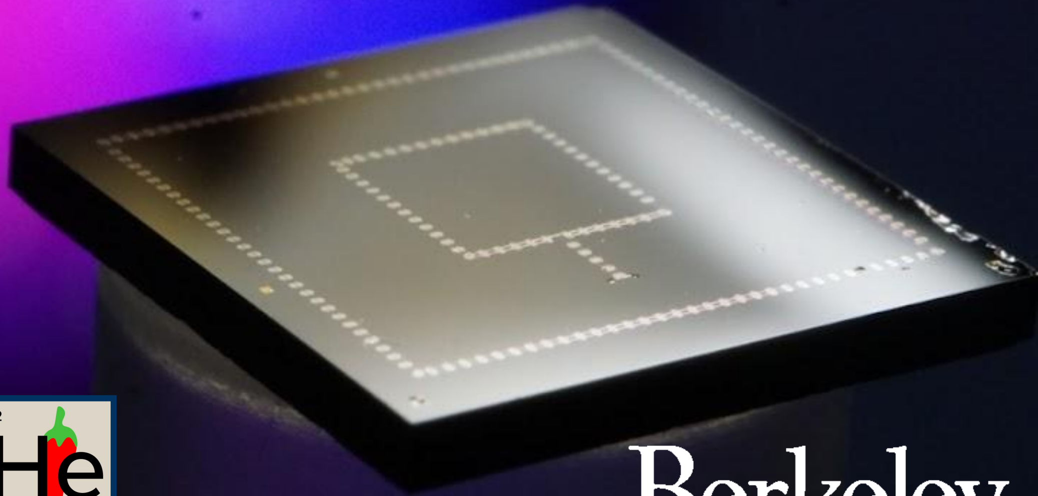
SPICE: A Search for Light (MeV - GeV) Dark Matter Using Polar Crystal Calorimeters



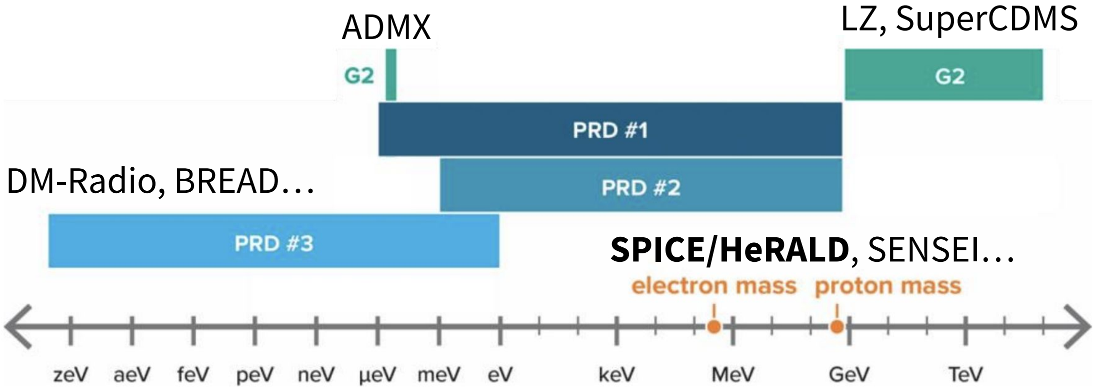
Roger K. Romani for the SPICE/HeRALD Collaboration

Berkeley
UNIVERSITY OF CALIFORNIA

The Search for DM Direct Detection 30 Years On

Still no sign of DM in the laboratory!

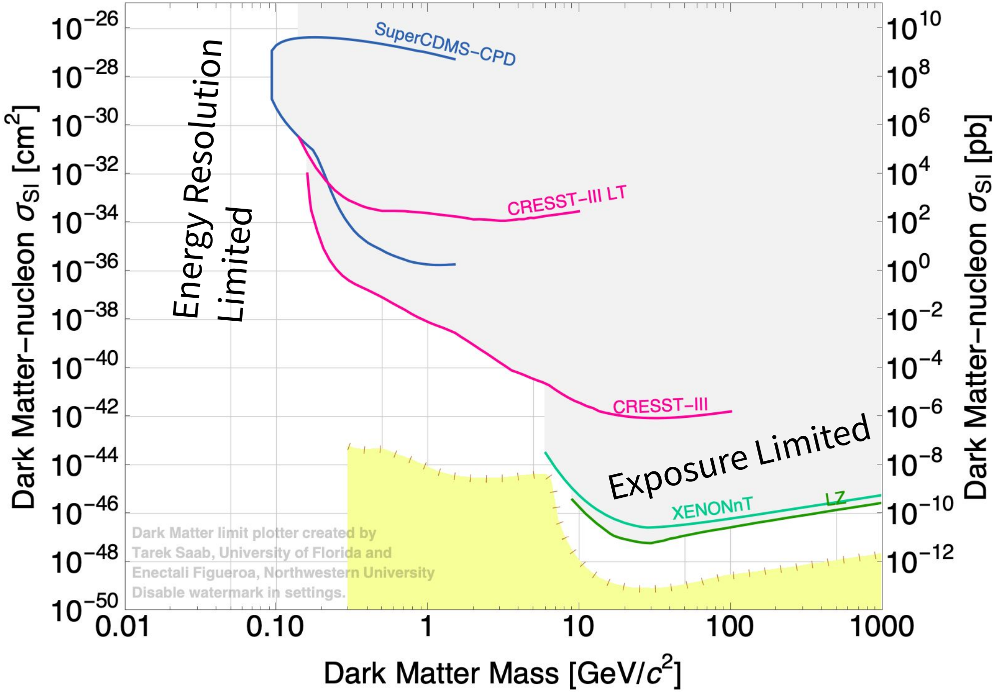
- WIMPs (~10 GeV - ~100 TeV): mature technologies, big collaborations, nearing limits
- Axions/ALPs (less than 1 eV): rapid development of many good ideas
- **“Light DM” (~100 keV- ~1 GeV): exciting new technologies, new motivations**



“Basic Research Needs for Dark Matter Small Projects New Initiatives”, 2018

General Light DM Direct Detection Design Drivers

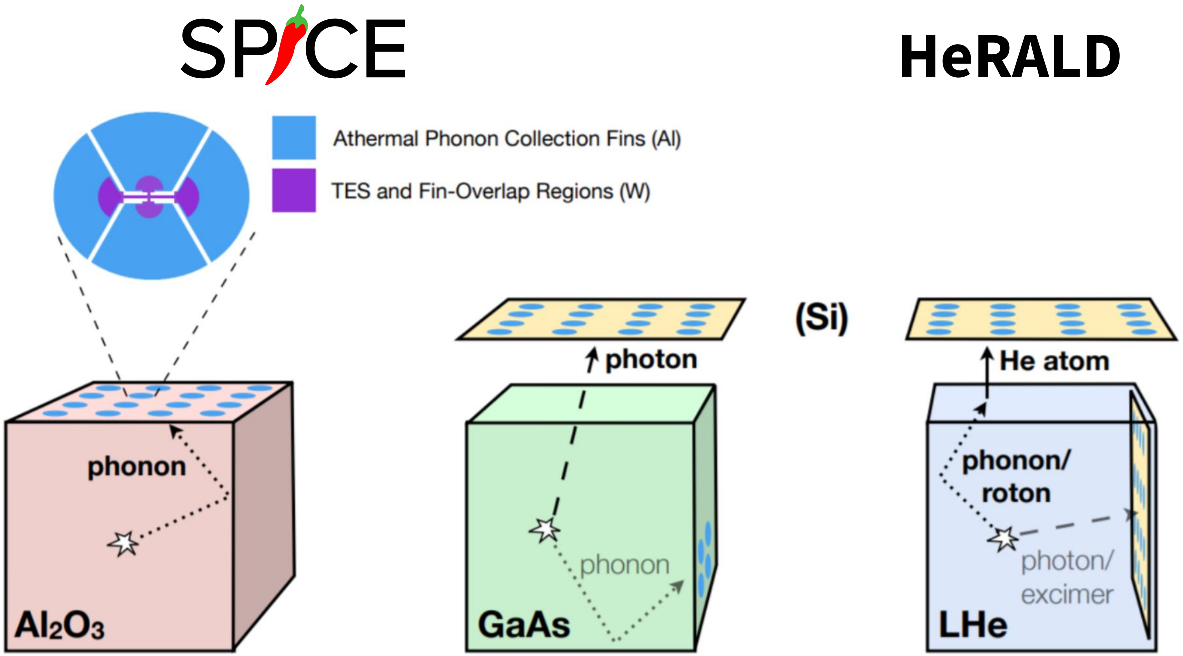
- As M_{DM} goes down, n_{DM} goes up given constant ρ_{DM}
  - **Don't need huge exposure** to get to interesting cross sections
- As M_{DM} goes down, E_{dep} goes down as well
  - Main challenge of light DM direct detection: **detect very small energy depositions**
  - True even for different models, materials



R. K. Romani

SPICE/HeRALD*: A New Light DM Collaboration

Different direct detection mediums unified by a **Transition Edge Sensor** based readout



*also called TESSERACT

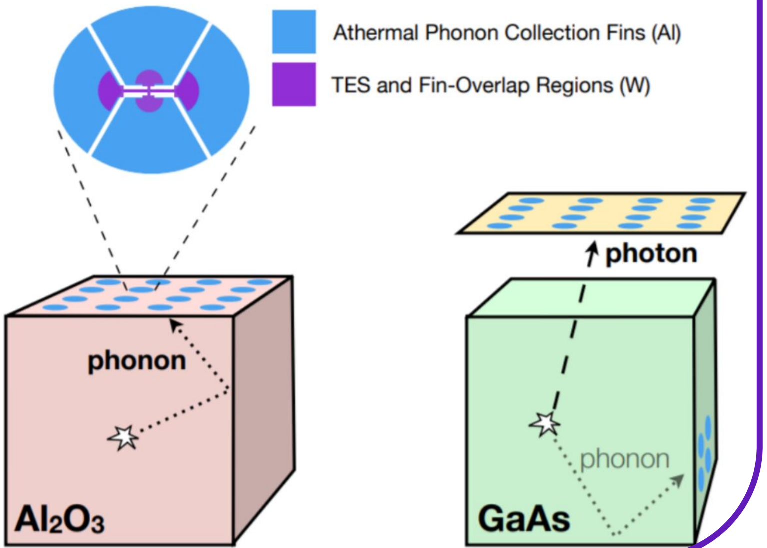
R. K. Romani

SPICE/HeRALD: A New Light DM Collaboration

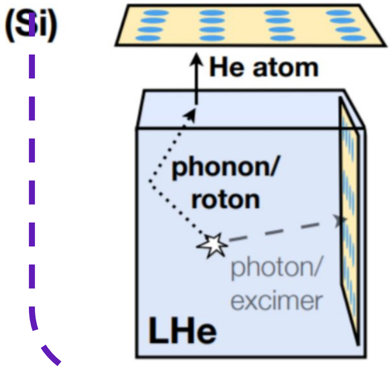
Different direct detection mediums unified by a **Transition Edge Sensor** based readout

This Talk

SPICE



HeRALD

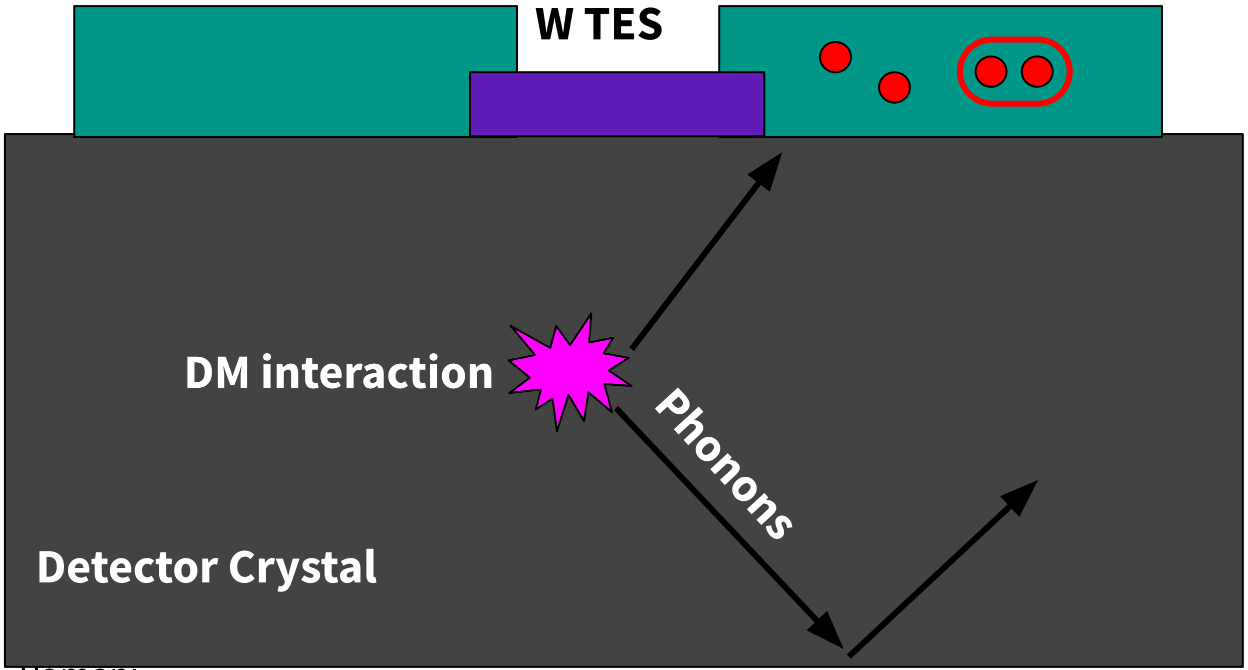


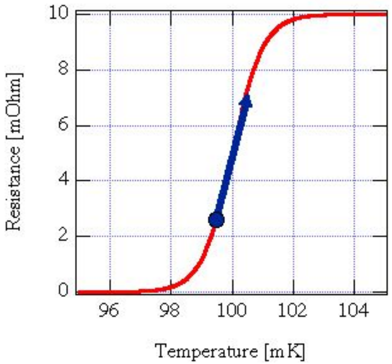
Stick around for Prof. Scott Hertel's talk!

TES Based Calorimetry Basics

Al Fins

Phonons break Cooper pairs in fins, make quasiparticles





*all at ~10 mK in dilution refrigerator

Materials

Different Models, Different Materials of Choice

Light dark photon mediator (Sec. III, Fig. 1)			
Detection channel	Quantity to maximize to reach …		Best materials
	… lower m_χ	… lower $\overline{\sigma}_e$	
(Optical) phonons	ω_O^{-1} (Eq. (24))	quality factor Q defined in Eq. (27)	SiO_2, Al_2O_3, $CaWO_4$
Electron transitions	E_g^{-1} (Eq. (28))	depends on details of electron wavefunctions	InSb, Si
Nuclear recoils	$(A\omega_{\mathrm{min}})^{-1}$ (Eq. (29))	$(Z/A)^2\,\omega_{\mathrm{min}}^{-1}$ (Eq. (31))	diamond, LiF

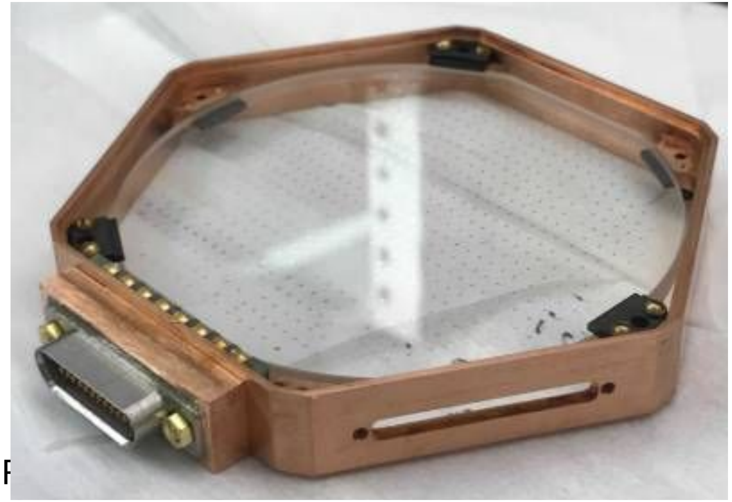
Hadrophilic scalar mediator (Sec. IV, Figs. 2, 3)			
Detection channel	Quantity to maximize to reach …		Best materials
	… lower m_χ	… lower $\overline{\sigma}_n$	
(Acoustic) phonons	$c_s/\omega_{\mathrm{min}}$ (Eq. (36))	Light mediator: $\omega_{\mathrm{min}}^{-1}$ (Eq. (35))	diamond, SiO_2
		Heavy mediator: c_s^{-1} or $\omega_{\mathrm{ph}}^{-1}$ or $A\omega_{\mathrm{ph}}$ depending on m_χ (Eqs. (37), (38), (39))	all complementary
Nuclear recoils	$(A\omega_{\mathrm{min}})^{-1}$ (Eq. (29))	Light mediator: $\omega_{\mathrm{min}}^{-1}$ (Eq. (40))	diamond, LiF
		Heavy mediator: A (Eq. (43))	CsI, Pb compounds

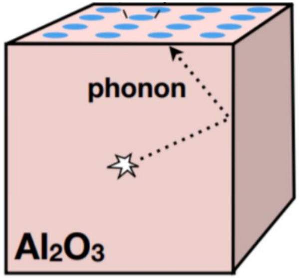
\+ **Superfluid helium!**

arXiv: 1910.10716 Griffin et. al. 2021

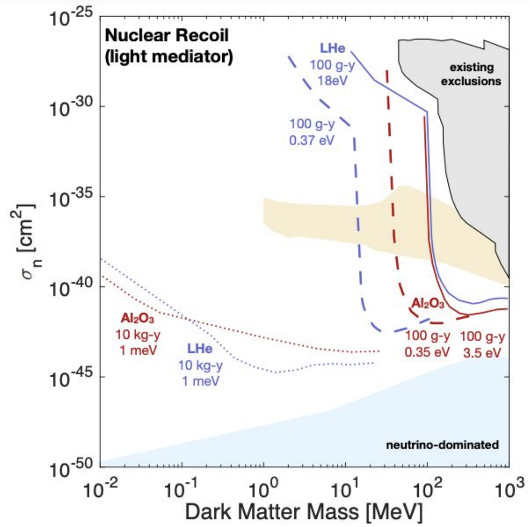
Sapphire as a SPICE Target

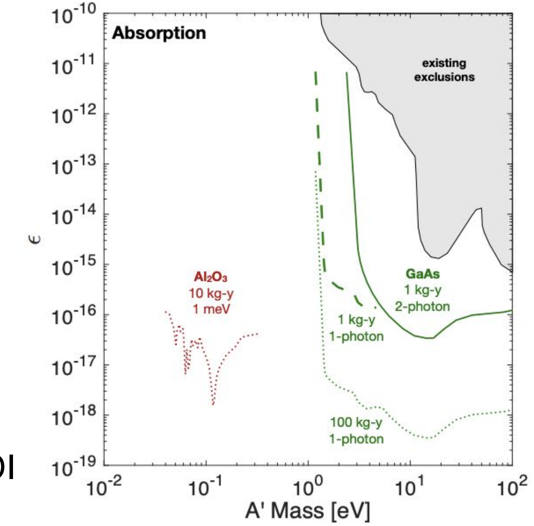
- Low mass oxygen nuclei as NRDM scattering target
- Polar unit cell: optical phonons down to 100s of meV
  - Dark photon coupling due to differently charged nuclei
- Prototype detector has been run





TESSERACT
SNOWMASS LOI





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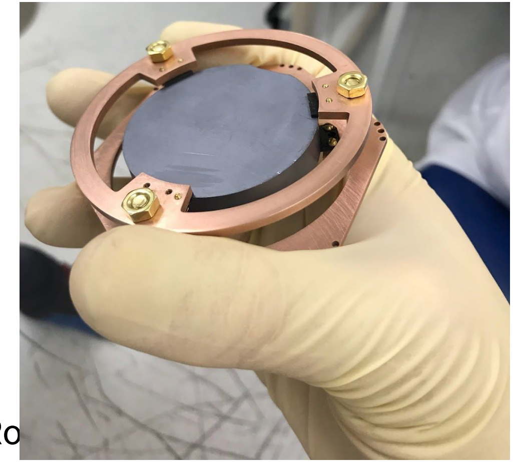
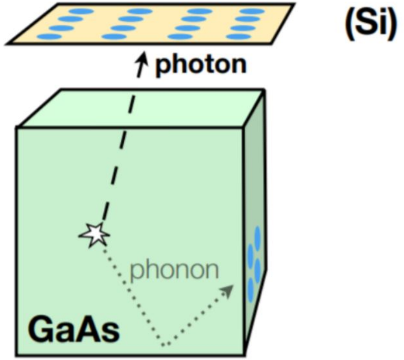
GaAs as a SPICE Target

- Polar crystal: coupling to dark photons
- Scintillation + phonon signal allows for NR/ER discrimination down to eV scale signals
- GaAs scintillation yield being measured





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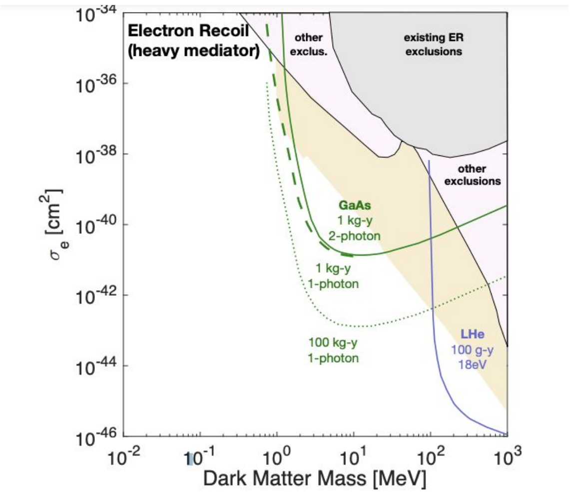
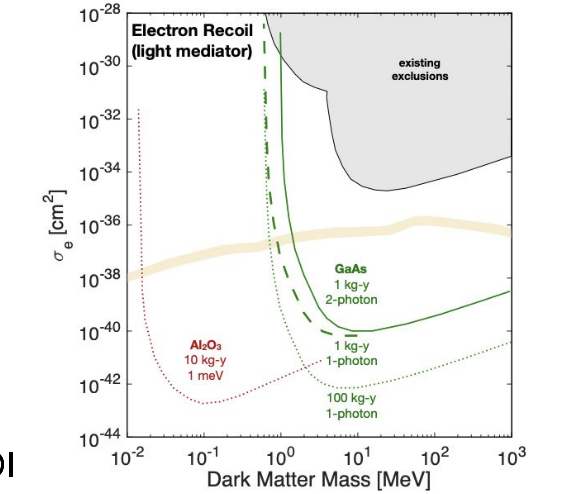
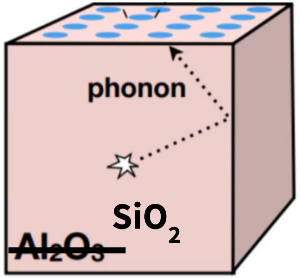
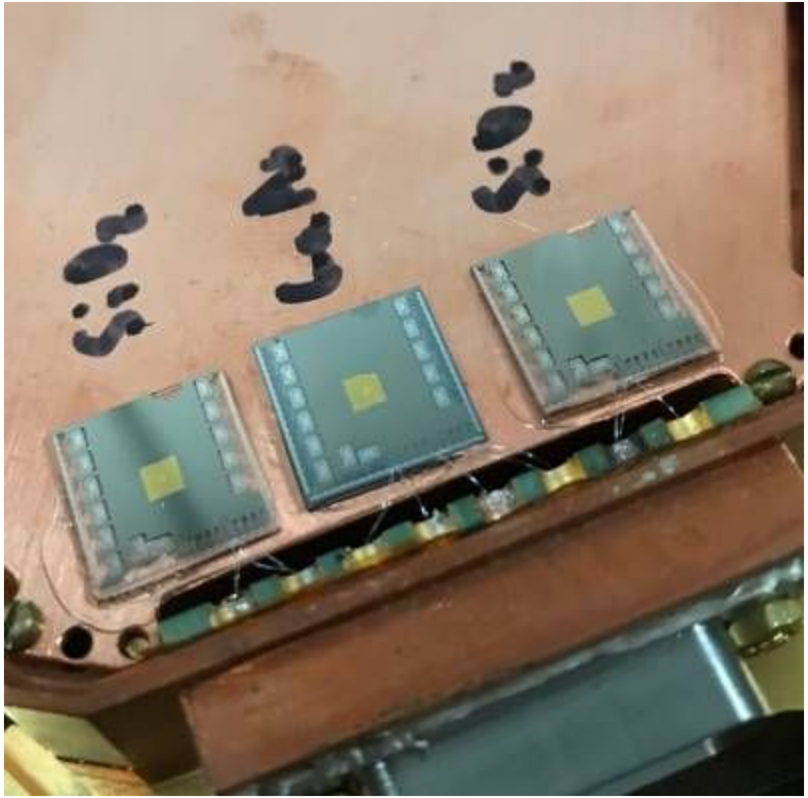




SiO2 as a SPICE Target

- Excellent coupling to dark photons, high “quality factor”
  - See arXiv: 1910.10716
- TESs on SiO2 substrate tested



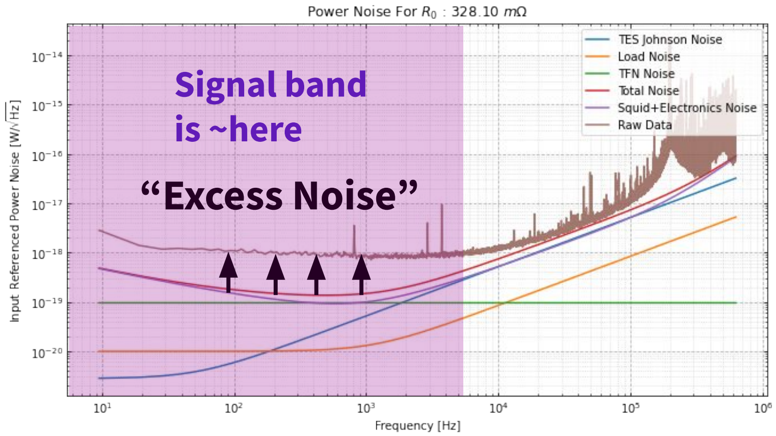


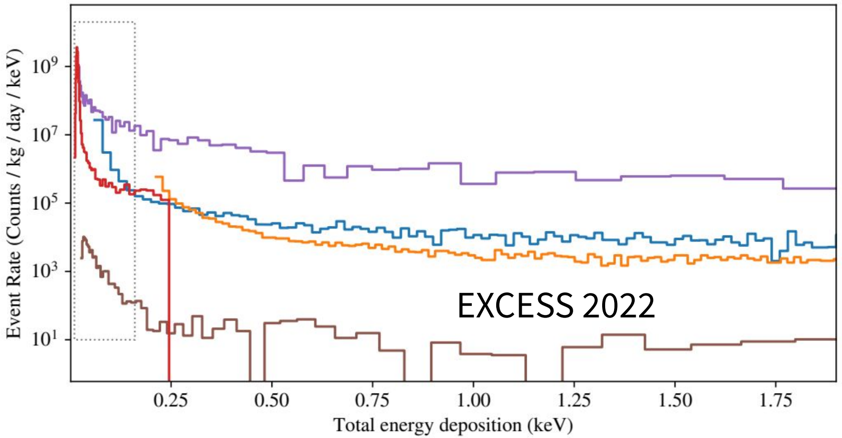
TES Readout Technology

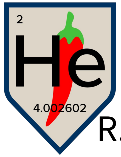
Two Key Design Drivers:

- Good energy resolution
  - Excess noise limits resolution
- Low background
  - Excess events limits reach

Don’t understand either!







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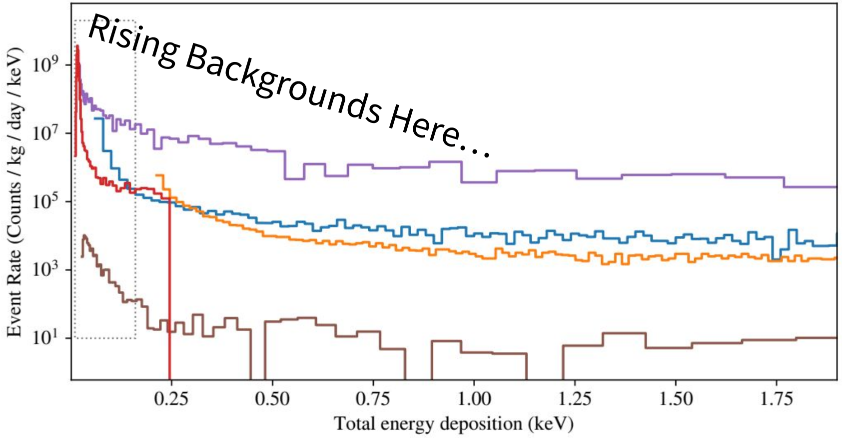
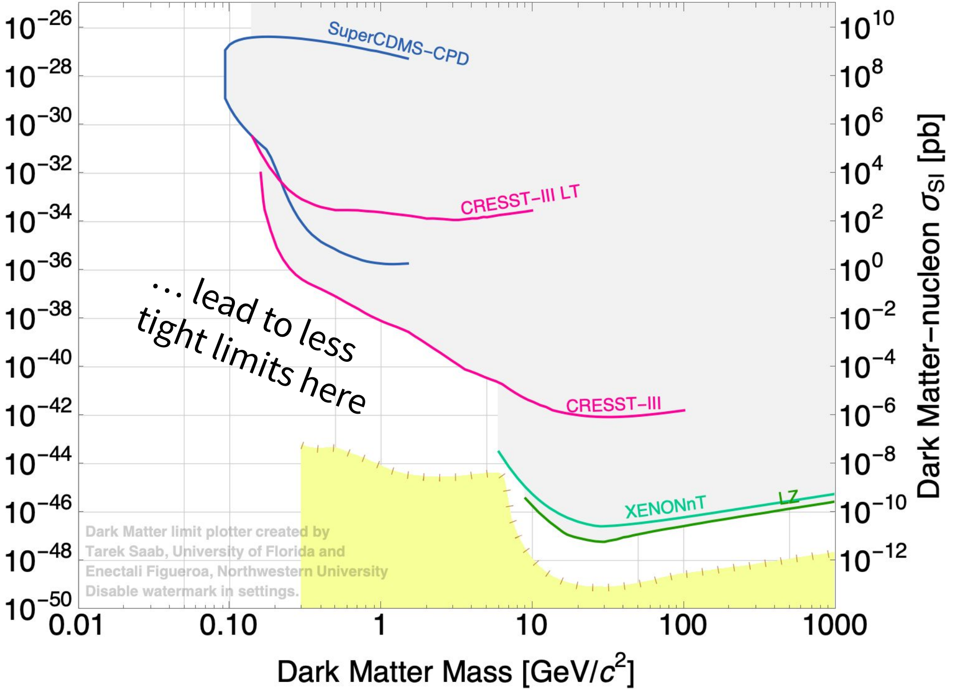
Low Energy Backgrounds: “LEE”



EXCESS 2022



See EXCESS 2023 Review by Dan Baxter

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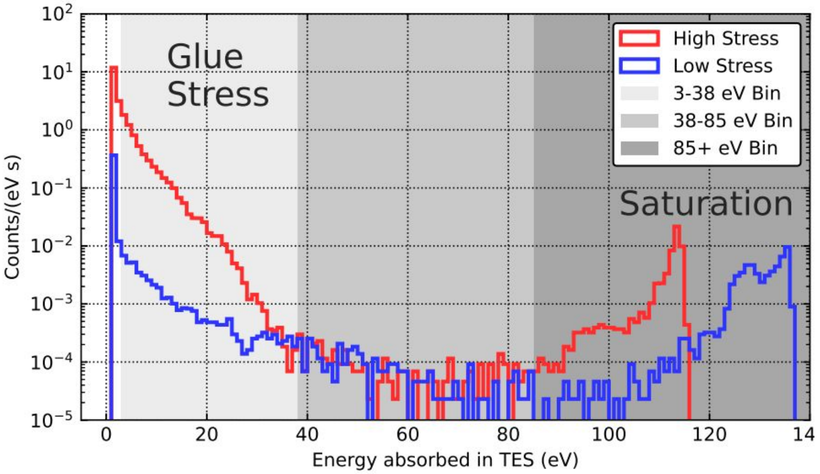
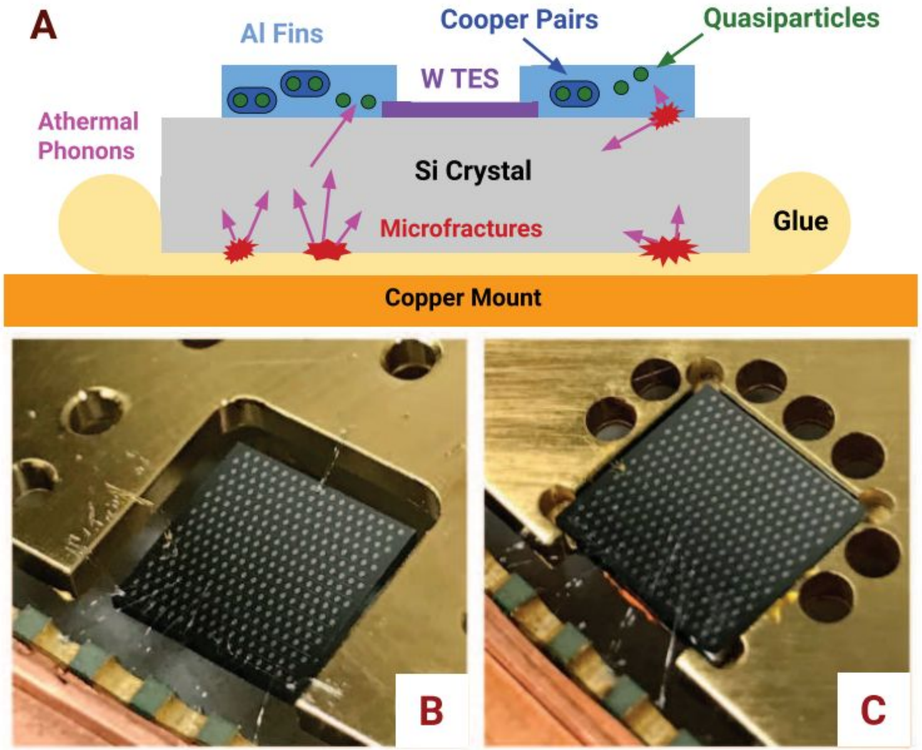
Stress Causes LEE-Like Events!

- Compare: high/low stress (hanging/glued) detectors
- Found: stress causes LEE-like events!
- Another source… films?

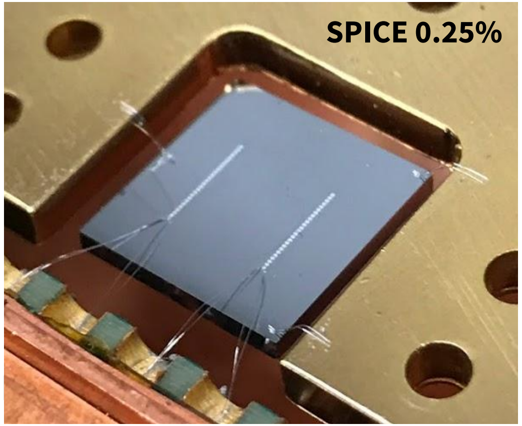


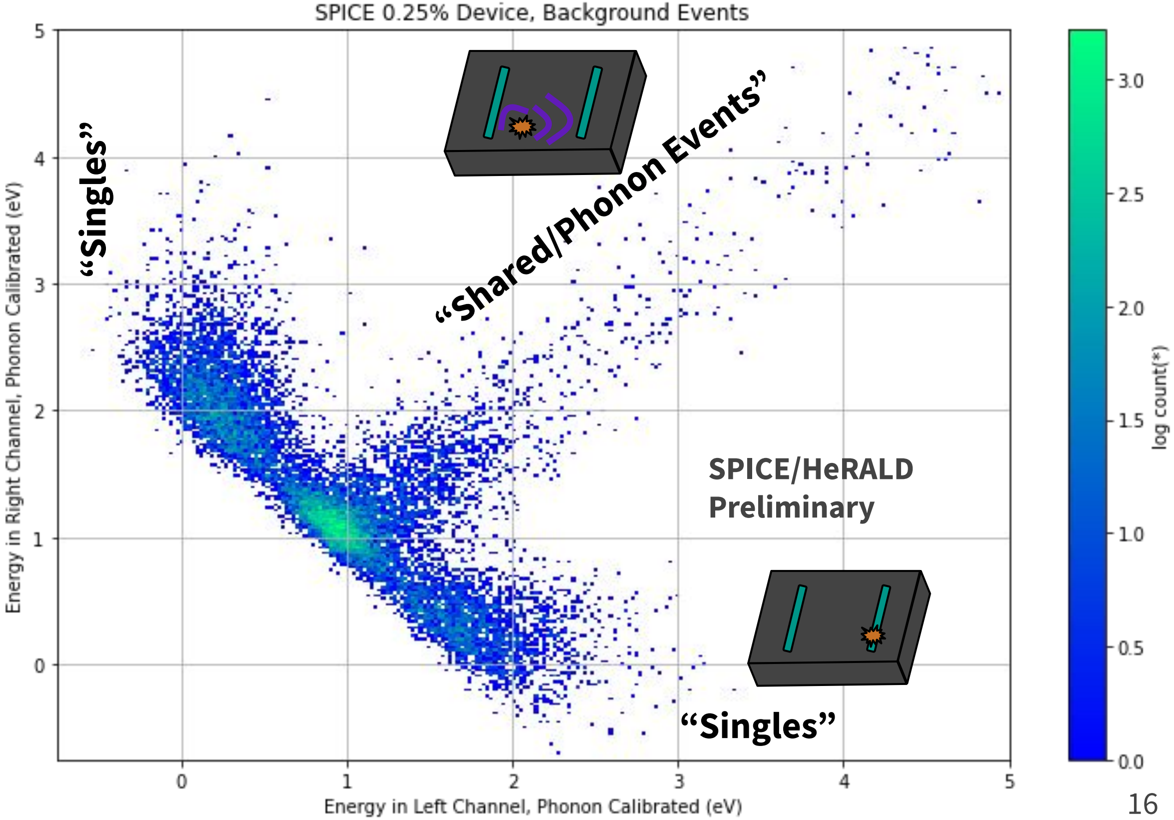


Films Cause LEE? Two Channel Devices

Two components of LEE:

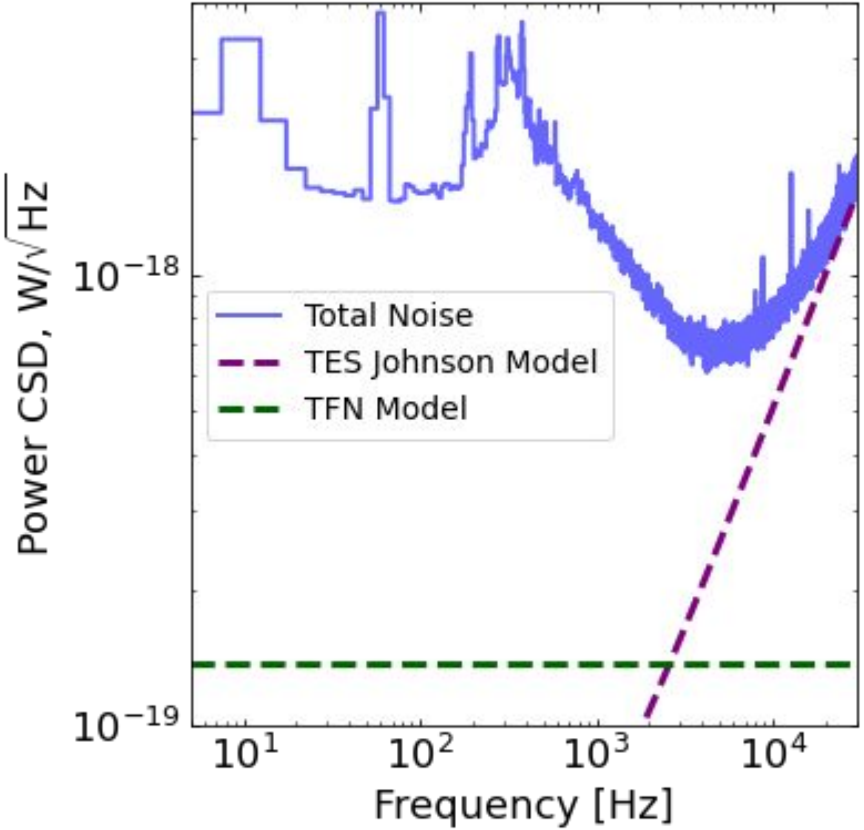
- "Shared" events: phonon pulse shape, partitioning
- "Singles:" single channel partitioning, faster pulse
  - **Film events!**





Excess Noise

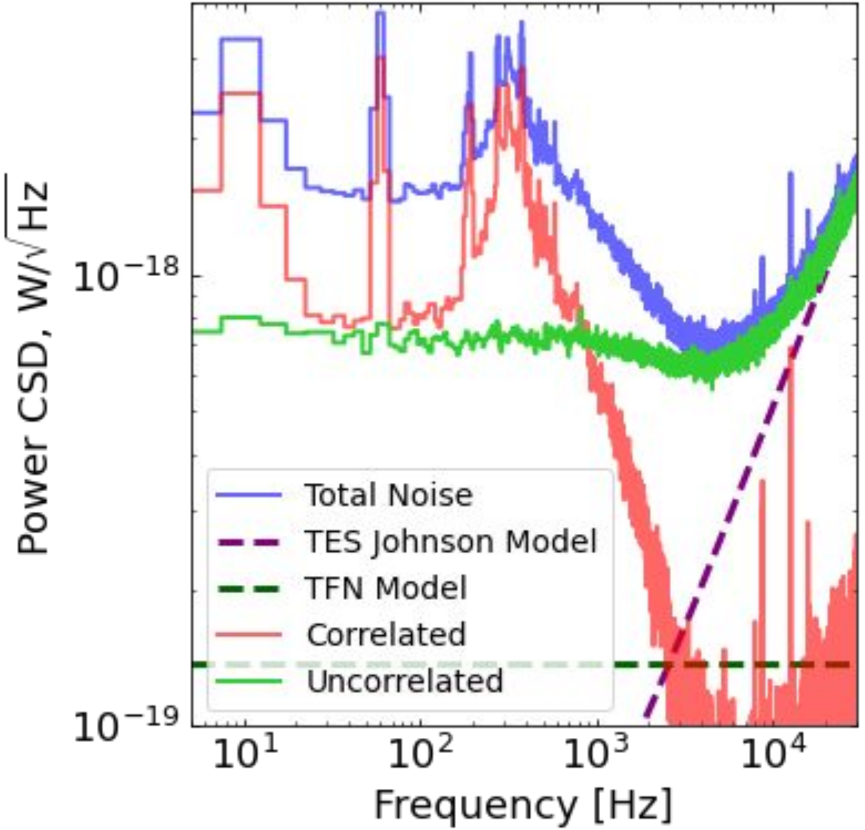
- Signal band: completely dominated by excess noise
  - Can't improve by lowering Tc, shrinking TESs…
- Split into noise in one sensor, shared between two sensors…



Excess Noise

- Signal band: completely dominated by excess noise
  - Can't improve by lowering Tc, shrinking TESs…
- Correlated: consistent with excess very small phonon pulses
- Uncorrelated: consistent with fast events right in TESs

Excess noise: sub-threshold shared/single events?

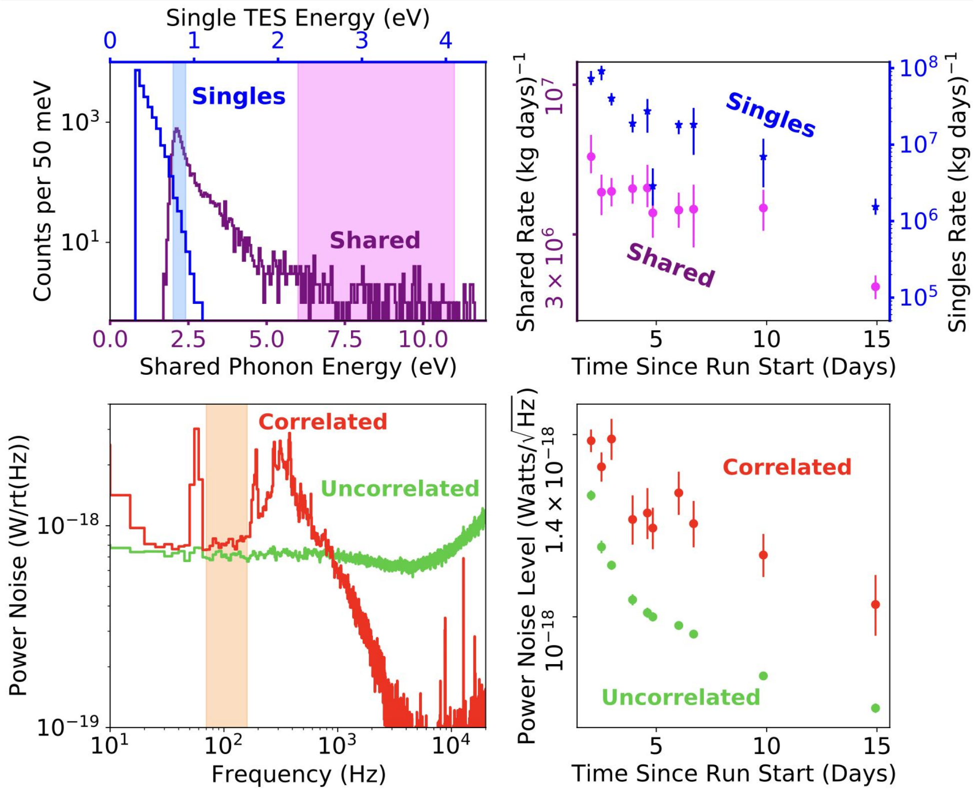


Everything Goes Down Over Time!

Relaxation (of stress?) causing both problems: excess events + excess noise

- Excess noise limiting mass reach
- Excess events limiting cross section reach/backgrounds

Solve this problem, low mass DM searches are open for business!



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SPICE/HeRALD: An Exciting Light DM Program

- A suite of materials, with advantages for different model and readouts
- Cutting edge calorimeter R&D, making strong progress towards solving LEE
- An exciting near-term program of DM limits expected