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GRAVITHELIUM
Gravitational wave detectors cooled with superfluid helium

Modal Analysis for Q-factor measurements of cryogenic suspensions for ET-LF in GRAVITHELIUM

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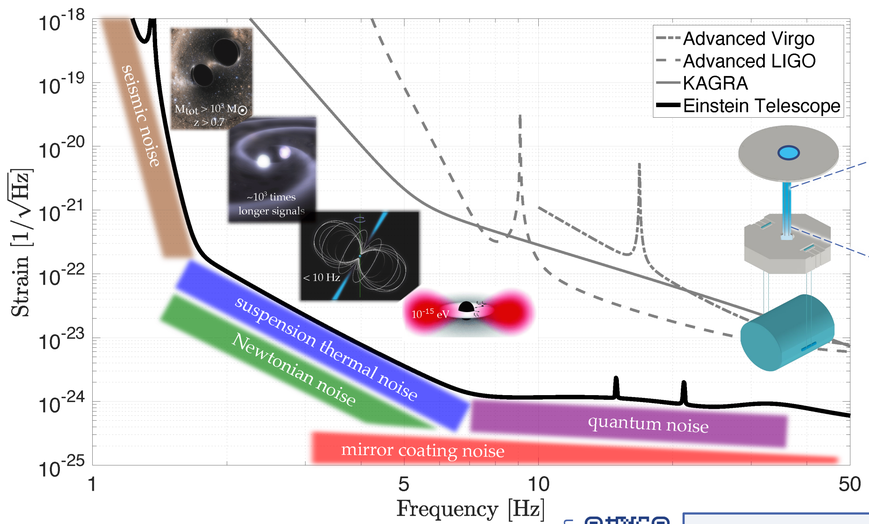
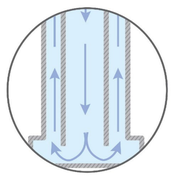
Baseline Design of Einstein Telescope Low-Frequency Cryogenic Payload



Reference: S. D. Pace et al. (2022), DOI: 10.3390/galaxies10030065

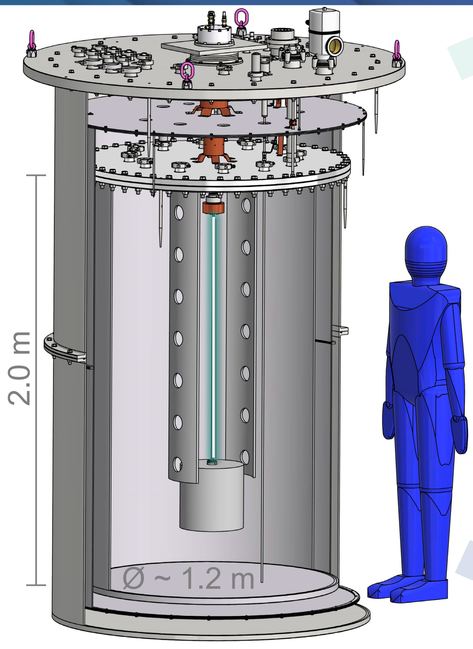
Publication

He-II at steady-state operation

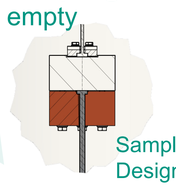


He-I flow for cool-down

✓ STN compatible with ET sensitivity goal [1]

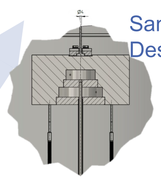


Phase I Experimental Campaigns
Monolithic suspensions and empty titanium suspension tubes



Sample holder Design Phase I

$$\phi_{susp}(f) = \phi_{bulk} + \phi_{surface} + \phi_{thermoelastic} + \phi_{extrinsic}$$ [1]



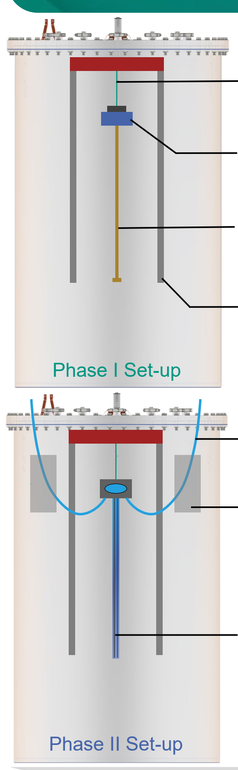
Sample holder Design Phase II

Phase II Experimental Campaigns
He-II filled titanium suspension tubes

$Q^{-1} = \varphi$ (loss angle at resonance), a **key parameter in STN** modelling

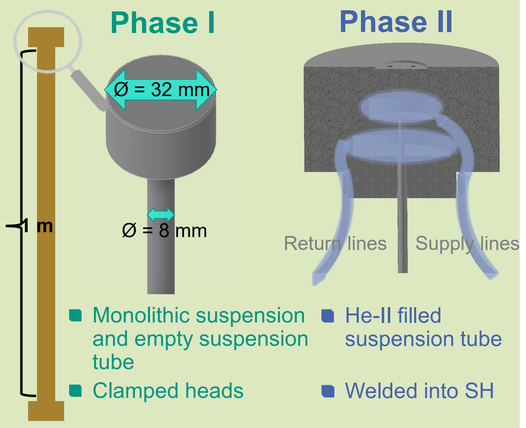
Experimental Investigation of **dissipation in suspensions** via Q-measurements!

FEM Based Design Approach for Low Dissipative Sample Holder



Modal Analysis of Sample

- FEM Modal Analysis defines $f_{natural,SA}$
- Which modes are feasible to measure

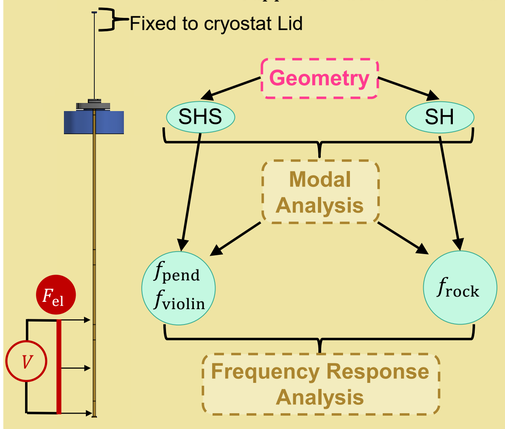


- Monolithic suspension and empty suspension tube
- He-II filled suspension tube
- Clamped heads
- Welded into SH

$f_{natural,SA}$

Modal Analysis of Support Structure

- FEM defines $f_{natural,Support\ Structure}$
- Low response $x_{Support\ Structure}$ @ $f_{natural,SA}$



$x_{Support\ Structure}$

Energetic Evaluation of Set-Up

- FEM based strain energy U_i loss angle
- Major decisions on materials used in Set-Up

SA Materials	$\phi_{bulk}(T = 4\ K)$
Titanium	10^{-6}
Silicon	10^{-8}
Sapphire	10^{-8}

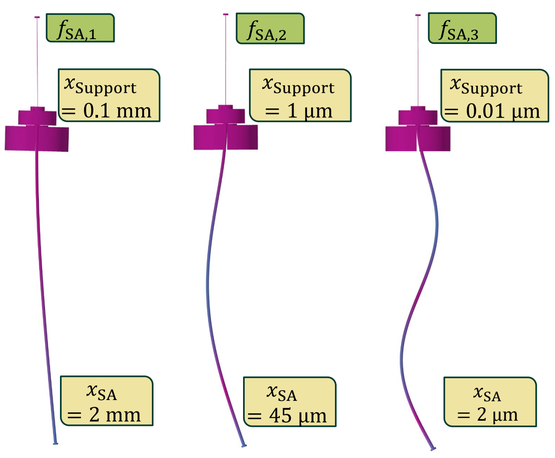
Set − Up Materials	$\phi_{bulk}(T = 4\ K)$
Aluminium	10^{-6}
Ti-6Al-4V	10^{-4}
Tungsten	10^{-6}
SST	10^{-4}
Copper	10^{-4}

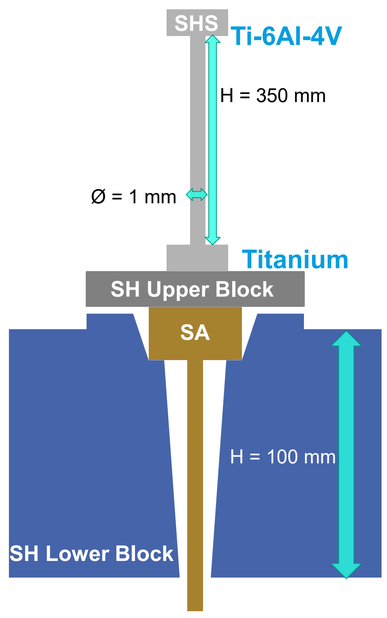
$$\sum \hat{\phi}_{Set-Up} = \underbrace{U_{SA}\phi_{SA}}_{\hat{\phi}_{intrinsic}} + \underbrace{U_{SHS}\phi_{SHS} + U_{SH}\phi_{SH}}_{\hat{\phi}_{extrinsic}}$$ [2]

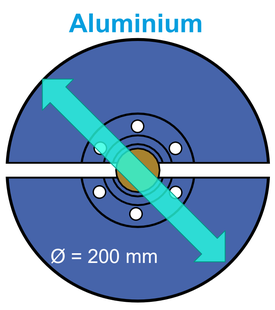
$\hat{\phi}_{Set-Up}$

Current Status of Low Dissipative Sample Holder

	$f_{SA,1}$ / Hz	$f_{SA,2}$ / Hz	$f_{SA,3}$ / Hz
Suspension tube	5	38	120
Silicon	6	41	120
Sapphire	8	60	205







$M_{SH} = 10\ kg$

Sapphire SA	$\hat{\phi}_{intrinsic}$	$\hat{\phi}_{extrinsic}$	$\sum \hat{\phi}_{Set-Up}$
$f_{SA,1}$	10^{-8}	2×10^{-8}	3×10^{-8}
$f_{SA,2}$	10^{-8}	6×10^{-10}	10^{-8}
$f_{SA,3}$	10^{-8}	3×10^{-10}	10^{-8}

Titanium SA	$\hat{\phi}_{intrinsic}$	$\hat{\phi}_{extrinsic}$	$\sum \hat{\phi}_{Set-Up}$
$f_{SA,1}$	10^{-6}	2×10^{-8}	10^{-6}
$f_{SA,2}$	10^{-6}	2×10^{-8}	10^{-6}
$f_{SA,3}$	10^{-6}	2×10^{-10}	10^{-6}

Conclusions
- Development of a systematic design approach
- Q-measurements at $f_{SA,2}$ and $f_{SA,3}$ most feasible
- Low dissipation at 300 K to 3 K

Outlook
- Cool down studies using He as contact gas
- Include $\phi_{SH,thermoelast}$@ $f_{SA,1}$
- Experimental investigation

[1] X. Koroveshi et al. "Cryogenic payloads for the Einstein Telescope: Baseline design with heat extraction, suspension thermal noise modeling, and sensitivity analyses", In: Physical Review D, 108, 2023
[2] A. V. Cumming et al. "Silicon mirror suspensions for gravitational wave detectors" In: Classical and Quantum Gravity 31.2, 2013

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