Cosmic Explorer instrument update

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for the
Cosmic Explorer Project

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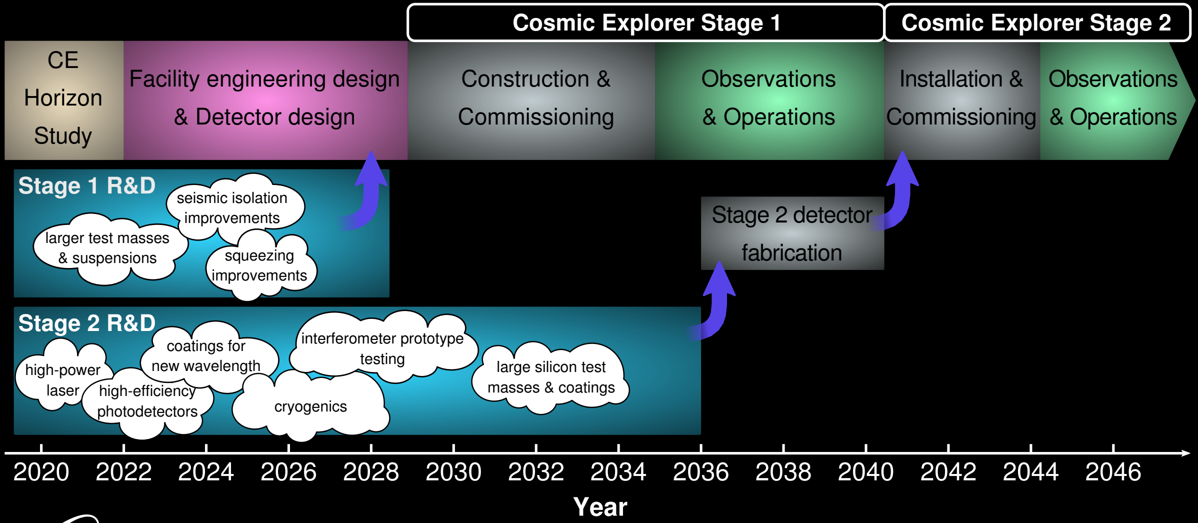
CE–G2000029

As of 2019...



Cosmic Explorer Stage 1
Cosmic Explorer Stage 2
CE Horizon Study
Facility engineering design & Detector design
Construction & Commissioning
Observations & Operations
Installation & Commissioning
Observations & Operations
Stage 1 R&D
seismic isolation improvements
larger test masses & suspensions
squeezing improvements
Stage 2 detector fabrication
Stage 2 R&D
high-power laser
coatings for new wavelength
interferometer prototype testing
high-efficiency photodetectors
cryogenics
large silicon test masses & coatings
2020 2022 2024 2026 2028 2030 2032 2034 2036 2038 2040 2042 2044 2046
Year

As of 2019...

Cosmic Explorer Stage 1: *a 40 km LIGO A+*

Room temperature glass, 1 μm laser, aLIGO seismic isolation, scaled-up aLIGO suspensions and masses, 6 dB squeezing, no gravity gradient subtraction...

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Cosmic Explorer Stage 1: *a 40 km LIGO A+*

Room temperature glass, 1 µm laser, aLIGO seismic isolation, scaled-up aLIGO suspensions and masses, 6 dB squeezing, no gravity gradient subtraction...

Cosmic Explorer Stage 2: *a 40 km LIGO Voyager*

123 K silicon, 2 µm laser, novel seismic isolation, scaled-up Voyager suspensions and masses, 10 dB squeezing, gravity gradient subtraction...

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Now in 2020...

Construction and observing schedule remain the same, but

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Is CE1 too pessimistic?

By 2030 we may have better seismic isolation, better squeezing, improved suspension technologies, etc.

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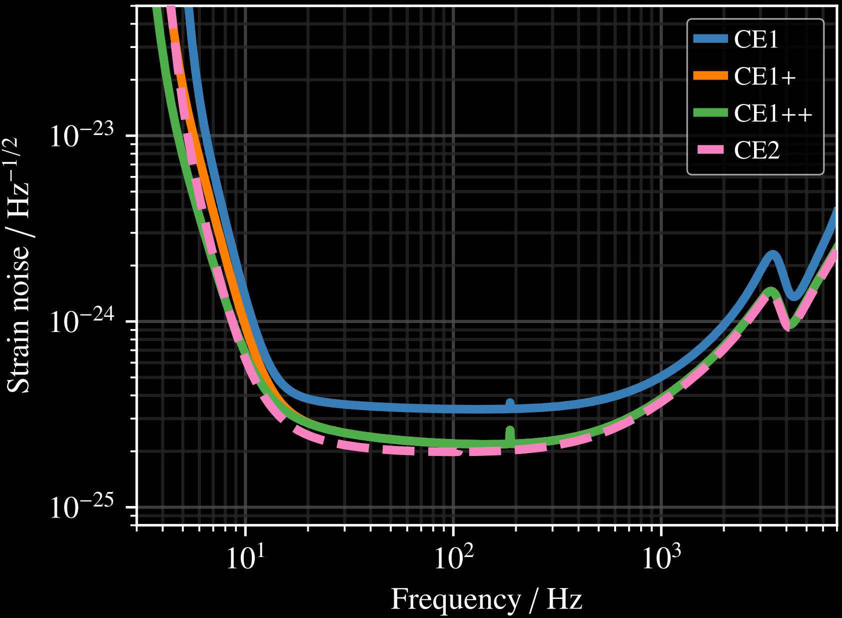
Is CE1 too pessimistic?

By 2030 we may have better seismic isolation, better squeezing, improved suspension technologies, etc.

Should this „CE1+" be the baseline instead?

Can we achieve CE2 performance by iterating on CE1 technology?

Forget about silicon and 2 μm — aim for „CE1++" in the 2040s?



CE1
CE1+
CE1++
CE2
10^{-23}
10^{-24}
10^{-25}
Strain noise / $\mathrm{Hz}^{-1/2}$
10^{1}
10^{2}
10^{3}
Frequency / Hz

Site seismicity assumptions

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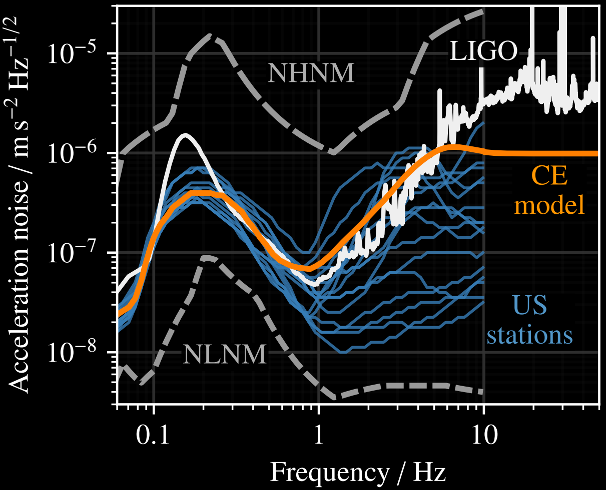
Site seismicity assumptions



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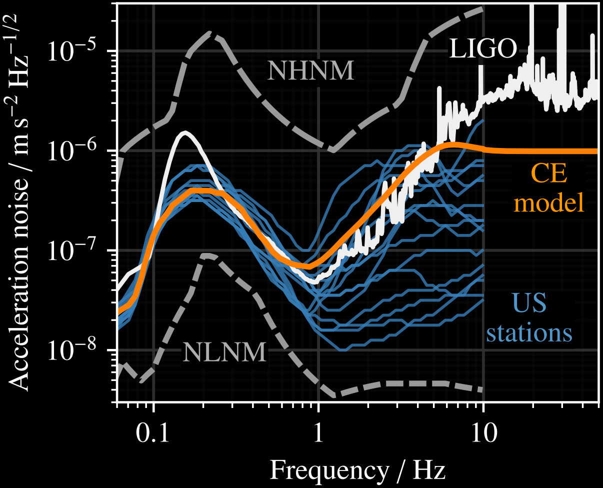
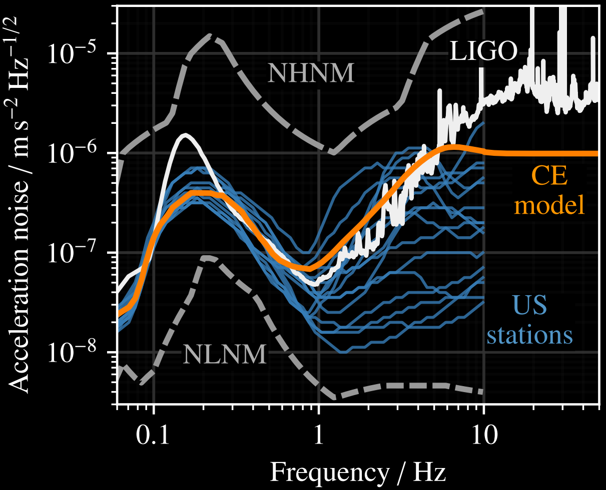


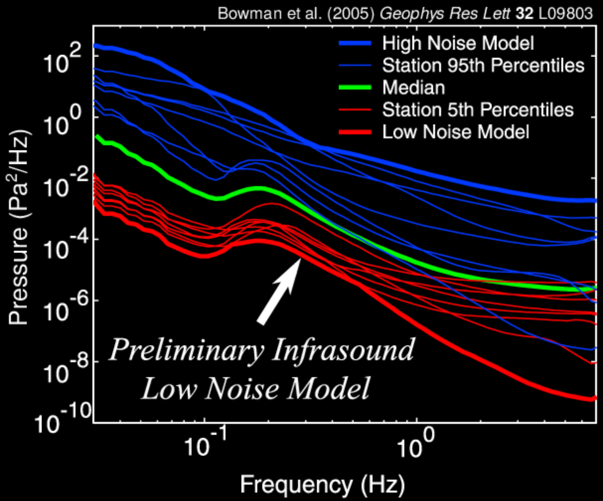
☞ Above 1 Hz, dominated by Rayleigh (surface) waves produced by local sources.

Site seismicity assumptions

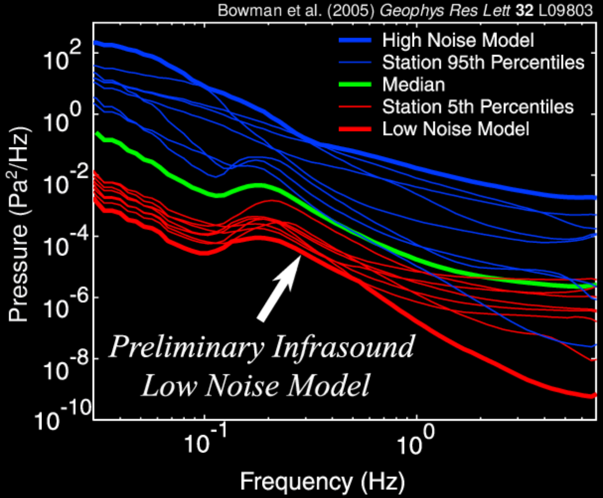


- ☞ Above 1 Hz, dominated by Rayleigh (surface) waves produced by local sources.
- ☞ P- and S-wave (body wave) amplitude not well known. We assumed 1/3 of the Rayleigh-wave amplitude.

Site acoustic noise assumptions



Site acoustic noise assumptions



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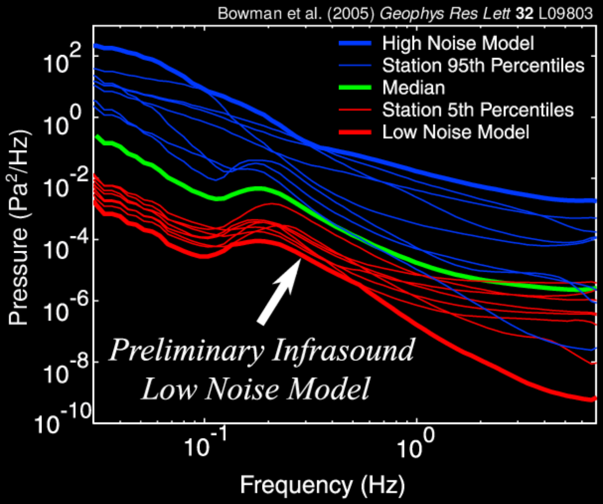
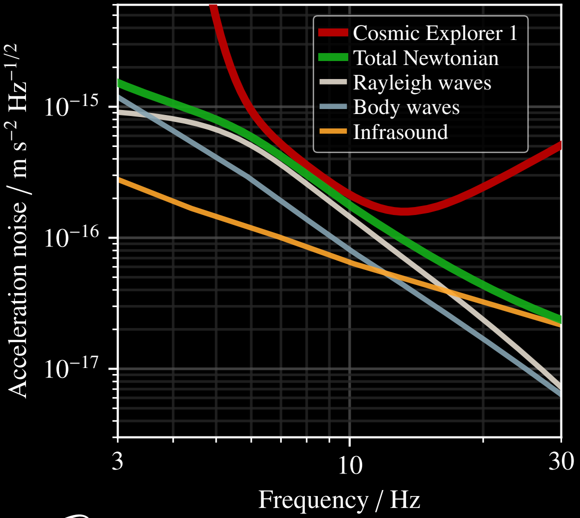
Site acoustic noise assumptions



- ☞ Assume a flat infrasound model: $1\,\mathrm{mPa\,Hz}^{-1/2}$
- ☞ Less certain than seismic model: infrasound surveys are focused on $f \lesssim 5\,\mathrm{Hz}$, and are confused by wind turbulence

Newtonian noise



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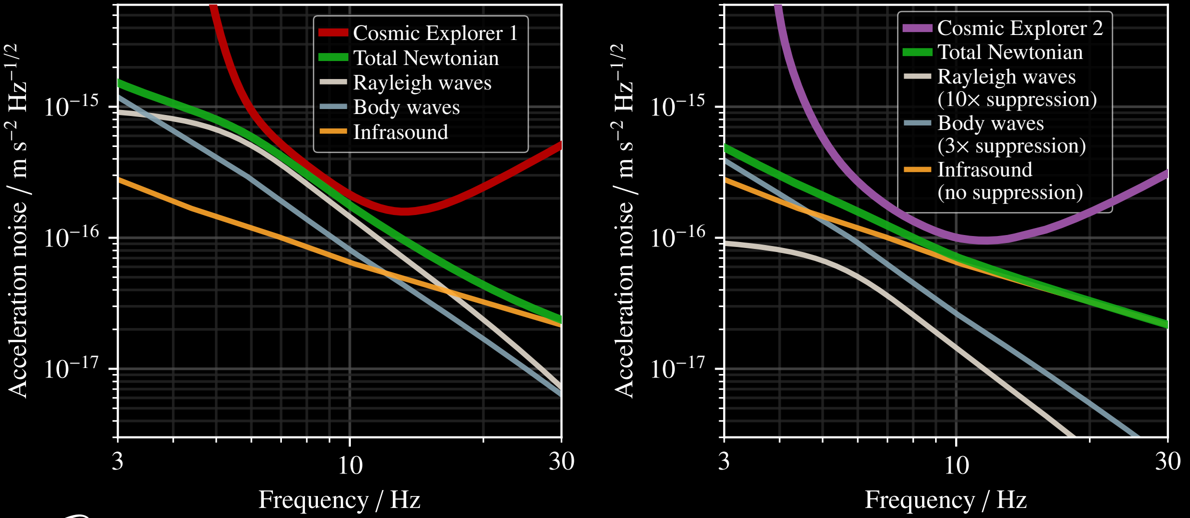
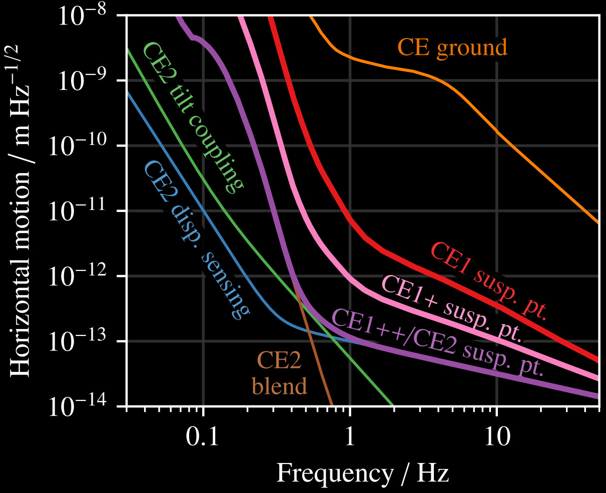
Newtonian noise



Seismic isolation



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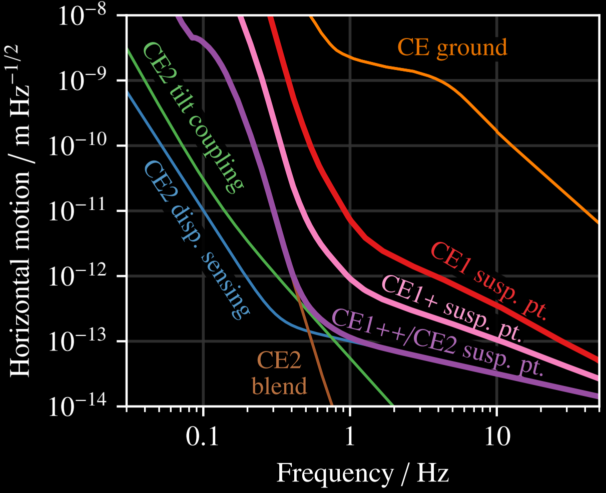

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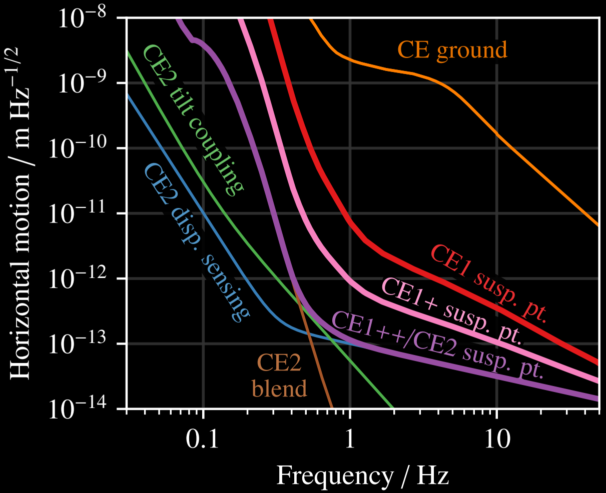
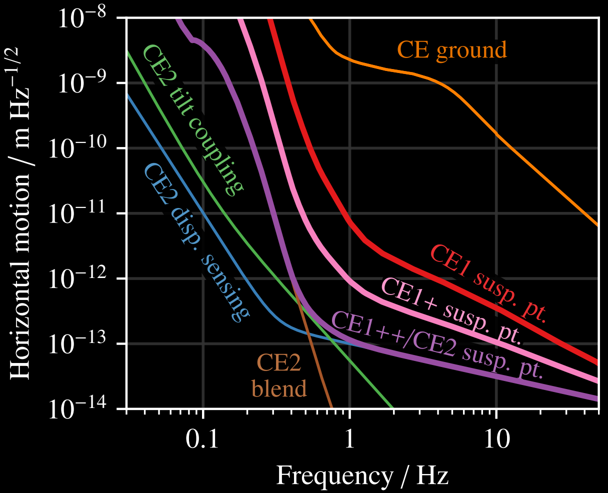
Seismic isolation



- ☞ CE1 assumes BSC-ISI performance
- ☞ For CE2, the GS13 is replaced with a novel inertial isolator. The blend frequencies of other sensors are lowered.

Seismic isolation



- ☞ CE1 assumes BSC-ISI performance
- ☞ For CE2, the GS13 is replaced with a novel inertial isolator. The blend frequencies of other sensors are lowered.
- ☞ Several novel isolator ideas: Mow-Lowry & Martynov, van Heijningen, …

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- ☞ CE2 uses silicon ribbons and blade springs.
  - ✌ The breaking stress is uncertain, and we currently use the optimistic value of 400 MPa.

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Suspensions

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- ☞ CE1 uses silica fibers at 1.2 GPa with no blade springs.
- ☞ CE2 uses silicon ribbons and blade springs.
  - ✌ The breaking stress is uncertain, and we currently use the optimistic value of 400 MPa.
- ☞ CE1+/++ additionally uses 800 MPa silica blades.
  - ✌ The softer silica suspensions are responsible for CE1++'s better low frequency sensitivity.

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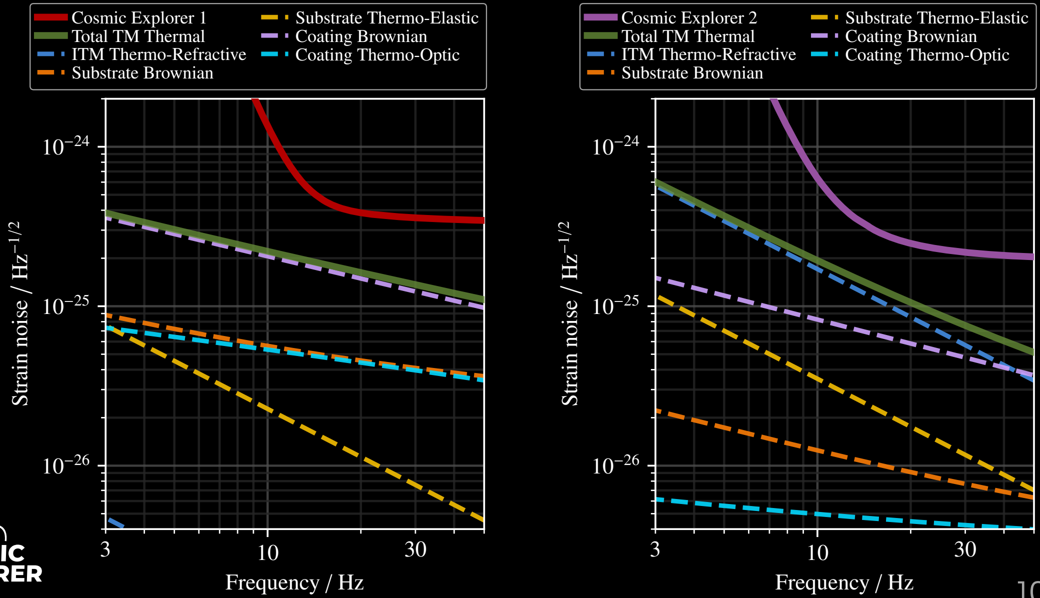
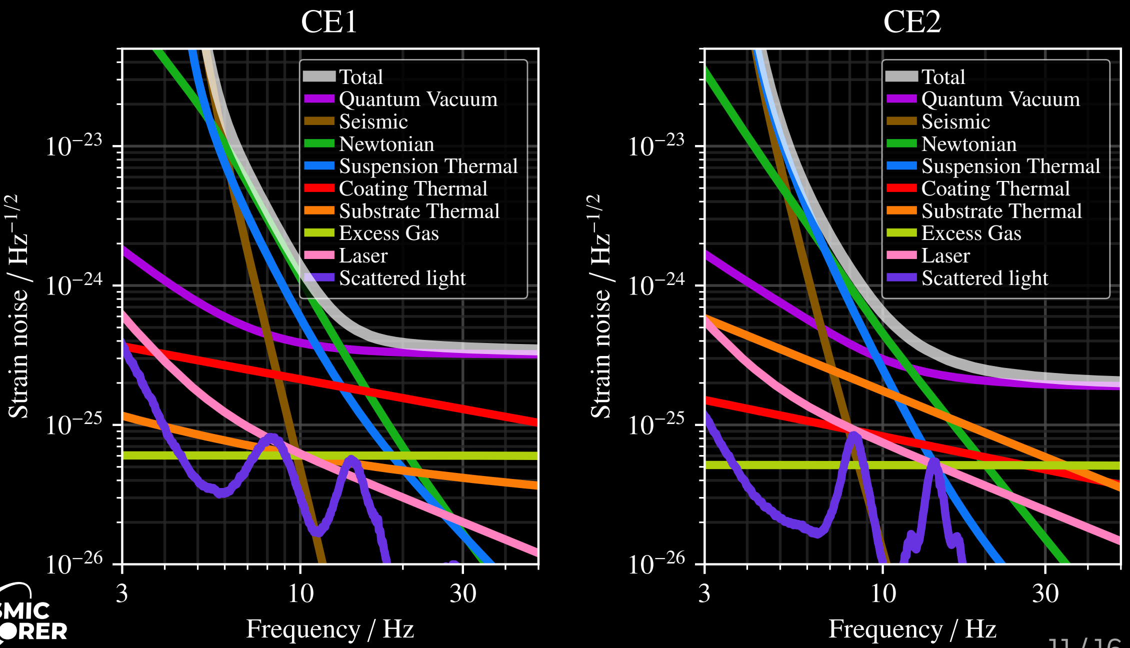
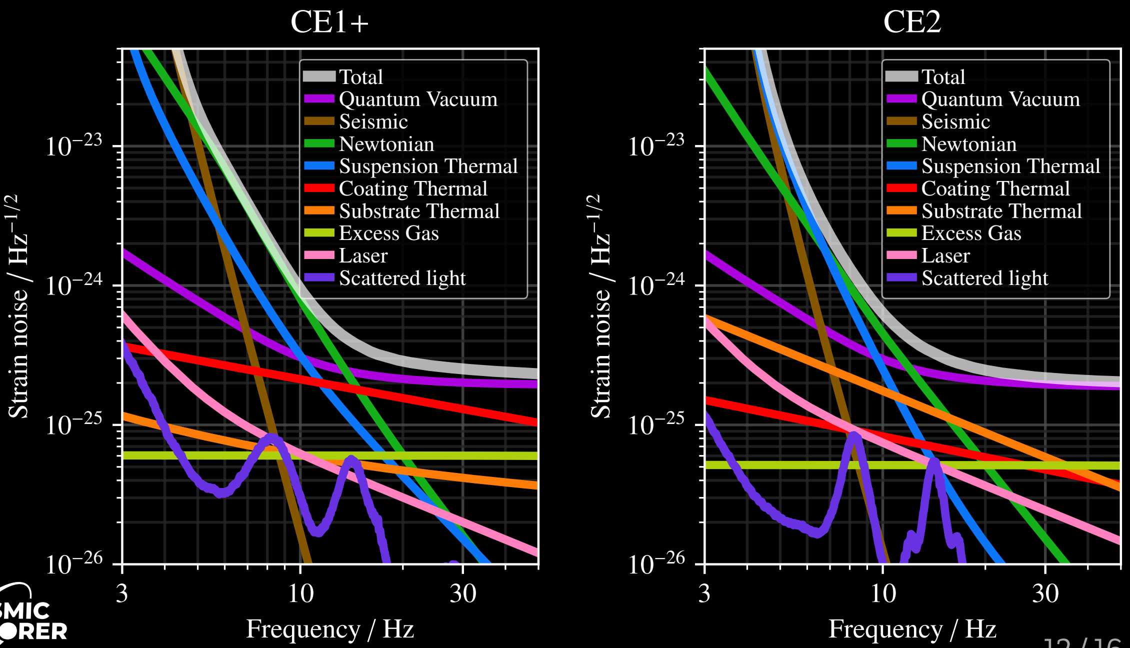
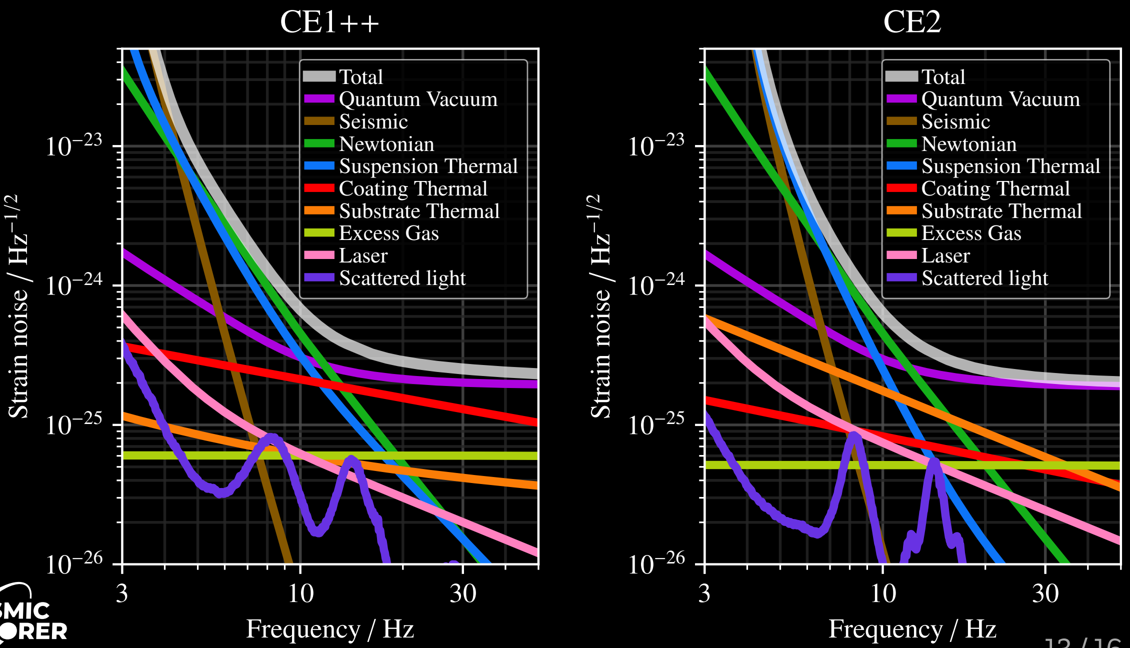
Test mass thermal noise





COSMIC EXPLORER


CE1+
CE2
Total
Quantum Vacuum
Seismic
Newtonian
Suspension Thermal
Coating Thermal
Substrate Thermal
Excess Gas
Laser
Scattered light
Strain noise / Hz$^{-1/2}$
10^{-23}
10^{-24}
10^{-25}
10^{-26}
3
10
30
Frequency / Hz



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Some CE2 challenges not addressed by Voyager

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- How do we manufacture 80 cm diameter silicon mirrors?
  - Factor of 2 larger than the current achievable silicon boule size.
  - Can multiple pieces of silicon be bonded while retaining strict optical and mechanical loss requirements?

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Some CE2 challenges not addressed by Voyager

- How do we manufacture 80 cm diameter silicon mirrors?
  - Factor of 2 larger than the current achievable silicon boule size.
  - Can multiple pieces of silicon be bonded while retaining strict optical and mechanical loss requirements?
- Voyager needs silicon suspensions as well, however their low frequency requirements do not demand the same performance as does CE2’s.

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What technology should we pursue?

Parameter Summary

Quantity	Units	CE1	CE1+	CE1++	CE2
Arm power	MW	1.5	1.5	1.5	3
Wavelength	μm	1	1	1	2
Squeezing	dB	6	10	10	10
Temperature	K	297	297	297	123
Final stage blade		None	Silica	Silica	Silicon
Rayleigh wave suppr.		None	2×	10×	10×
Body wave suppr.		None	None	3×	3×
Susp. point motion		aLIGO	intermediate	6D	6D
ITM spot size	cm	10	10	10	14
ETM spot size	cm	13	13	13	18
Mass	kg	442	442	442	468
Finesse		630	630	630	630
SRM Transmissivity	%	1.4	1.4	1.4	1.4

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