LIGO: The A+ Upgrade

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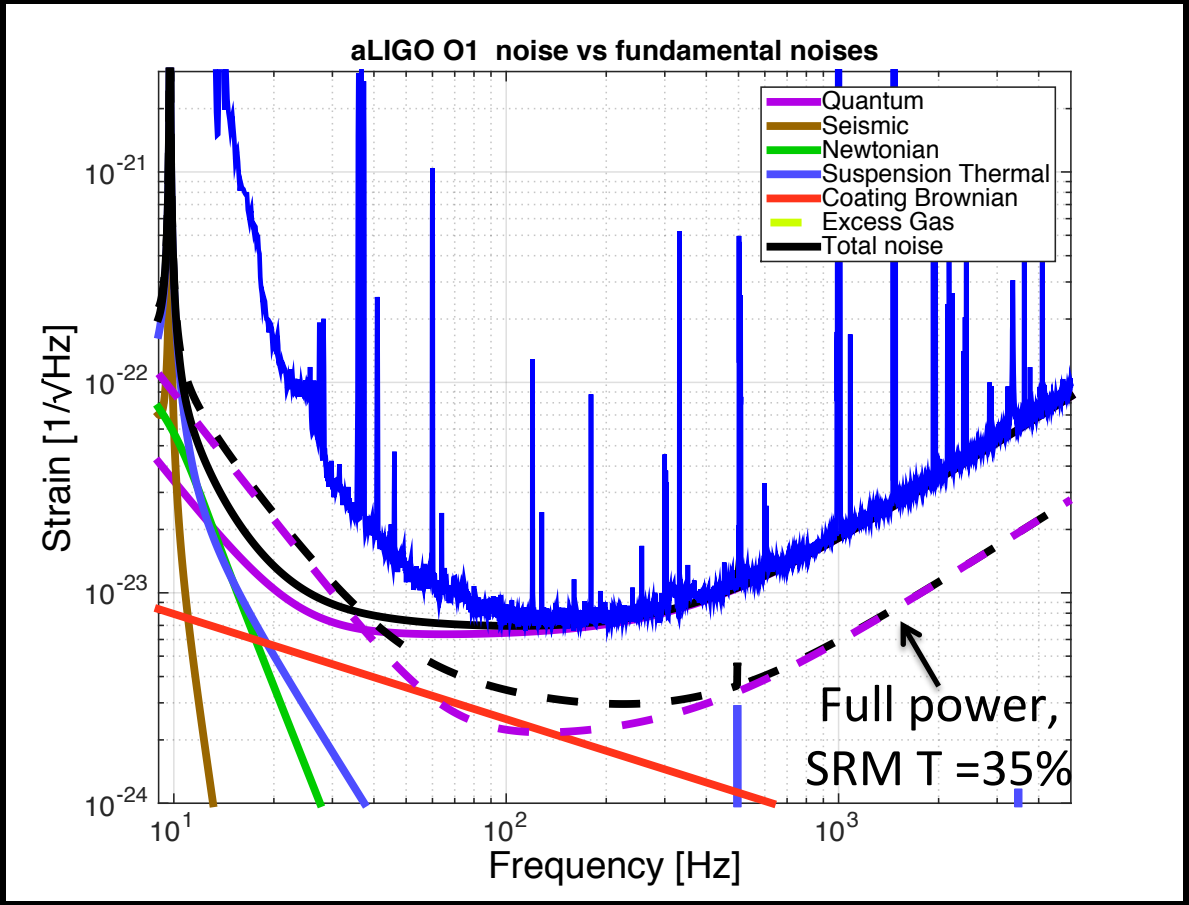
aLIGO near term progression



- Technical noise reduction, higher power, "fixes", improvements from lessons learned
- Sequence of observing runs; global GW network expansion
- Some squeezing enhancement

aLIGO+ (a.k.a A+): what

- Upgrade to aLIGO in current facility that leverages existing technology
- 34 cm/40 kg optics, fused silica, 1064nm, room temperature, power as high as possible
- Targeting a factor of 2 reduction in coating thermal noise and quantum noise over aLIGO design:
  - Frequency dependent squeezing with low loss injection/readout
  - Lower coating thermal noise
    (more on this later - baseline idea: recoat spare substrates with improved room temperature, 1064nm coating, once available)
  - Also incorporate “major” lessons learned from aLIGO (possibly: larger beam splitter, lower loss arm mirrors, …)

A+ “conservative” curve
(from LSC instrument science white paper T1500290)

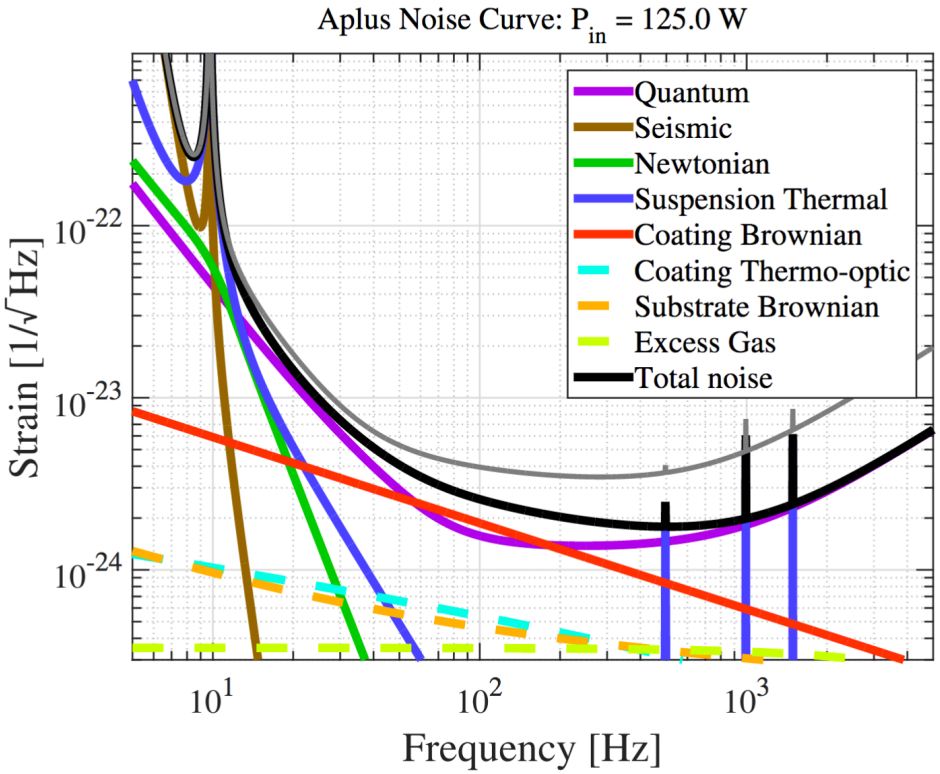


Figure 3: Strain sensitivity of A+ (BNS range of 320 Mpc). The results of improved quantum noise (16 m filter cavity and 6 dB of measured squeezing at high frequency) and modestly improved thermal noise (factor of two lower loss high index material), are shown. The Advanced LIGO sensitivity curve is show in gray for reference.

A+: how

- Can imagine a 2-phase scenario:
  - low loss squeezing enhancement at high frequency first (with short filter cavity for “no damage” at low frequency), as well as incorporate “major” lessons learned from aLIGO
  - then replace optics for lower coating thermal noise and consider “better” filter cavity (possibly longer) for broadband quantum noise enhancement

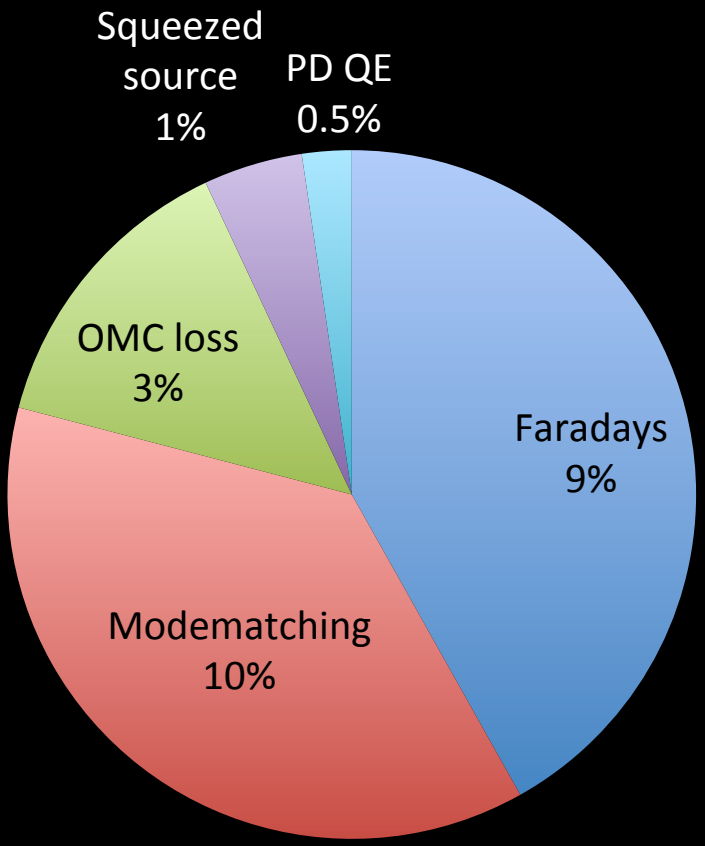
(Comoving) Ranges

	BNS (Mpc)	BBH (Gpc)
aLIGO full power, no technical noises	200	1.4
"Modest" quantum noise reduction ONLY	240	1.7
A factor of 4 coating mechanical loss reduction ONLY	240	1.7
Both improvements together	330	2.1

Inspiral range with cosmology (J. Miller, T1500491)
Calculations based on "Prospects for doubling the range of Advanced LIGO"
John Miller et al, Phys. Rev. D 91, 062005

Loss

If we were injecting squeezing in aLIGO today,
we would have at least 25% loss coming from well quantified sources



Mode matching is tricky..

Active Wavefront Control white paper: https://dcc.ligo.org/T1500188-v5 , A. Brooks et al.

- 8 modes
  - SRC, PRC
  - XARM, YARM
  - OMC, IMC
  - SQZ, FC
- Multiple mode matching actuators required
- Have to match beam size and ROC

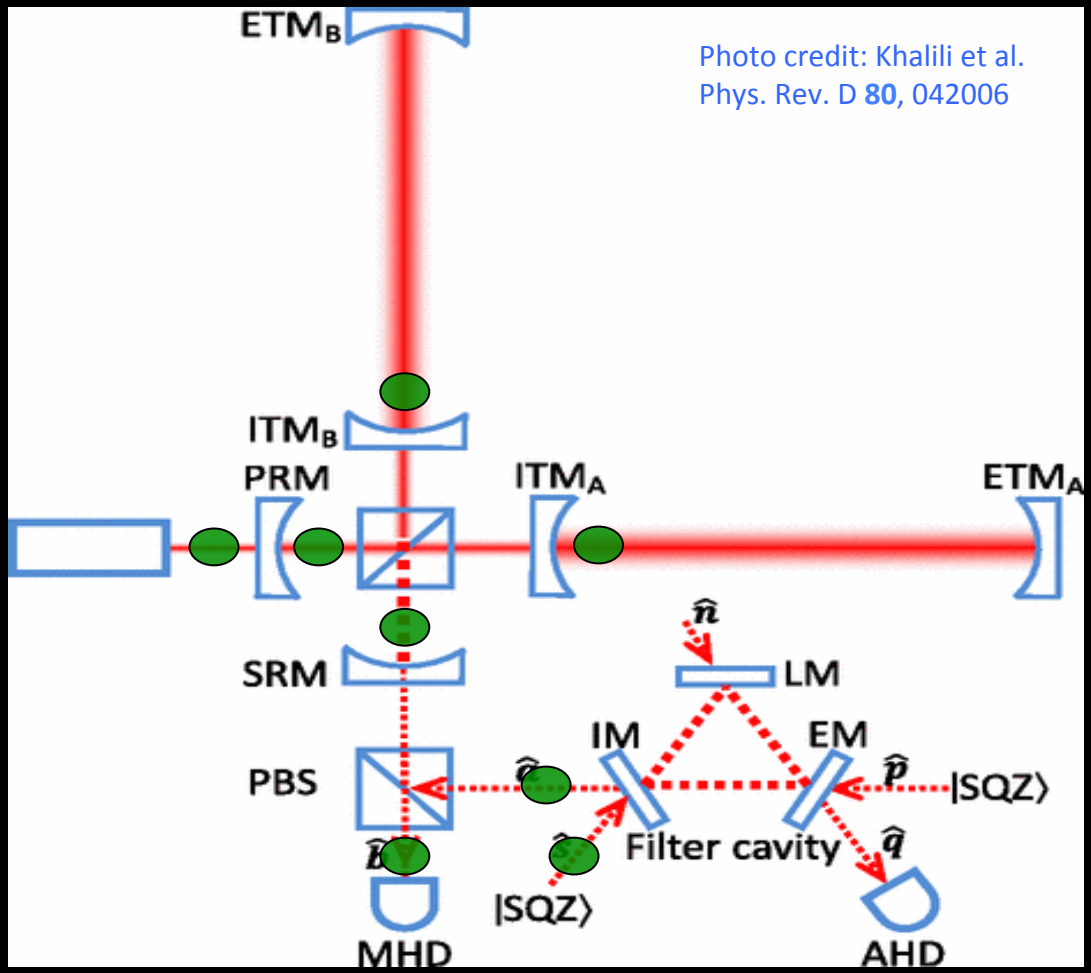


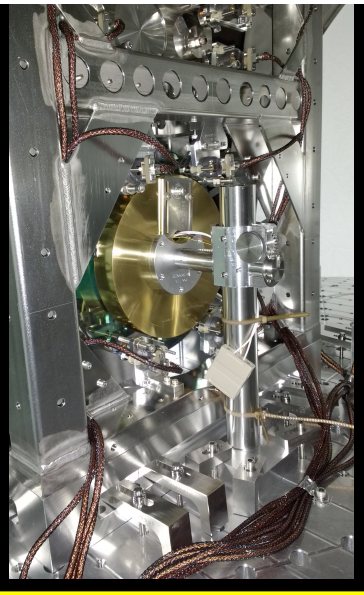
Photo credit: Khalili et al.
Phys. Rev. D **80**, 042006

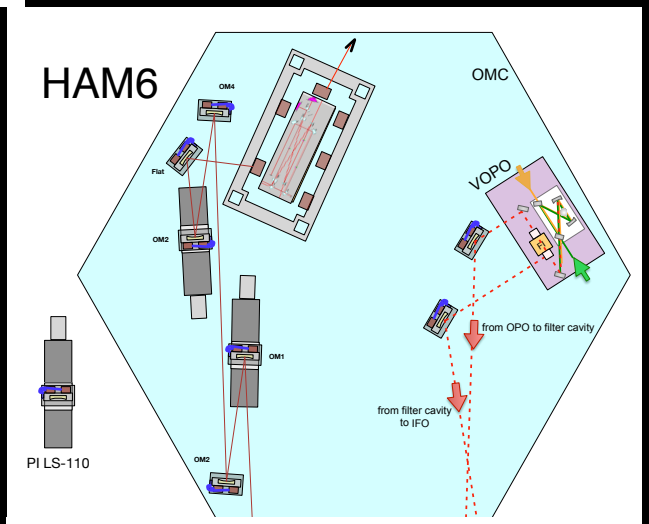
Tentative mode matching targets

Active Wavefront Control white paper: https://dcc.ligo.org/T1500188-v5 , A. Brooks et al.

- Quantify and understand interferometer matching problems[1]:
  - ARM > SRC > OMC
- O3: Add actuators[2]
  - SR3, PR3, OMC x 2
  - SQZ, FC?
- O3: Sensors at output
  - Bullseye[3]
  - Phase camera
- O3: Control strategy
  - Actuation matrix[4]
  - Gain hierarchy
  - **What range is required?**
- A+: Plug n' Play actuator[5]

Signal Recycling Cavity mirror (SR3) heating element just installed at LLO

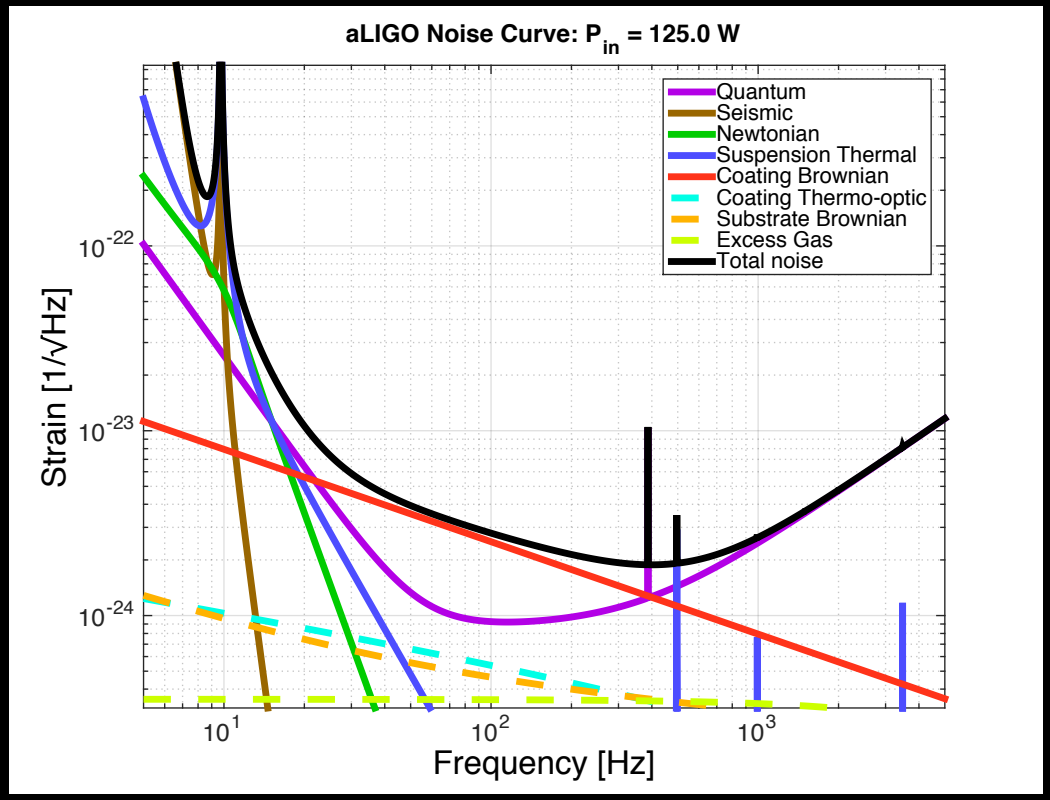




Possible optical layout [Syracuse]

[1] aLIGO measurements
[2] G1601166 (Syracuse, CIT)
[3] G1501376 (Florida, Syracuse)
[4] G1600770 (Florida, CIT)
[5] G1601156 (Adelaide)

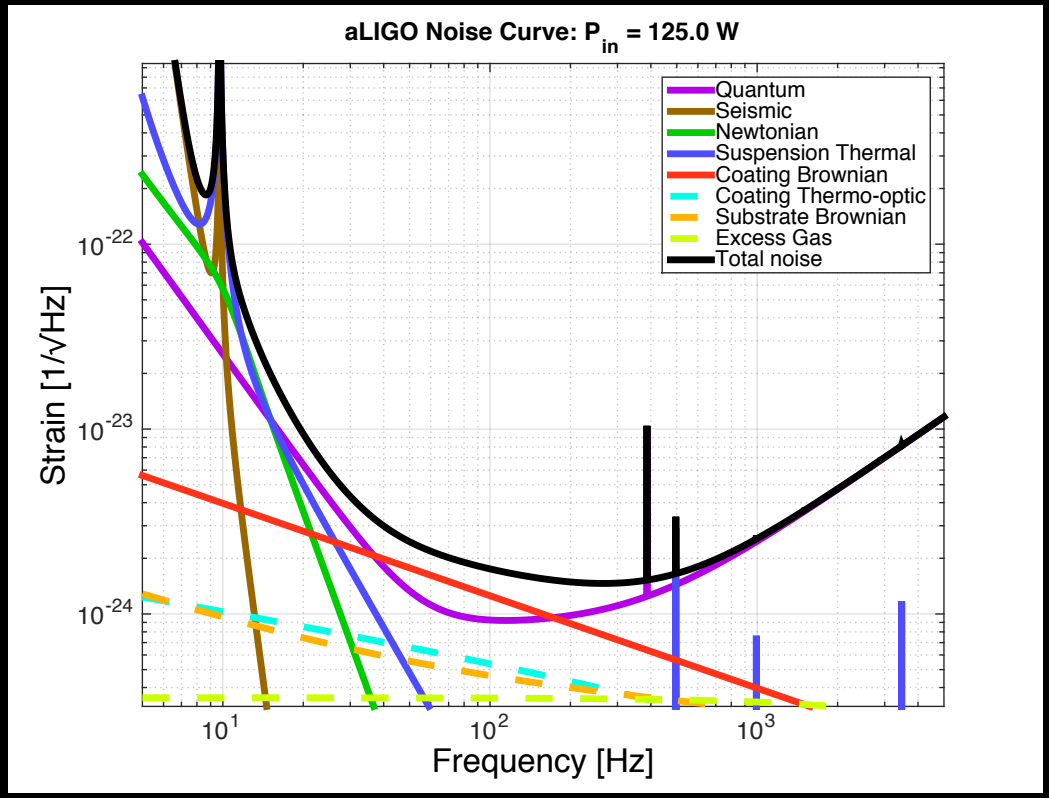
Low loss, optimistic squeezing (but no coating improvement)



You are injecting 12 dB of squeezing with optimal frequency dependent squeezing angle

Laser Power: 125.00 Watt
SRM Detuning: 0.00 degree
SRM transmission: 0.3500
ITM transmission: 0.0140
PRM transmission: 0.0300
Finesse: 446.41
Power Recycling Factor: 40.54
Arm power: 710.81 kW
Power on beam splitter: 5.07 kW
Thermal load on ITM: 0.385 W
Thermal load on BS: 0.051 W
BNS range: 278.18 Mpc (comoving)
BBH range: 1.85 Gpc (comoving, z = 0.5)

Low loss, optimistic squeezing and twice lower coating thermal noise



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Power on beam splitter: 5.07 kW
Thermal load on ITM: 0.385 W
Thermal load on BS: 0.051 W
BNS range: 399.28 Mpc (comoving)
BBH range: 2.46 Gpc (comoving, z = 0.7)

Conclusions

- Post-detection era will see a sequence of observing runs and incremental upgrades
- A+ targets quantum noise and coating thermal noise reduction, up to a factor of 2 improvements over aLIGO design
  - "Flow" of improvements, following noise hunting and power increase progress
  - incorporate lessons learned from aLIGO