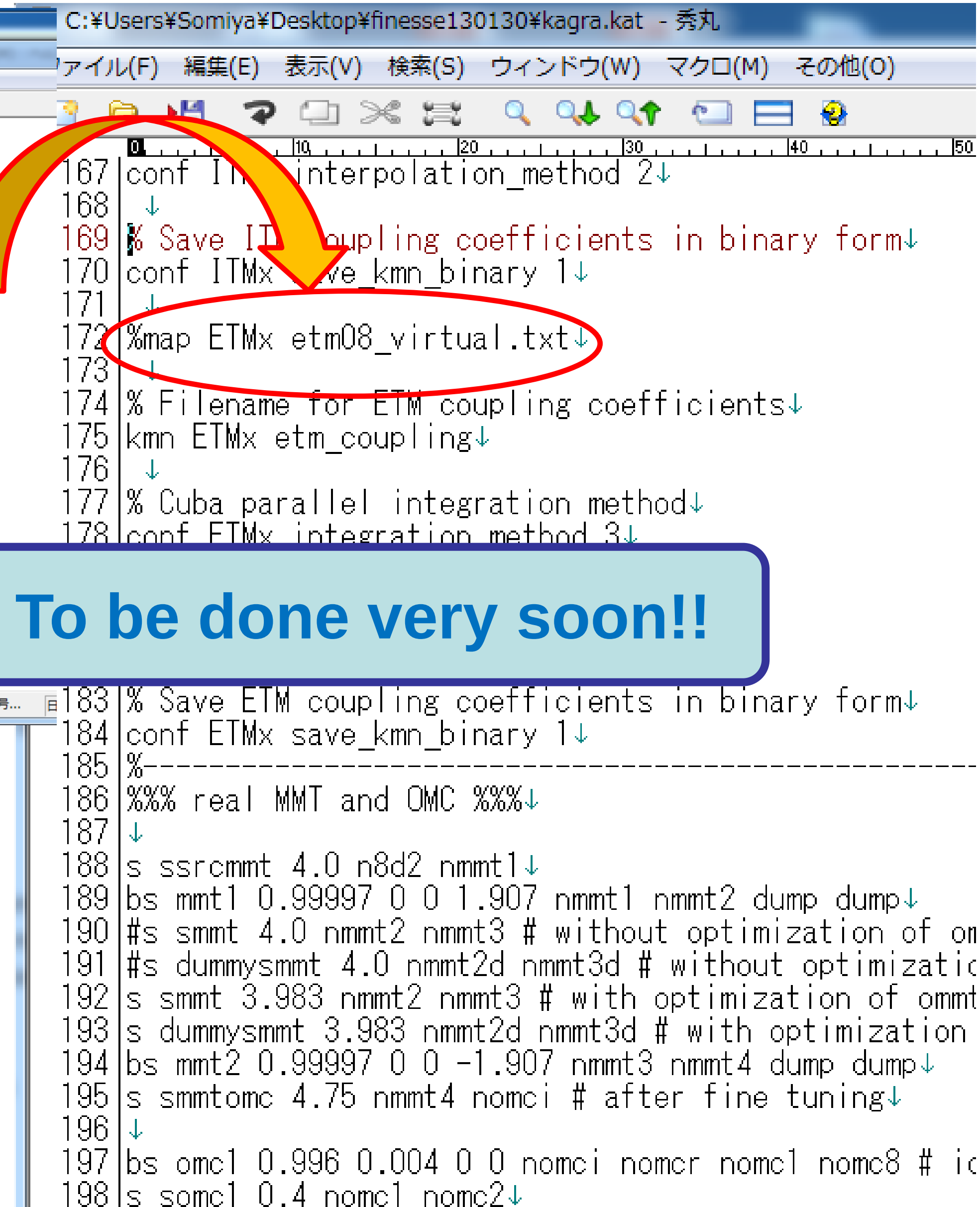
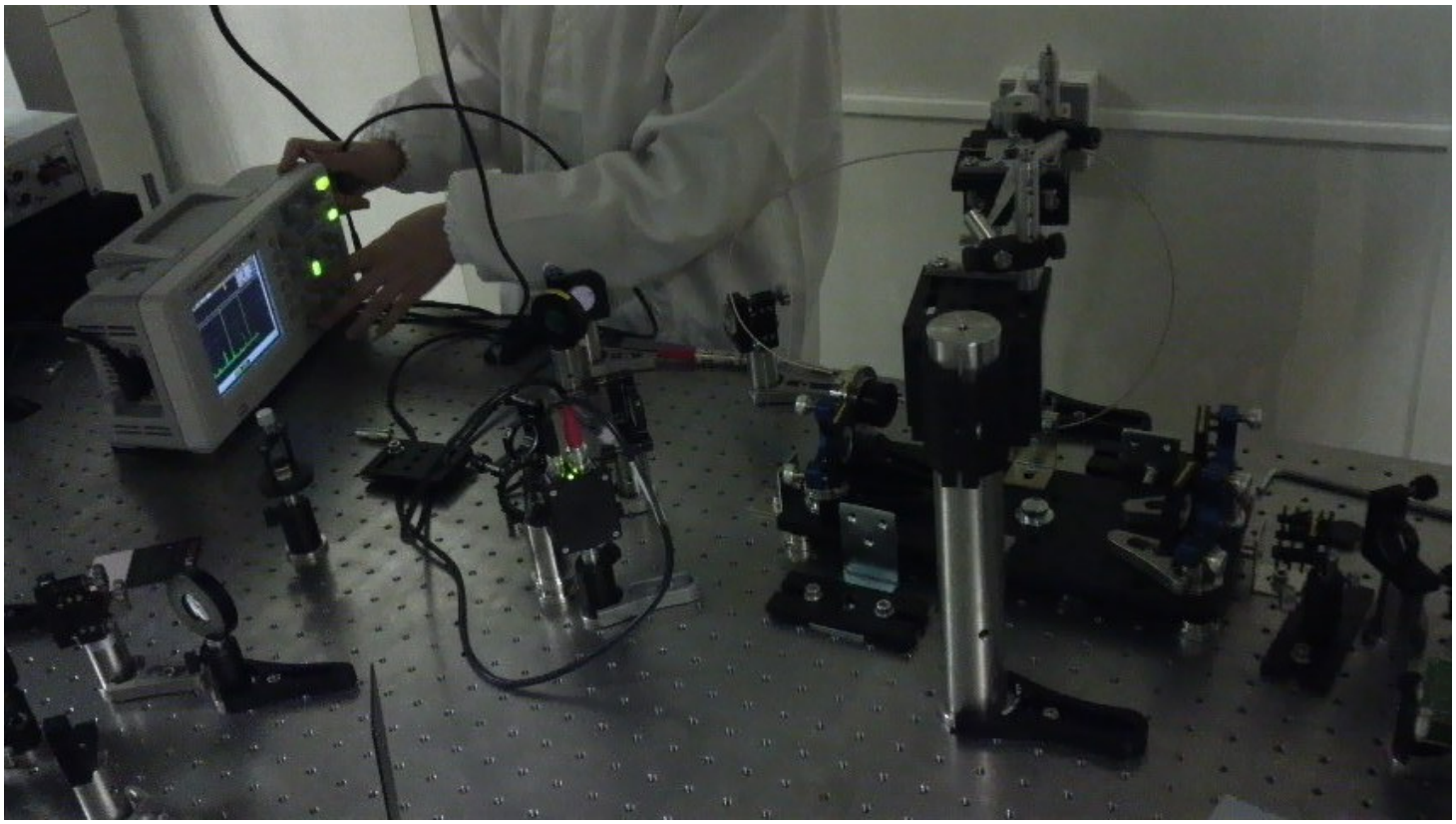




To be done very soon!!

Prototype experiment



- on-board 4-mirror cavity suspended on a blade spring
- length-sensing signal has been obtained (not locked yet)
- alignment-sensing scheme will be developed next year
- to be locked with a Michelson ifo using a dither DDM

To-do list

- Recalculation with a new design
- Loop-noise calculation (FINESSE/Optickle)
- Alignment control scheme development
- Simulation with a fake mirror map
- DDM length locking and ASC
- Procurement of the real OMC (~2015)

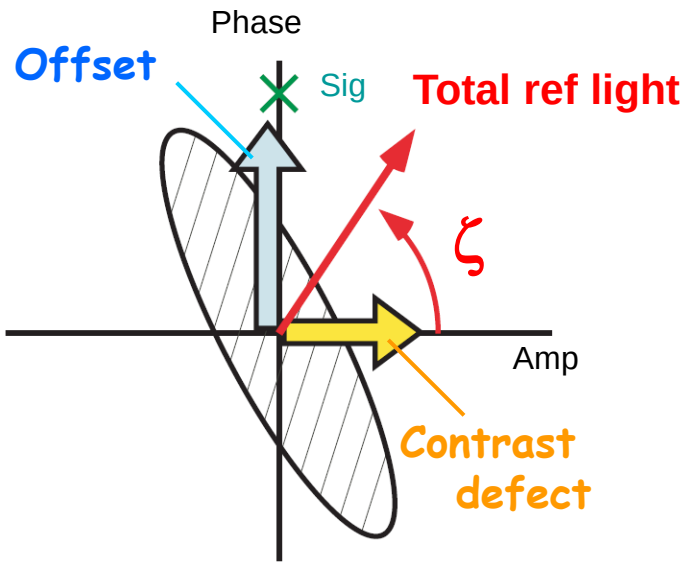
Supplementary slides

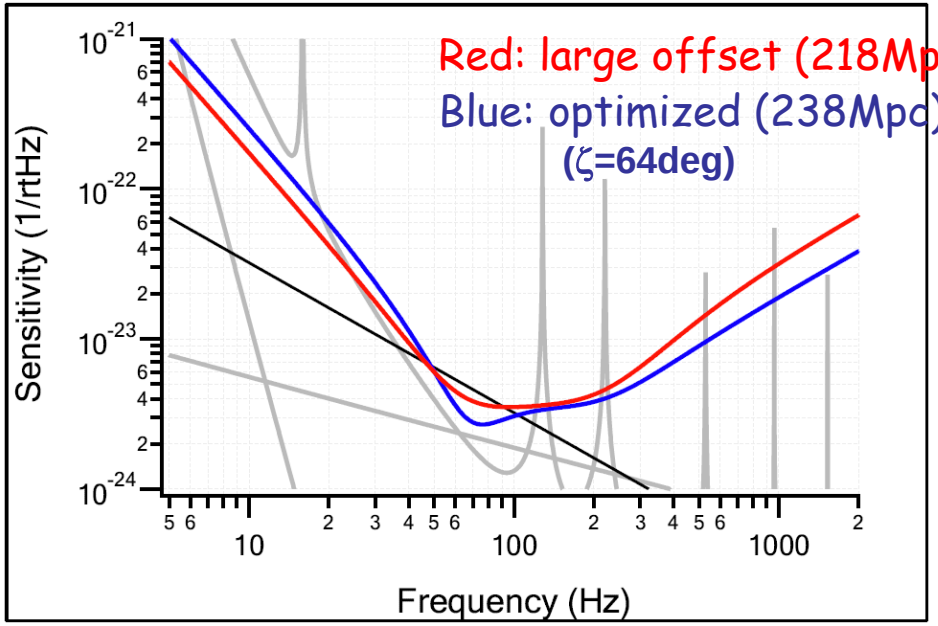
Confirmation of the accuracy

highest mode	TEM00
1	0.0001954
3	0.0016304
5	0.0042656
7	0.0056478
9	0.0058341
11	0.0058838
13	0.0058732
15	0.0058757
17	0.0058744
19	0.0058739

We should better calculate up to at least the 7^{th} mode.
It was 5 for the calculations shown in the slides, though.

Optimization of the readout phase





KAGRA sensitivity

Contrast defect comes from the loss difference of the arm cavities.

Merit of optimization: Inspiral range increases by 10%

Risk of optimization: Ref light gets weak if the loss imbalance is small

~ harder requirement on OMC

With 2% error

* 2% diff error on ETM
* TM loss: 41ppm/49ppm
* Finesse difference 0.5%

RF						DC					
TEM00	TEM20	TEM02	TEM40	TEM04	TEM22	TEM00	TEM20	TEM02	TEM40	TEM04	TEM22
85mW	0.1mW	0.1mW	4uW	4uW	3uW	1.3mW	42mW	42mW	43uW	43uW	28uW

Requirement to OMC

4 times bigger
2nd HOM

(i) Signal reduction for optical loss < ~2% <- 2% degrade
-> finesse < 1000 (30ppm/mirror)

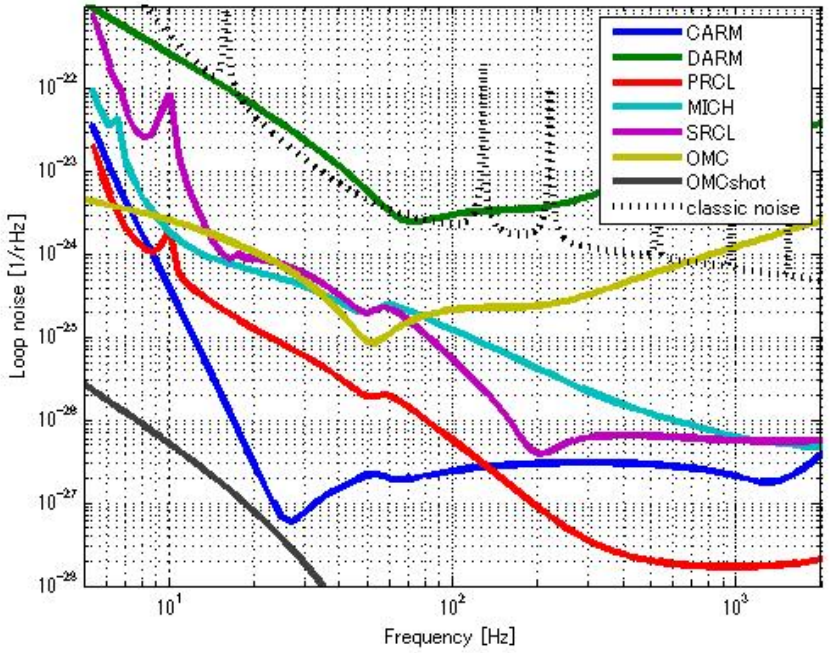
(ii) RF SB should be less than 13uW (x1/6500) <- 2% degrade
-> Lomc > 80cm

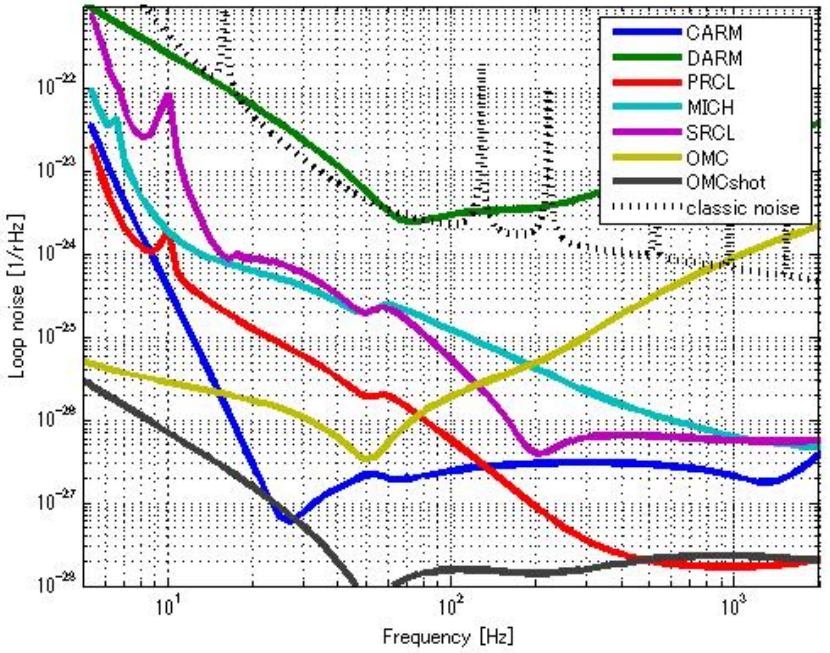
(iii) TEM20/02 should be less than 3.3uW (x1/13000) <- 0.5% degrade
-> Gouy phase = 11~79 deg (finesse=800)

(iv) Other HOM should be less than 0.6uW (x1/200~) <- 0.5% degrade
-> Less solution with longer OMC; astigmatism issue

* The requirement depends on the loss imbalance

OMC shot noise (Optickle)





- PDH signal at the OMC reflection port
- 1e-14m/rtHz displacement noise assumed
- Left: OMC UGF=20Hz, Right: OMC UGF=200Hz