Status of the TESSERACT Dark Matter Experiment

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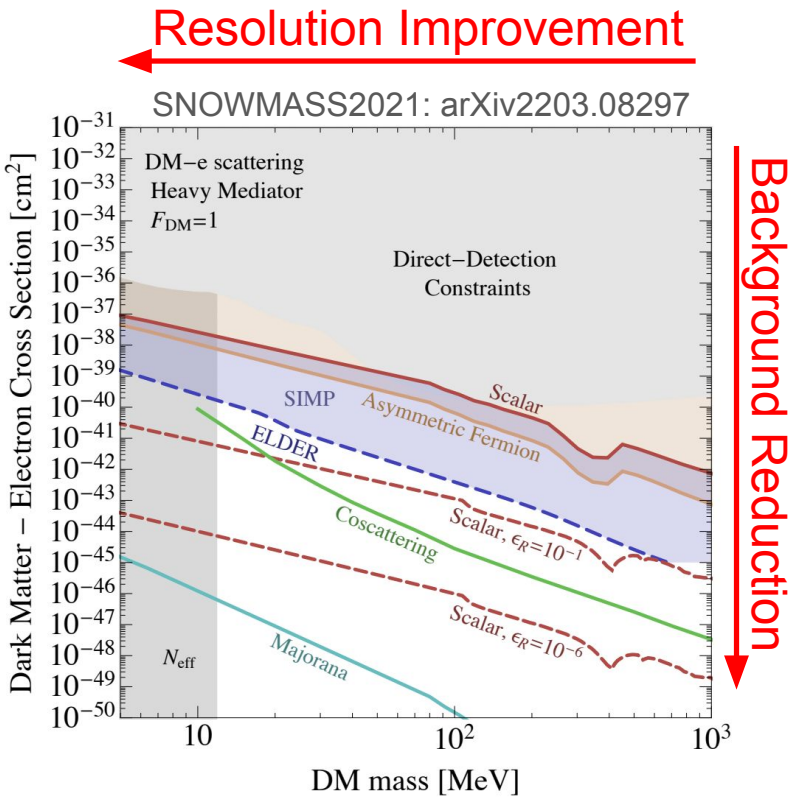
On behalf of the TESSERACT Collaboration
CPAD 2025
October 9th, 2025

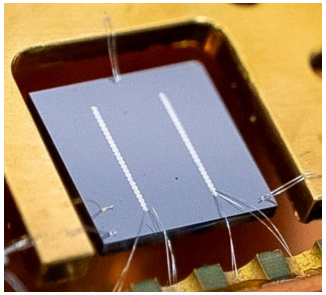
Dark Matter

- We'd like to observe (particle) dark matter in a terrestrial detector:
  - Scattering off of electron cloud or nuclei
- WIMP (>1 GeV) dark matter has dominated field over last few decades
  - Growing interest in "low-mass" (sub-GeV) dark matter
  - Detection ability to sense eV recoils and below!



TESSERACT Overview

- **T**ransition-**E**dge **S**ensors with **S**ub-**e**V **R**esolution **A**nd **C**ryogenic **T**argets
- Three core ingredients for TESSERACT:
  1. World-leading, instrumental background-reduced sensors
  2. Complementary targets optimized for low-mass dark matter
  3. Long-term, low-background, underground searches



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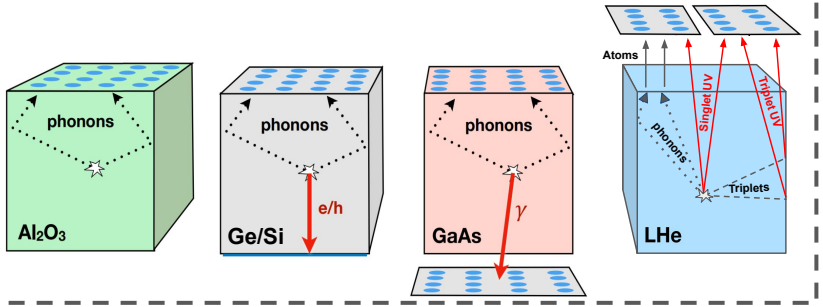

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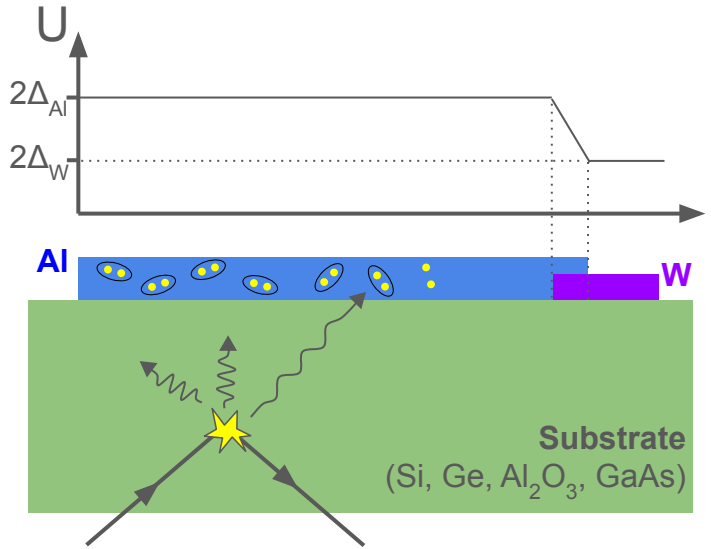
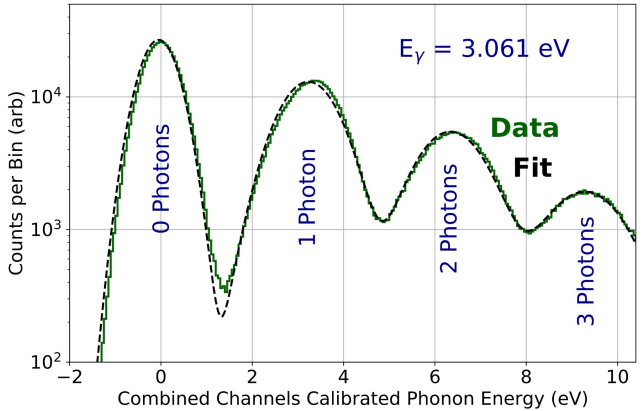
laboratoire Souterrain de Modane

TESSERACT Sensors

- W Transition-edge-sensors (TES) read out athermally
  - TES is sensing athermal phonons produced in substrate scattering
- Optimized for resolution
  - **258.5 ± .4 meV athermal phonon resolution** with Si substrate
  - ~4x better than competing experiments!

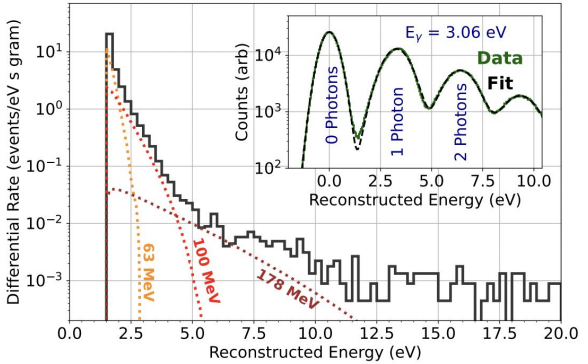


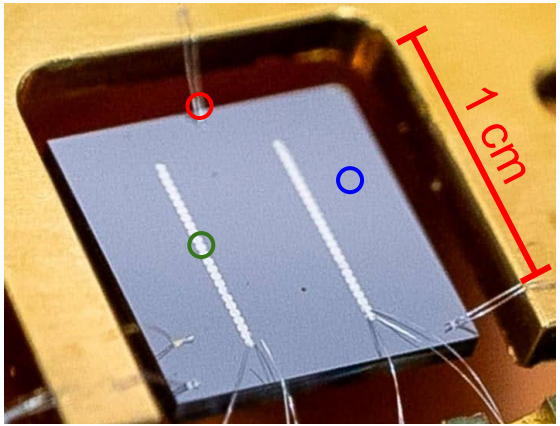


Instrumental Backgrounds

See Matt Pyle's Talk (Thurs. @ 3:40)

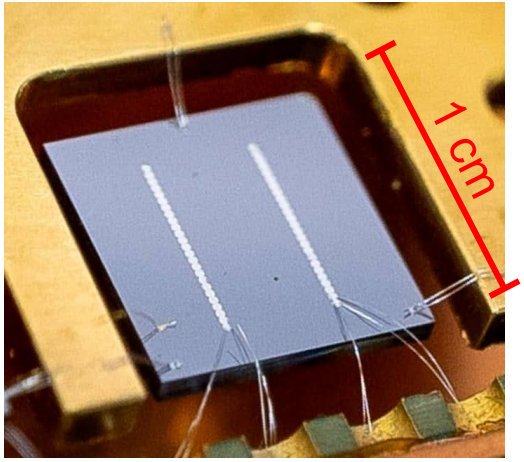
- All low-temperature sensors see an excess of backgrounds at low energies (LEE)
  - **It's not dark matter**: rate is time-dependent
  - It's not radiogenic: rate resets during thermal cycle
- What is it?
  - Burst of phonons generated inside the detector
  - Hypothesis: quasi-stable mechanical stress
- TESSERACT has isolated three origins of LEE:
  - Mounting
    - Gluing leads to stress under thermal contraction
    - Solution: Hang by wirebonds
  - Al/W Films
    - Stress at film/substrate interface or lattice dislocations within film
    - Solution: Require coincidence between 2 films
  - Bulk Substrates
    - Lattice dislocations in substrate?
    - Solution: Require coincidence between 2 substrates
    - Stay tuned; lots of effort here!

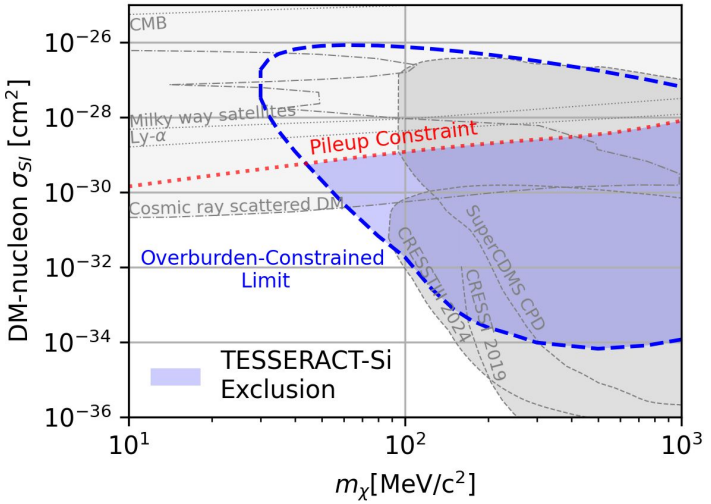




TESSERACT's First DM Search

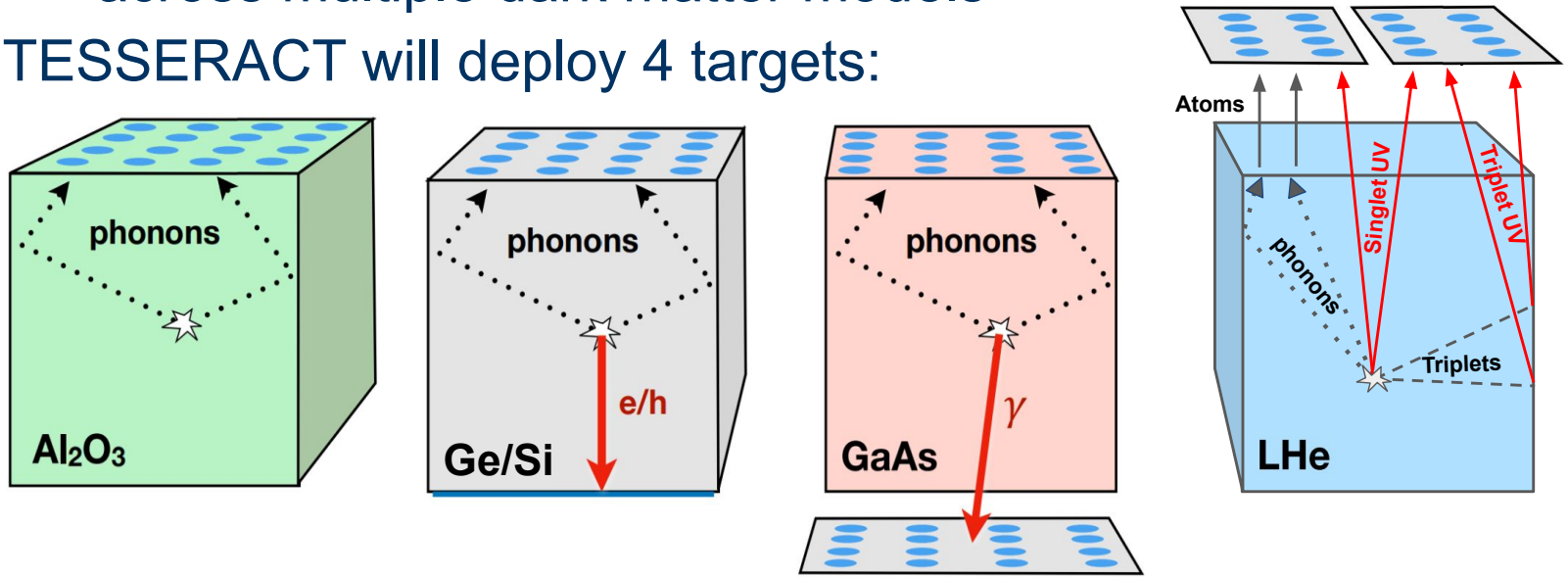
- Single TESSERACT cm^2 silicon chip in the basement of UC Berkeley
  - 0.233 g x 12 hours exposure
  - **361.5 ± .4 meV** photon resolution
    - Suboptimal due to film etching
  - Backgrounds: mainly bulk LEE
- **World-leading direct-detection limit set between 44 and 87 MeV/c^2**
  - See paper! arXiv 2503.03683
  - Accepted to PRL





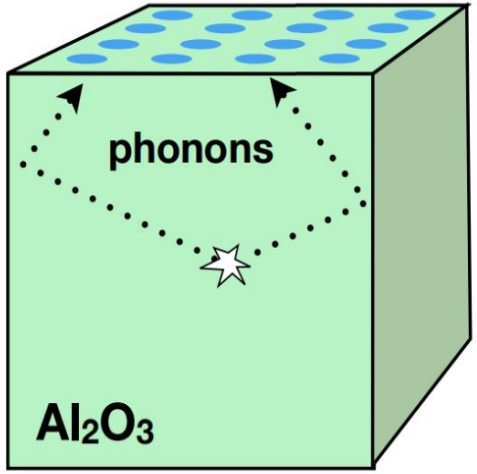
TESSERACT Targets

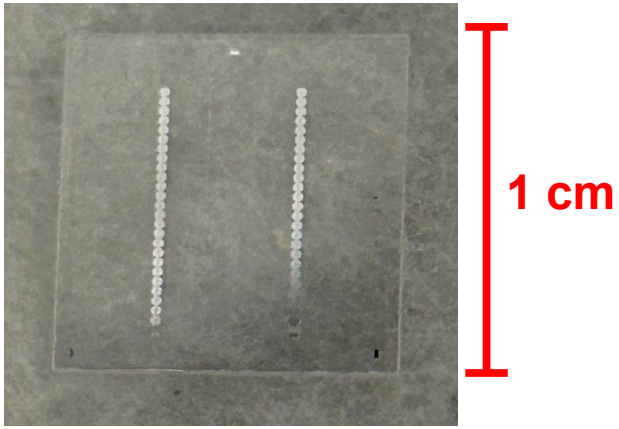
- TESSERACT's Si Sensors can already set new limits!
  - Different target materials will increase discovery potential across multiple dark matter models
- TESSERACT will deploy 4 targets:



Sapphire Target

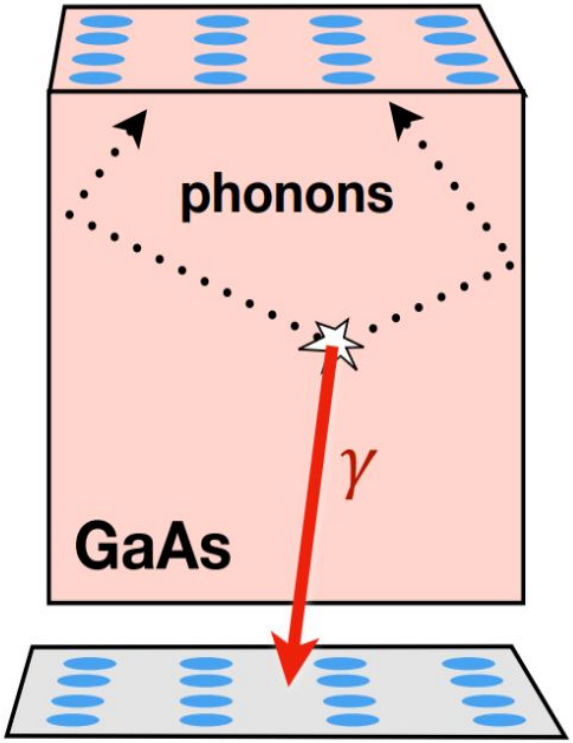
- 1 detection channel:
  - Heat/phonons
- Polar crystal => phonon modes couple to dark photon
- CRESST observes ~10x lower LEE rate compared to Si
  - Lower-backgrounds => better sensitivity
- First sensors have been fabricated, received, and cooled down at UCB!





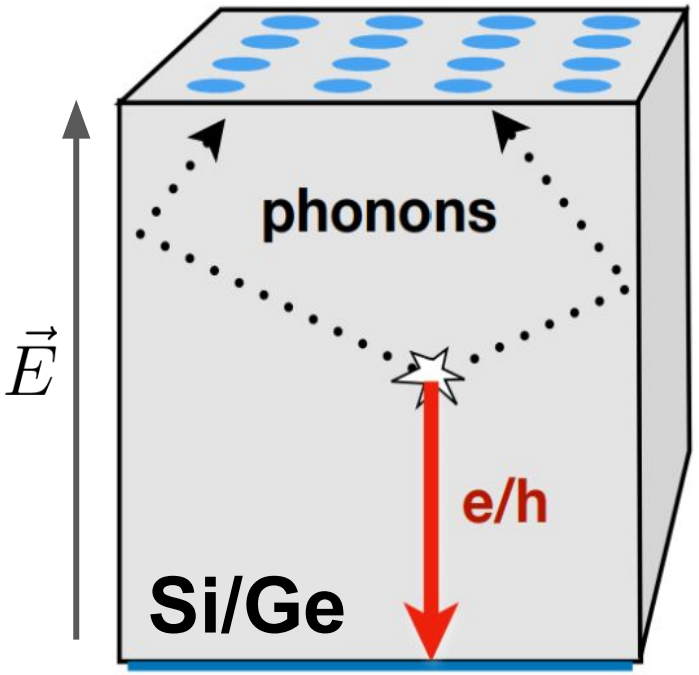
Gallium Arsenide Target

- **2** detection channels:
  - Heat/phonons
  - 1.3 eV scintillation (external sensors)
- Heat and light sensors are on different substrates
  - LEE phonons in one sensor cannot reach the other
  - Coincidence requirement => LEE veto
- Ratio of heat:light => ER/NR discrimination?
- Polar crystal => phonon modes couple to dark photon
- First sensors have been fabricated and received
  - Cooldowns upcoming at UCB/LBL!



Silicon/Germanium Targets

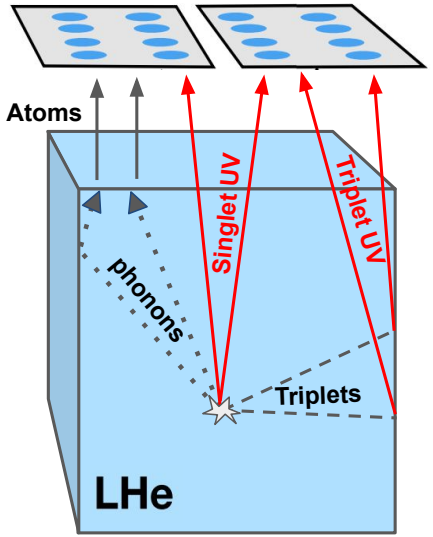
- **2** detection channels:
  - Heat/phonons
  - Ionization/charge
- Applied electric field tunable
  - HV: Phonon gain; lower threshold
  - LV: better NR/ER discrimination
- Choice of Si/Ge
  - Si: lower mass; “search wide”
  - Ge: lower backgrounds; “dive deep”
- Sensors in development in France!

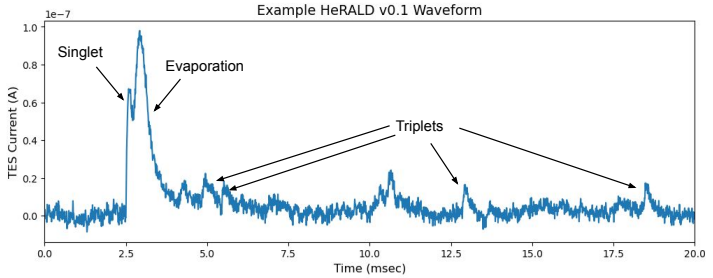


Superfluid Liquid Helium Target

See Joanna Wuko's Talk (Weds. @ 3:40)

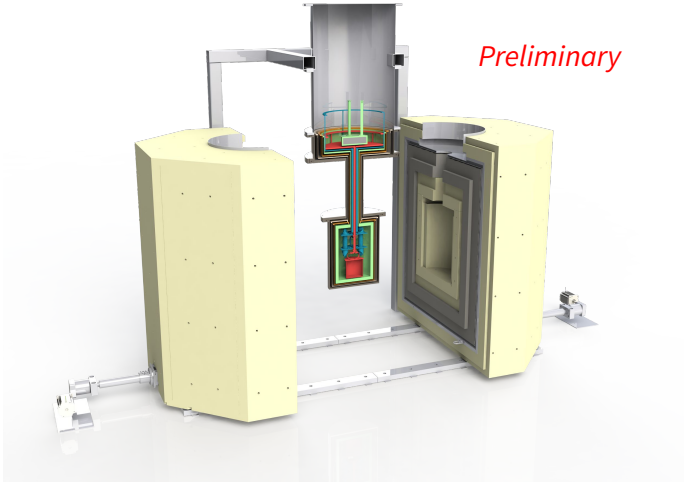
- Many sensors suspended above LHe bath
  - (Si or Sapphire substrates)
- **3** detection channels:
  - phonons/rotons => "Quantum Evaporation"
    - Van der Waals gain
  - Singlet excimer => scintillation (~16 eV)
  - Triplet excimers (~13s lifetime)
    - Delayed photon emission
- Multiple Sensors on different substrates
  - LEE phonons in one cannot reach the others
  - Coincidence requirement => LEE veto
- Test-stands at LBL and UMass

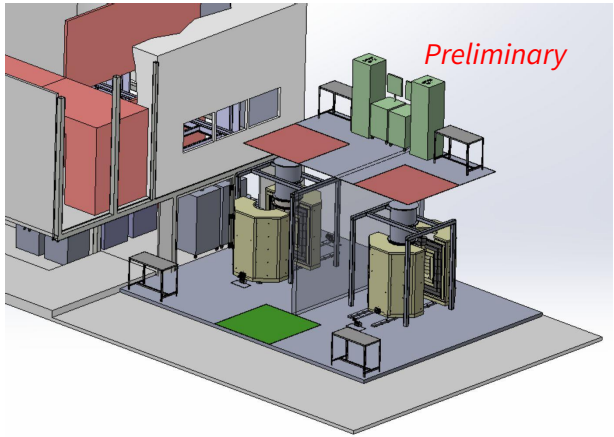




Moving Underground

- TESSERACT's first DM search was background-limited by LEE
  - He and GaAs targets have built-in LEE vetos, making radiogenic backgrounds dominant
- **TESSERACT will be moving into Modane underground lab starting in 2028**
  - Target: 1 DRU backgrounds
    - Nested Pb and borated-poly "clamshell" shielding
  - 2 dilution fridges
    - 2 DM searches can occur simultaneously





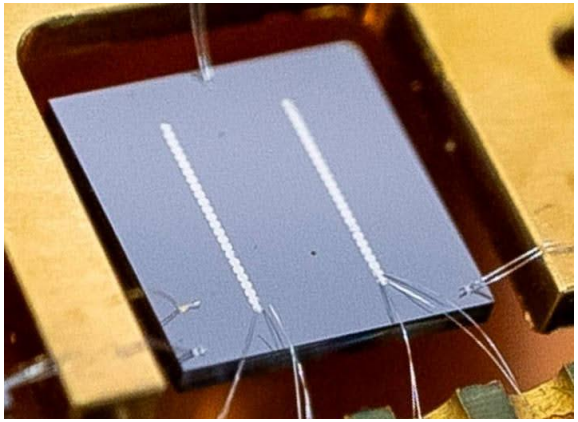
What to Remember

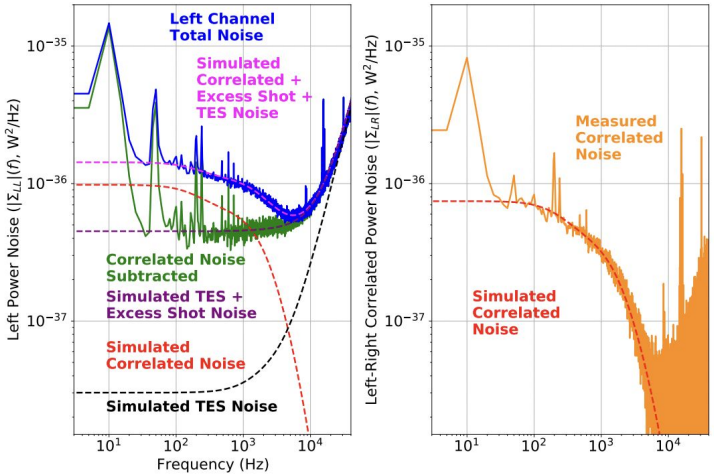
- TESSERACT's R&D has produced the world's best athermal phonon sensors
  - We can set world-leading dark matter limits with ~0.1 g-days of exposure!
- Progress on/plan for LEE backgrounds:
  - Eliminate what we can via mounting scheme
  - Reject other populations via coincidence requirements
  - More to come!
- Focus shifting toward development of target materials
  - Also: construction + deployment logistics
- Moving underground to LSM in **2028** for low-background searches!

Extra Slides

Correlated Noise

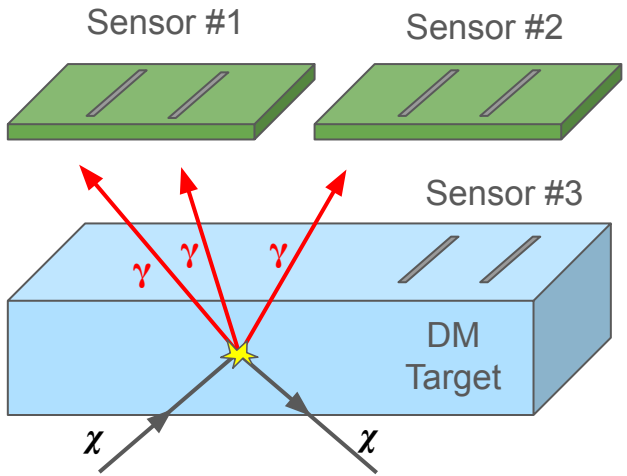
- 2 TESs on the same substrate
- We can model noise on the channels
  - Uncorrelated noise
    - TFN + Johnson + SQUID
  - Correlated noise
    - EMI/vibrations (hopefully sparse)
- We see an unexpected correlated noise
  - Shape looks like signal template FFT
- Interpretation: excess correlated noise is sub-threshold LEE
  - Corollary: Sub-threshold LEE increases noise; degrades resolution





A (Conditional) Solution to Bulk LEE

- Recall: the most troubling LEE population originates in the bulk substrate
  - This volume is also the one in which radiation scatters, so LEE looks just like a scattering event…
- Suppose we use this volume to sense secondary radiation (e.g. scintillation) from a separate target:
  - The scintillation light could be sensed by 2 or more sensors/substrates in coincidence
    - Heat could also be sensed in the target!
  - LEE in one substrate is uncorrelated to LEE in another
- Coincidence veto seems like a path forward!
  - Only if your substrate/target emits radiation that can leave its boundaries (i.e. not phonons)



Helium Target R&D

- HeRALD v0.1 (@ UMass Amherst)
  - Single monolithic ~50 cm^2 detector
  - Later upgrade to 2x ~25 cm detectors
- HeRALD v0.2 (@ LBL)
  - 4x cm^2 detectors suspended above helium
  - 4x cm^2 detectors submerged in helium
  - Recent upgrade: 3 eV calibration laser!
- HeRALD v1.0 (to-be-built)
  - 24x cm^2 detectors suspended above helium
  - To be commissioned at UC Berkeley
  - To be installed at LSM for science