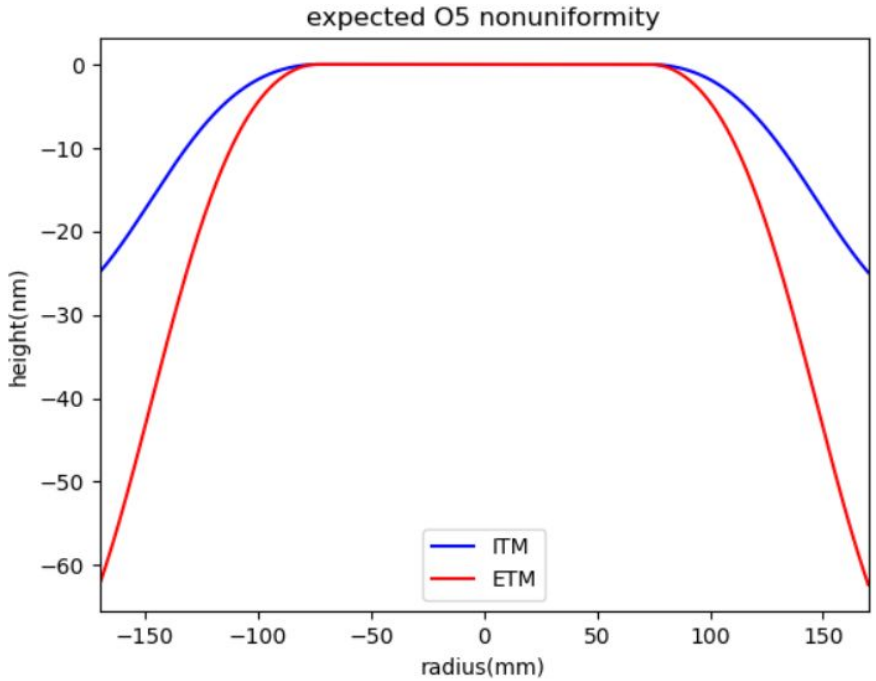
Nonspherical polishing profile design recommendation

Background

- Higher order mode is close to co-resonating with 00 mode at cold state and low arm power with current predictions of LIGO O5 coating. We would still like to eliminate this modal degeneracy
- The ITM and ETM absorption imbalance will significantly change compare to the case of O5
- We design a polish on top of the coating that appropriately move the location of higher order modes away from the 00 mode

Predicted O5 Coating Nonuniformity (Cross Section)



The predicted geometry is approximated from a plume guess based on a O4 ETM, multiplied by a scaling factor of 0.6 for O5 ITM, and 1.5 for O5 ETM

Analysis

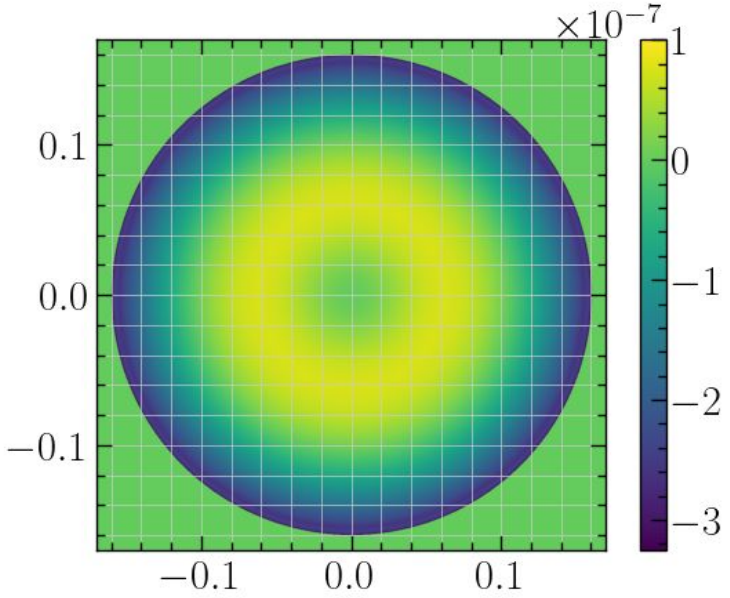
- We study the performance of each ETM surface geometry by looking at the power recycling gain, arm gain, observed squeezing with 9 dB of injected squeezing, and power recycling gain at the 9MHz and 45MHz sidebands across different ITM & ETM absorptivities at 750kW of arm power
- We applied optimal thermal actuations of our current TCS system, which for our predicted O5 coating with spherical polish involves a Co2 laser power of 17.30 W, and ring heater power of 20.47W for the ITM, and 19.38W for the ETM at 1W of absorption

Analysis

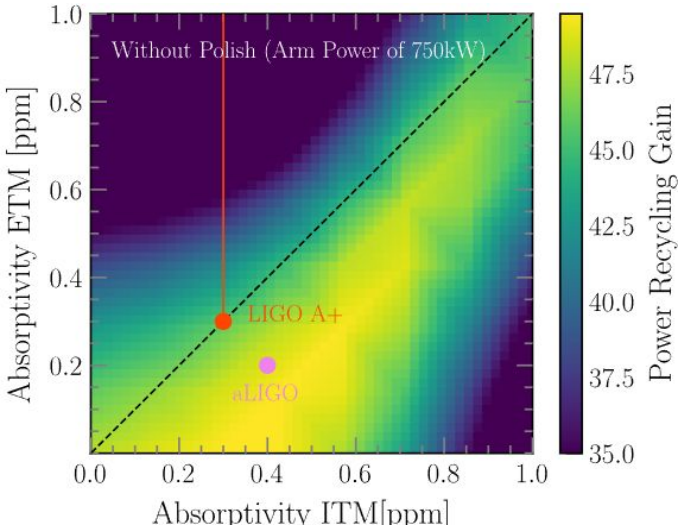
- TCS Power modeled for 0.3ppm on both mirror and 750kW of arm power

Compensation Device	Power (W)
ITM Ring Heater	3.55
ETM Ring Heater	4.38
CO2 Laser	4.76

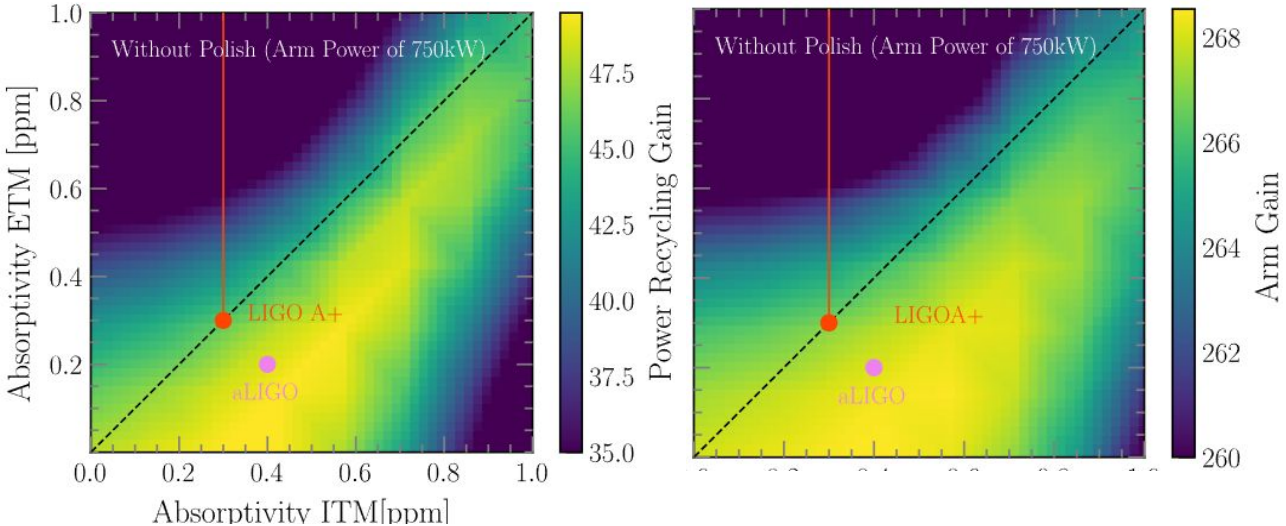
- Actuation profile for Co2 Laser



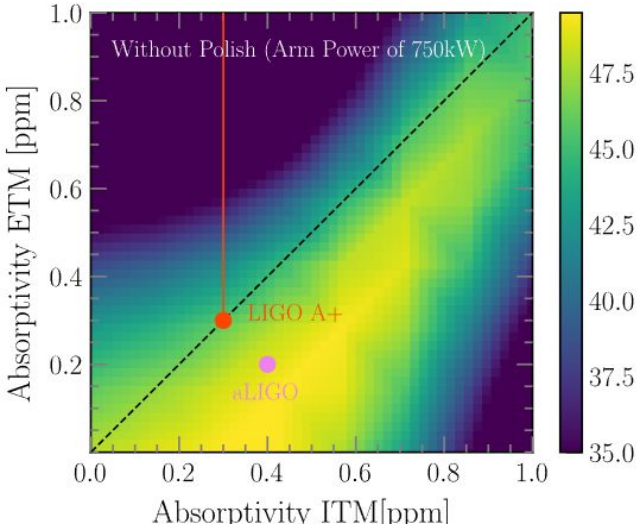
Baseline (Spherical Polish) performance across different ITM & ETM absorptivity

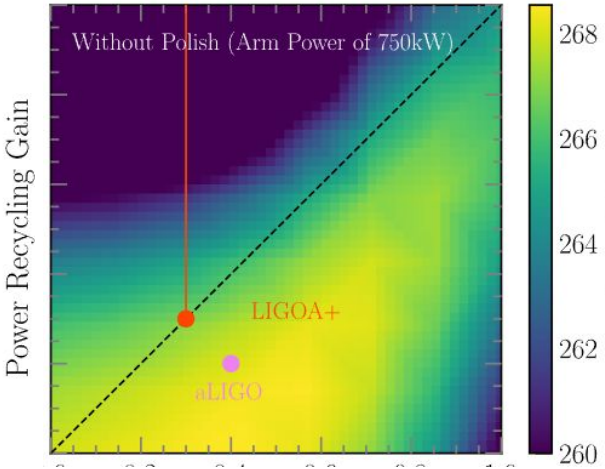


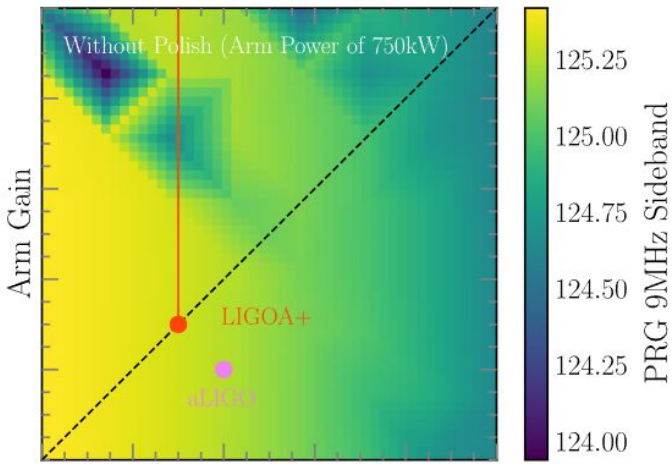
Baseline (Spherical Polish) performance across different ITM & ETM absorptivity



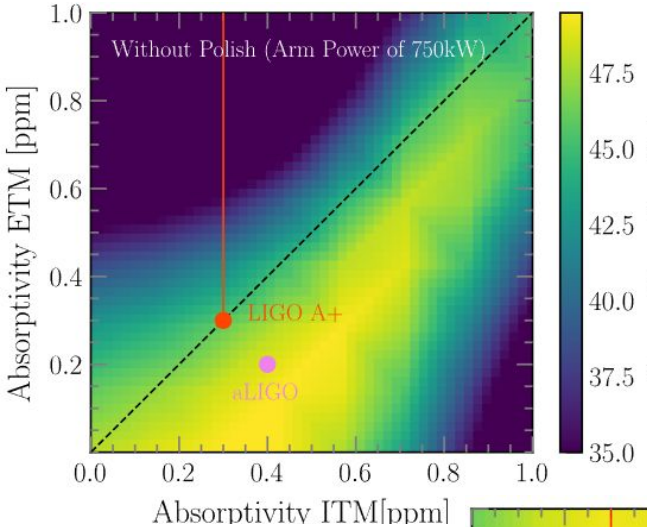
Baseline (Spherical Polish) performance across different ITM & ETM absorptivity

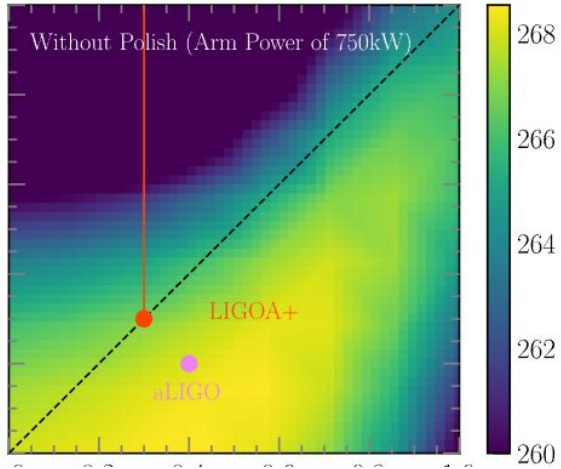


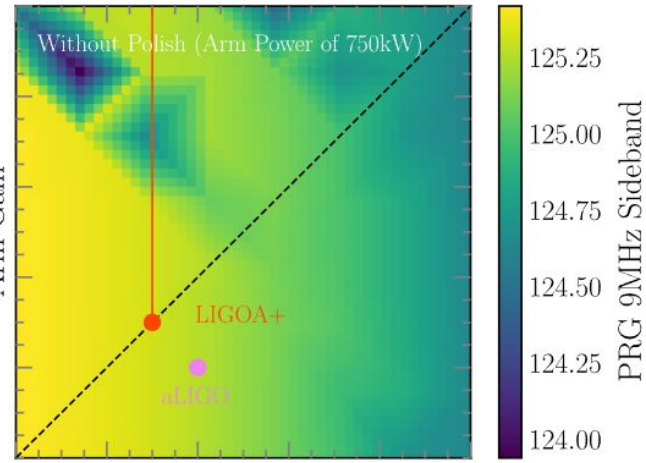


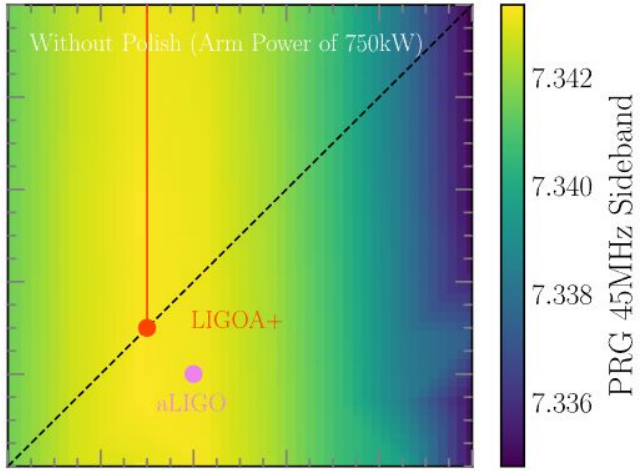


Baseline (Spherical Polish) performance across different ITM & ETM absorptivity

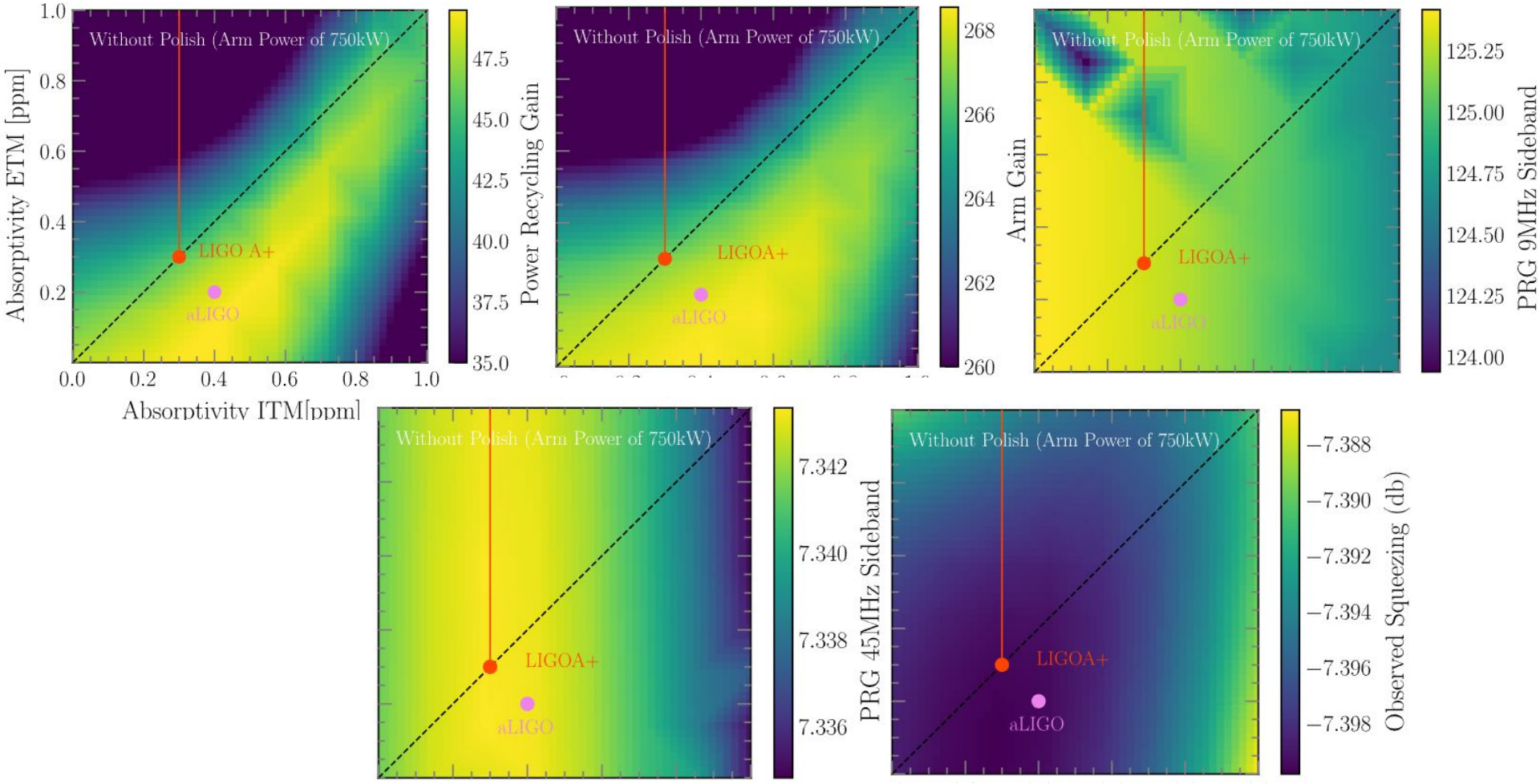






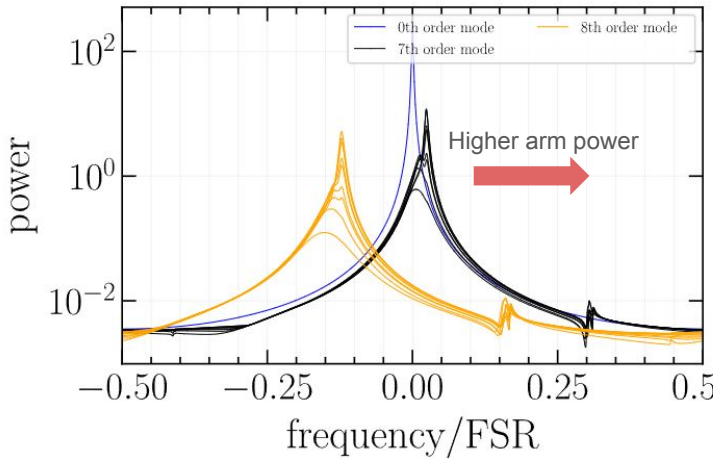


Baseline (Spherical Polish) performance across different ITM & ETM absorptivity

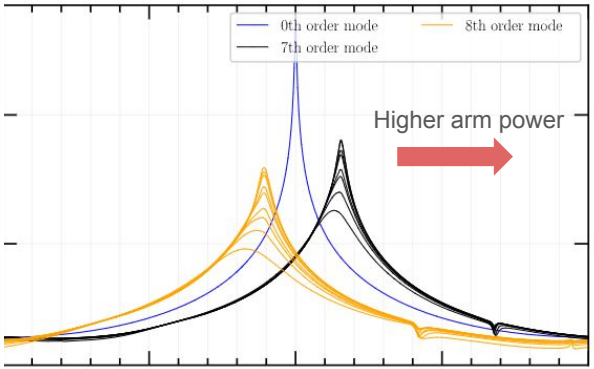


- With the current predicted O5 coating non-uniformity, the 7th order mode is very close to co-resonant at the cold state, with the resonance frequency location of each HOM shifted toward higher frequencies at higher arm power with the current TCS

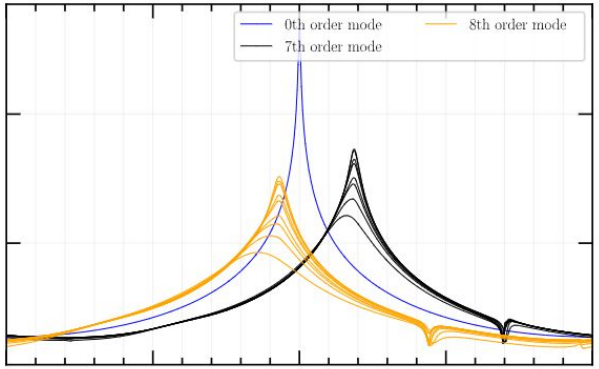
Frequency Sweep at Cold State



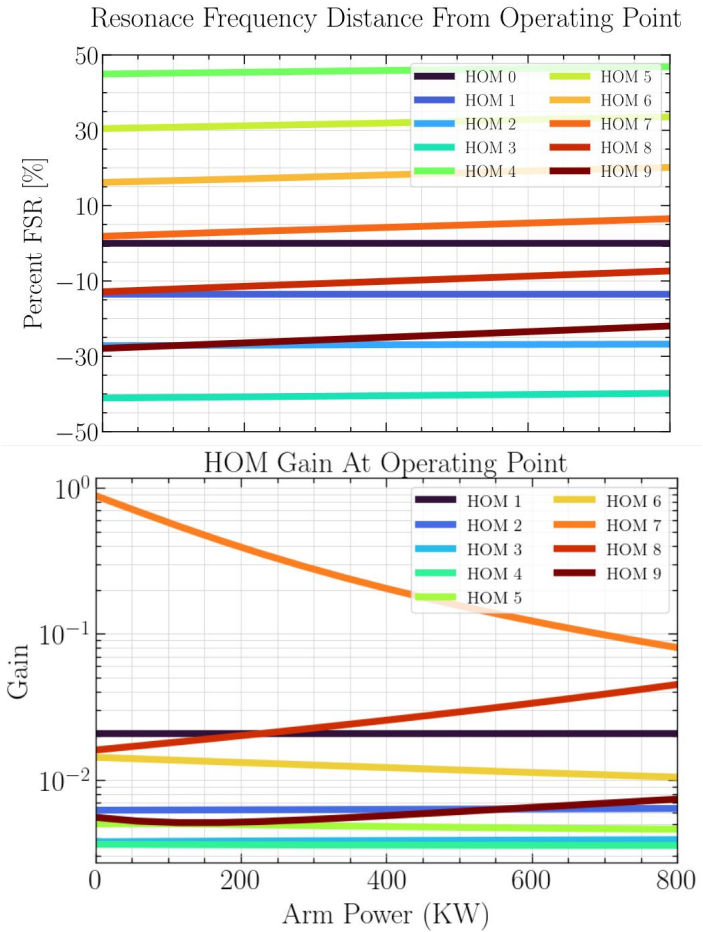
Frequency Sweep at 450 KW arm power
Absorptivity = 0.3ppm



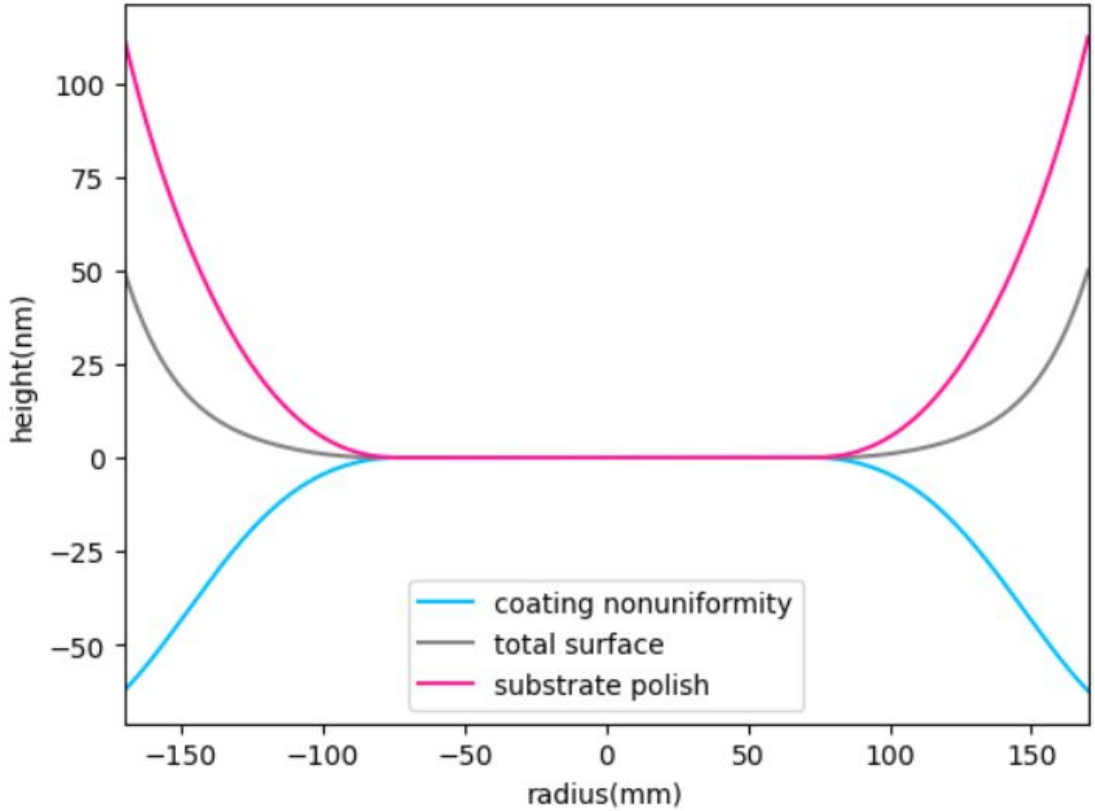
Frequency Sweep at 750 KW arm power
Absorptivity = 0.3ppm



Resonance Frequency evolution of higher order modes across arm powers and the relative gains of them at 00 resonant frequencies, with the current predicted coating and spherical polish



Proposed Polish, Coating & Total Surface Cross Section

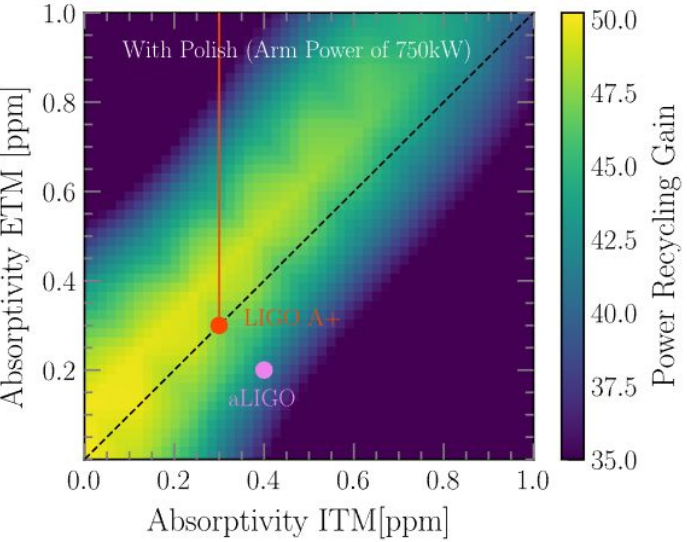


Analysis

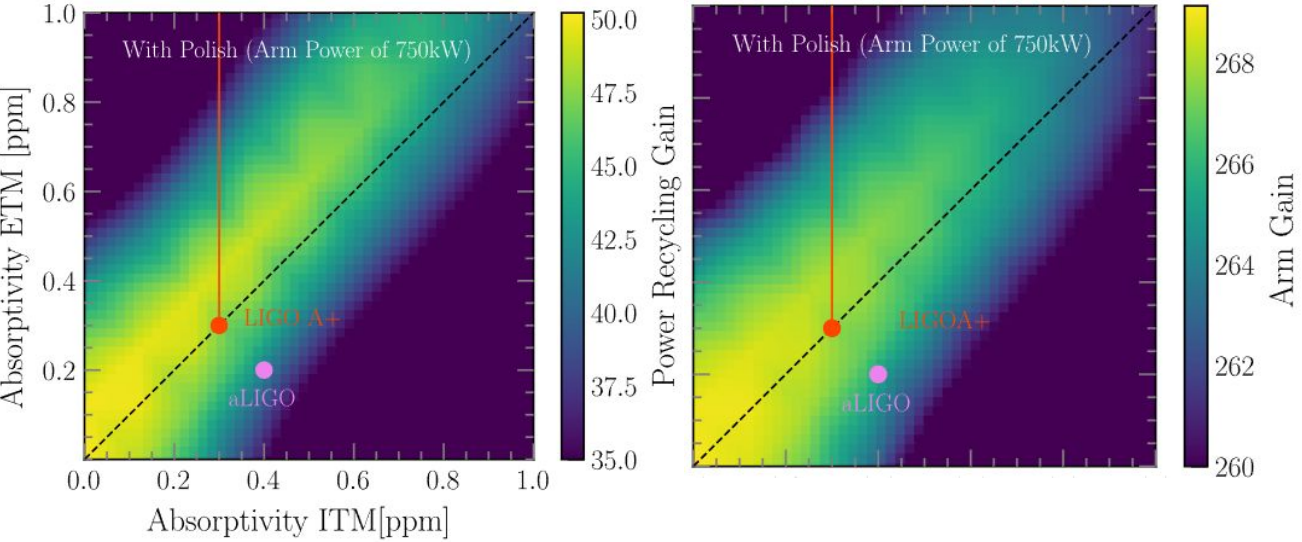
- TCS Power modeled for 0.3ppm on both mirror and 750kW of arm power

Compensation Device	Power (W)
ITM Ring Heater	3.55
ETM Ring Heater	4.38
CO2 Laser	4.76

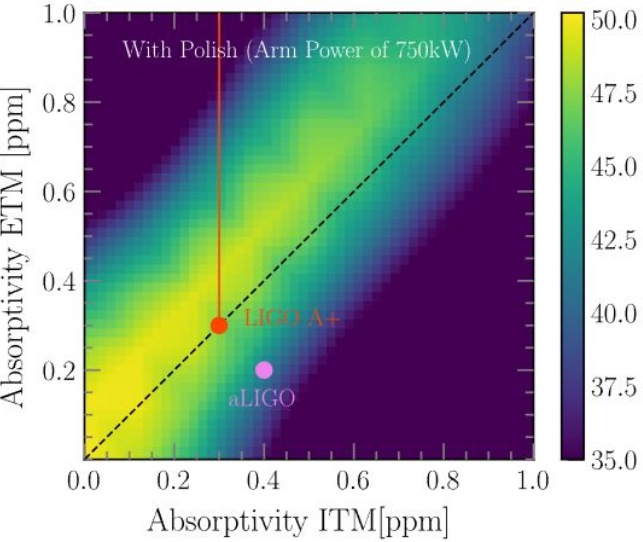
Proposed Polish Performance

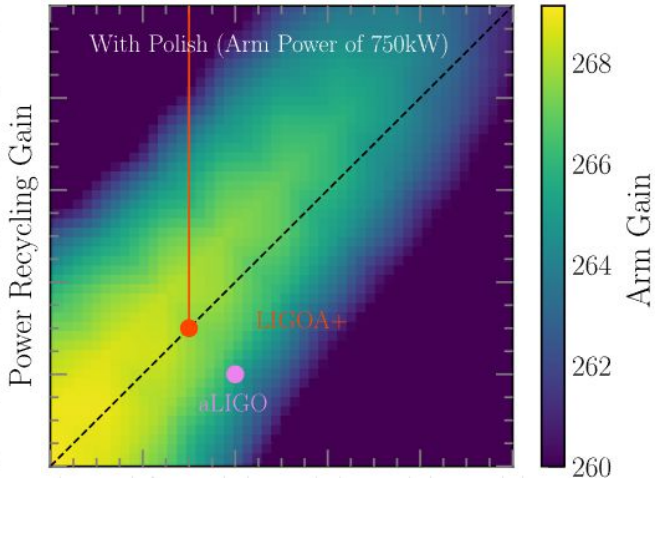


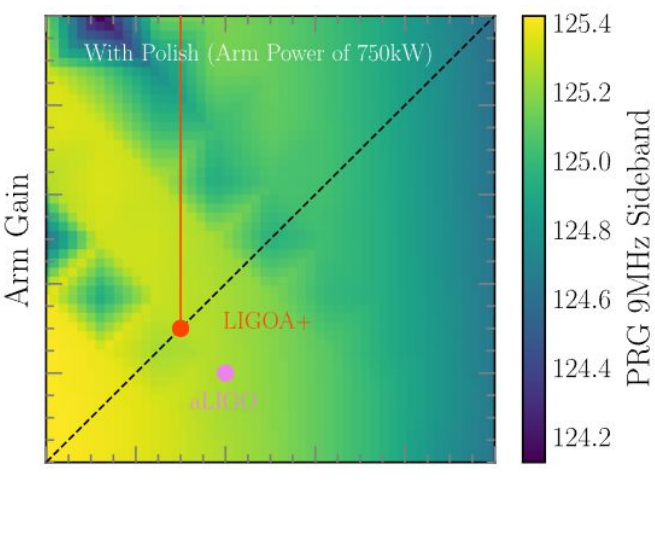
Proposed Polish Performance



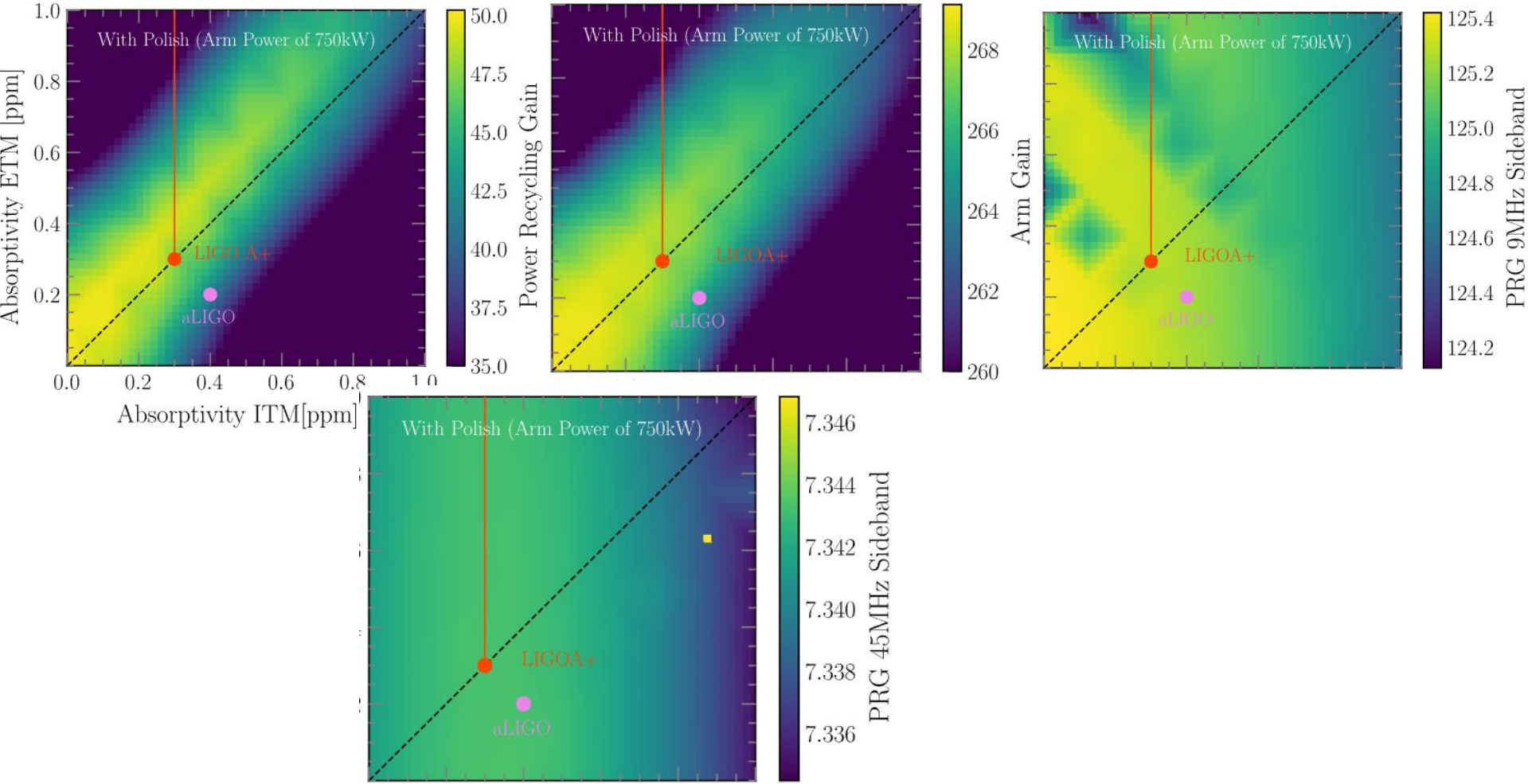
Proposed Polish Performance



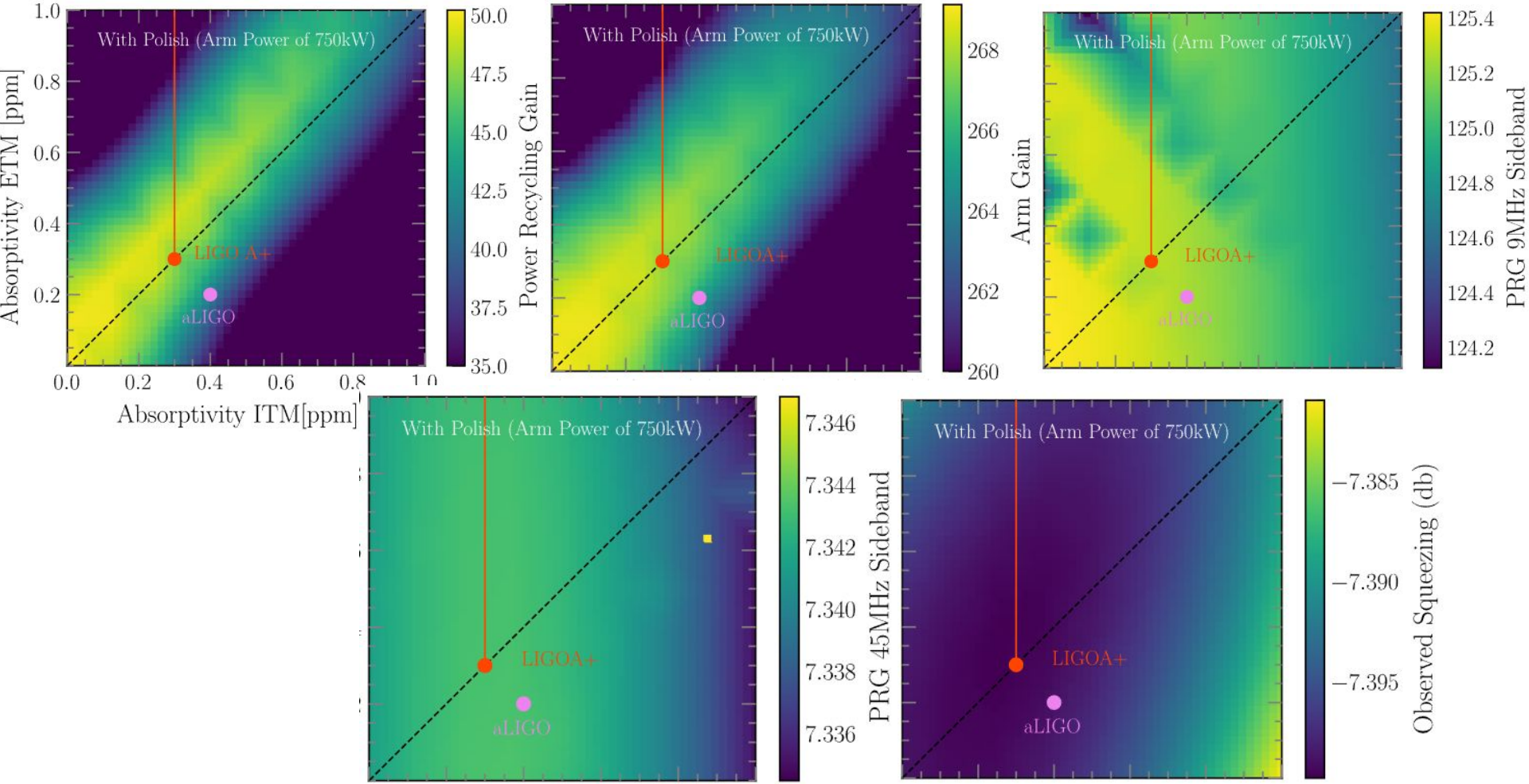




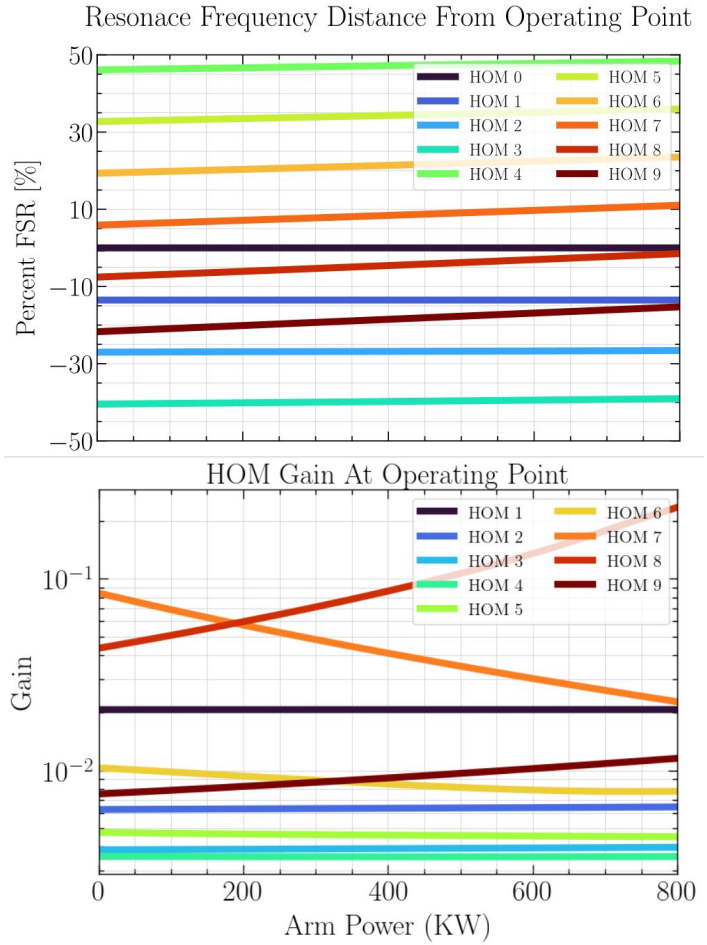
Proposed Polish Performance



Proposed Polish Performance



Resonance Frequency and gain evolution of higher order modes across arm powers with proposed polish

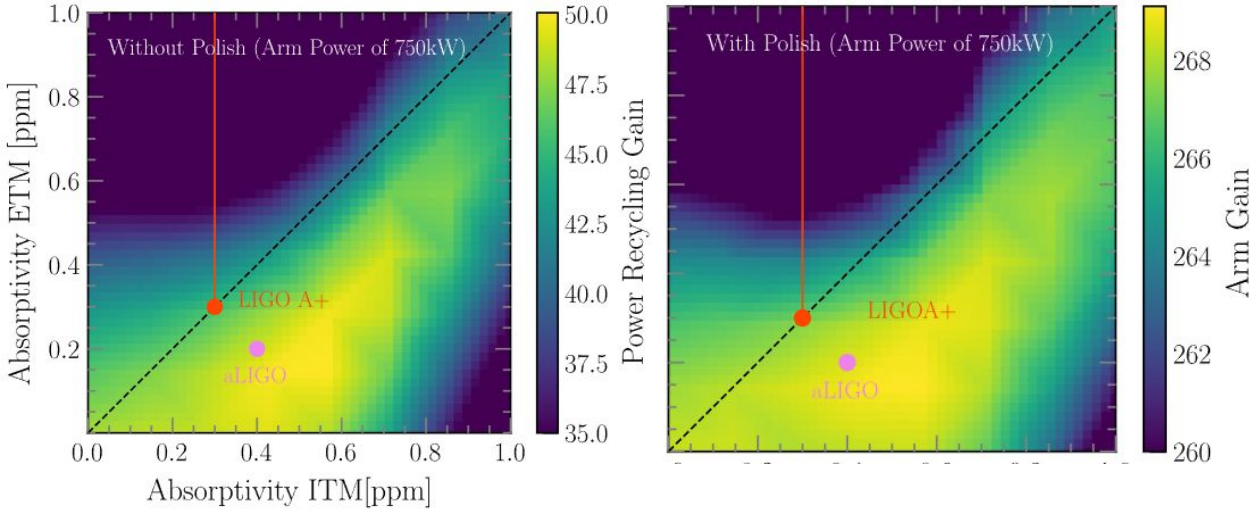


Impact of including FROSTIS

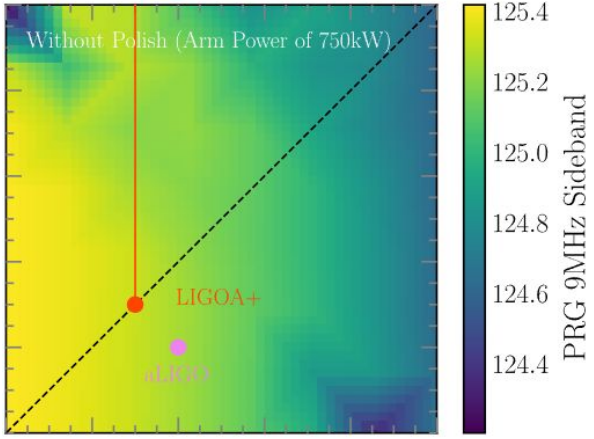
- The FROSTI device is predicted to not mitigate the imbalance issue
- We therefore recommend similar ETM polish in future TCS cases with FROSTI

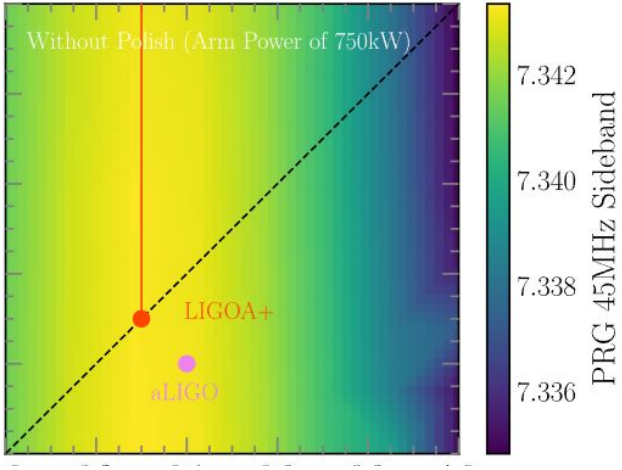
Additional Slides

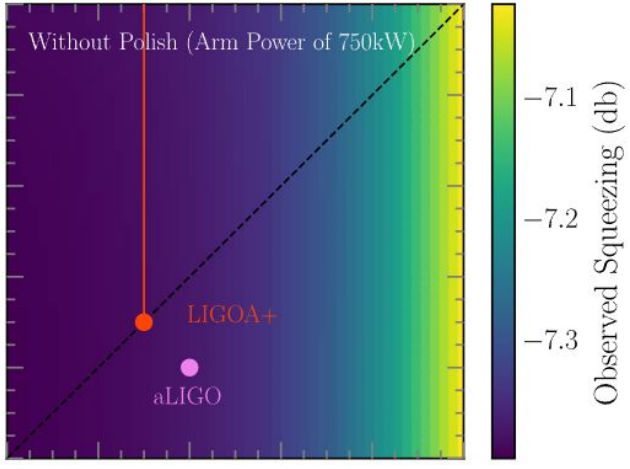
ITM FROSTI:


Without Polish (Arm Power of 750kW)
LIGO A+
aLIGO
Absorptivity ETM [ppm]
Absorptivity ITM[ppm]
Power Recycling Gain
1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
0.6
0.8
1.0
50.0
47.5
45.0
42.5
40.0
37.5
35.0

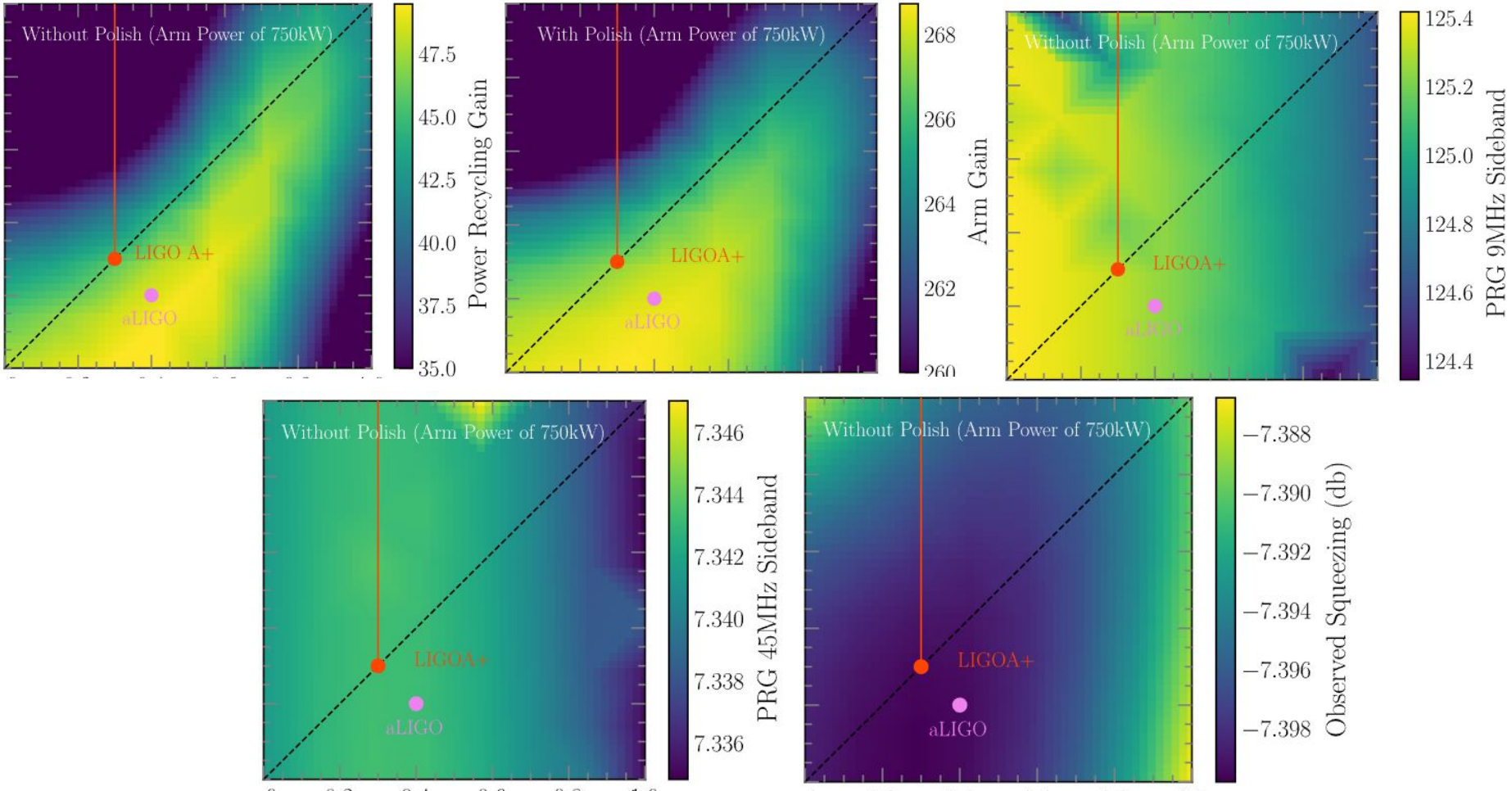
With Polish (Arm Power of 750kW)
LIGOA+
aLIGO
Arm Gain
268
266
264
262
260


Without Polish (Arm Power of 750kW)
LIGOA+
aLIGO
PRG 9MHz Sideband
125.4
125.2
125.0
124.8
124.6
124.4

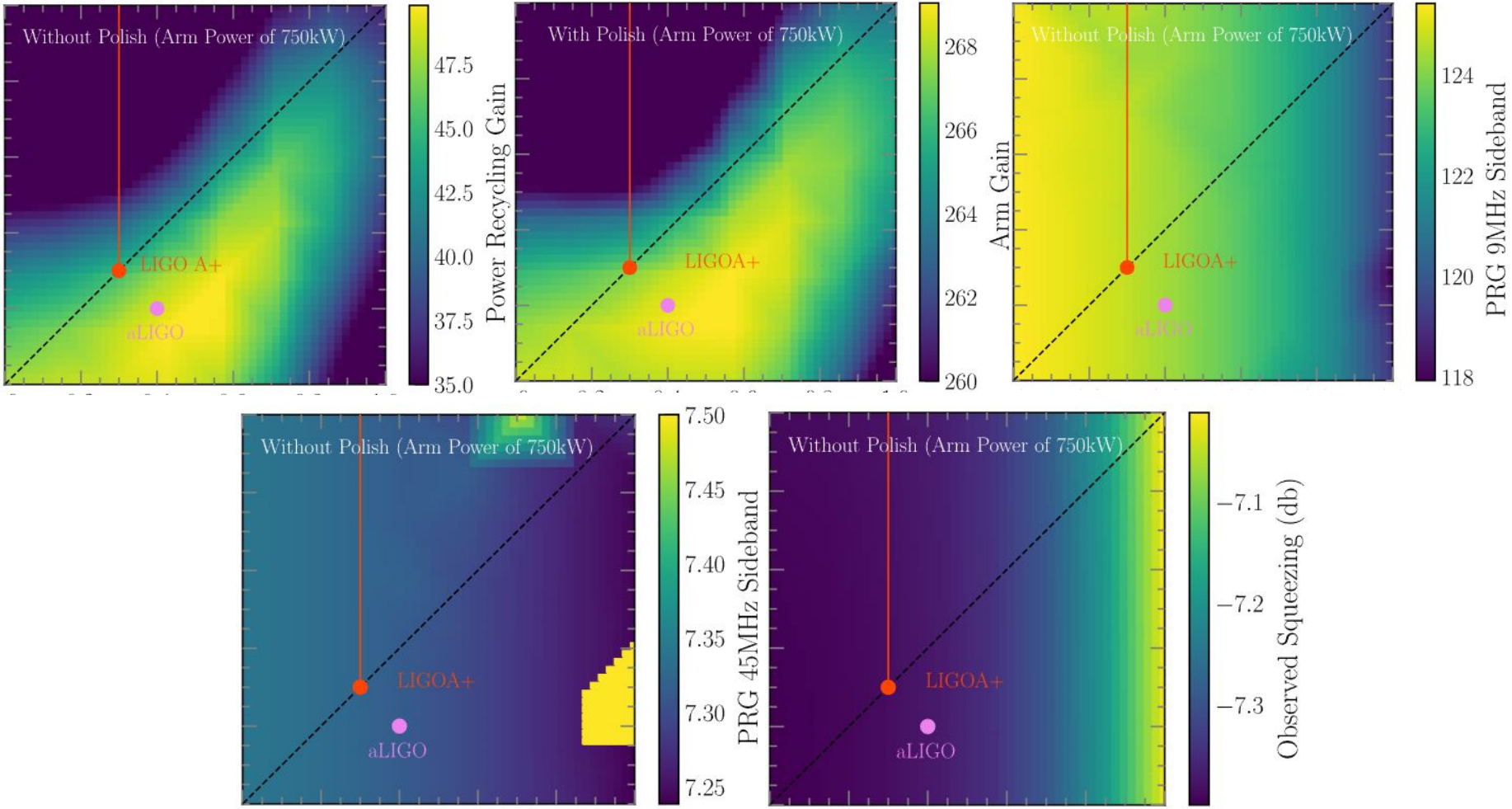

Without Polish (Arm Power of 750kW)
LIGOA+
aLIGO
PRG 45MHz Sideband
7.342
7.340
7.338
7.336


Without Polish (Arm Power of 750kW)
LIGOA+
aLIGO
Observed Squeezing (db)
−7.1
−7.2
−7.3

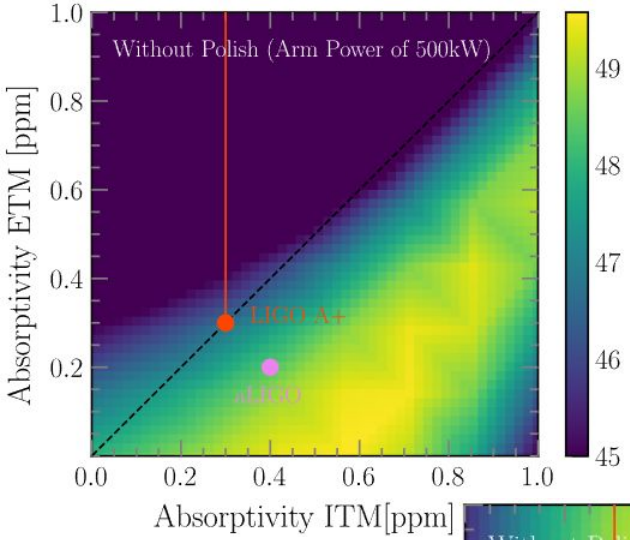
ETM FROSTI Case:

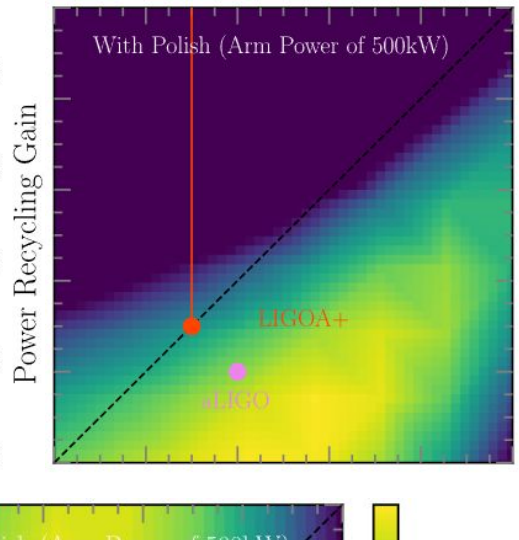


Dual Case:

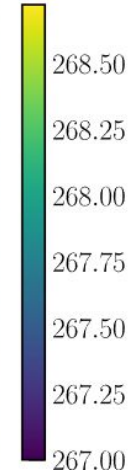

Without Polish (Arm Power of 750kW)
LIGO A+
aLIGO
47.5
45.0
42.5
40.0
37.5
35.0
Power Recycling Gain
With Polish (Arm Power of 750kW)
LIGOA+
aLIGO
268
266
264
262
260
Arm Gain
Without Polish (Arm Power of 750kW)
LIGOA+
aLIGO
124
122
120
118
PRG 9MHz Sideband
Without Polish (Arm Power of 750kW)
LIGOA+
aLIGO
7.50
7.45
7.40
7.35
7.30
7.25
PRG 45MHz Sideband
Without Polish (Arm Power of 750kW)
LIGOA+
aLIGO
−7.1
−7.2
−7.3
Observed Squeezing (db)

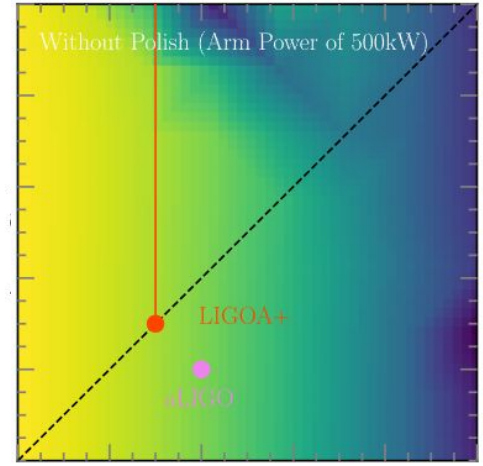
Current TCS

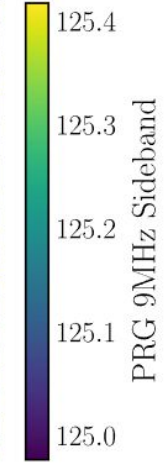

Without Polish (Arm Power of 500kW)
LIGO A+
aLIGO
Absorptivity ETM [ppm]
Absorptivity ITM[ppm]
1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
0.6
0.8
1.0

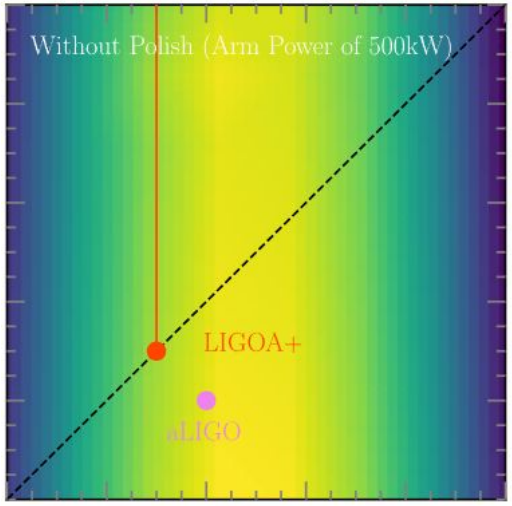

49
48
47
46
45
Power Recycling Gain

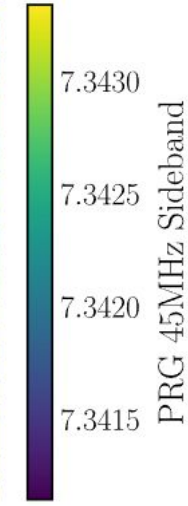
With Polish (Arm Power of 500kW)
LIGOA+
aLIGO

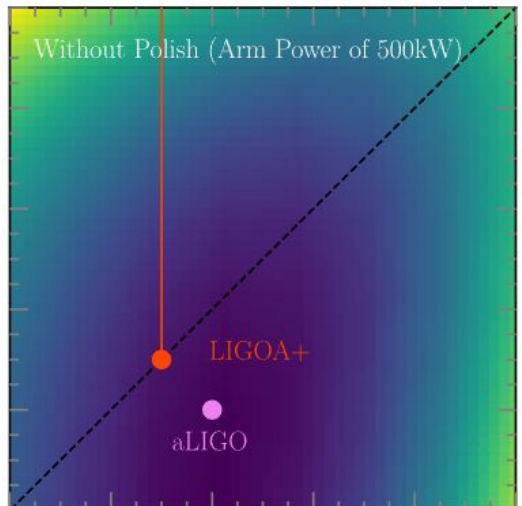

268.50
268.25
268.00
267.75
267.50
267.25
267.00

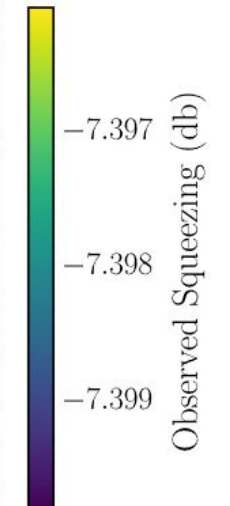

Without Polish (Arm Power of 500kW)
LIGOA+
aLIGO


125.4
125.3
125.2
125.1
125.0
PRG 9MHz Sideband

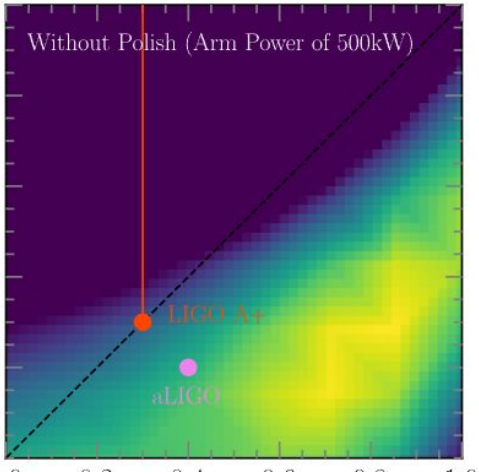

Without Polish (Arm Power of 500kW)
LIGOA+
aLIGO

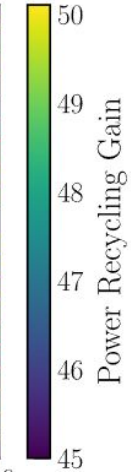

7.3430
7.3425
7.3420
7.3415
PRG 45MHz Sideband

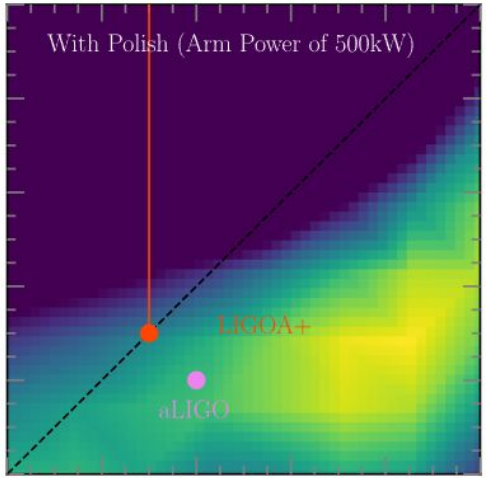

Without Polish (Arm Power of 500kW)
LIGOA+
aLIGO

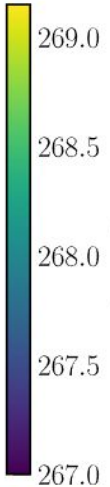

−7.397
−7.398
−7.399
Observed Squeezing (db)

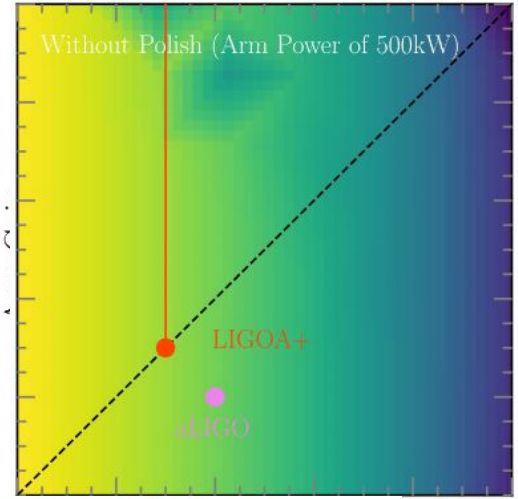
ITM FROSTI

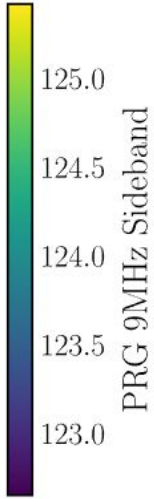

Without Polish (Arm Power of 500kW)
LIGOA+
aLIGO

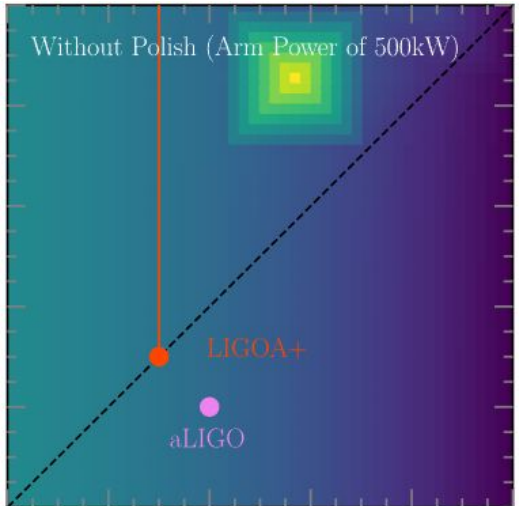

50
49
48
47
46
45
Power Recycling Gain


With Polish (Arm Power of 500kW)
LIGOA+
aLIGO

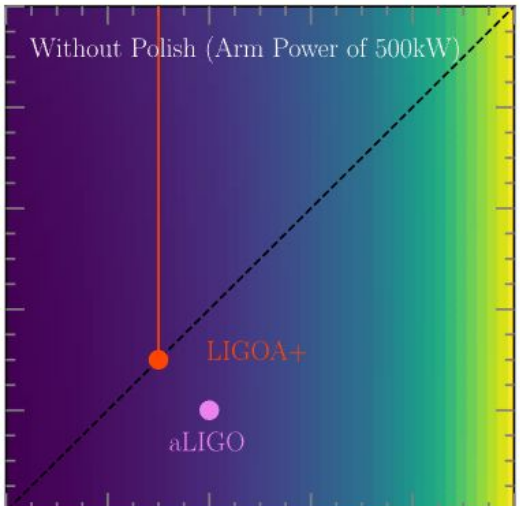

269.0
268.5
268.0
267.5
267.0

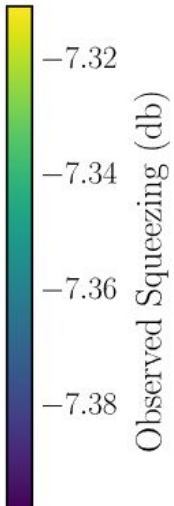

Without Polish (Arm Power of 500kW)
LIGOA+
aLIGO


125.0
124.5
124.0
123.5
123.0
PRG 9MHz Sideband

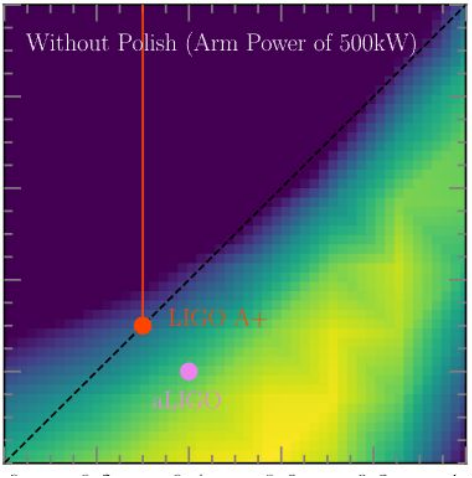

Without Polish (Arm Power of 500kW)
LIGOA+
aLIGO

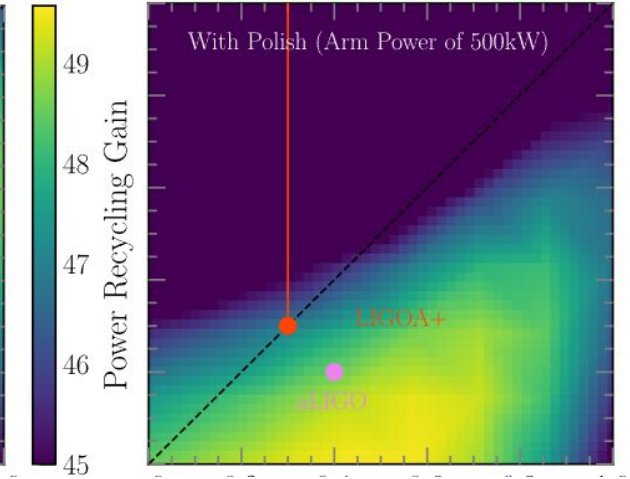

7.40
7.38
7.36
7.34
7.32
7.30
PRG 45MHz Sideband


Without Polish (Arm Power of 500kW)
LIGOA+
aLIGO

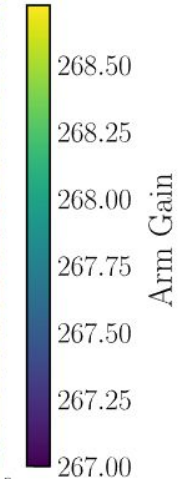

−7.32
−7.34
−7.36
−7.38
Observed Squeezing (db)

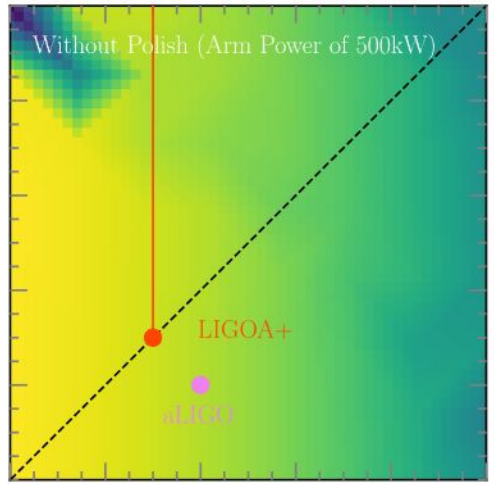
ETM FROSTI

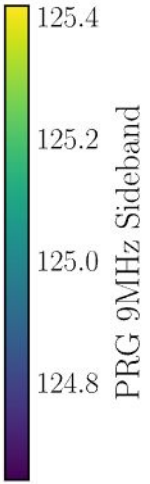

Without Polish (Arm Power of 500kW)
LIGO A+
aLIGO

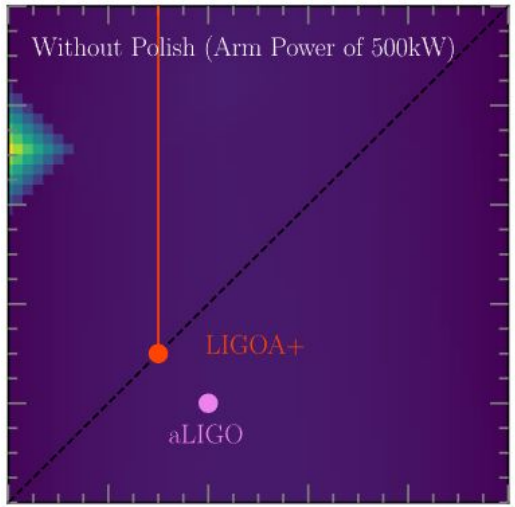

49
48
47
46
45
Power Recycling Gain

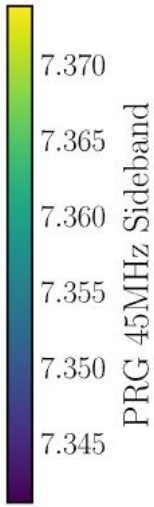
With Polish (Arm Power of 500kW)
LIGOA+
aLIGO

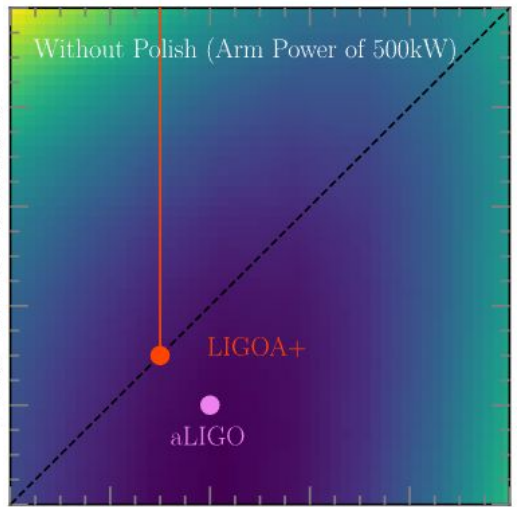

268.50
268.25
268.00
267.75
267.50
267.25
267.00
Arm Gain

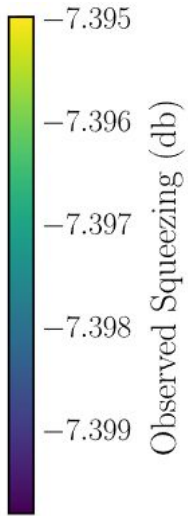

Without Polish (Arm Power of 500kW)
LIGOA+
aLIGO


125.4
125.2
125.0
124.8
PRG 9MHz Sideband

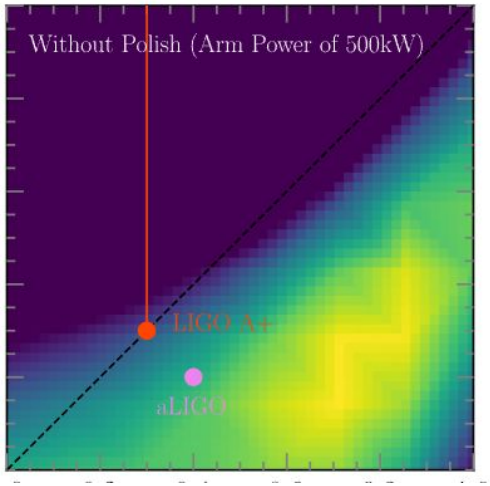

Without Polish (Arm Power of 500kW)
LIGOA+
aLIGO


7.370
7.365
7.360
7.355
7.350
7.345
PRG 45MHz Sideband

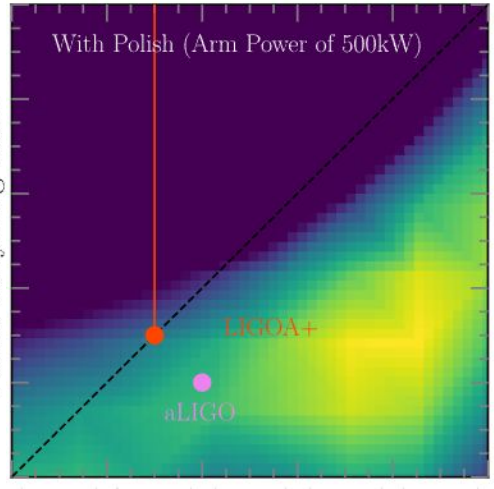

Without Polish (Arm Power of 500kW)
LIGOA+
aLIGO


−7.395
−7.396
−7.397
−7.398
−7.399
Observed Squeezing (db)

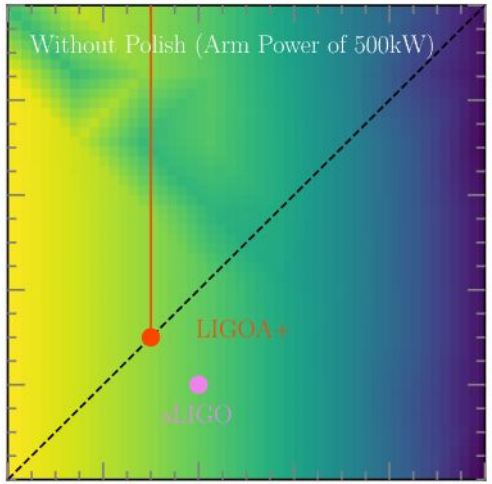
Dual

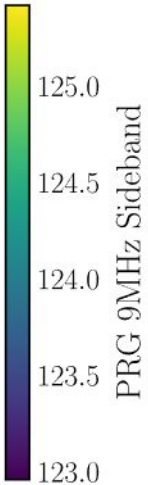

Without Polish (Arm Power of 500kW)
LIGO A+
aLIGO

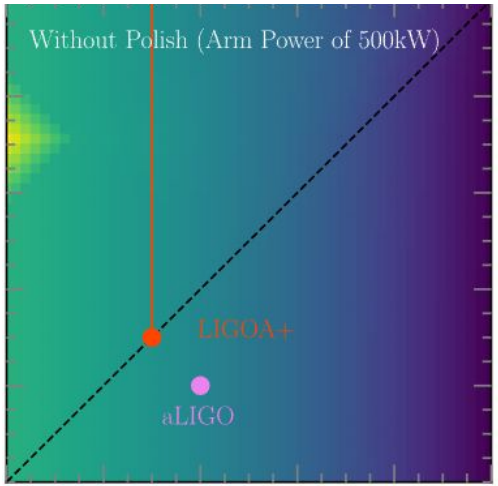

49
48
47
46
45
Power Recycling Gain

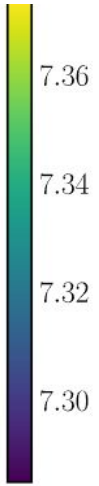

With Polish (Arm Power of 500kW)
LIGOA+
aLIGO

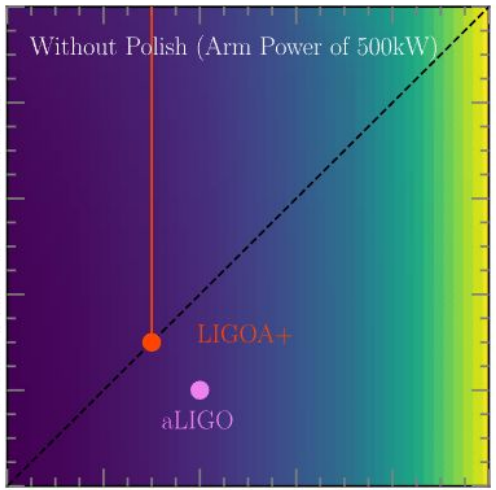

269.0
268.5
268.0
267.5
267.0
Arm Gain

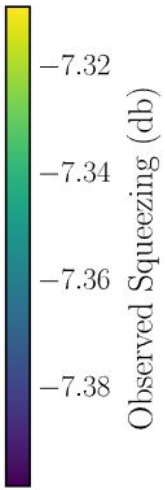

Without Polish (Arm Power of 500kW)
LIGOA+
aLIGO


125.0
124.5
124.0
123.5
123.0
PRG 9MHz Sideband

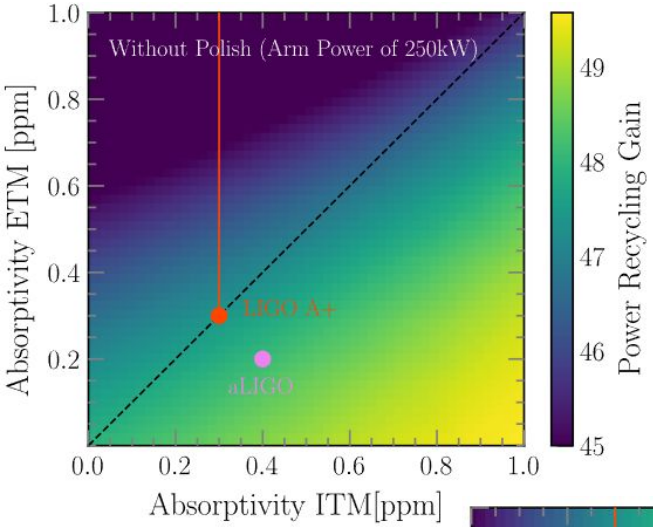

Without Polish (Arm Power of 500kW)
LIGOA+
aLIGO

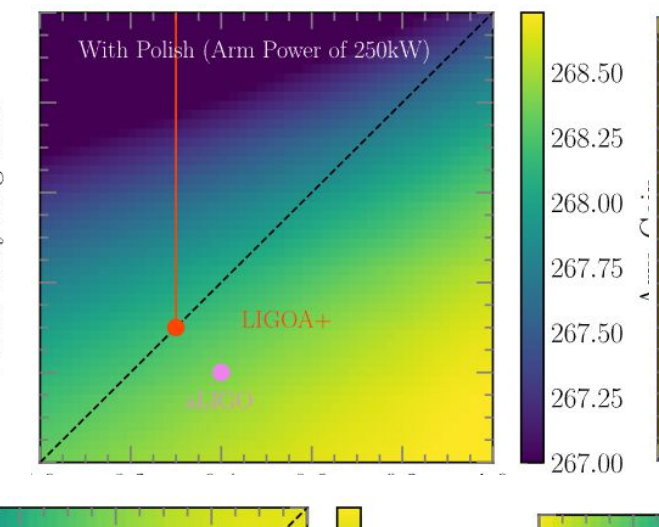

7.36
7.34
7.32
7.30
PRG 45MHz Sideband


Without Polish (Arm Power of 500kW)
LIGOA+
aLIGO


−7.32
−7.34
−7.36
−7.38
Observed Squeezing (db)

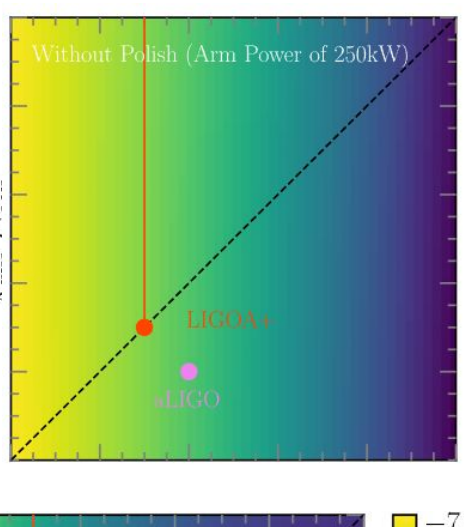
Current TCS

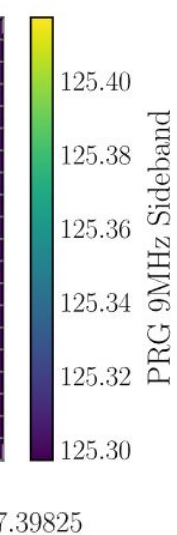

Without Polish (Arm Power of 250kW)
LIGO A+
aLIGO
Absorptivity ETM [ppm]
Absorptivity ITM[ppm]
1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
0.6
0.8
1.0

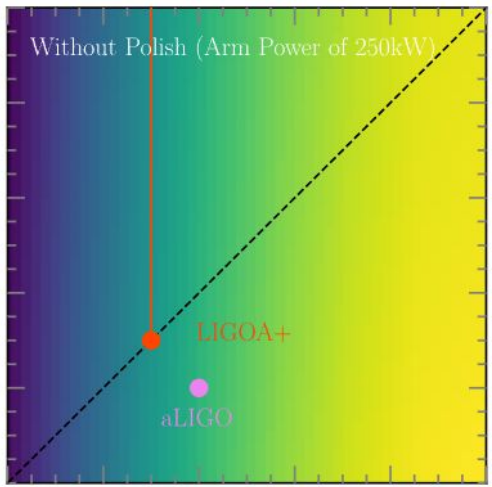

49
48
47
46
45
Power Recycling Gain

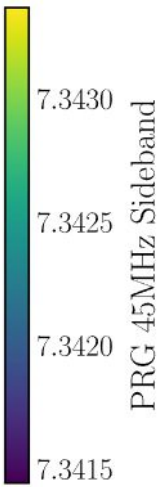
With Polish (Arm Power of 250kW)
LIGOA+
aLIGO

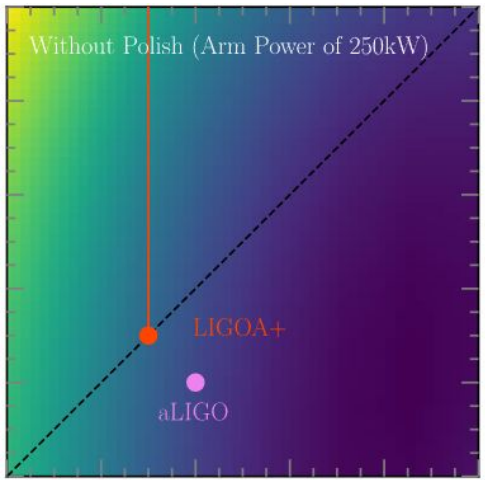
268.50
268.25
268.00
267.75
267.50
267.25
267.00

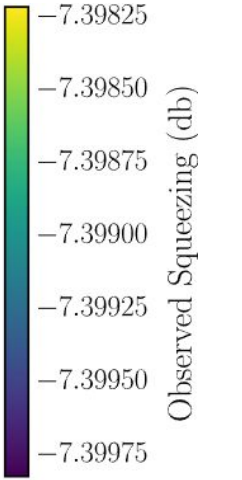

Without Polish (Arm Power of 250kW)
LIGOA+
aLIGO


125.40
125.38
125.36
125.34
125.32
125.30
PRG 9MHz Sideband

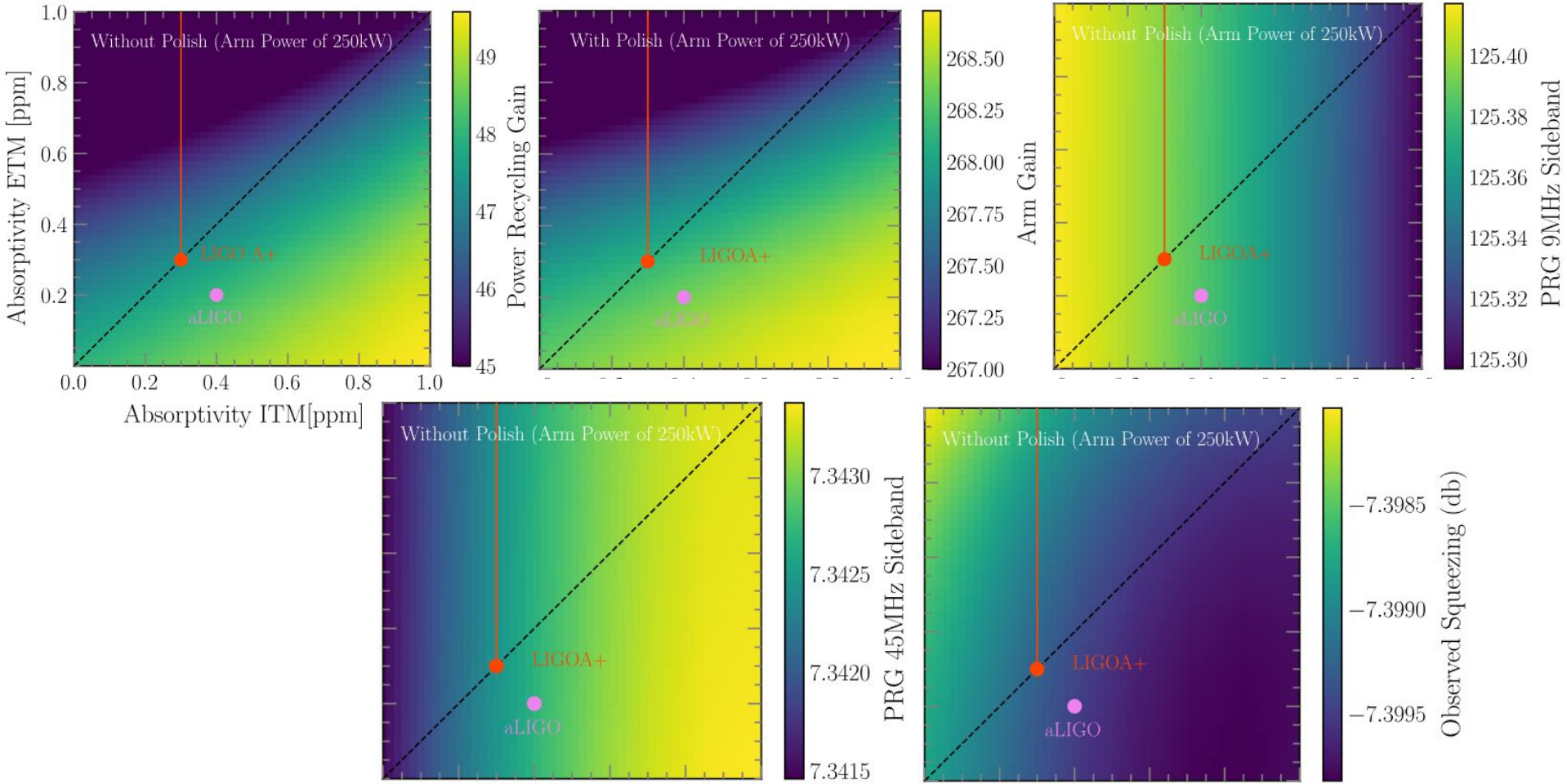

Without Polish (Arm Power of 250kW)
LIGOA+
aLIGO


7.3430
7.3425
7.3420
7.3415
PRG 45MHz Sideband

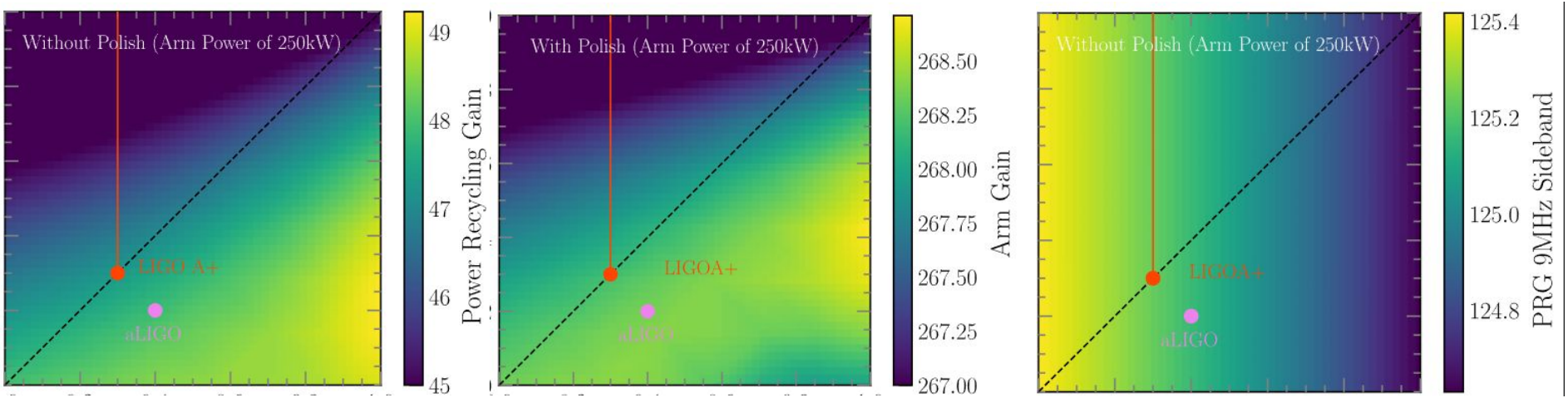

Without Polish (Arm Power of 250kW)
LIGOA+
aLIGO

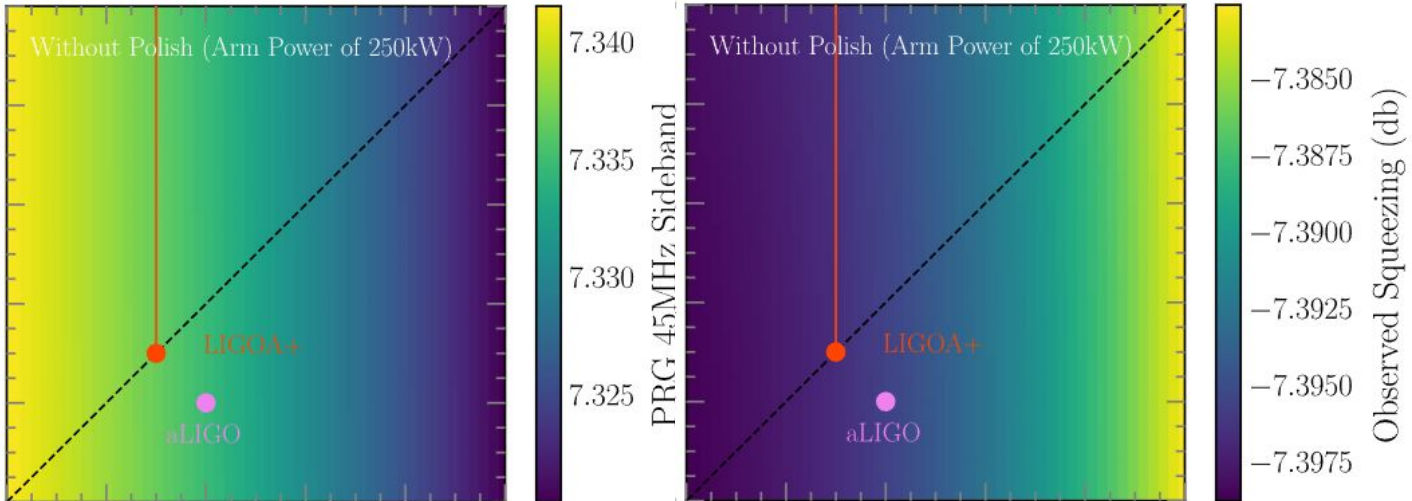

−7.39825
−7.39850
−7.39875
−7.39900
−7.39925
−7.39950
−7.39975
Observed Squeezing (db)

ETM FROSTI

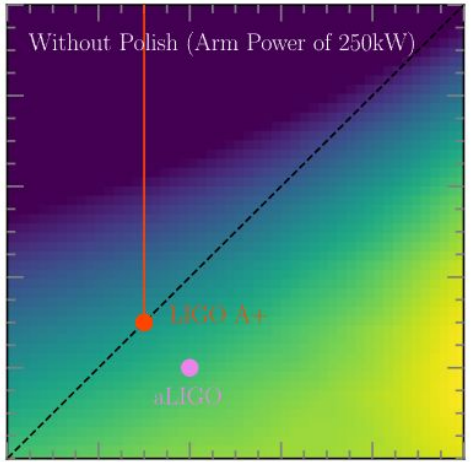

Without Polish (Arm Power of 250kW)
LIGOA+
aLIGO
Absorptivity ETM [ppm]
Absorptivity ITM[ppm]
1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
0.6
0.8
1.0
49
48
47
46
45
With Polish (Arm Power of 250kW)
Power Recycling Gain
268.50
268.25
268.00
267.75
267.50
267.25
267.00
Without Polish (Arm Power of 250kW)
Arm Gain
125.40
125.38
125.36
125.34
125.32
125.30
PRG 9MHz Sideband
Without Polish (Arm Power of 250kW)
PRG 45MHz Sideband
7.3430
7.3425
7.3420
7.3415
Without Polish (Arm Power of 250kW)
−7.3985
−7.3990
−7.3995
Observed Squeezing (db)

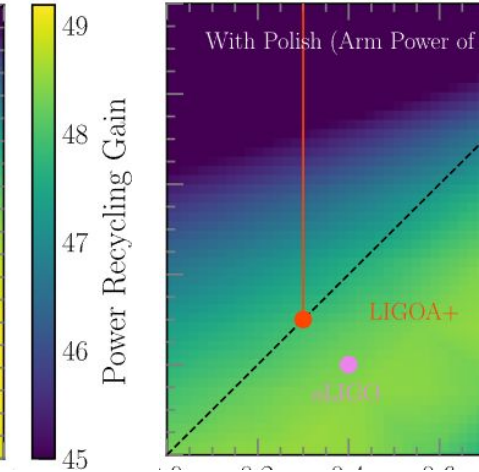
ITM FROSTI


Without Polish (Arm Power of 250kW)
LIGO A+
aLIGO
49
48
47
46
45
Power Recycling Gain
With Polish (Arm Power of 250kW)
LIGOA+
aLIGO
268.50
268.25
268.00
267.75
267.50
267.25
267.00
Arm Gain
Without Polish (Arm Power of 250kW)
LIGOA+
aLIGO
125.4
125.2
125.0
124.8
PRG 9MHz Sideband

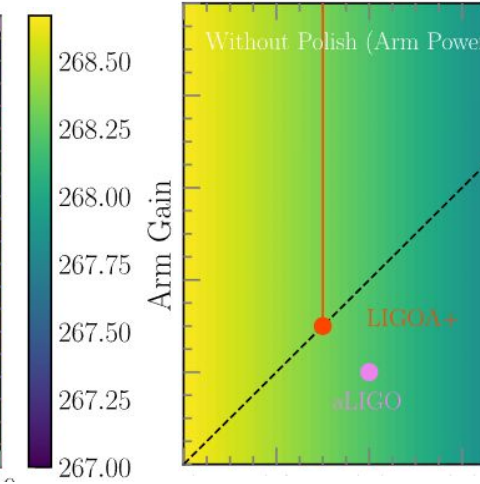

Without Polish (Arm Power of 250kW)
LIGOA+
aLIGO
7.340
7.335
7.330
7.325
PRG 45MHz Sideband
Without Polish (Arm Power of 250kW)
LIGOA+
aLIGO
−7.3850
−7.3875
−7.3900
−7.3925
−7.3950
−7.3975
Observed Squeezing (db)

Dual

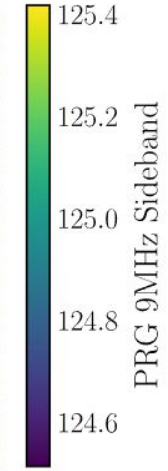

Without Polish (Arm Power of 250kW)
LIGO A+
aLIGO

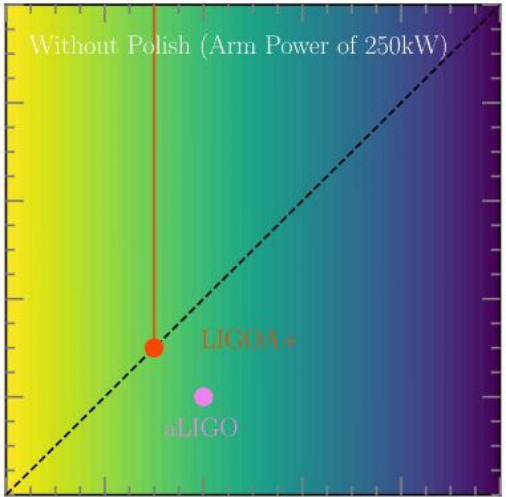

49
48
47
46
45
Power Recycling Gain

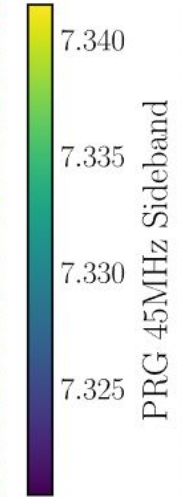
With Polish (Arm Power of 250kW)
LIGOA+
aLIGO

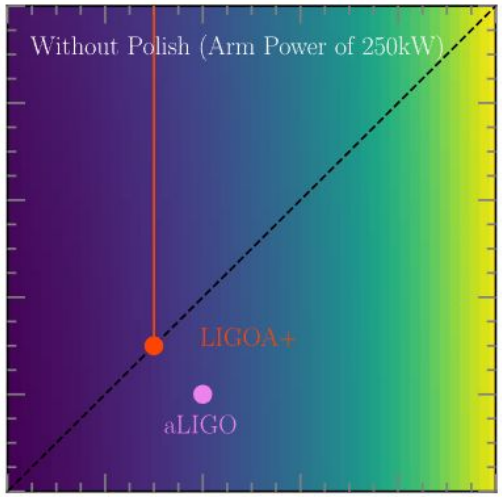

268.50
268.25
268.00
267.75
267.50
267.25
267.00
Arm Gain

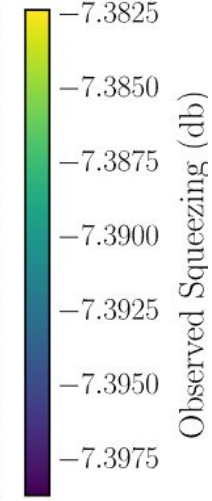
Without Polish (Arm Power of 250kW)
LIGOA+
aLIGO


125.4
125.2
125.0
124.8
124.6
PRG 9MHz Sideband

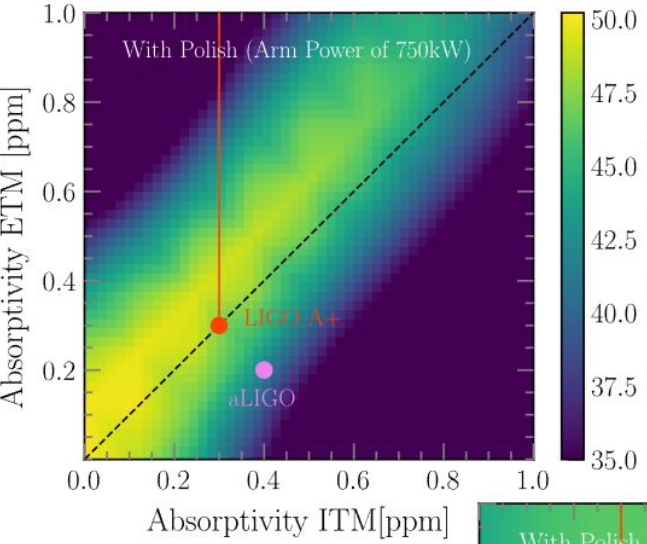

Without Polish (Arm Power of 250kW)
LIGOA+
aLIGO

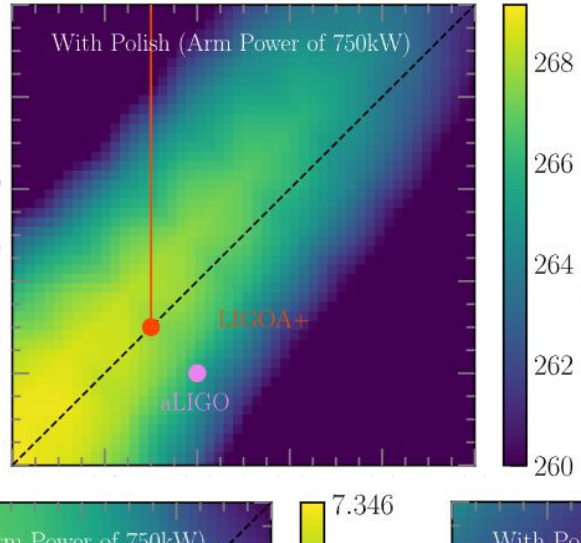

7.340
7.335
7.330
7.325
PRG 45MHz Sideband

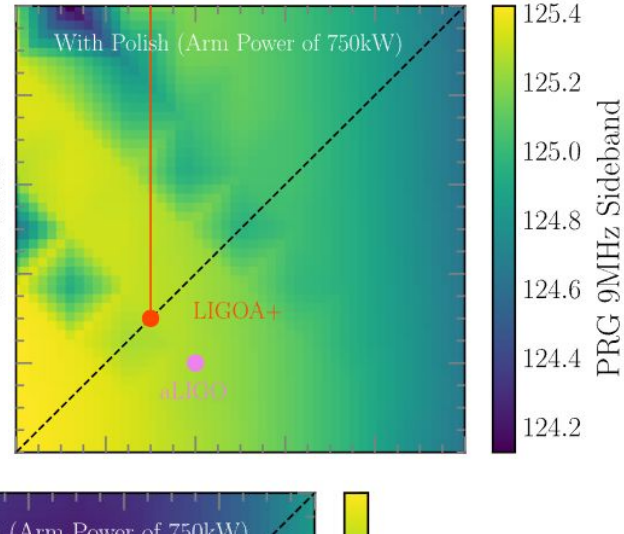

Without Polish (Arm Power of 250kW)
LIGOA+
aLIGO

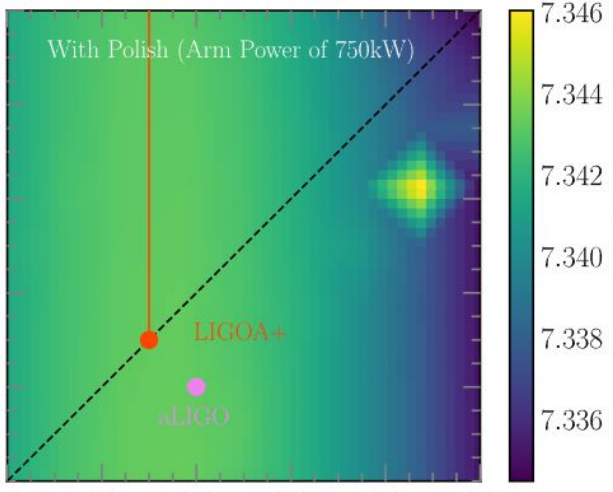

−7.3825
−7.3850
−7.3875
−7.3900
−7.3925
−7.3950
−7.3975
Observed Squeezing (db)

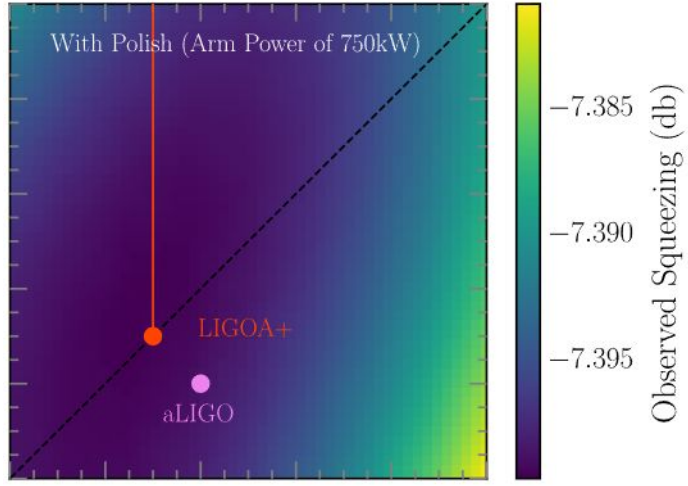
Current 750kw



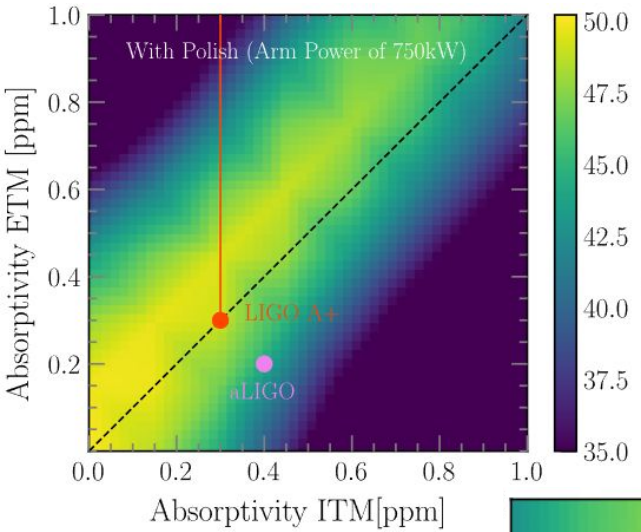


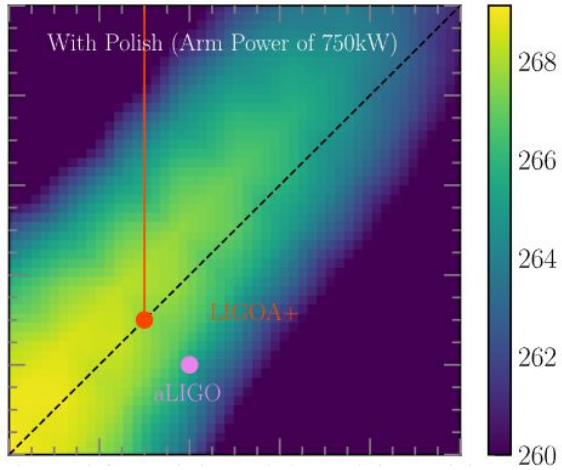


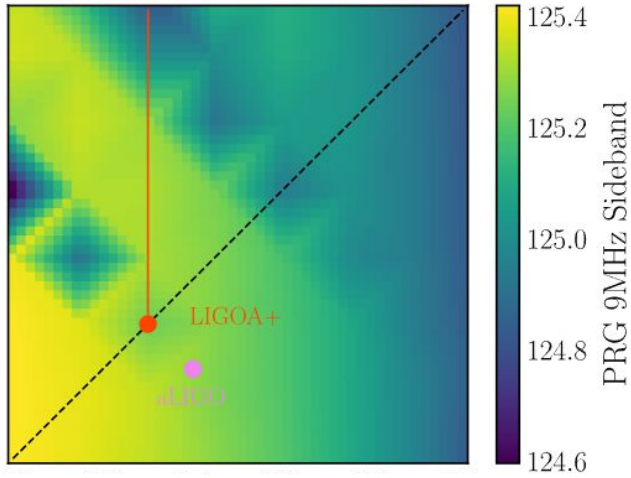


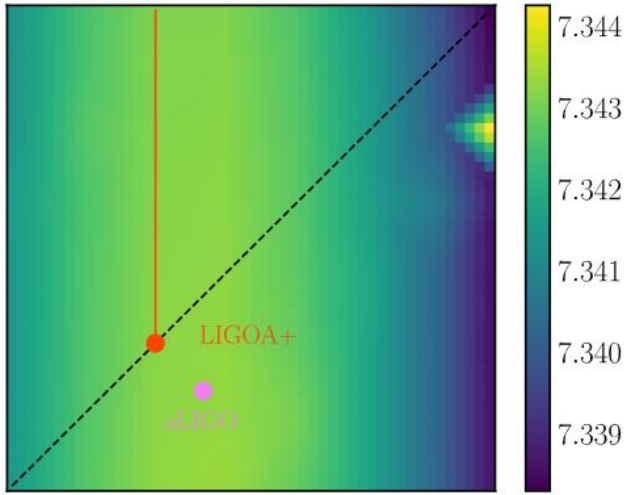


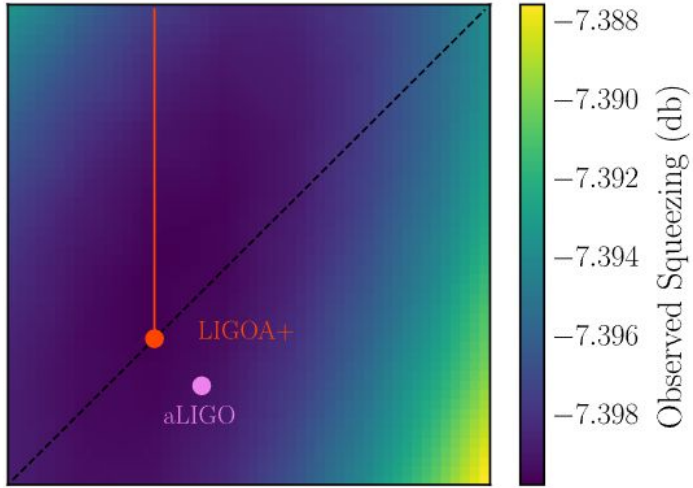
ITM 750kw


With Polish (Arm Power of 750kW)
LIGO A+
aLIGO
Absorptivity ETM [ppm]
Absorptivity ITM[ppm]
1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
0.6
0.8
1.0
50.0
47.5
45.0
42.5
40.0
37.5
35.0

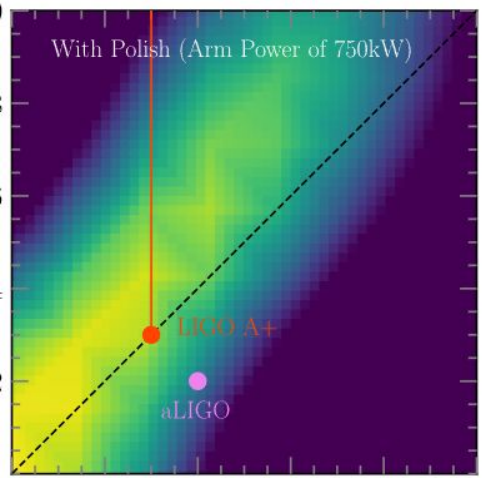

With Polish (Arm Power of 750kW)
LIGOA+
aLIGO
Power Recycling Gain
268
266
264
262
260

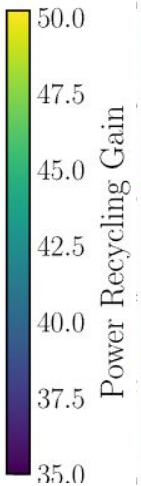

LIGOA+
aLIGO
Arm Gain
PRG 9MHz Sideband
125.4
125.2
125.0
124.8
124.6

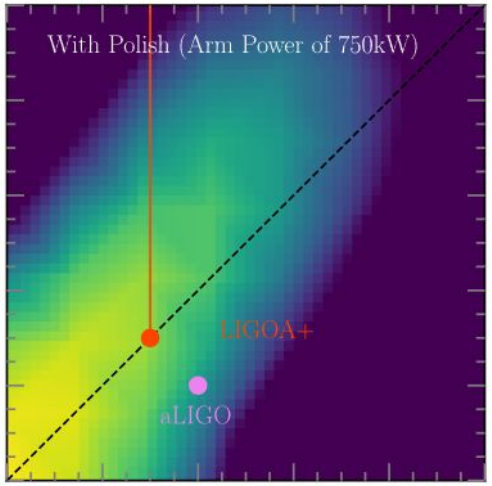

LIGOA+
aLIGO
PRG 45MHz Sideband
7.344
7.343
7.342
7.341
7.340
7.339

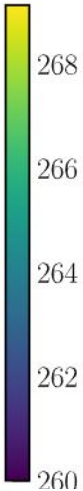

LIGOA+
aLIGO
Observed Squeezing (db)
−7.388
−7.390
−7.392
−7.394
−7.396
−7.398

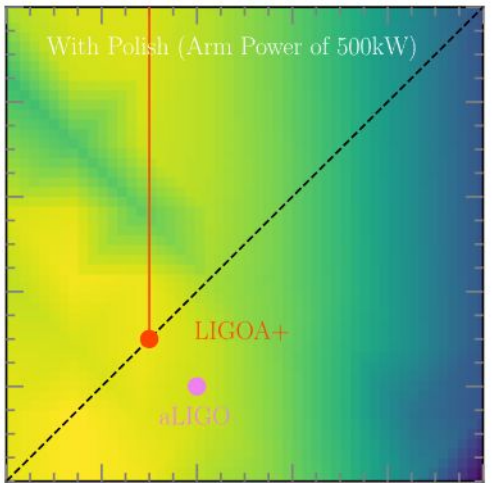
ETM 750kw

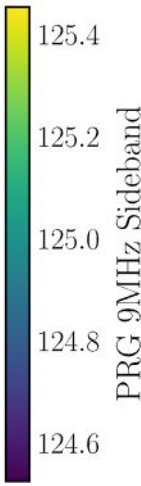

With Polish (Arm Power of 750kW)
LIGO A+
aLIGO

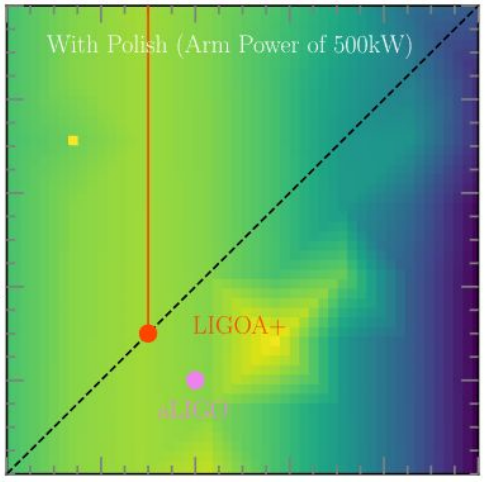

50.0
47.5
45.0
42.5
40.0
37.5
35.0
Power Recycling Gain

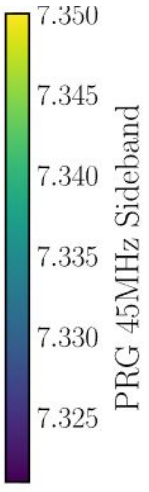

With Polish (Arm Power of 750kW)
LIGOA+
aLIGO

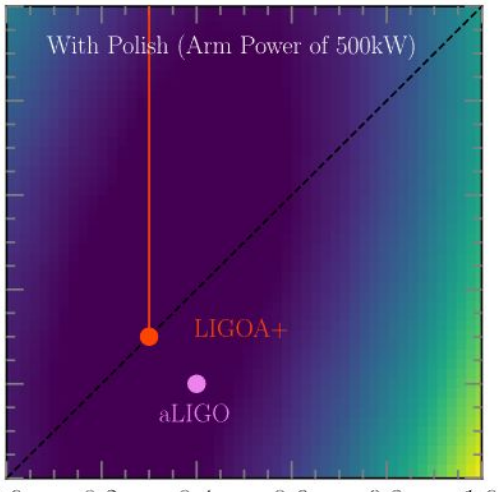

268
266
264
262
260
Arm Gain

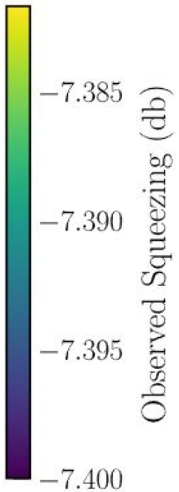

With Polish (Arm Power of 500kW)
LIGOA+
aLIGO


125.4
125.2
125.0
124.8
124.6
PRG 9MHz Sideband

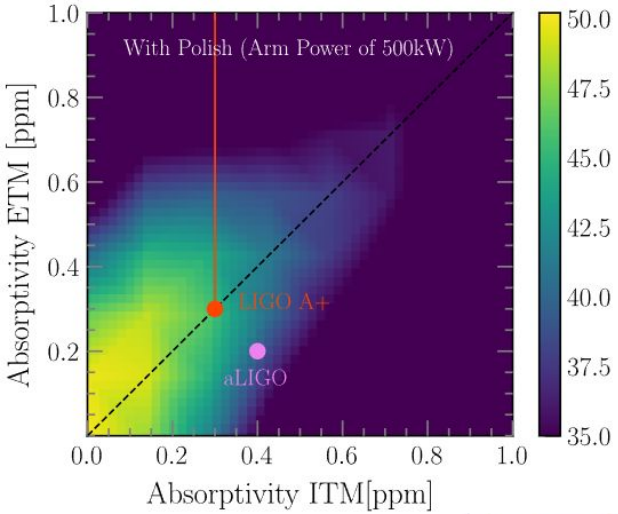

With Polish (Arm Power of 500kW)
LIGOA+
aLIGO

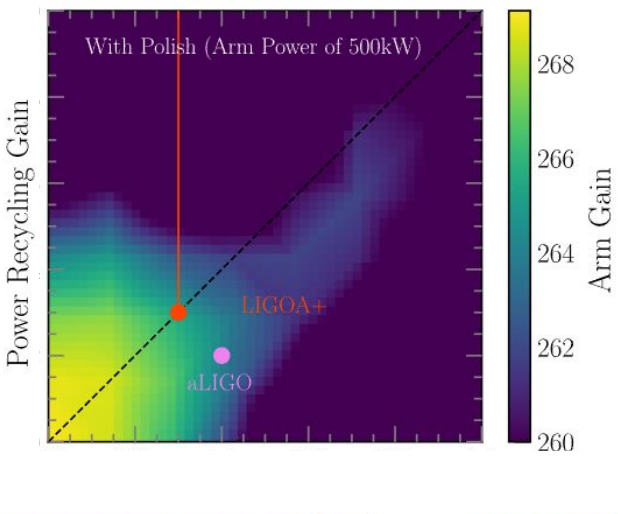

7.350
7.345
7.340
7.335
7.330
7.325
PRG 45MHz Sideband

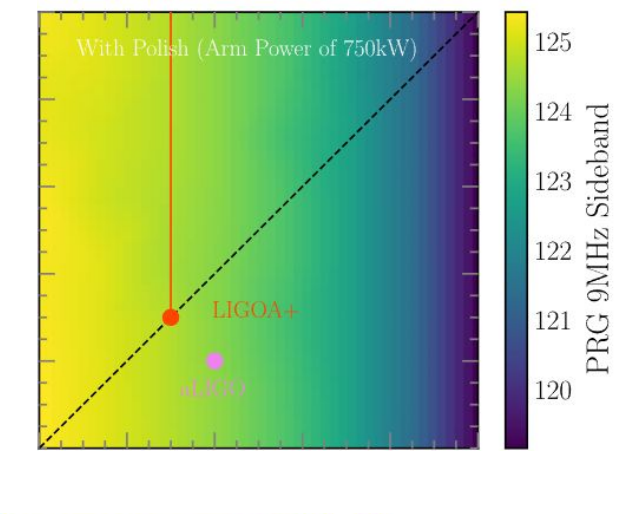

With Polish (Arm Power of 500kW)
LIGOA+
aLIGO


−7.385
−7.390
−7.395
−7.400
Observed Squeezing (db)

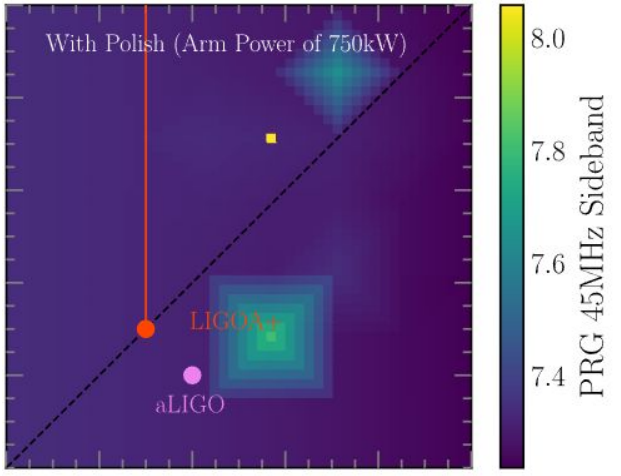
Dual 750kw

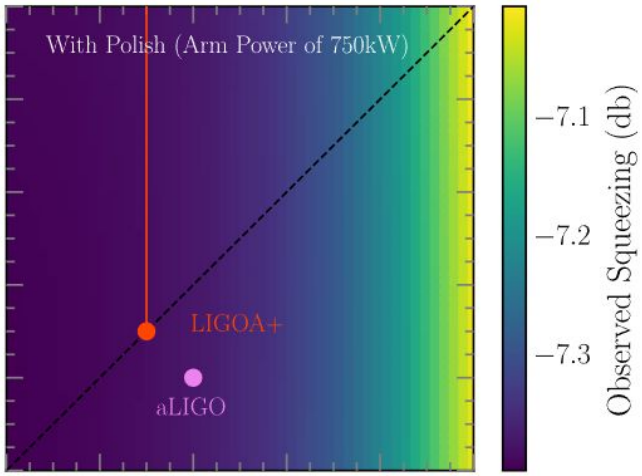

With Polish (Arm Power of 500kW)
LIGO A+
aLIGO
Absorptivity ETM [ppm]
Absorptivity ITM[ppm]
1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
0.6
0.8
1.0


With Polish (Arm Power of 500kW)
LIGOA+
aLIGO
Power Recycling Gain
50.0
47.5
45.0
42.5
40.0
37.5
35.0

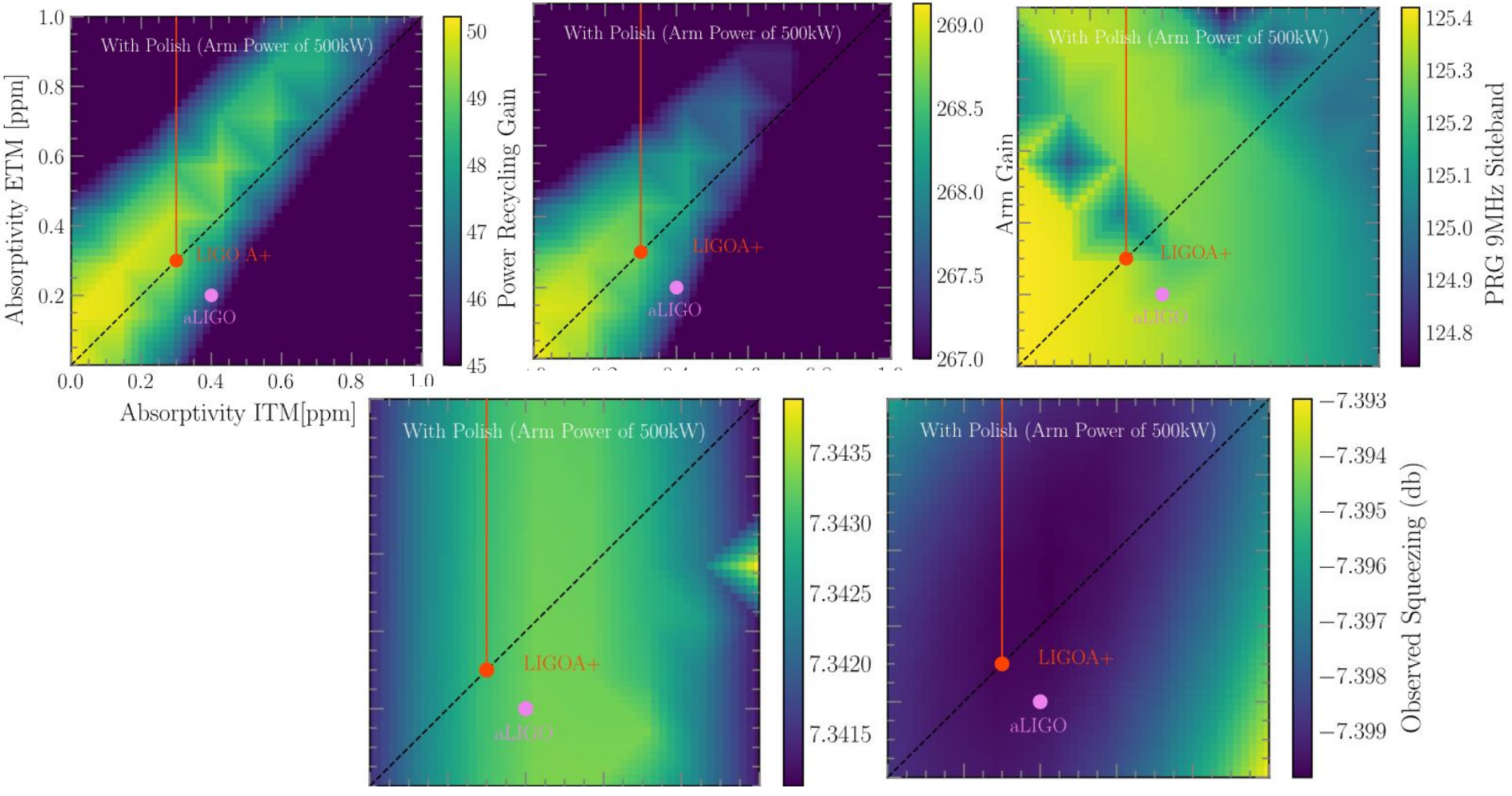

With Polish (Arm Power of 750kW)
LIGOA+
aLIGO
Arm Gain
268
266
264
262
260

With Polish (Arm Power of 750kW)
LIGOA+
aLIGO
PRG 9MHz Sideband
125
124
123
122
121
120

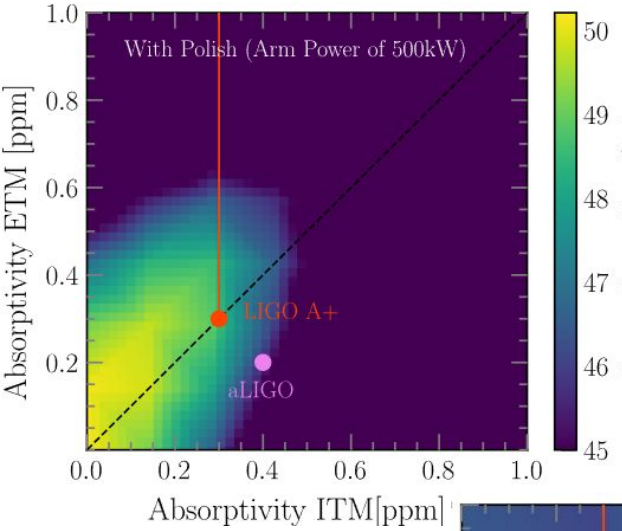

With Polish (Arm Power of 750kW)
LIGOA+
aLIGO
PRG 45MHz Sideband
8.0
7.8
7.6
7.4

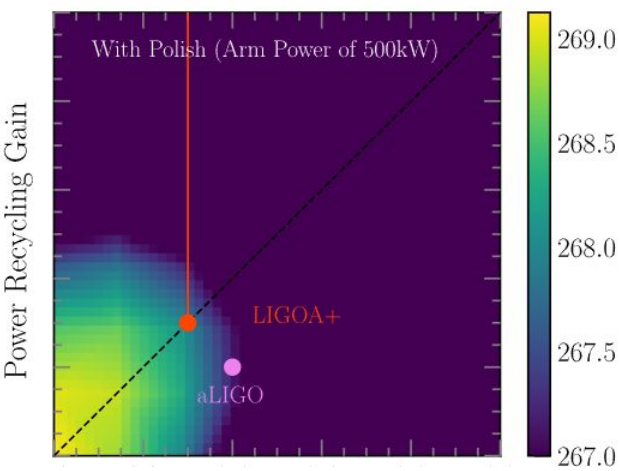

With Polish (Arm Power of 750kW)
LIGOA+
aLIGO
Observed Squeezing (db)
−7.1
−7.2
−7.3

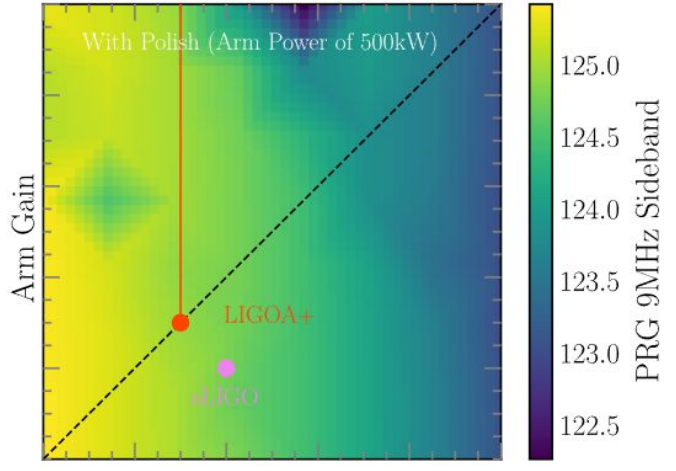
Current 500kw

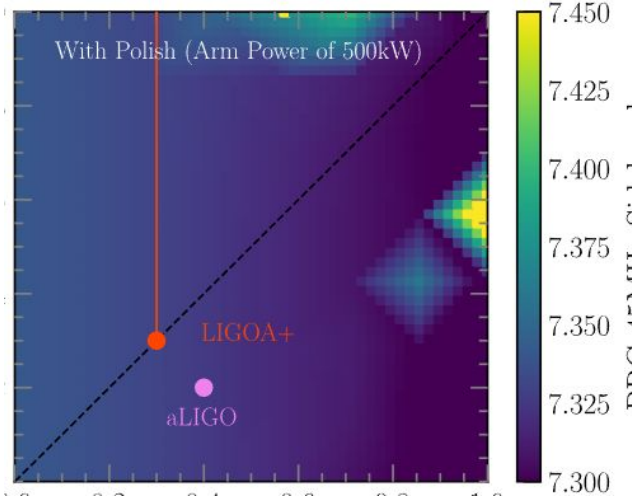


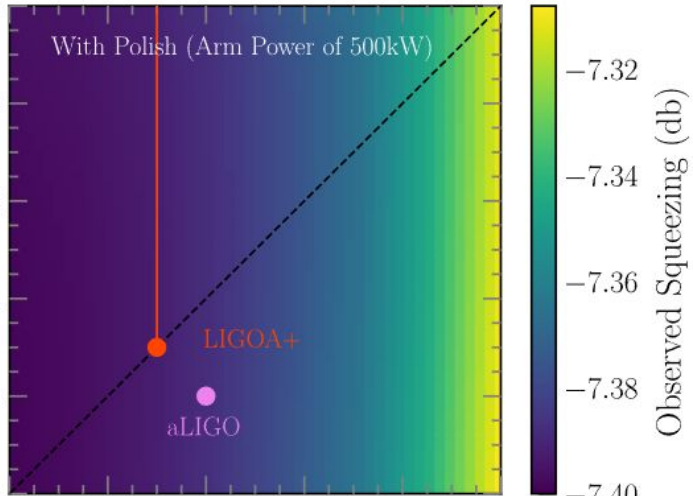
ITM 500kw


With Polish (Arm Power of 500kW)
LIGO A+
aLIGO
Absorptivity ETM [ppm]
Absorptivity ITM[ppm]
1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
0.6
0.8
1.0

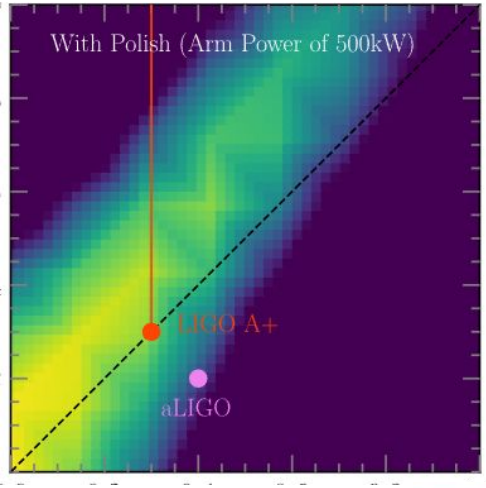

With Polish (Arm Power of 500kW)
LIGOA+
aLIGO
Power Recycling Gain
50
49
48
47
46
45

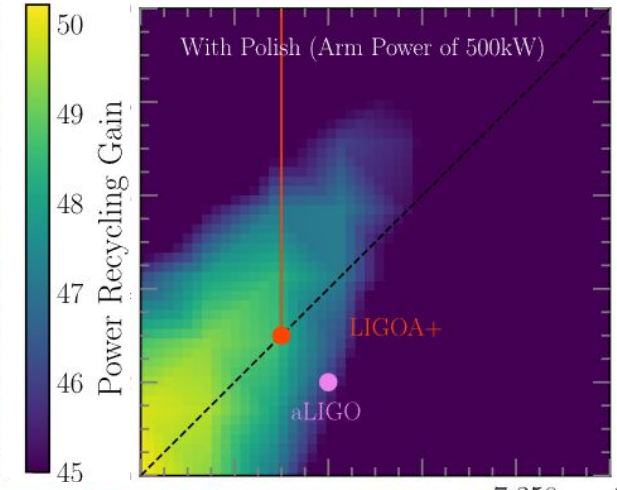

With Polish (Arm Power of 500kW)
LIGOA+
aLIGO
Arm Gain
PRG 9MHz Sideband
269.0
268.5
268.0
267.5
267.0
125.0
124.5
124.0
123.5
123.0
122.5


With Polish (Arm Power of 500kW)
LIGOA+
aLIGO
PRG 45MHz Sideband
7.450
7.425
7.400
7.375
7.350
7.325
7.300

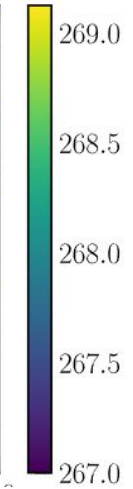

With Polish (Arm Power of 500kW)
LIGOA+
aLIGO
Observed Squeezing (db)
−7.32
−7.34
−7.36
−7.38
−7.40

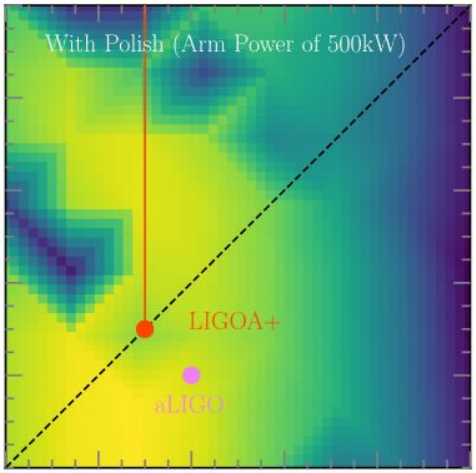
ETM 500kw

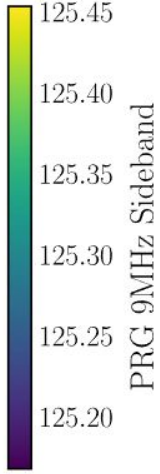

With Polish (Arm Power of 500kW)
LIGO A+
aLIGO

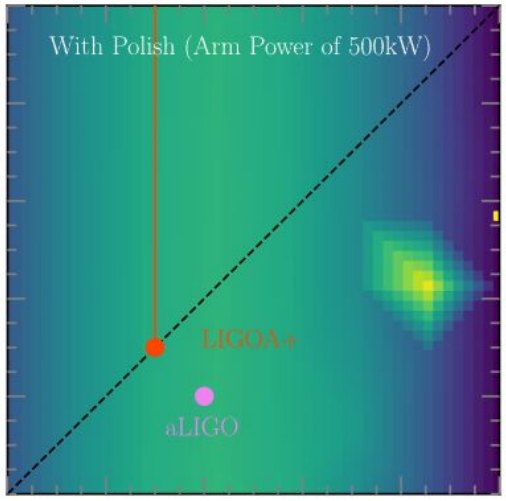

50
49
48
47
46
45
Power Recycling Gain

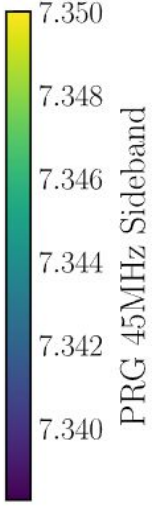
With Polish (Arm Power of 500kW)
LIGOA+
aLIGO

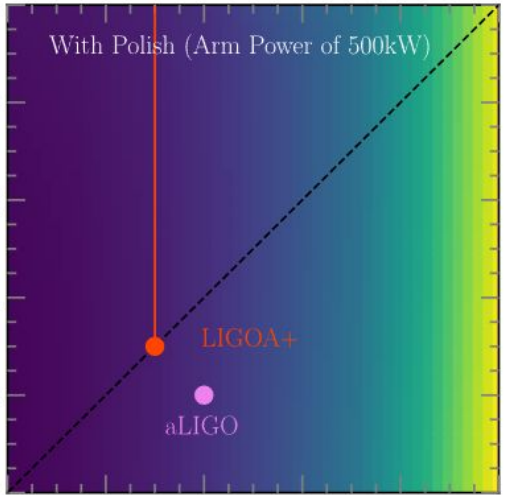

269.0
268.5
268.0
267.5
267.0
Arm Gain

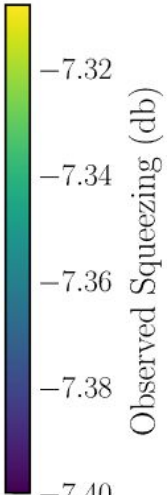

With Polish (Arm Power of 500kW)
LIGOA+
aLIGO


125.45
125.40
125.35
125.30
125.25
125.20
PRG 9MHz Sideband

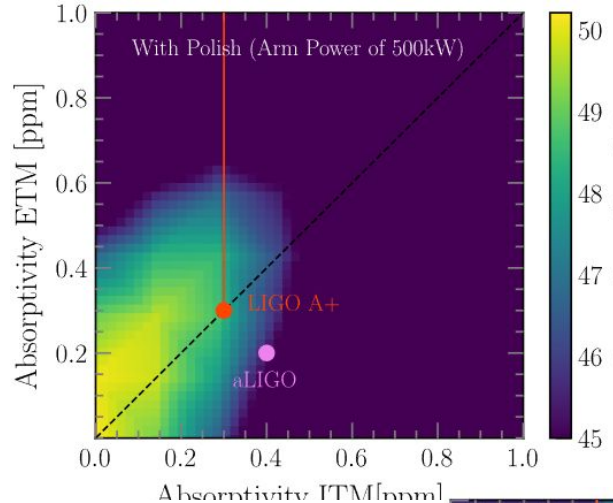

With Polish (Arm Power of 500kW)
LIGOA+
aLIGO

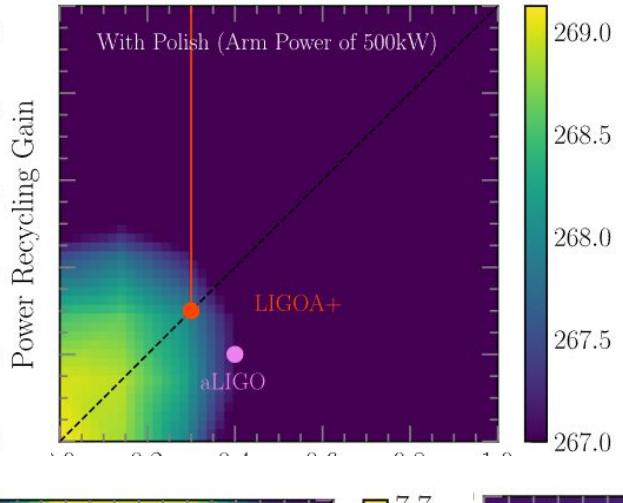

7.350
7.348
7.346
7.344
7.342
7.340
PRG 45MHz Sideband

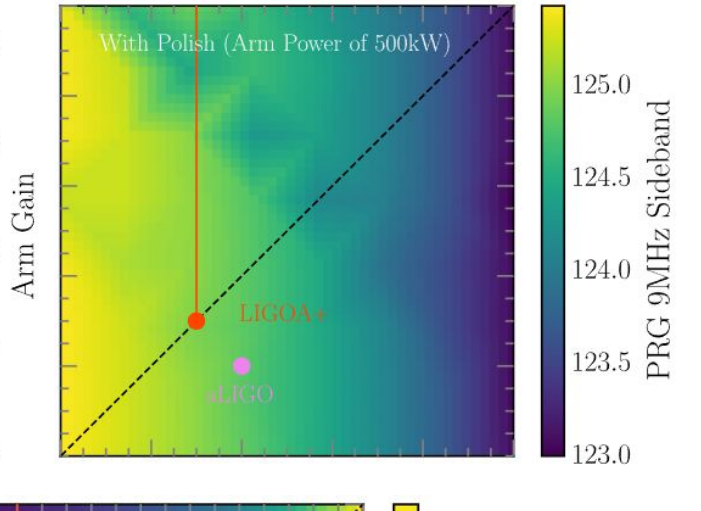

With Polish (Arm Power of 500kW)
LIGOA+
aLIGO

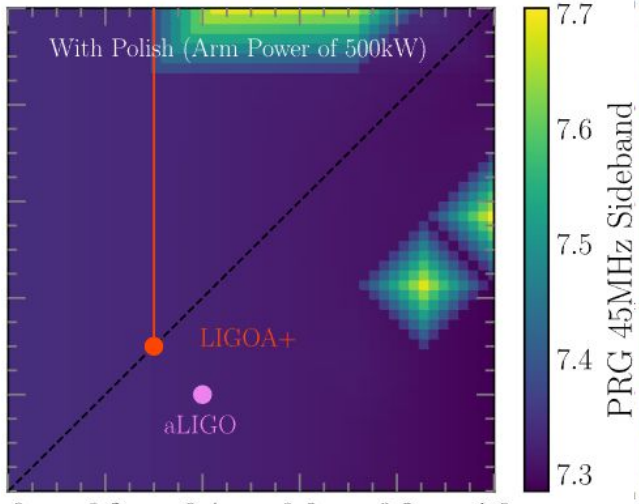

−7.32
−7.34
−7.36
−7.38
−7.40
Observed Squeezing (db)

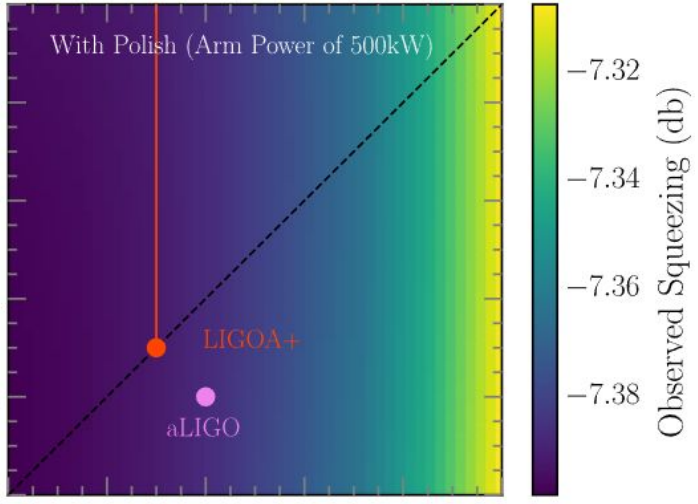
Dual 500kW


With Polish (Arm Power of 500kW)
LIGO A+
aLIGO
Absorptivity ETM [ppm]
Absorptivity ITM[ppm]
0.0
0.2
0.4
0.6
0.8
1.0
45
46
47
48
49
50

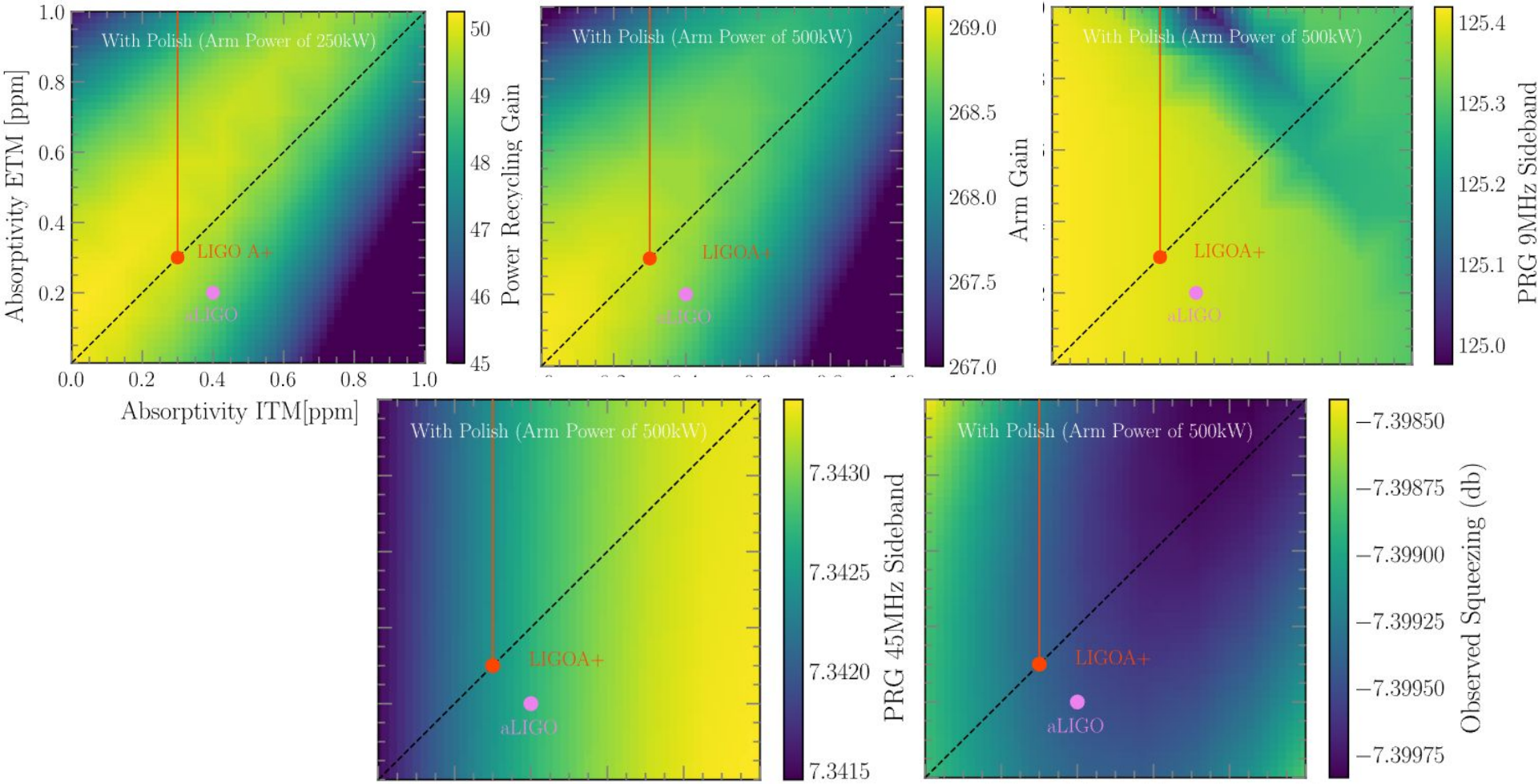

With Polish (Arm Power of 500kW)
LIGOA+
aLIGO
Power Recycling Gain
267.0
267.5
268.0
268.5
269.0


With Polish (Arm Power of 500kW)
LIGOA+
aLIGO
Arm Gain
PRG 9MHz Sideband
123.0
123.5
124.0
124.5
125.0

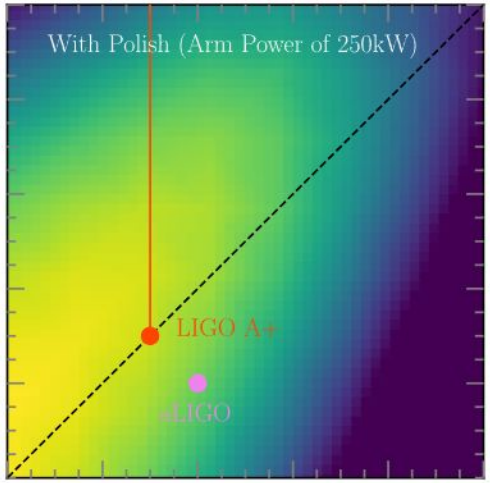

With Polish (Arm Power of 500kW)
LIGOA+
aLIGO
PRG 45MHz Sideband
7.3
7.4
7.5
7.6
7.7

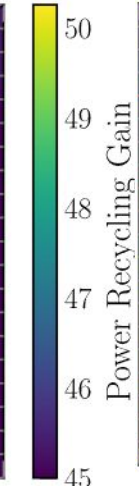

With Polish (Arm Power of 500kW)
LIGOA+
aLIGO
Observed Squeezing (db)
−7.38
−7.36
−7.34
−7.32

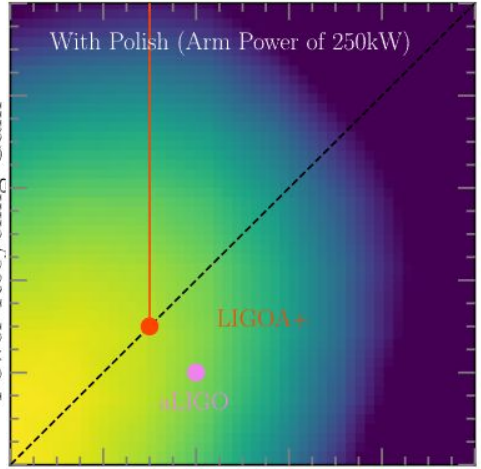
Current (250kw)

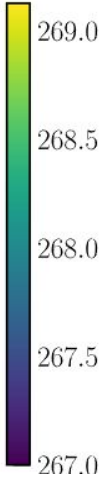


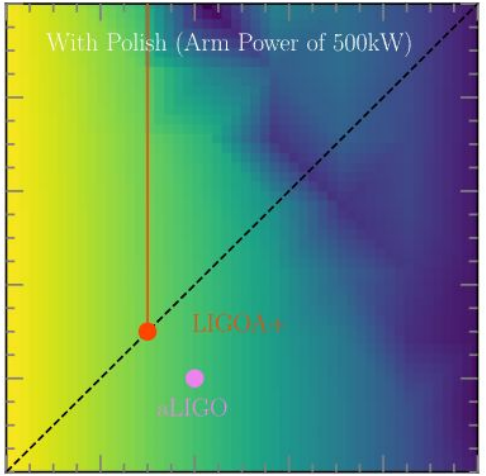
ITM 250kw

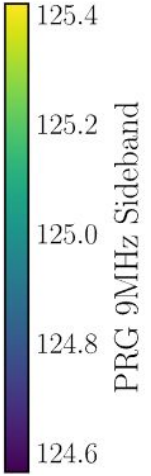

With Polish (Arm Power of 250kW)
LIGO A+
aLIGO

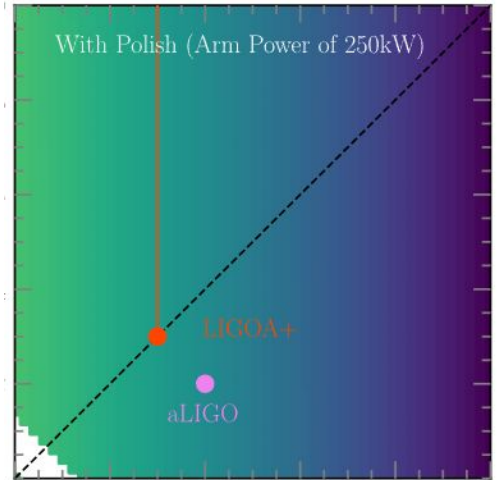

50
49
48
47
46
45
Power Recycling Gain

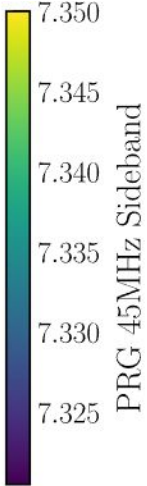

With Polish (Arm Power of 250kW)
LIGOA+
aLIGO

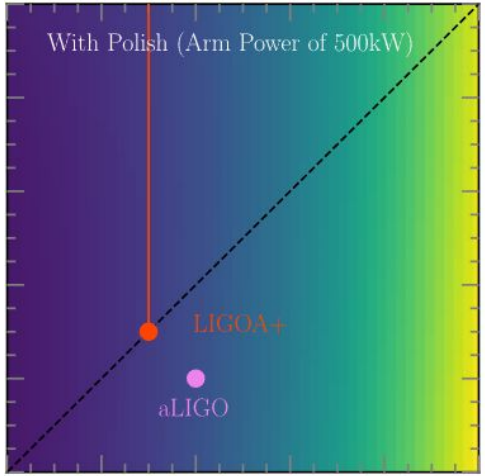

269.0
268.5
268.0
267.5
267.0
Arm Gain

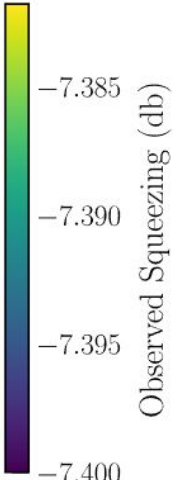

With Polish (Arm Power of 500kW)
LIGOA+
aLIGO


125.4
125.2
125.0
124.8
124.6
PRG 9MHz Sideband

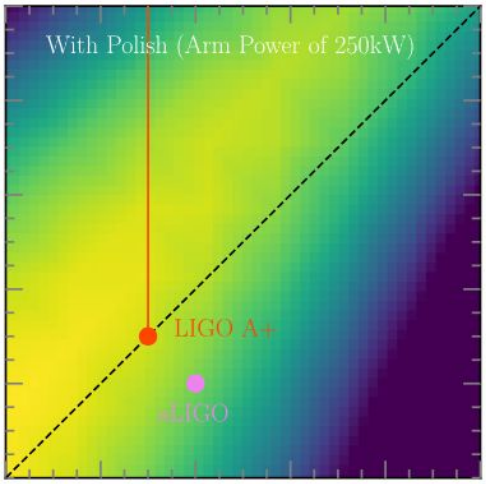

With Polish (Arm Power of 250kW)
LIGOA+
aLIGO

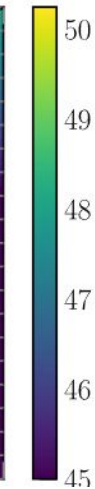

7.350
7.345
7.340
7.335
7.330
7.325
PRG 45MHz Sideband

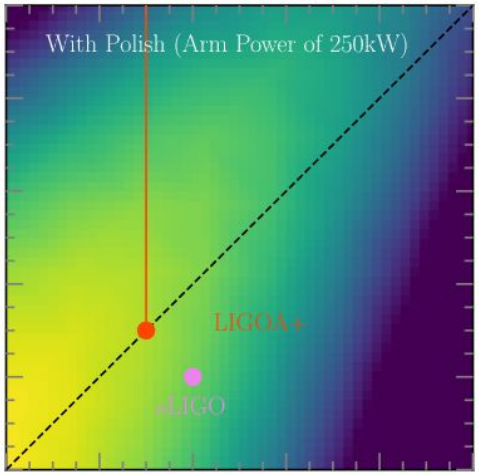

With Polish (Arm Power of 500kW)
LIGOA+
aLIGO


−7.385
−7.390
−7.395
−7.400
Observed Squeezing (db)

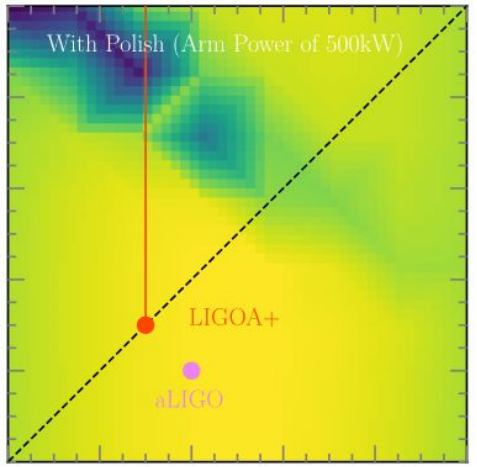
ETM 250kw

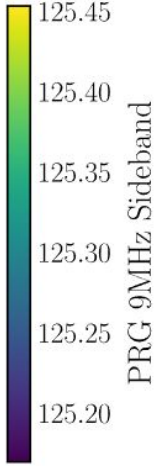

With Polish (Arm Power of 250kW)
LIGO A+
aLIGO

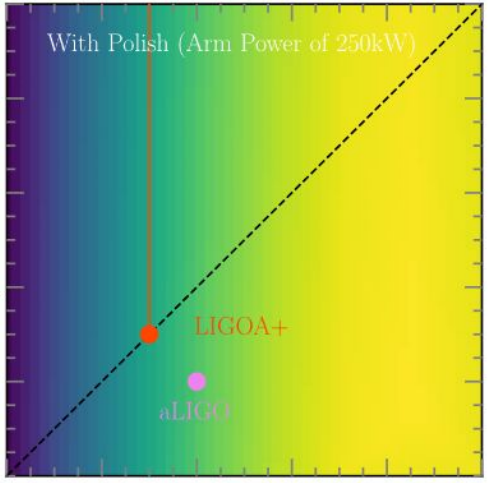

50
49
48
47
46
45
Power Recycling Gain

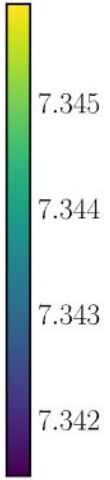

With Polish (Arm Power of 250kW)
LIGOA+
aLIGO

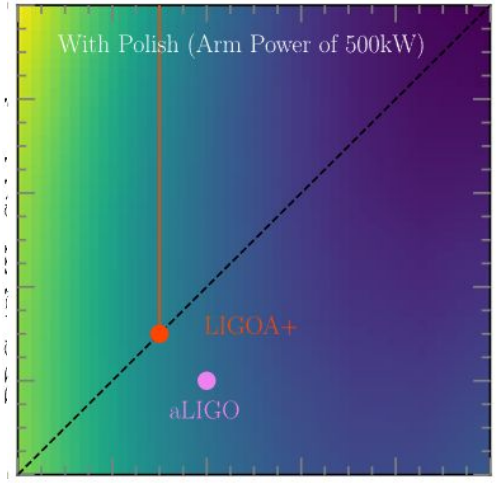

269.0
268.5
268.0
267.5
267.0
Arm Gain

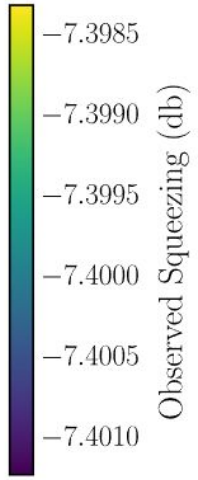

With Polish (Arm Power of 500kW)
LIGOA+
aLIGO


125.45
125.40
125.35
125.30
125.25
125.20
PRG 9MHz Sideband

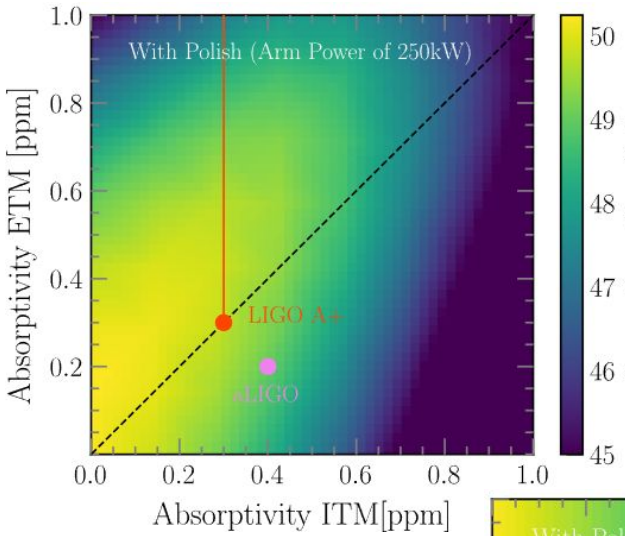

With Polish (Arm Power of 250kW)
LIGOA+
aLIGO

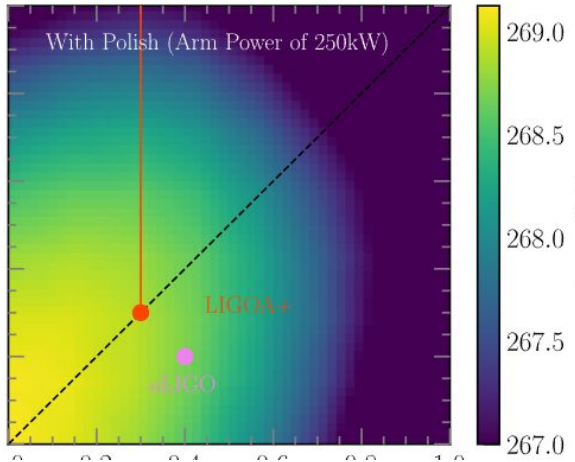

7.345
7.344
7.343
7.342

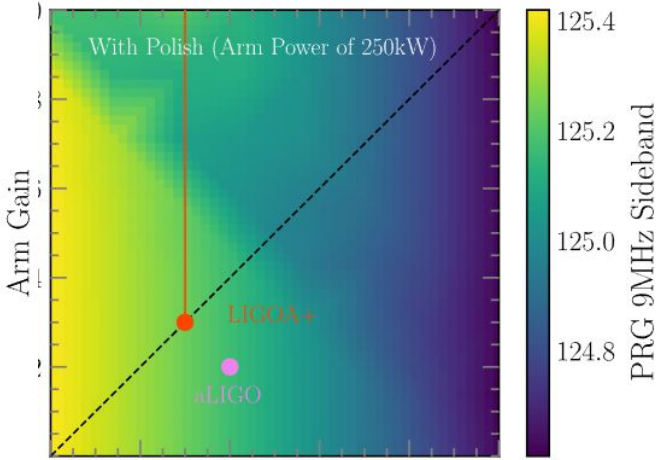

With Polish (Arm Power of 500kW)
LIGOA+
aLIGO

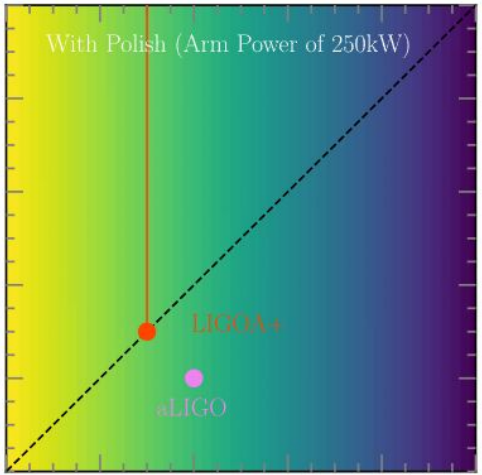

−7.3985
−7.3990
−7.3995
−7.4000
−7.4005
−7.4010
Observed Squeezing (db)

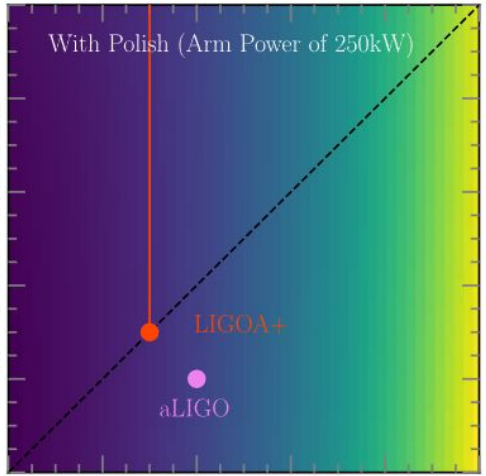
Dual 250kw


With Polish (Arm Power of 250kW)
LIGO A+
aLIGO
Absorptivity ETM [ppm]
Absorptivity ITM[ppm]
1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
0.6
0.8
1.0
50
49
48
47
46
45


With Polish (Arm Power of 250kW)
LIGOA+
aLIGO
Power Recycling Gain
269.0
268.5
268.0
267.5
267.0


With Polish (Arm Power of 250kW)
LIGOA+
aLIGO
Arm Gain
PRG 9MHz Sideband
125.4
125.2
125.0
124.8


With Polish (Arm Power of 250kW)
LIGOA+
aLIGO
7.340
7.335
7.330
7.325


With Polish (Arm Power of 250kW)
LIGOA+
aLIGO
PRG 45MHz Sideband
Observed Squeezing (db)
−7.3825
−7.3850
−7.3875
−7.3900
−7.3925
−7.3950
−7.3975