LIGO

What comes next for LIGO?

Improving the mid-frequency range

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Washington State

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LIGO-G1500599

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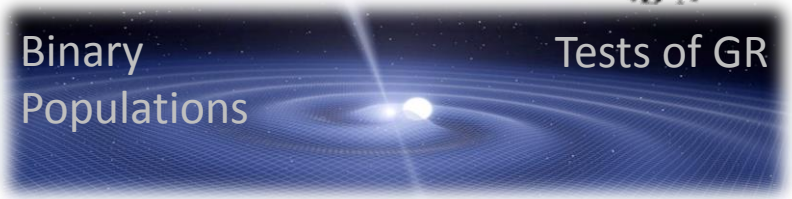
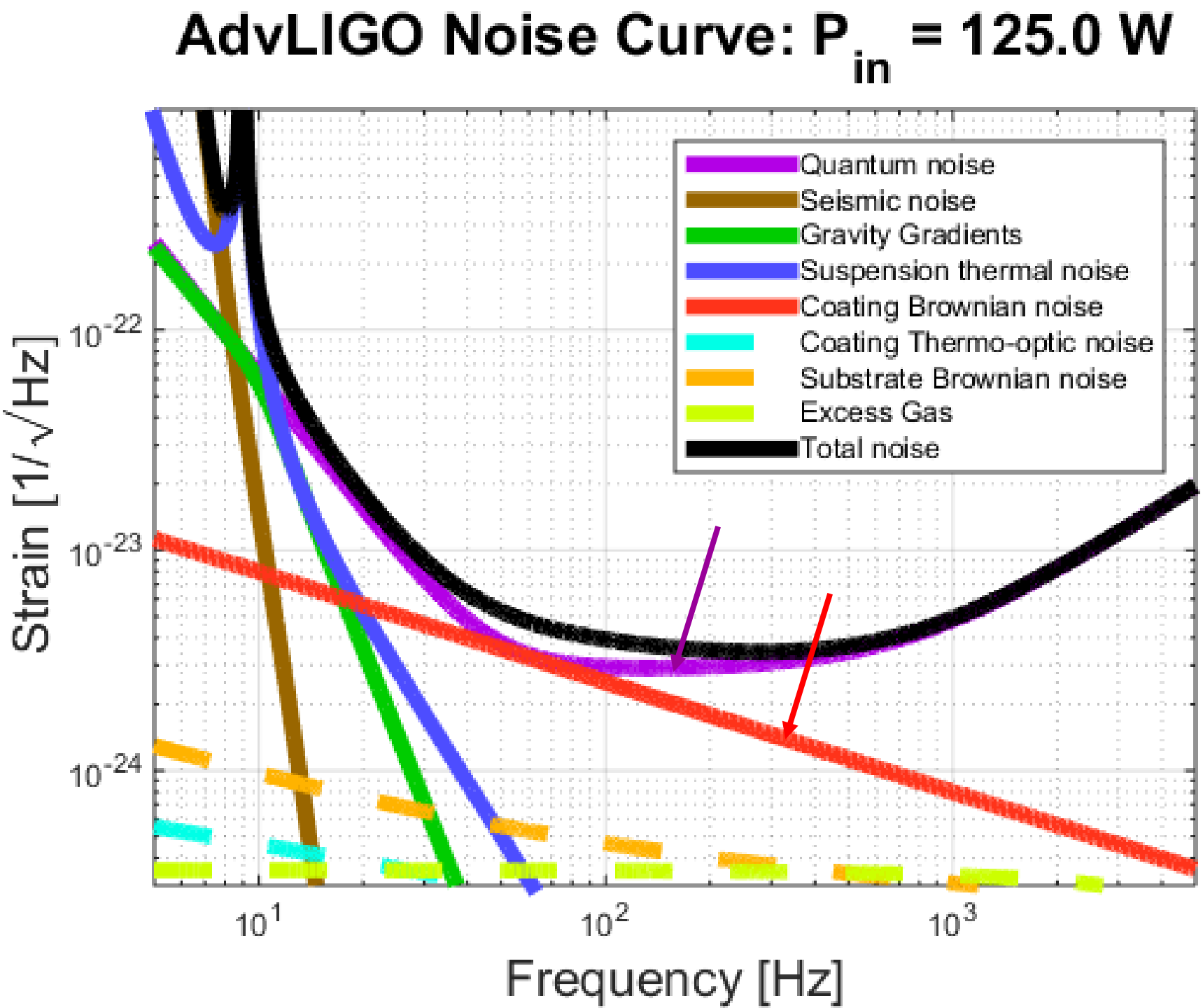
LIGO

Mid frequency

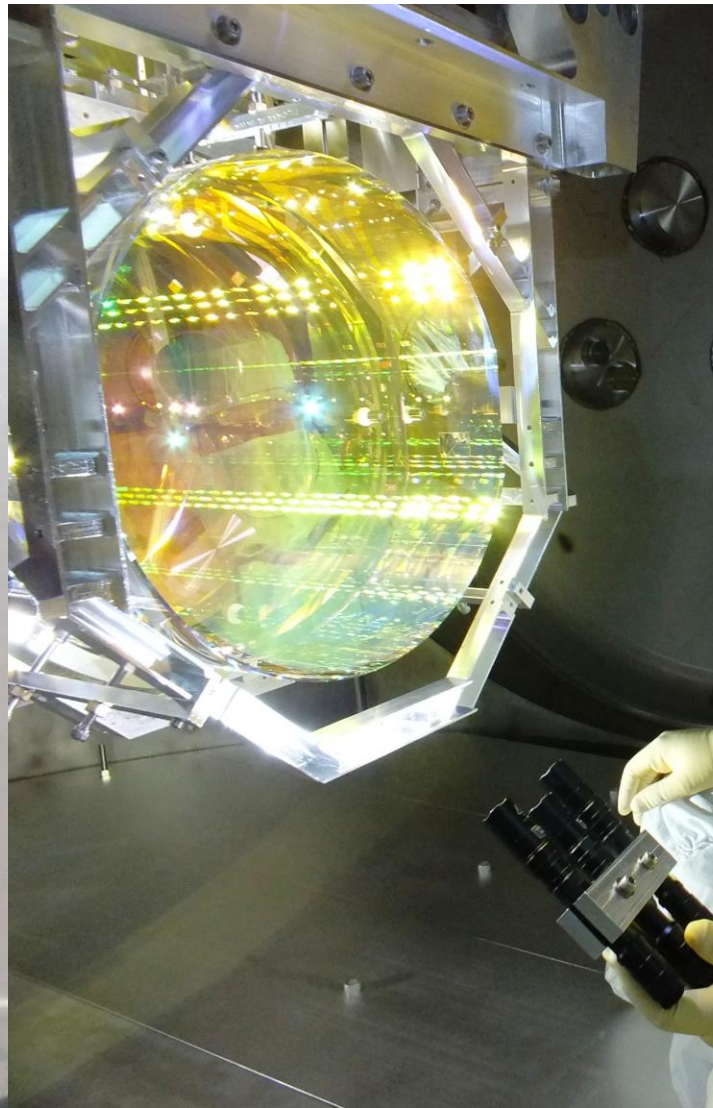


- ~30Hz - ~300Hz
  - (above seismic wall, below pure shot noise)
- Limited by
  - Quantum noise dominant in aLIGO (by design)
    - Can be lowered (Squeezing, detuning, SRM transm.) see Lisa's talk
  - Coating Brownian Noise
    - Just below quantum noise – reduces benefits from quantum noise improvements


AdvLIGO Noise Curve: P in = 125.0 W
Quantum noise
Seismic noise
Gravity Gradients
Suspension thermal noise
Coating Brownian noise
Coating Thermo-optic noise
Substrate Brownian noise
Excess Gas
Total noise
Strain [1/√Hz]
10-22
10-23
10-24
101
102
103
Frequency [Hz]

Coating Brownian Noise in aLIGO

- Dielectric coating:
  - Ti-doped Ta_2O_5 : SiO_2
  - Dominates mechanical loss
    - Ti:Ta_2O_5 Loss angle: ~2.5e-4 (Class. Quantum Grav. 24 405 (2007))
- This was just good enough for aLIGO
  - Drove the quantum noise design



Improving Coating Brownian Noise - 1

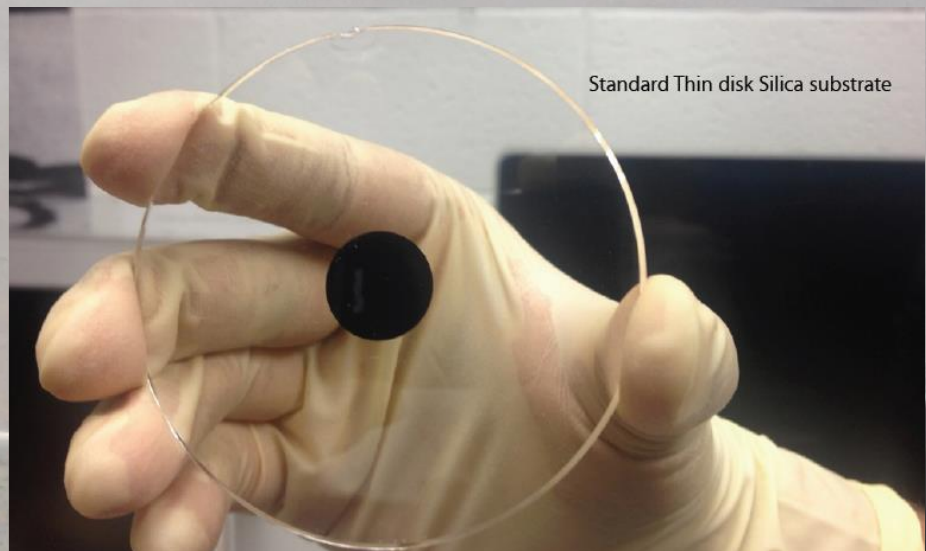
- Zirconia-Tantala stabilized coatings (very preliminary, LIGO-G1500350)
  - Trick:
    - 33-40% Zirconium prevents crystallization during annealing up to 800°C
    - Higher annealing temp. → lower mechanical loss
  - Early results indicate loss angles around 6e-5
  - Multi-material coating approach could use most of this even if optical absorption is high (Phys. Rev. D 91, 042002 (2015))

Improving Coating Brownian Noise - 1

- Best measurement so far:
  - loss angle = ~6e-5
  - Amplitude TN improvement over aLIGO: x 0.62
- With multi-material approach:
  - Assuming the Zirconia-Tanta optical absorption remains bad
  - Amplitude TN improvement over aLIGO: x 0.69

Improving Coating Brownian Noise - 2

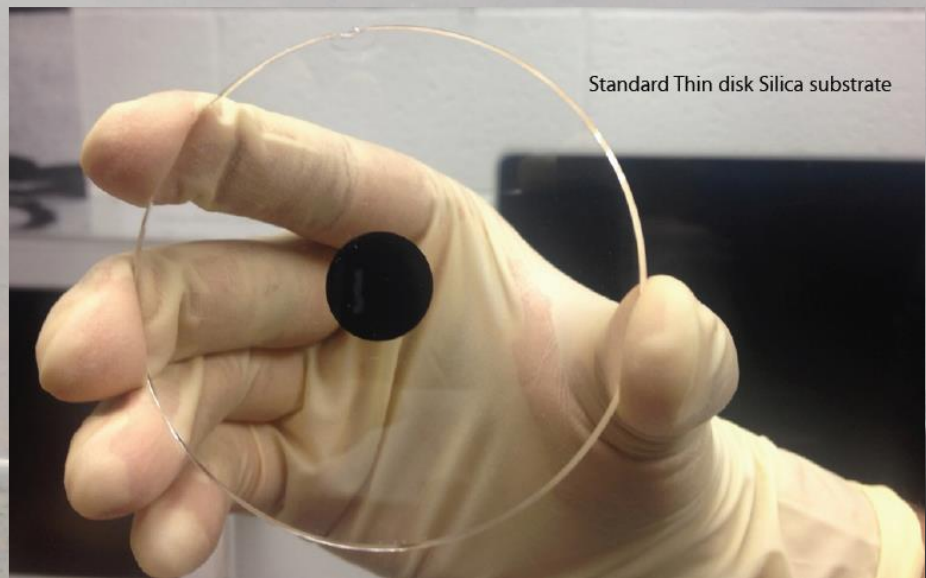
- $Al_{(1-x)}Ga_xAs$ crystalline coatings
  - Grown separately and transferred to substrate
  - Low thermal noise demonstrated:
    - Nature Photonics 7, 644–650 (2013): Loss angle ~2.5e-5
    - LIGO-G1500350 Ring-down: Loss angle ~3e-5
    - Amplitude TN improvement over aLIGO: x 0.4 (2.5 times better)
  - Thermal noise meas. in GW band in progress



Improving Coating Brownian Noise - 2

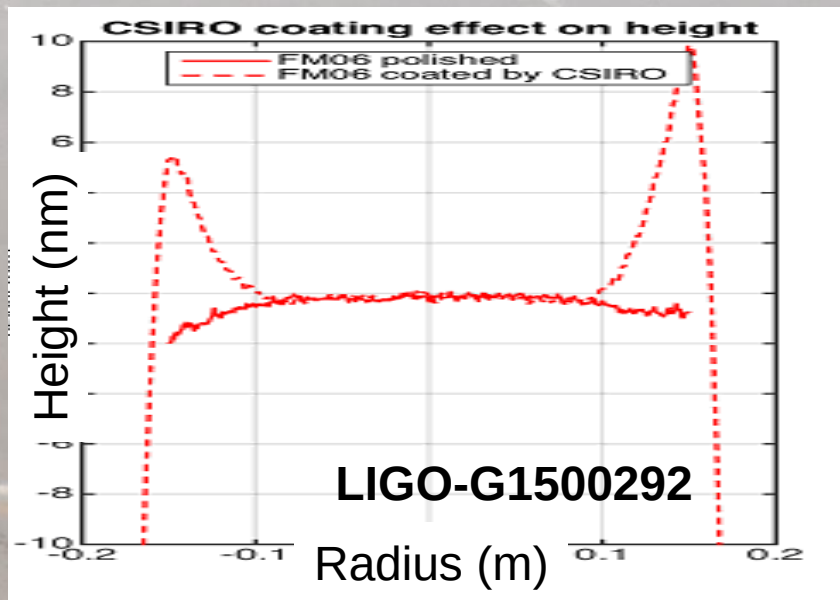
- Big remaining challenge for $Al_{(1-x)}Ga_xAs$:
  - Manufacture them with 34cm diameter
  - Transfer to LIGO-size optic

- R&D required
  - O(5 years)
  - O($10M) [roughly]

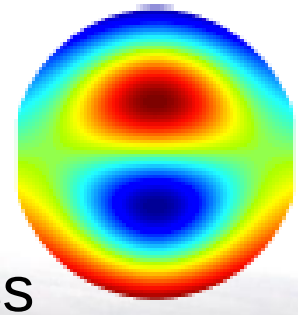


Improving Coating Brownian Noise - 3

- Alt. approach: Make beams BIGGER
  - Large area averaging helps: ampl. TN (beam w)
    - Current size optic, but better coating: x 0.83 (7.2cm)
    - 40cm diameter, better coating: x 0.67 (9cm)
    - 45cm diameter, better coating: x 0.60 (10cm)
  - Challenge:
    - Need flatter coatings
    - Alignment sensitivity ~w^6
    - Several limiting apertures
    - Requires suspension improvements

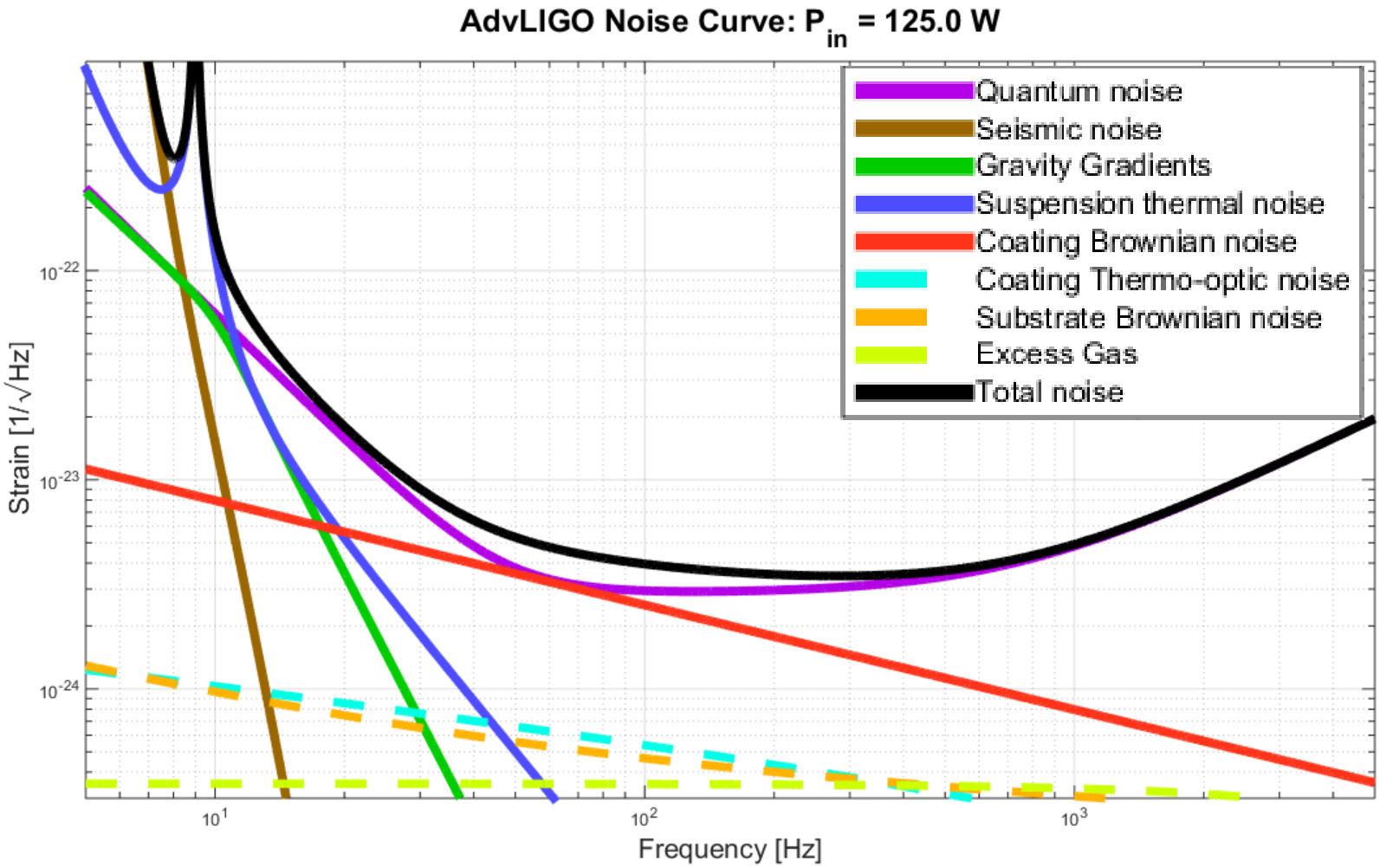


Improving Coating Brownian Noise - 3

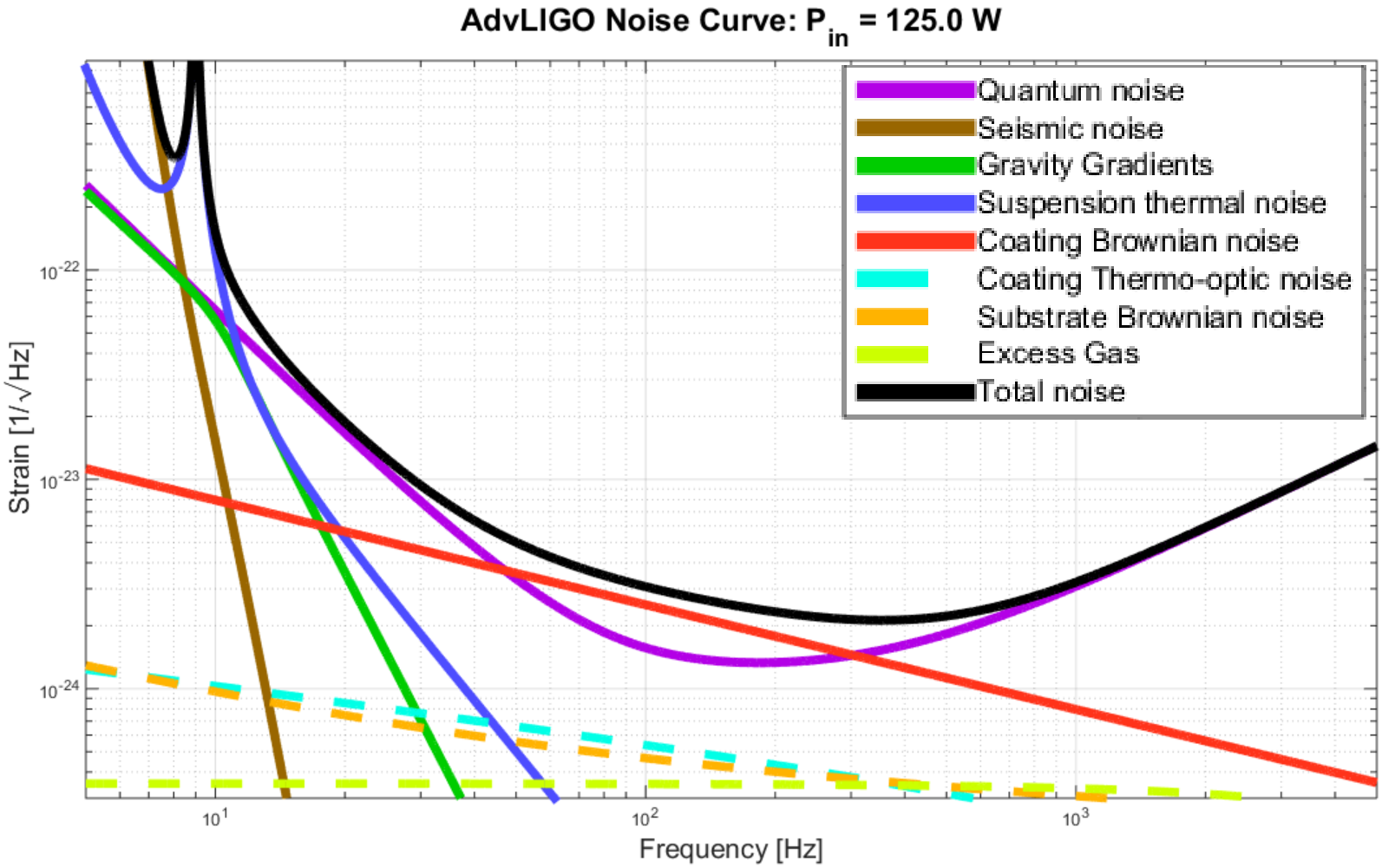


- Alt. approach: Make beams BIGGER
  - Side benefit:
    - Bigger beams →> slightly higher clipping loss (still not dominating the arm round trip loss)
    - Will make centering more important, BUT:
    - Helps reducing Parametric Instabilities (Higher loss in higher order spatial modes)

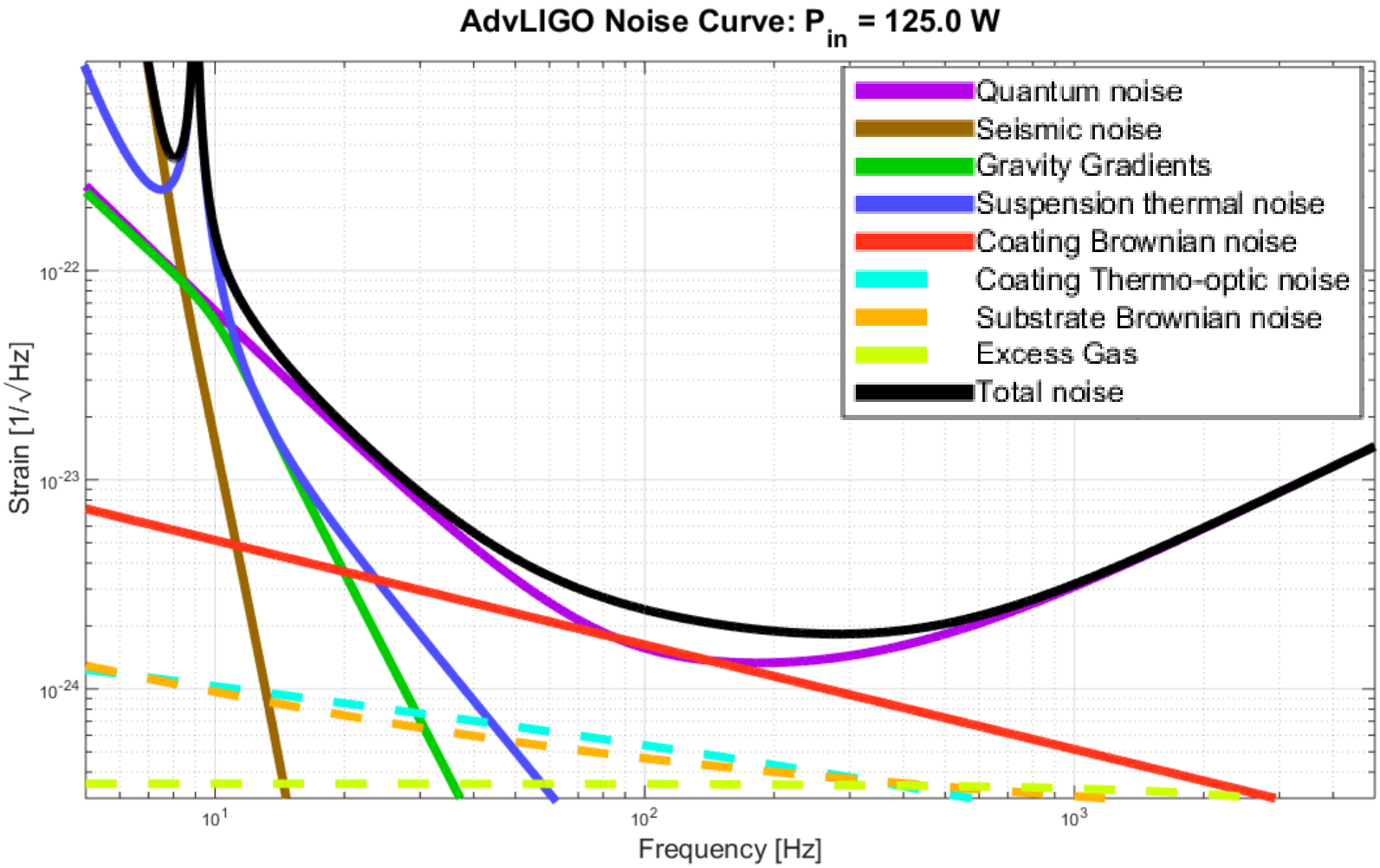
aLIGO: 210 Mpc



Sqz only: 260 Mpc

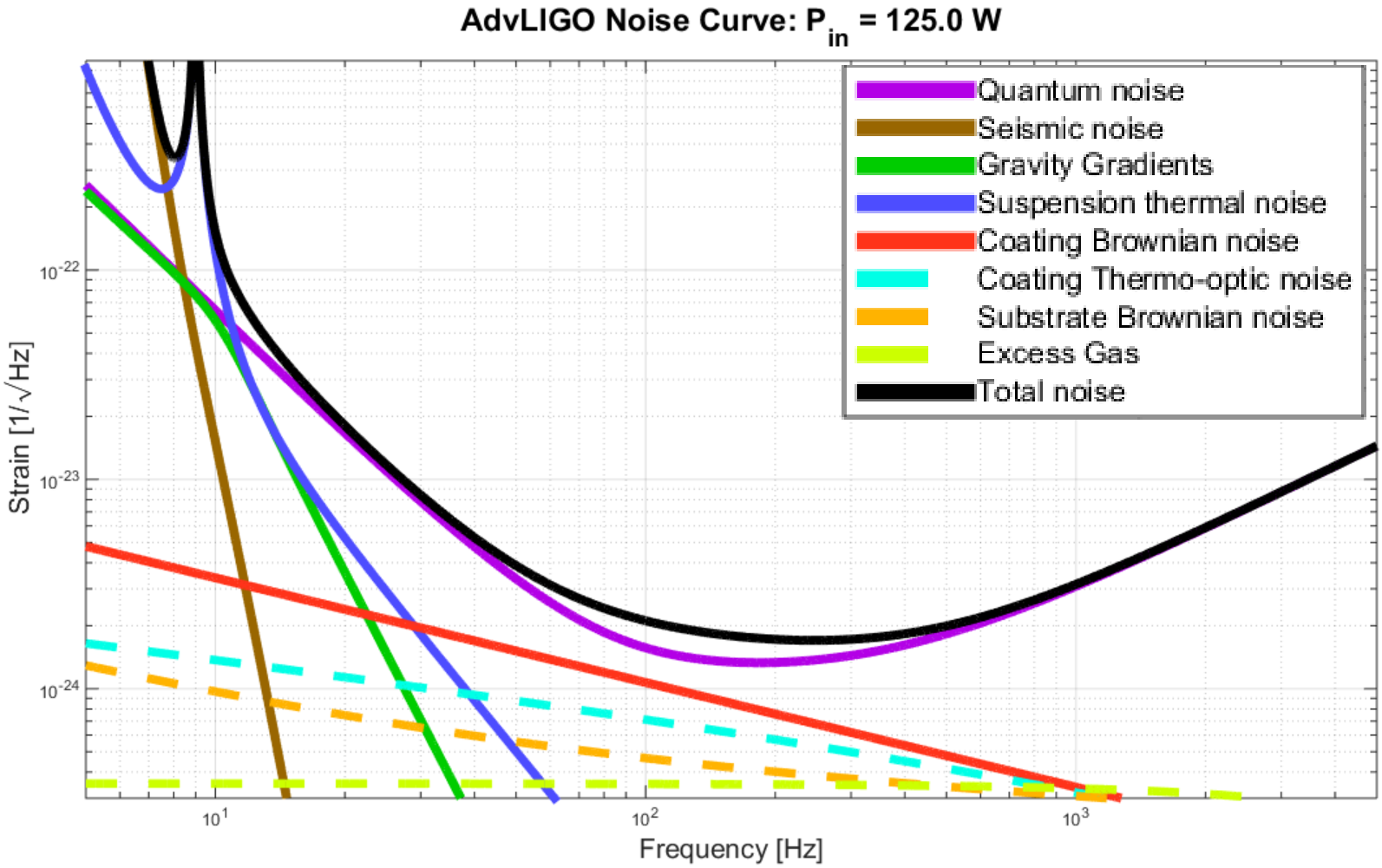


LIGO Sqz+Zirconia: 320 Mpc



LIGO Sqz+AlGaAs: 350 Mpc

Coating optimized for reducing thermo-optic noise



Achievable Improvements

- Here I already assume frequency-dependent squeezing (see Lisa's talk)
  - NS/NS Inspiral range (sky-average):
    - aLIGO: 210 Mpc
    - Sqz only: 260 Mpc
    - Sqz + Zirconia: 320 Mpc
    - Sqz + AlGaAs: 350 Mpc
- Detailed analysis of interdependencies:
  Phys. Rev. D 91, 062005

LIGO Cost and Readiness

- Very rough estimates:
  - New set of 40kg masses for 2 IFO: $5.5M
  - Used & spares republished/recoated: $4M
  - New set of 80kg masses for 2 IFO: $11M

  - R&D for Zirconia coatings: <1M over 1yr
  - R&D for scaling up AlGaAs: ~$10M over 5yrs

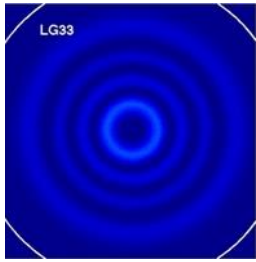
Conclusion
Mid-frequencies

- Reduce Coating Brownian noise key
  - At least two coating approaches promising
  - Larger beams can help a little
- Investment of ~ $5M - $10M needed
- Quantum noise upgrade (squeezing) is needed to take advantage

LIGO

Extra slides

Improving Coating Brownian Noise - 4



- Other geometries:
  - Laguerre-Gaussian beams
    - Larger averaging area for same Gaussian beam size
      - (Phys. Rev. Lett. 105, 231102)
    - But difficult to maintain good contrast defect (degeneracy)
      - (Phys. Rev. D 84, 102001)
  - Folded arm cavities
    - Ampl TN improvement of x 0.5 possible
      - (Phys. Rev. D 88, 062004)
    - Requires significant suspension and optics changes

LIGO aLIGO Risk mitigation?

- What is the actual thermal noise?
  - No direct TN measurement of LIGO optics yet
  - Best measurement so far: *Metrologia* **52** 17 (2015)
    - But different type of coating
- Reducing Coating Thermal noise could become top priority…