Impact of Coatings on the Cosmic Explorer Sensitivity

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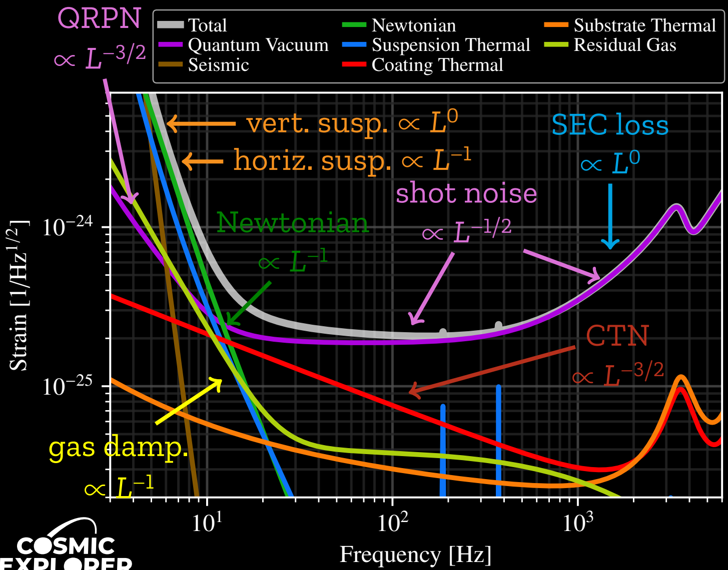
COSMIC EXPLORER

Scaling of fundamental noises



CTN not as significant in long detectors because

- CTN scales as $1/Lw$
- For fixed arm cavity geometry, beamspot size $w \propto \sqrt{L}$ and CTN scales as $L^{-3/2}$
- For fixed instrument bandwidth, quantum shot noise scales as $L^{-1/2}$

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Baseline Cosmic Explorer coating parameters

- Baseline Cosmic Explorer coatings are the same as the, as yet unrealized, A+ coating target: a factor of two CTN below current aLIGO coatings and 0.5 ppm absorption
- Can also consider AlGaAs coatings with even less loss. Take as an estimate here the upper limit of 20 % aLIGO CTN measured in LIGO-G2001592. (Thermo-optic noise is not included here.)
- Beams need to be minimized in a 40 km detector to fit in the 120 cm beam tubes. Baseline symmetric arm cavity with stability $g^2 = 0.11$.
- Minimum possible beam (corresponding to an unstable cavity*) used for AlGaAs in these estimates, resulting in the following beam radii on the test masses

Coating	stability g^2	40 km	20 km
A+/aLIGO	0.11	12.0 cm	8.5 cm
AlGaAs	0.00	11.6 cm	8.2 cm

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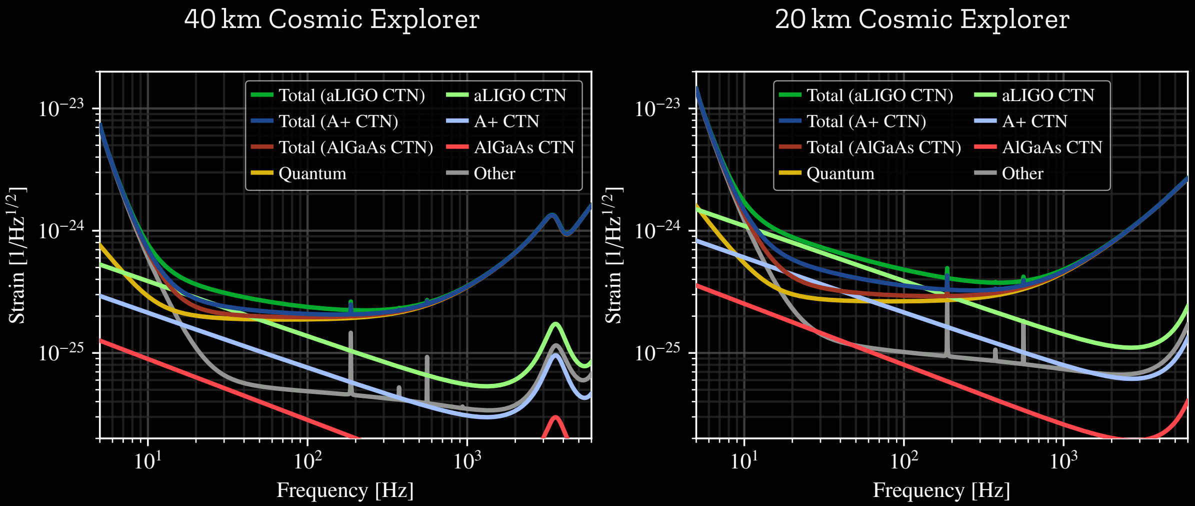
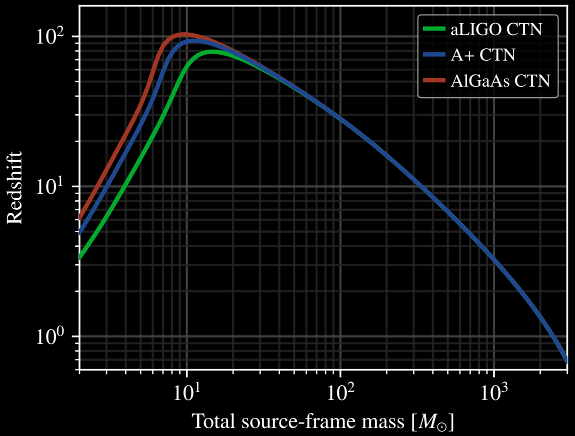
*I'll quit if we actually try to do this.

Strain sensitivity for different coatings



Astrophysical performance of a 40 km detector

Equal mass binary horizons



- Improvement beyond A+ coatings has minimal impact
  - 6 % improvement in BNS range, 10 % improvement in maximum detectable redshift
  - No improvement in BBH range or early warning time

	Range [Mpc]			
Coating	BNS	BBH	t_{early} [min]	$z_{\max}$
aLIGO	3200	6000	100	79
A+	3600	6100	100	94
AlGaAs	3900	6100	100	103

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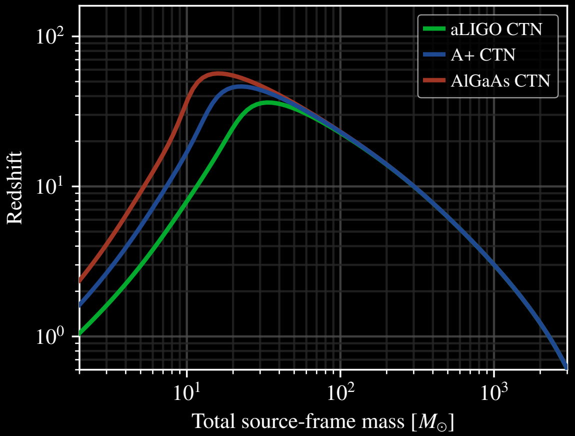
Astrophysical performance of a 20 km detector

Equal mass binary horizons



- Improvement beyond A+ coatings has a modest impact
  - 20 % improvement in BNS range, 2 % improvement in BBH range, 22 % improvement in maximum detectable redshift
  - No improvement in early warning time

Coating	Range [Mpc] BNS	BBH	t_{early} [min]	z_{max}
aLIGO	1800	5600	91	36
A+	2400	5900	91	46
AlGaAs	2800	6000	91	57

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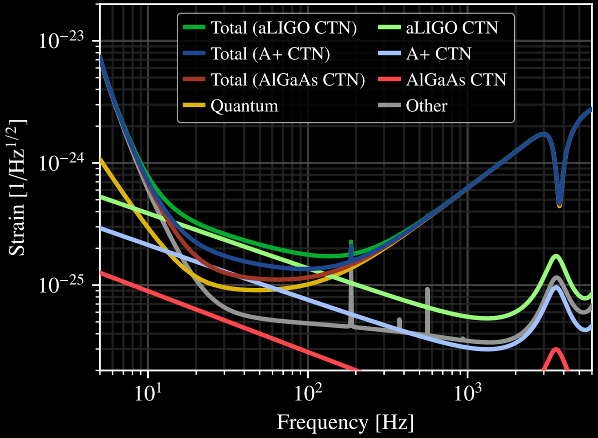
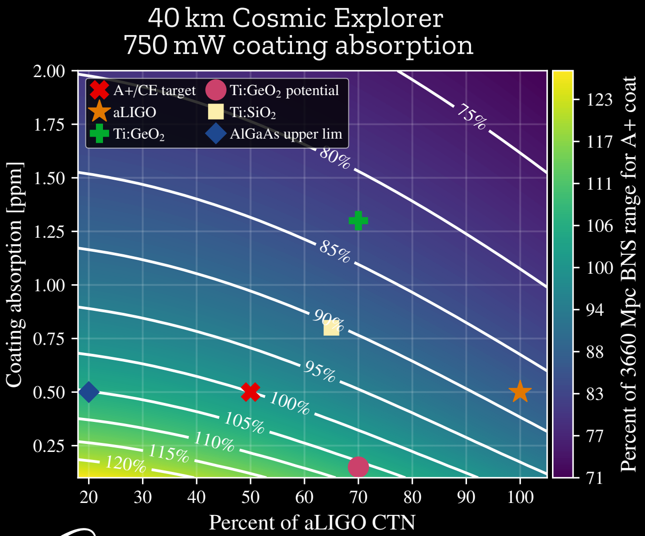
Low frequency tuning for a 40 km detector



- Improvement beyond A+ coatings would have a modest impact for a 40 km detector tuned for low frequency sensitivity
  - 11 % improvement in BNS range, 20 % improvement in maximum detectable redshift
  - No improvement in BBH range or early warning time

	Range [Mpc]			
Coating	BNS	BBH	t_{early} [min]	z_{max}
aLIGO	3500	6100	100	82
A+	4200	6100	100	103
AlGaAs	4600	6100	100	123

Coating absorption: It's not all about loss



- Achieving the 1.5 MW arm power target will be one of the most significant challenges in reaching the CE design sensitivity
- Adjust arm power to keep absorbed power constant as a rough metric for the relative importance of reducing absorption and CTN
- Low absorption more important for a 40 km detector since the noise is dominated by shot noise

$$P_{\mathrm{arm}} = 1.5\,\mathrm{MW} \times \left(\frac{0.5\,\mathrm{ppm}}{\alpha_{\mathrm{coat}}}\right)$$

Note: Beam size not reduced for AlGaAs

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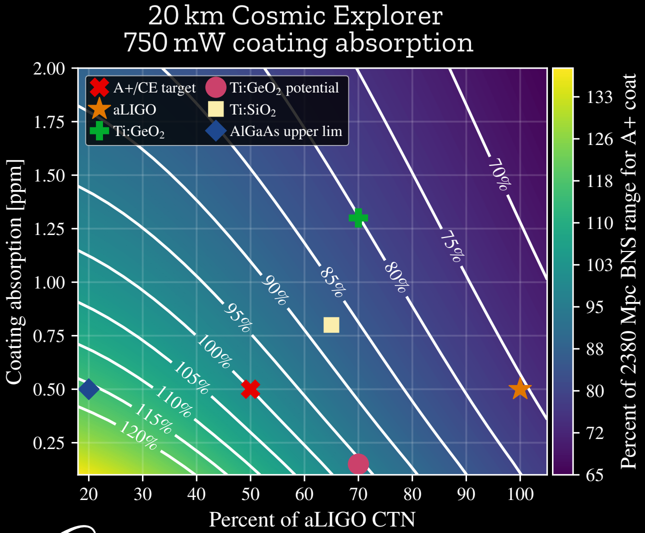
Coating absorption: It's not all about loss



- Achieving the 1.5 MW arm power target will be one of the most significant challenges in reaching the CE design sensitivity
- Adjust arm power to keep absorbed power constant as a rough metric for the relative importance of reducing absorption and CTN
- Low absorption more important for a 40 km detector since the noise is dominated by shot noise
- Absorption and CTN of more similar importance for a 20 km detector

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$$P_{\mathrm{arm}} = 1.5\,\mathrm{MW} \times \left(\frac{0.5\,\mathrm{ppm}}{\alpha_{\mathrm{coat}}}\right)$$

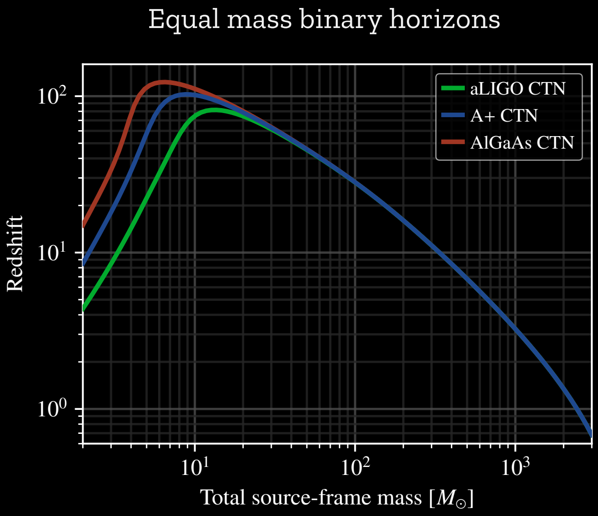
Note: Beam size not reduced for AlGaAs

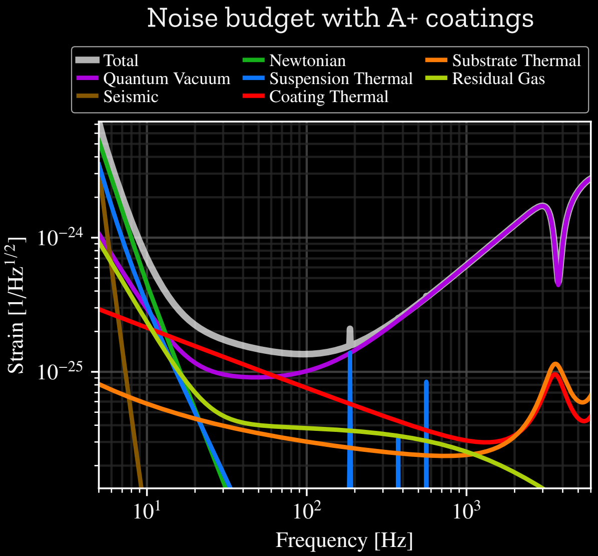
Summary

- Coating Brownian noise is less significant in long detectors because it scales as $L^{-3/2}$ (for fixed arm cavity geometry) while quantum shot noise scales as $L^{-1/2}$ (for fixed instrument bandwidth).
- Improving CTN beyond the nominal CE target of A+ coatings has a minimal impact for a 40 km detector and a modest impact for a 20 km detector or a 40 km detector tuned for low frequency sensitivity.
- Keeping coating absorption low is critical to achieving the goal of 1.5 MW arm power.
- AlGaAs coatings would need to support beams with radii on the test masses in excess of 8.2 cm for a 20 km detector and 11.6 cm for a 40 km detector.

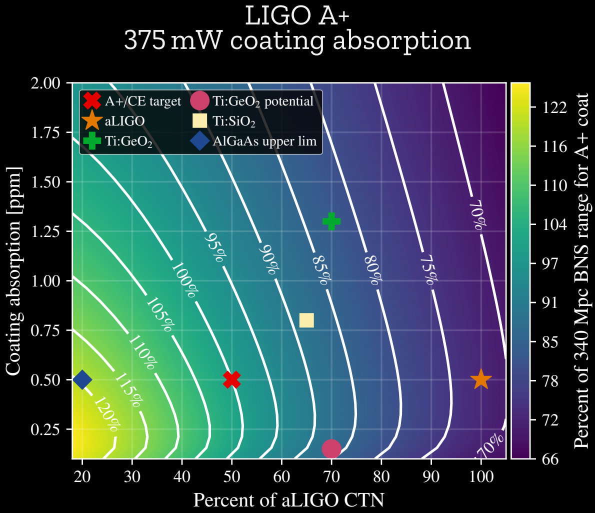
Extra

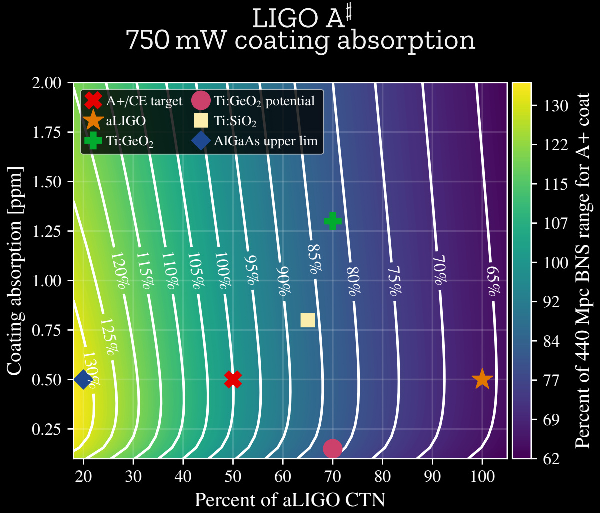
40 km low frequency tuning





Coating absorption and CTN for LIGO detectors





$$P_{\text{arm}} = 750\,\text{kW} \times \left(\frac{0.5\,\text{ppm}}{\alpha_{\text{coat}}} \right)$$

Note: Beam size not reduced for AlGaAs

$$P_{\text{arm}} = 1.5\,\text{MW} \times \left(\frac{0.5\,\text{ppm}}{\alpha_{\text{coat}}} \right)$$