Large Format X-ray Microcalorimeter Arrays Based on Thermal MKIDs (TKIDs)

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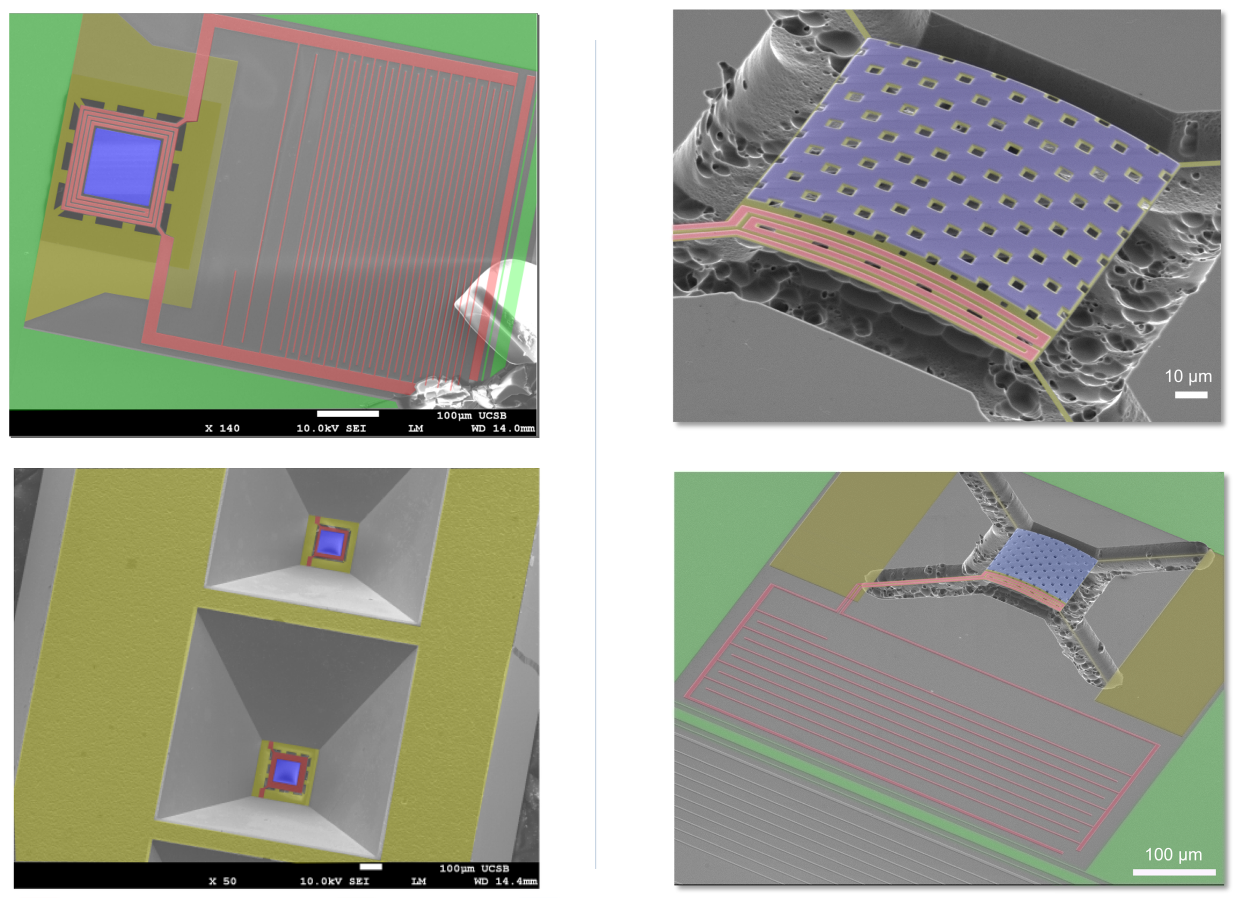
INTRODUCTION

Our goal is to use microwave kinetic inductance detectors (MKIDs) to measure the temperature of the absorber of a microcalorimeter, to within 10 eV for a 5.9 keV X-ray absorption event. We design for similar sensitivity over the X-ray energy range 2 – 12 keV, and we would like to demonstrate 1,000 microcalorimeters in a tiled array.

Goal: 10 eV resolution at 6 keV
Goal: 2 – 12 keV operation range
Goal: 1,000+ microcalorimeter array.



Colorized micrograph of XR-8, top side (Top), and bottom side (Bottom).

Colorized micrograph of XR-7, top side (Top), and bottom side (Bottom).

We are in the fabrication stages of a third iteration microcalorimeter design. A previous iteration, XR-7, achieved 75 eV at 5.9 keV[1], resolution. They used XeF_2 and KOH etches for the membrane release, and had difficulty controlling sensitivity and heat capacity.

REFERENCES

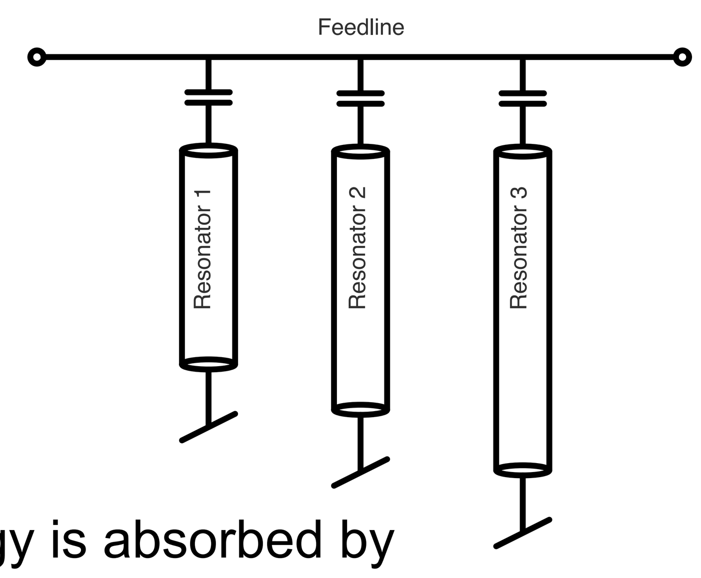
1. G. Ulbricht et al. , "Highly multiplexible thermal kinetic inductance detectors for x-ray imaging spectroscopy," *Appl. Phys. Lett.*, vol. 106, no. 25, p. 251103, 2015.

Supported by NASA grant NX15AJ26G

MKID Physics

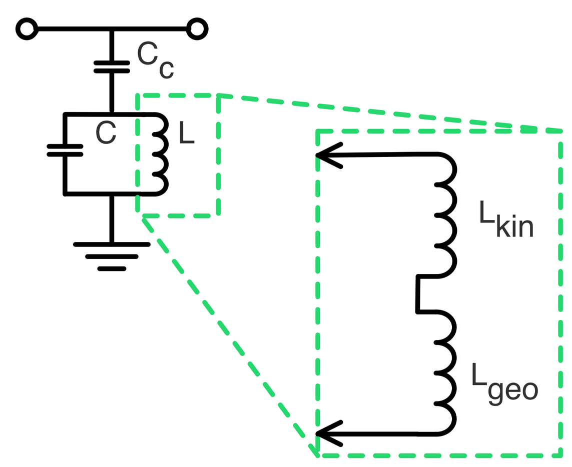
- MKIDs are resonant circuits patterned out of superconducting thin films.
- Each resonant circuits has a unique geometry which gives it a unique resonant frequency (f_0) and bandwidth, i.e. quality factor (Q).
- Numerous resonators are usually shunt-coupled to a common feedline, a superconducting transmission line.
- They are easy to bias and read out by multiplexing over the frequency domain, currently for a cost of ~$10 resonator or less.

Numerous resonators can be read out from a common feedline.



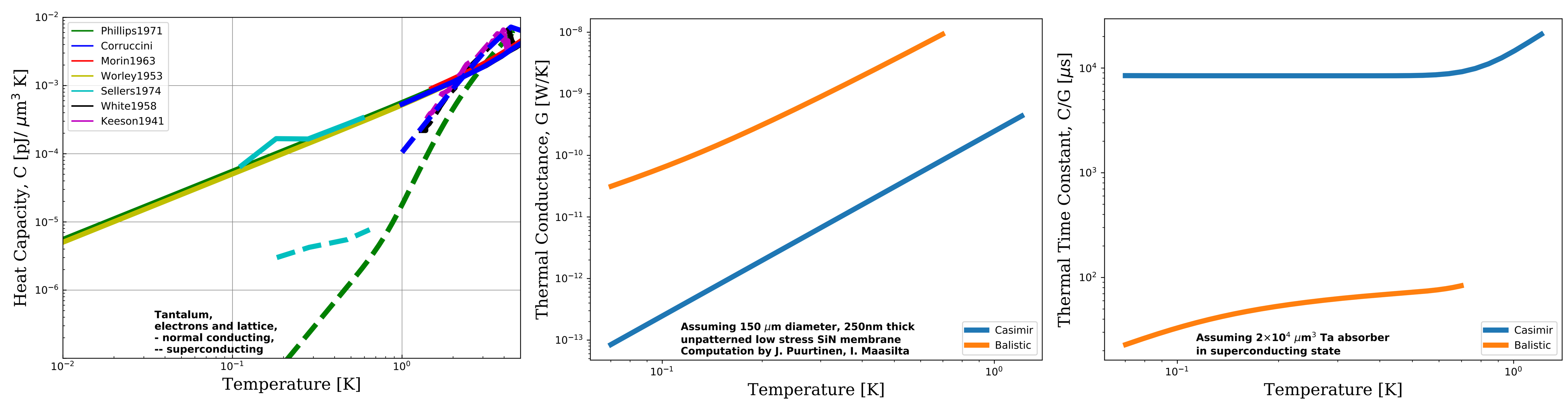
- When pair-breaking energy is absorbed by resonator, the component of the surface inductance due to the supercurrent (L_{kin}) increases and changes f_0 and Q in proportion to the amount of energy.

The inductance of each resonator contains a geometric part and a kinetic part, which corresponds to the number of Cooper pairs.



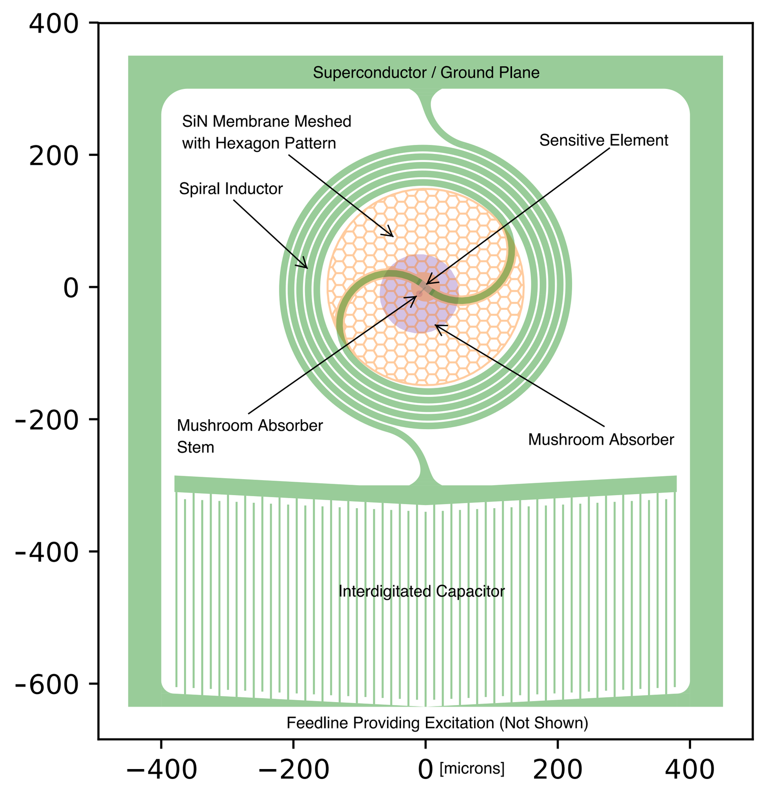
- A microcalorimeter is made by connecting a resonator to an absorber, so that heat from X-ray absorption breaks cooper pairs in the film.

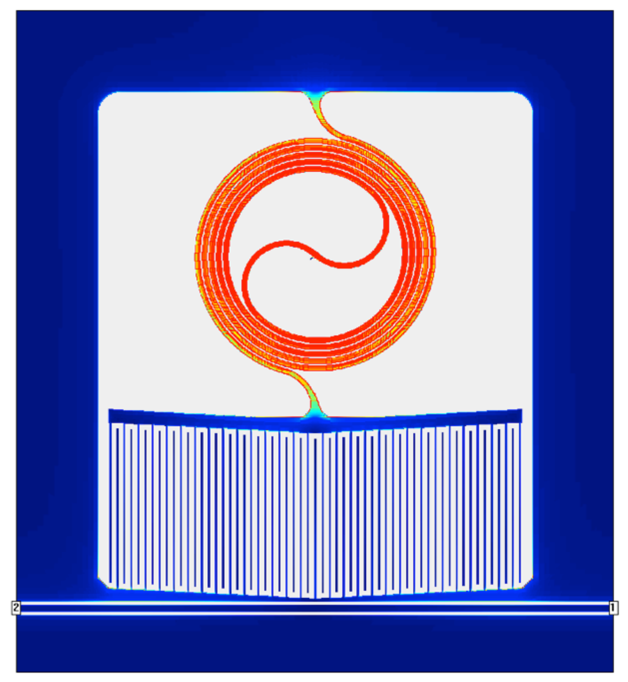
Tantalum heat capacity, SiN_x membrane conductance, and resulting thermal time constant.



Approach

- To increase energy resolution: (a) we increase readout power handling using a wide inductor, i.e. 10 μm. (b) we decrease two-level system noise by using a large capacitor, i.e. low E-field.





Left: Diagram of XR-9 microcalorimeter with various features labeled.
Right: The current distribution in the resonator on resonance.

- This iteration, XR-9, uses cantilevered (tantalum) absorbers to enable close packed tiling of adjacent microcalorimeters.
- Resonators are made of a high T_C material (Niobium) with a section of low T_C material in close proximity to the absorber, where the δT from X-ray absorption is greatest and affects a large δL_{kin}.
- Membrane release is done by a back side Bosch trench etch through the silicon wafer substrate followed by a HF dip to remove a SiO_2 etch stop layer and any excess surface states created by processing that lead to anomalously high heat capacity and noise.
- Thermal time constant tunable by membrane geometry and absorber volume/material choice.