Athermal Phonon Sensors for Low-Mass Dark Matter

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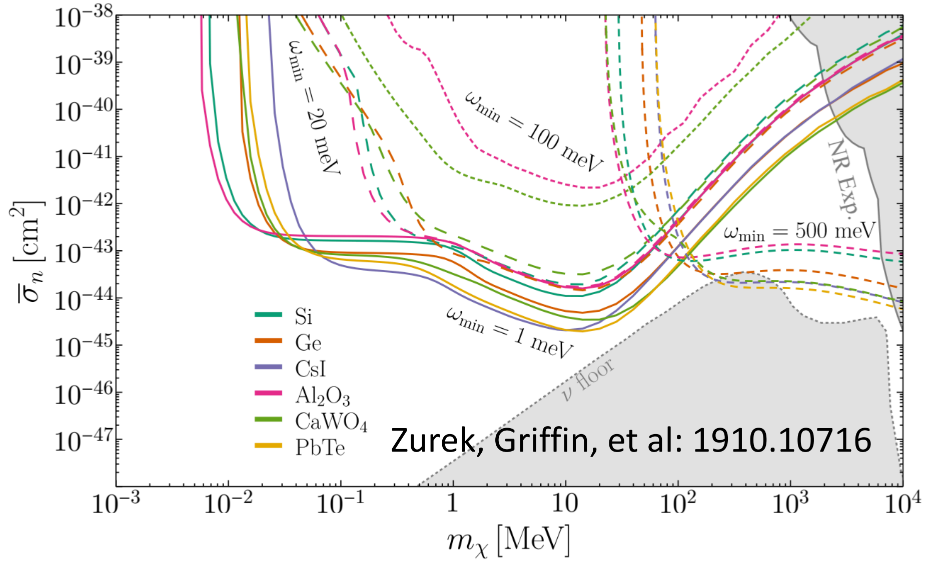
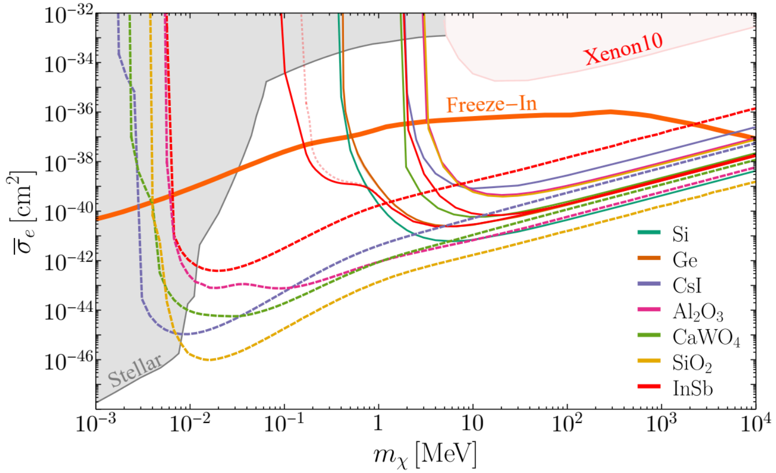
Minimal Motivation

- Primary design driver for low mass dark matter is energy sensitivity
- To detect both nuclear and electron recoil dark matter, we need detectors that have thresholds of 1–100meV

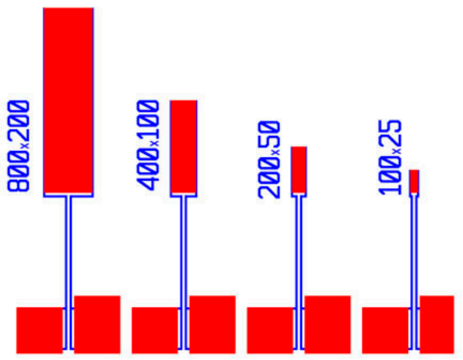
Heavy Mediator Single Phonon Sensitivity



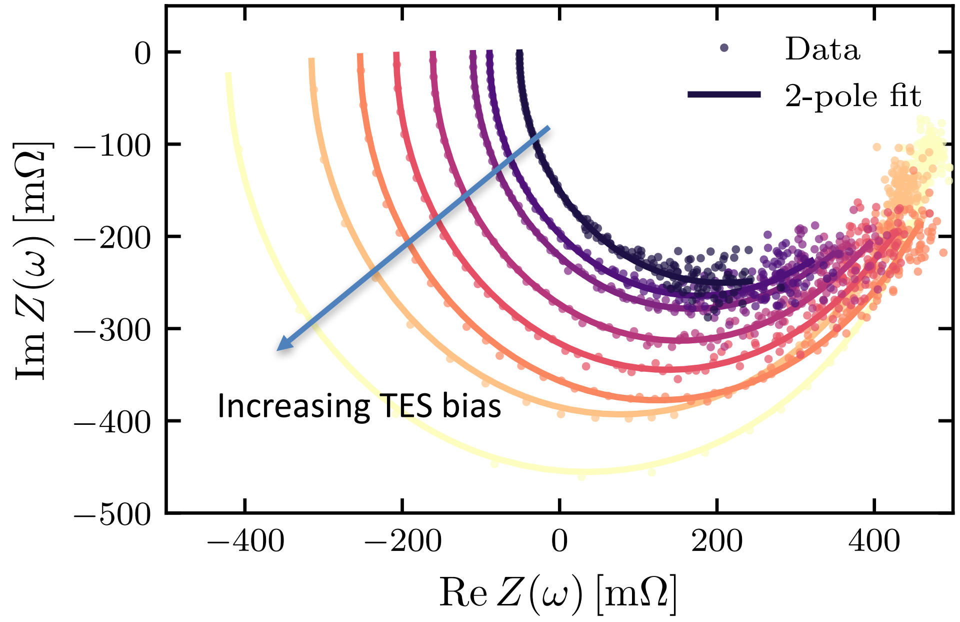
Scattering via Light Dark Photon



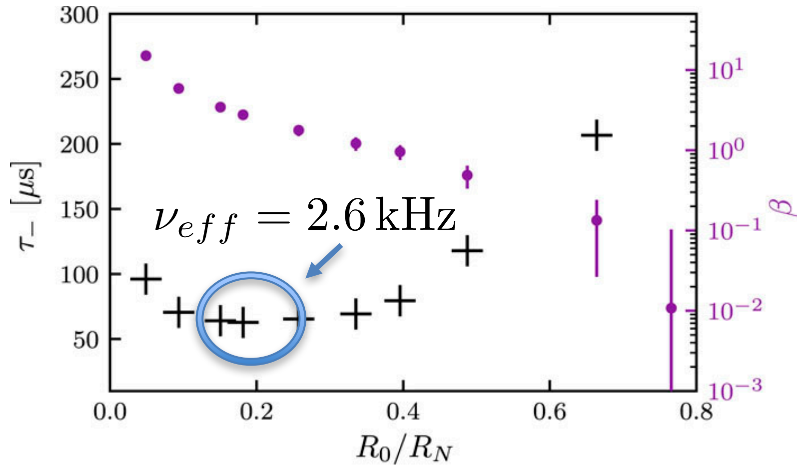
Tungsten TES R&D



- Studied simple tungsten TES structures
- Fabricated sets with Tc’s of 40mK and 68mK



- Complex impedance data shows that these TESs are well described by a simple single thermal body model



- Relatively high sensor bandwidth, (2.6kHz for 100x400 40mK TES)

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Tungsten TES R&D

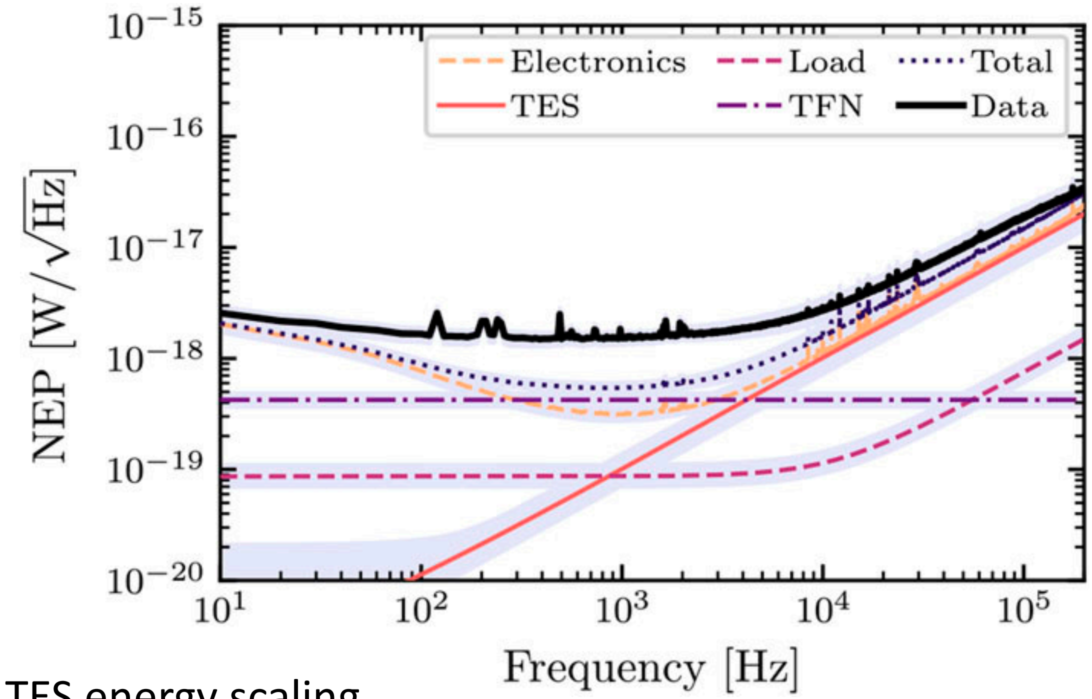
- Observe excess noise of about x2-3 for all the TESs we tested
- However, relatively large bandwidth still allows for excellent energy resolution

	TES dimensions	σ_E (meV)
T_c (mK)	(μm × μm ×nm)	estimated
40	100 × 400 × 40	40 ± 5
68	50 × 200 × 40	44 ; 5
68	100 × 400 × 40	104 ± 10

Confirms expected TES energy scaling with volume and Tc

$$\sigma_E \propto \sqrt{V T_c^3}$$

100x400um 40mK



Small detector mass makes exposure difficult for DM detector by itself.

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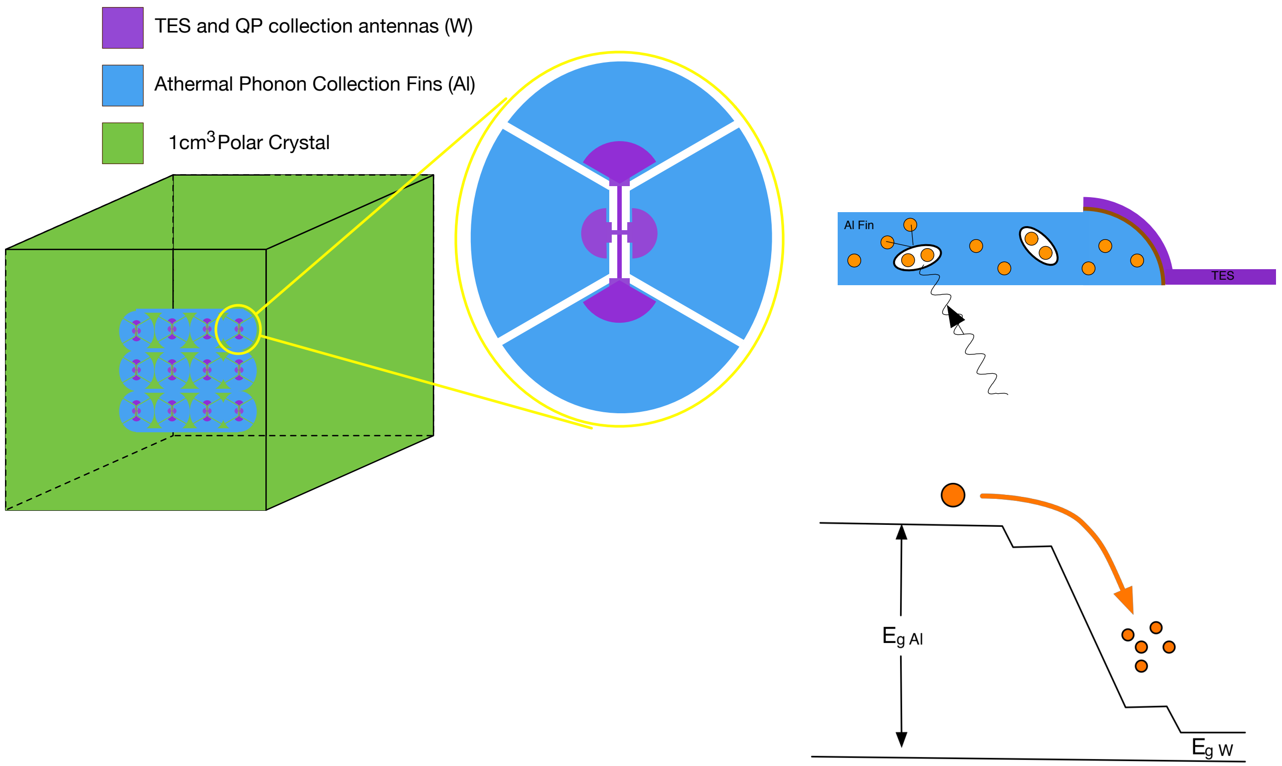
Athermal Phonon Sensors (QET)

- Collect and concentrate athermal phonon energy into Al fins
- Phonons break Al cooper pairs
- Quasiparticles are absorbed by W TES connected to Al fin
- Allows for large collection area without paying the penalty of having a large sensor heat capacity
- Signal is degraded by phonon collection efficiency factor, typically measured to be ~20% <-- Working to increase this

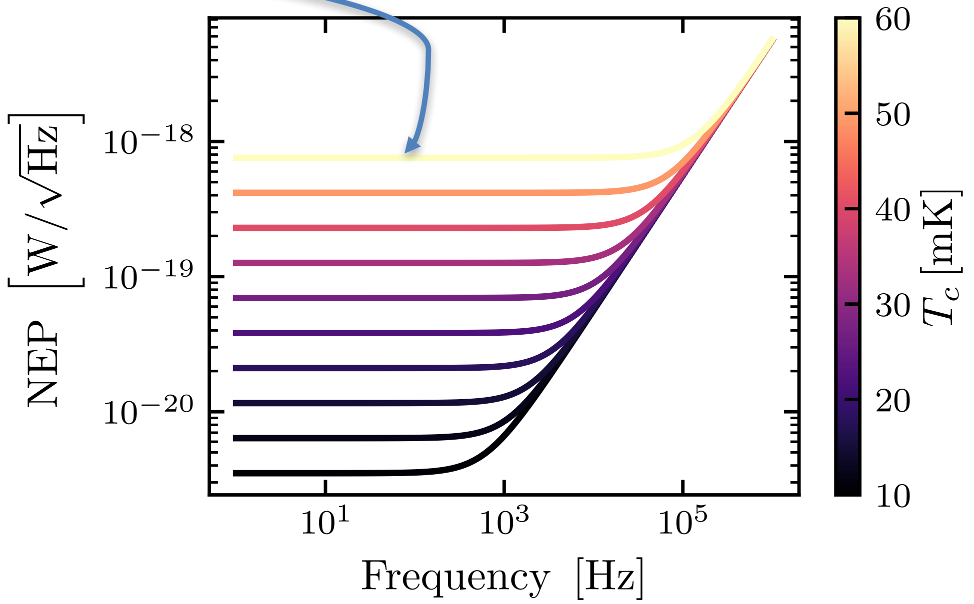


QET: -> **Q**uasiparticle-trap-assisted **E**lectrothermal-feedback **T**ransition-edge sensors

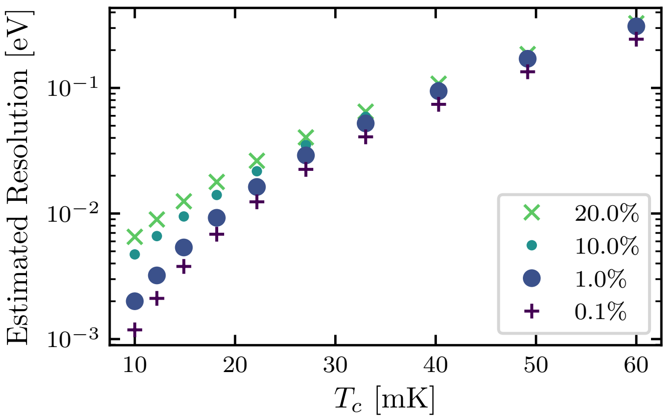
Optimizing Athermal Phonon Sensors

- Lowering volume and Tc will greatly decrease the NEP of the TES
- However, this also lowers the bandwidth of the sensor
- -> **the Al surface coverage must be reduced to stay bandwidth matched** (sensor bandwidth > phonon collection bandwidth)

Simulated Noise and Resolution as a function of Tc and instrumented surface coverage



$$G \propto T_c^4$$
$$S_{ptfn} = 4k_b T_c^2 G$$
$$\propto T_c^6$$
$$\sigma_E \propto T_c^3$$



Need detector targets with long ballistic phonon lifetimes

Conclusion

- The measured resolution of our current TESs allows them to have immediate uses as
  - Inelastic electron recoil athermal phonon sensors without NTL gain
    - Resolution of 40meV should allow for sub-eV trigger threshold when coupled to Al fin with 20% collection efficiency in Si target
  - Photon sensor for optical haloscope application

- To reach ultimate meV scale energy sensitivity. To do this, we are implementing the following R&D plan:

TES Work Plan

- Lower T_c from 40mK -> 10mK.
  ->x8 sensitivity improvement
- Lower volume by x16
  ->x4 sensitivity improvement
- **Decrease environmental noise!**

QET Work Plan

- Optimize Collector/TES (W/Al) interface
- Improve quasi-particle trapping in collector fin