Current State of Thermal Kinetic Inductance Detectors for Ground-Based Millimeter Wave Cosmology

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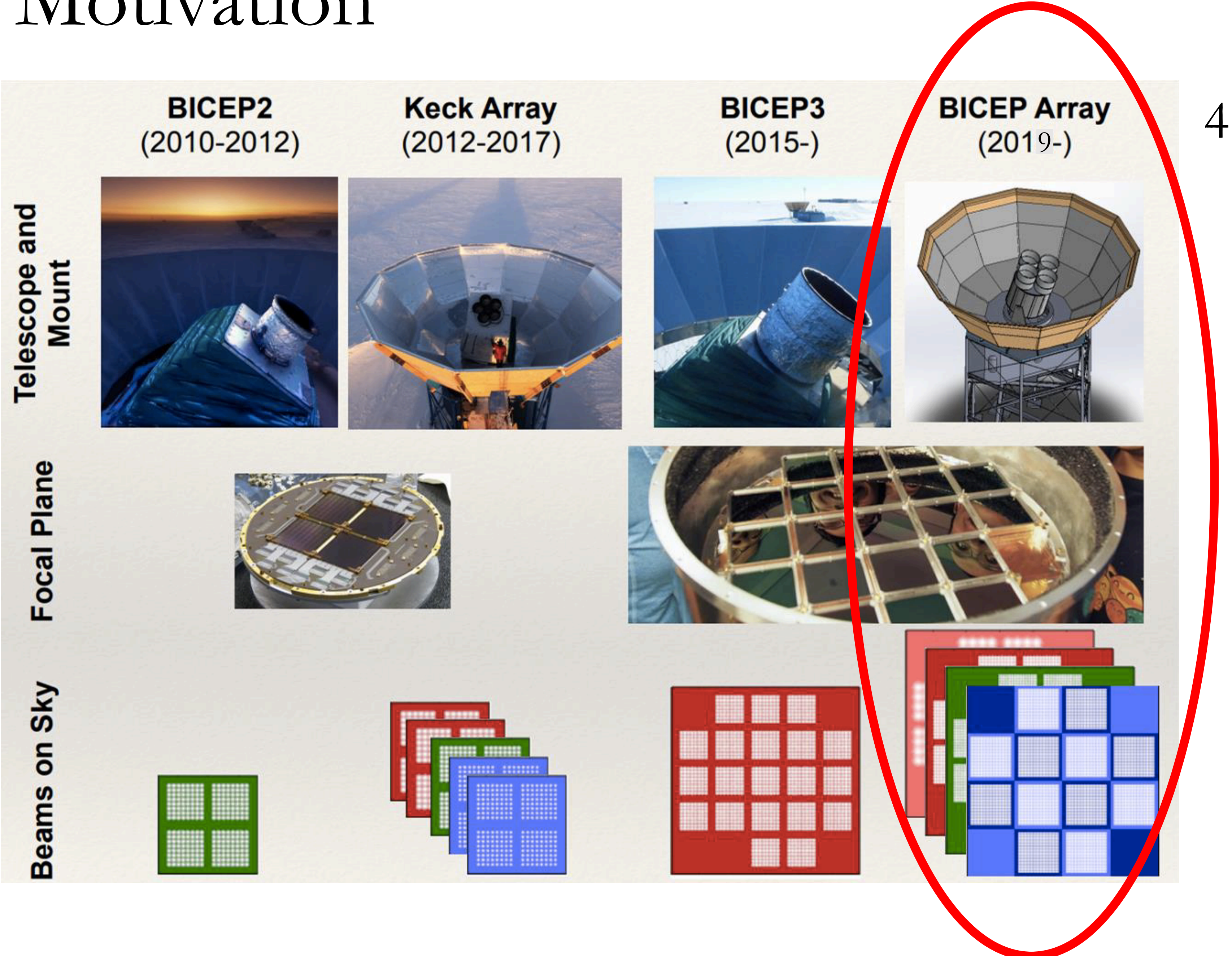
Motivation

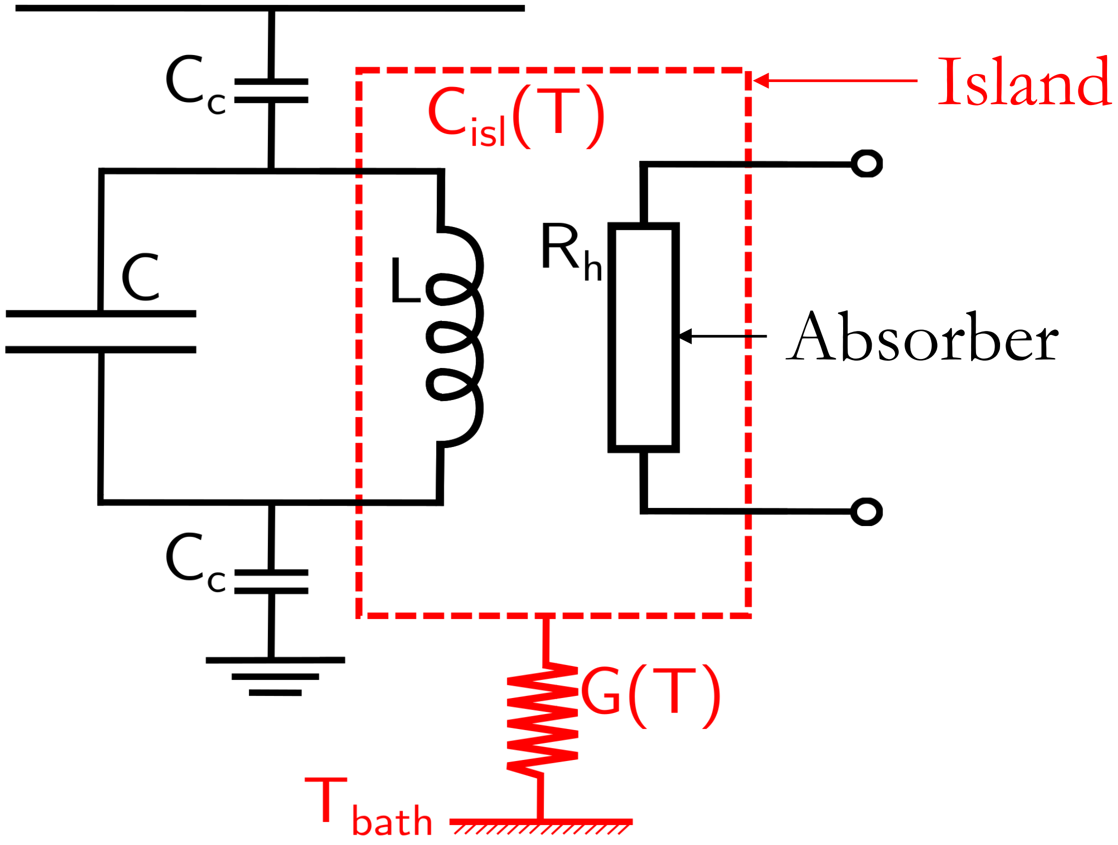


4 receivers

- 30/40 GHz
- 95 GHz
- 150 GHz
- 220/270 GHz

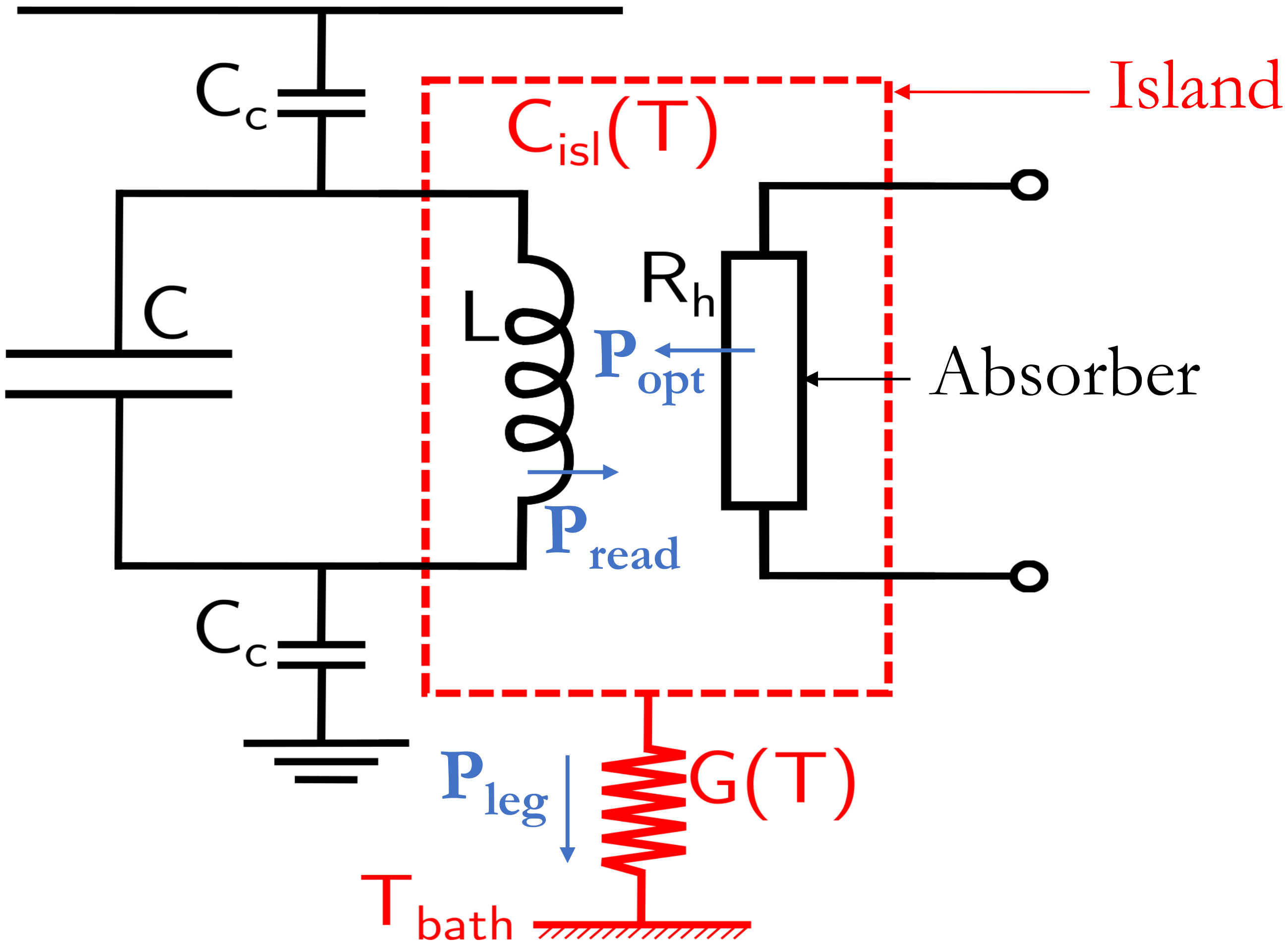
At 220/270 GHz require nearly 20,000 detectors

Thermal Kinetic Inductance Detectors



- Inherits ease of integration and multiplexing from KIDs
- More design parameters:
  - Absorber distinct from inductor
  - Leg Conductance
  - Bolometer Island temperature
  - Inductor Volume
- Bonus: ease of calibration
- Easy to hybridize
- Not susceptible to cosmic rays

TKID Model



$$P_{\rm opt} + \boxed{P_{\rm read}} = P_{\rm leg}$$

$$P_{\rm read} \ll P_{\rm opt}$$

No electrothermal feedback

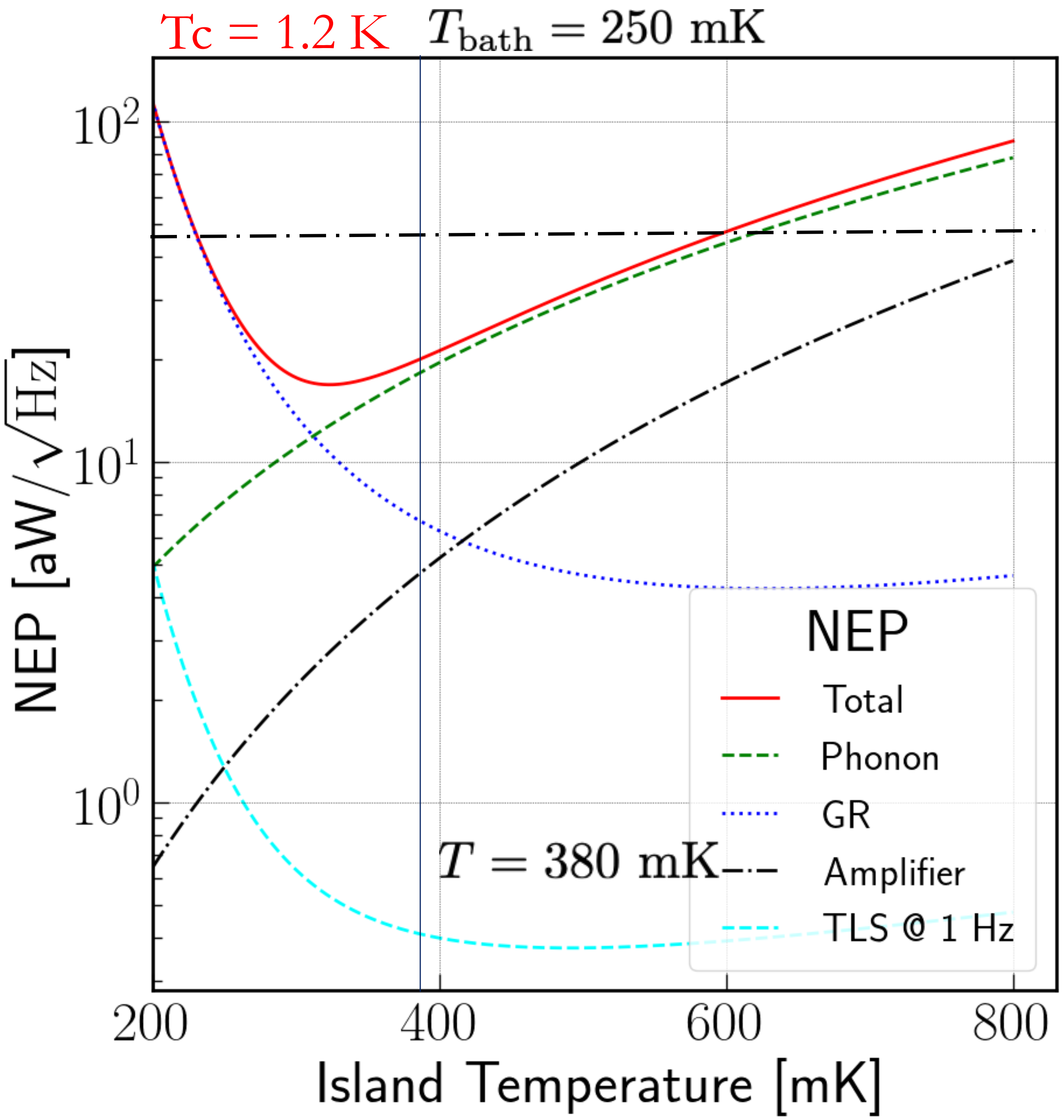
$$\delta T(\nu) = \frac{\delta P(\nu)}{G(T)} \cdot \frac{1}{1 + j2\pi\nu\tau}$$

$$\tau = \frac{C}{G}$$

Noise Predictions

$P \sim 5\ \text{pW}$

$$\text{NEP}_{\text{photon}} \ = \ 43\ \text{aW}/\sqrt{\text{Hz}}$$



Noise Predictions

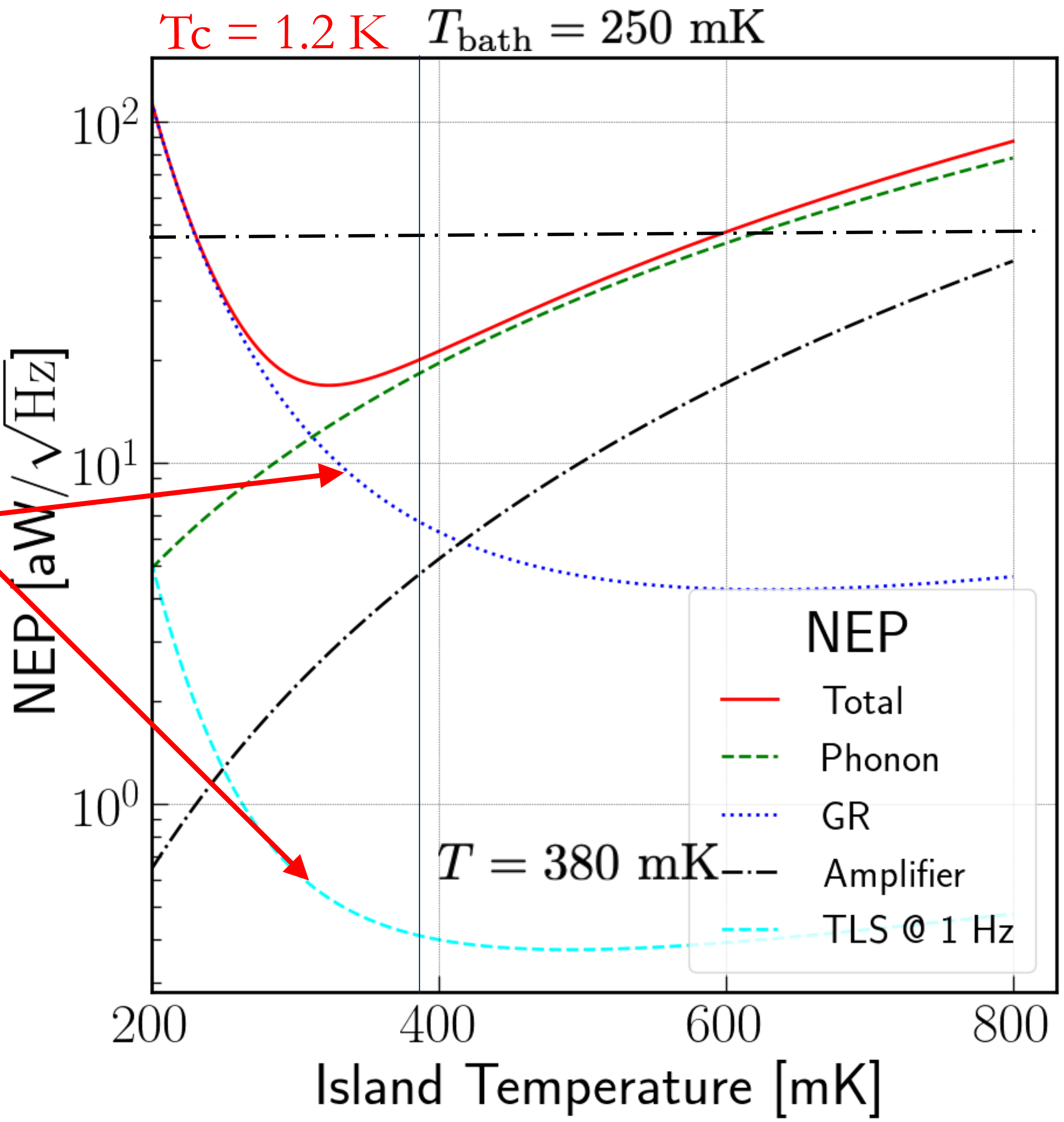
$P \sim 5 \text{ pW}$

$$\text{NEP}_{\text{photon}} = 43 \text{ aW}/\sqrt{\text{Hz}}$$

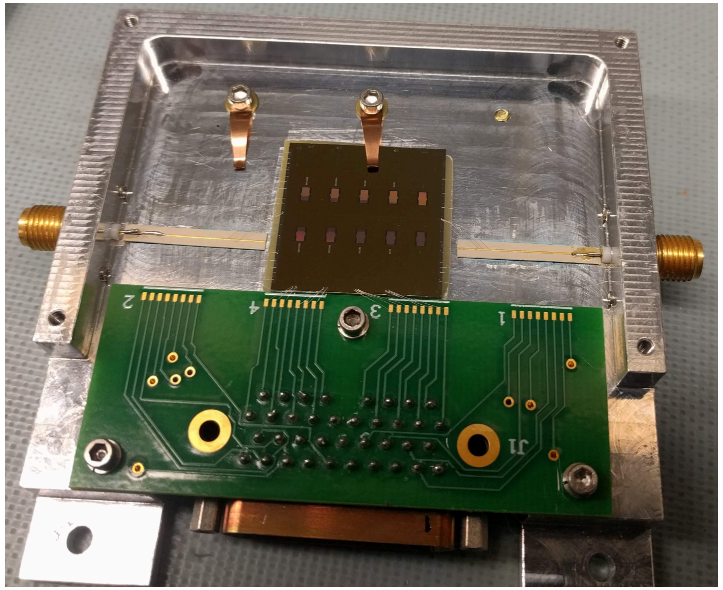
Suppression in GR and TLS noise due to increase in responsivity

$$S = \frac{\delta f_r}{\delta P} = \frac{\delta f_r}{\delta x} \cdot \frac{\delta x}{\delta n_{qp}} \cdot \frac{\delta n_{qp}}{\delta T} \cdot \frac{\delta T}{\delta P}$$

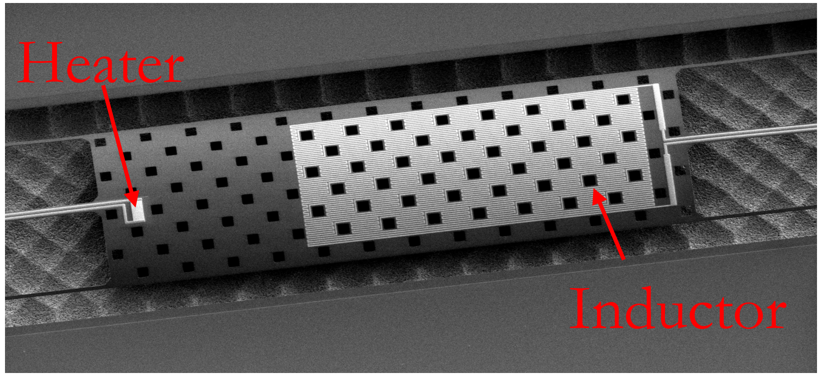
$$S = \frac{\delta f_r}{\delta P} = f_r(T) \cdot \frac{\beta(\omega, T)\kappa(T)}{2Q_i \; G(T)T}$$

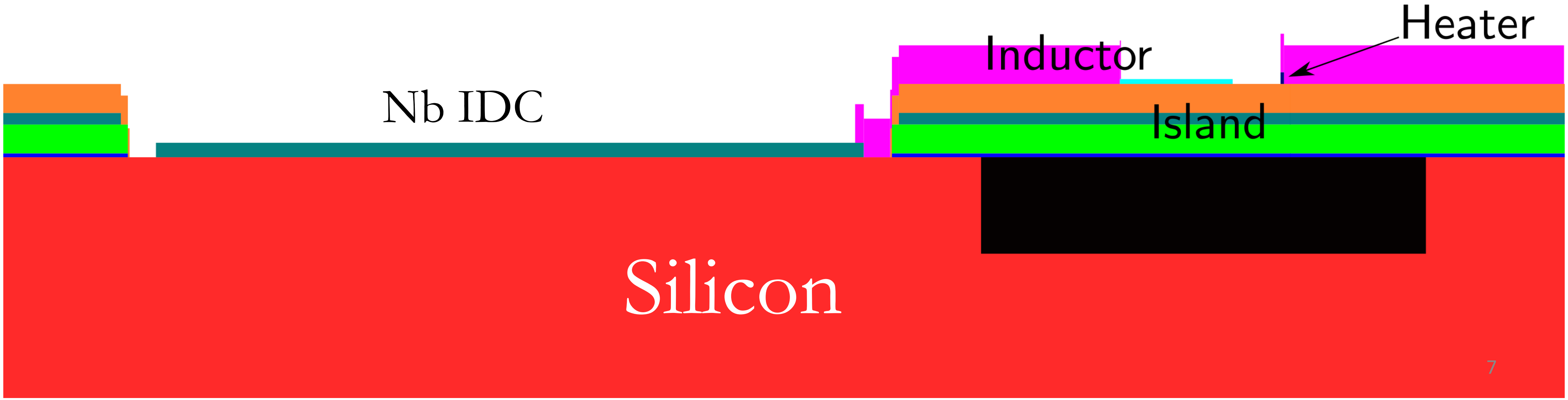


Waffle TKIDs

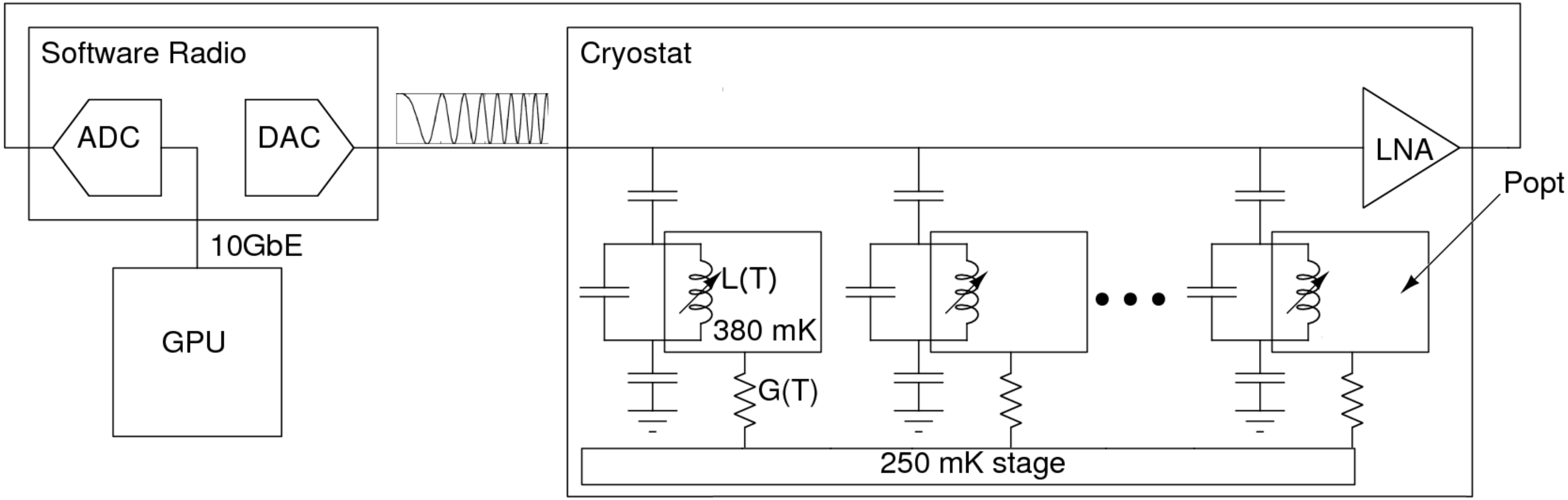


- Niobium capacitor sits on the bare Si to avoid TLS effects
- Au heater allows us to directly measure the responsivity and NEP





TKID Multiplexing

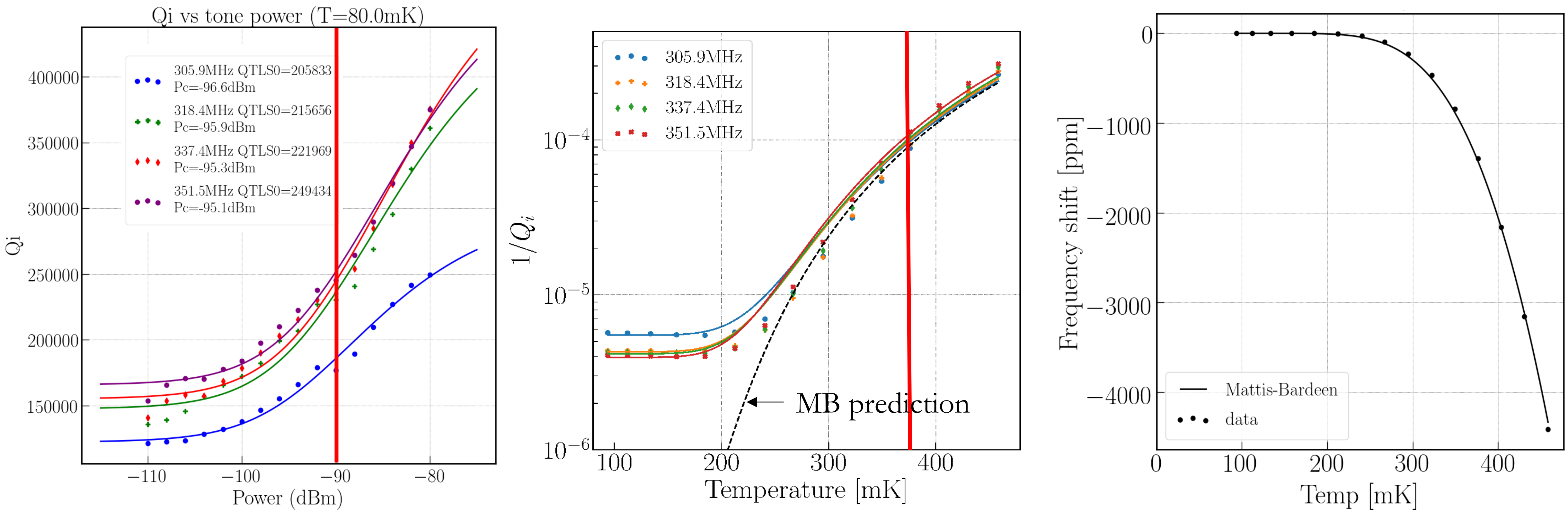


- GPU Accelerated multitone Readout based on the Ettus Research USRP X300 Software Radio Platform

More details: [10.1109/TASC.2019.2912027](https://doi.org/10.1109/TASC.2019.2912027)

https://github.com/nasa/GPU_SDR

Resonator Properties

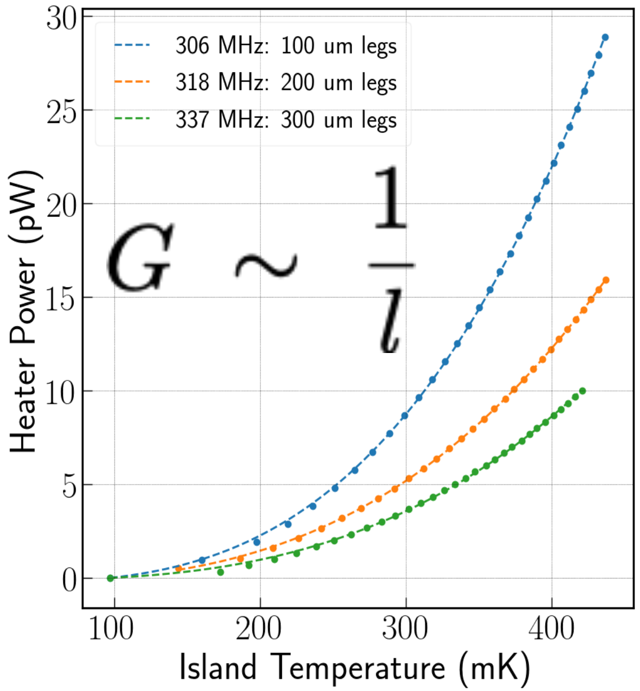


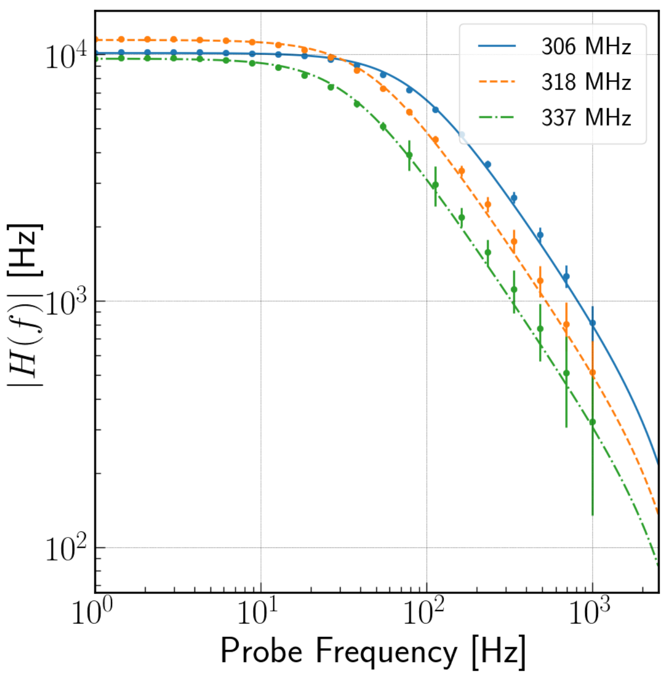
Power sweeps exhibit TLS power dependence

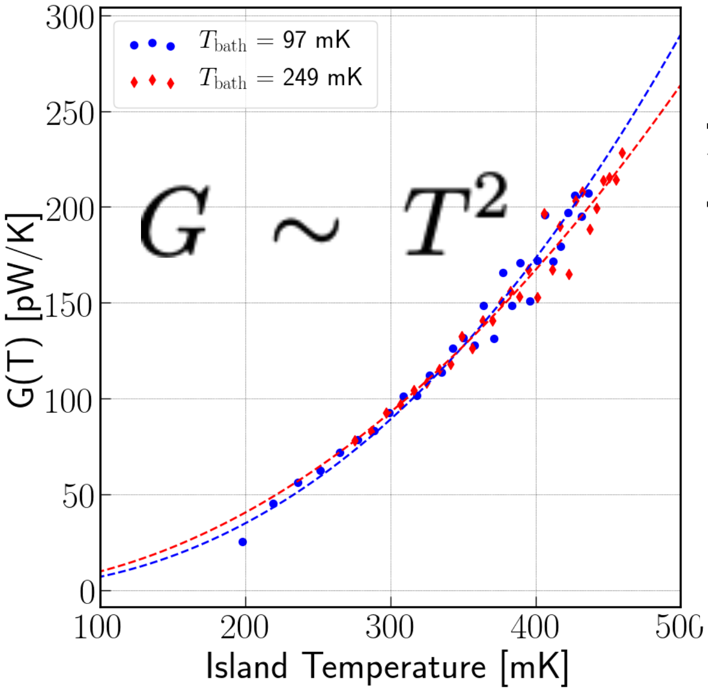
At operating temperature well described by Mattis-Bardeen

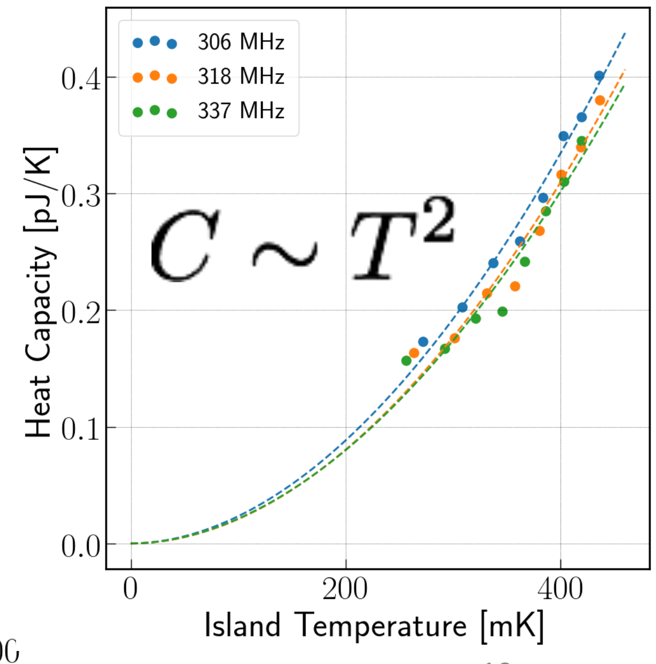
Bolometer Properties

- Calibration measurements enabled by the calibration heater
- We see excess heat capacity in our devices
- Likely a surface effect? XeF_2 contamination?
- Consistent with our experience from TES bolometers

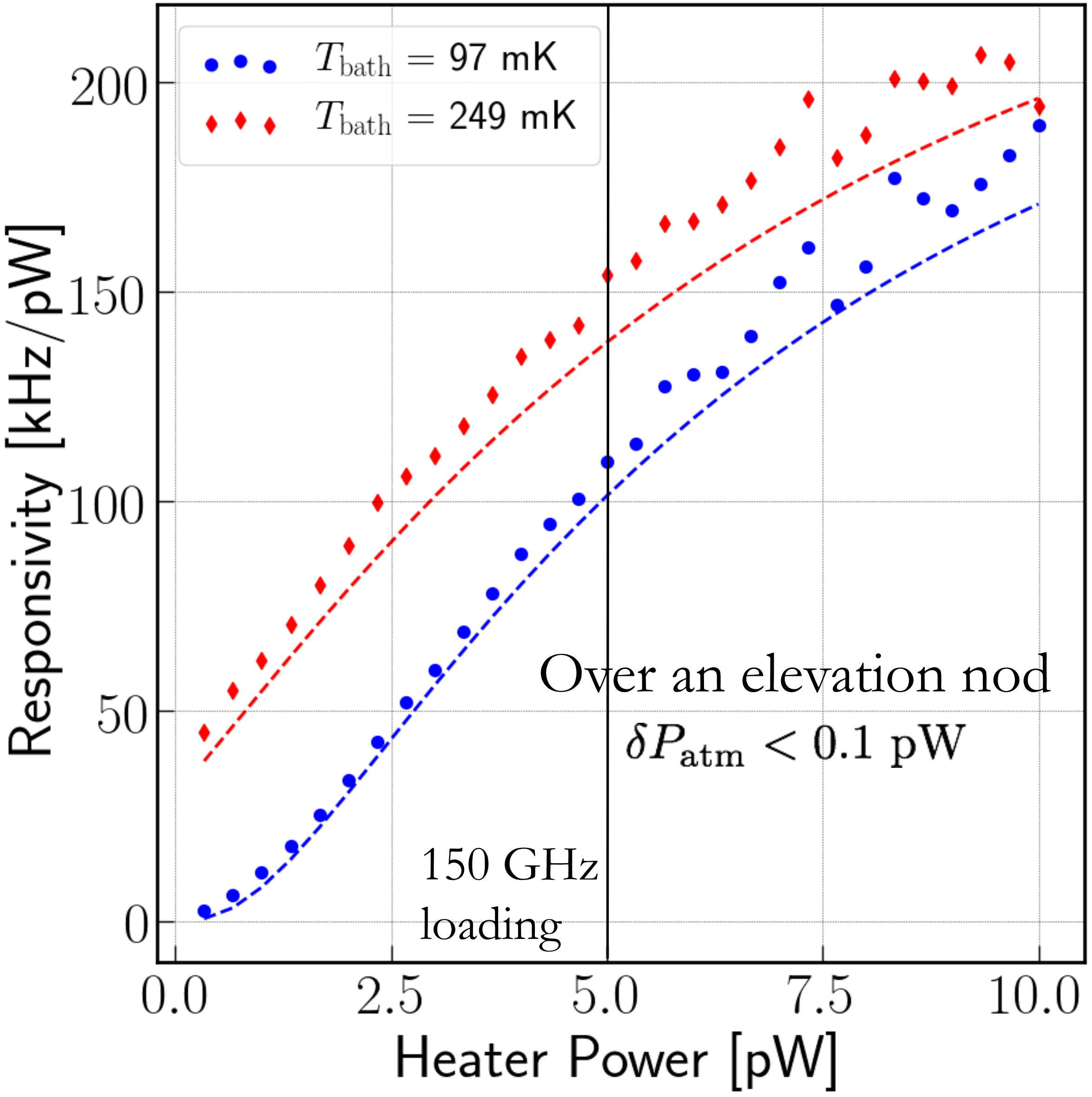


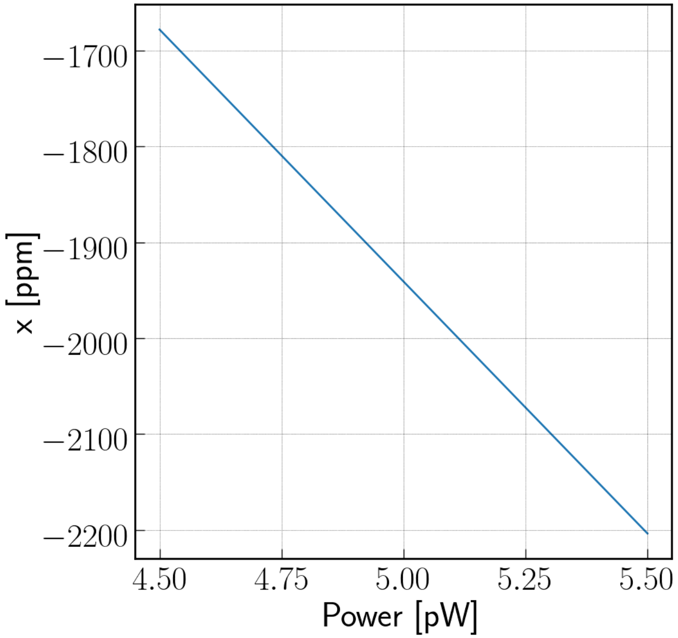


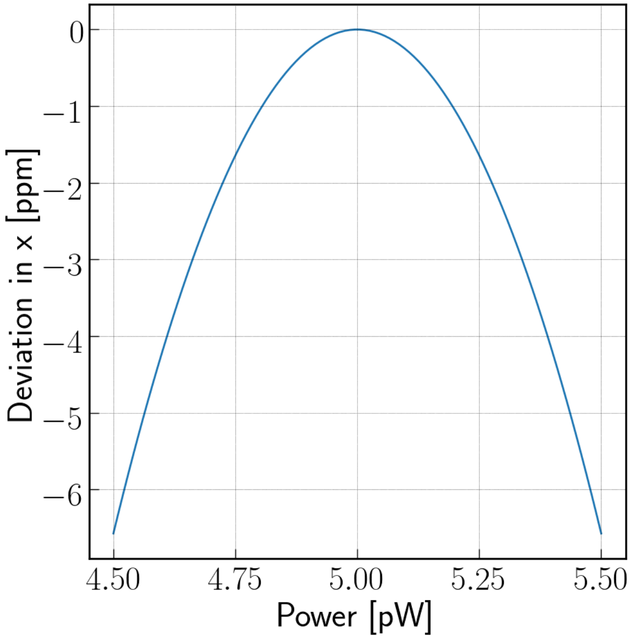


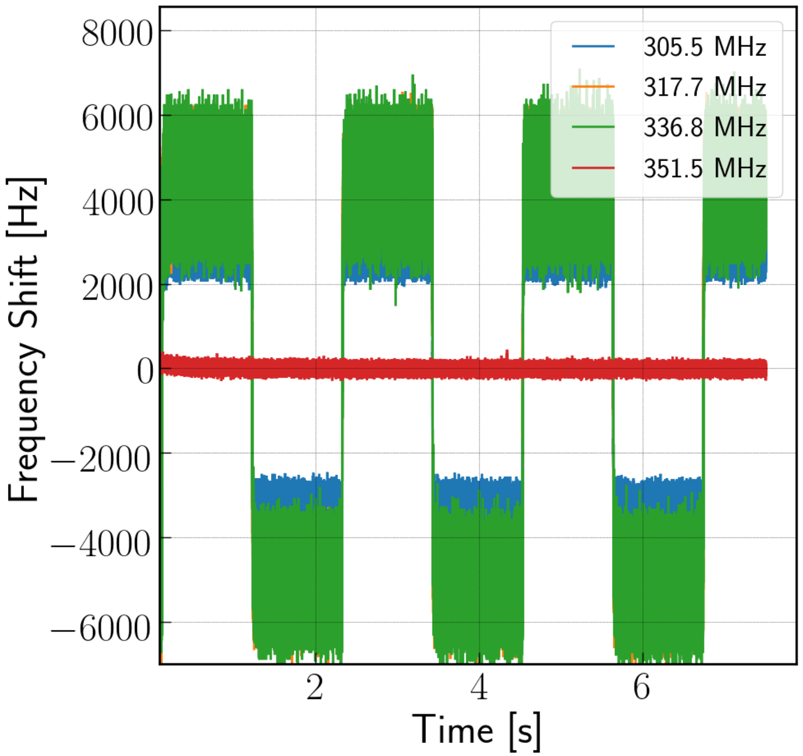


Responsivity



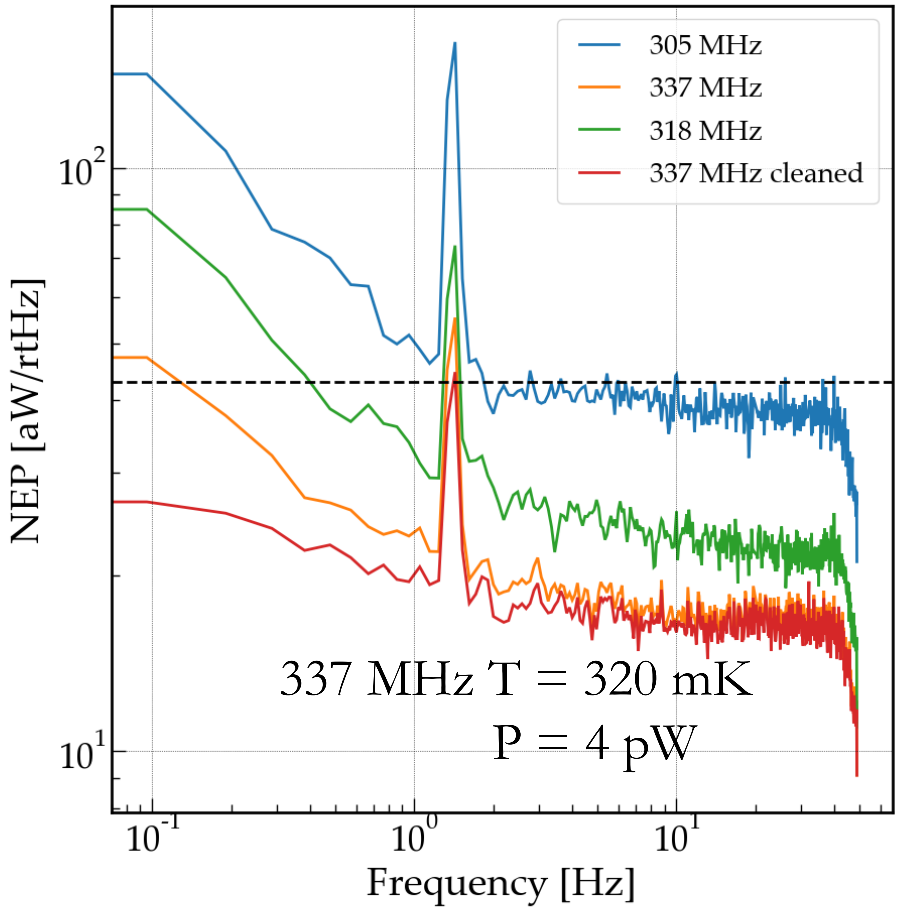




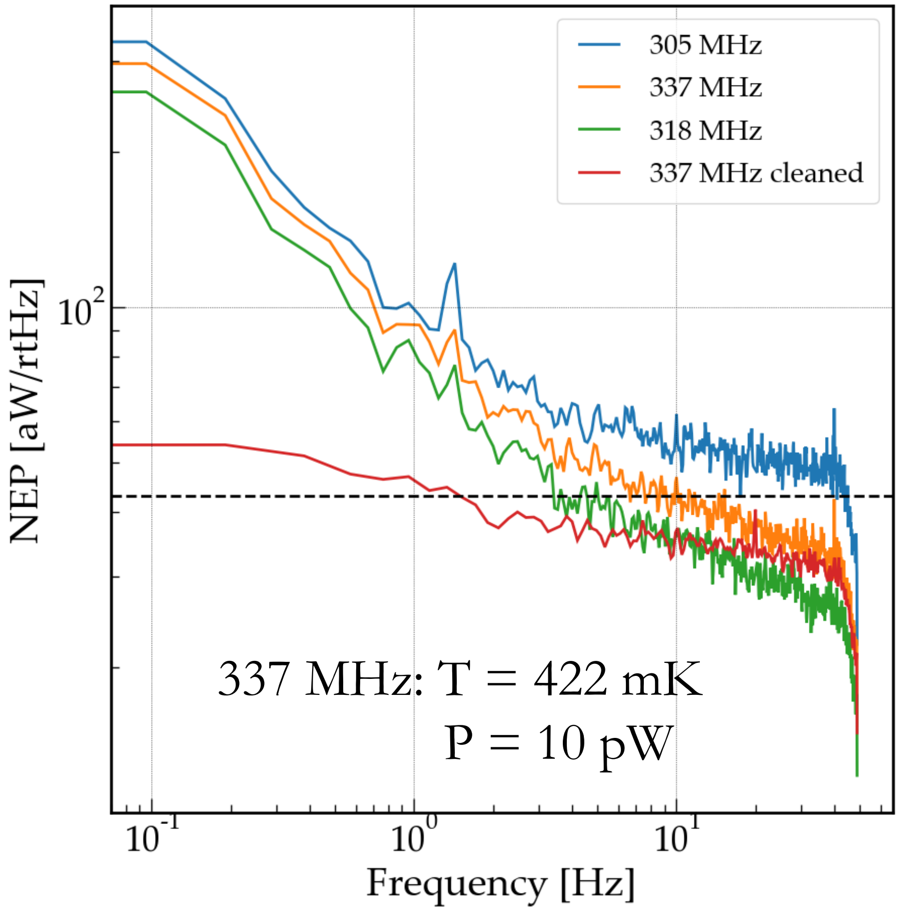


Non-linearity in response comparable to Planck

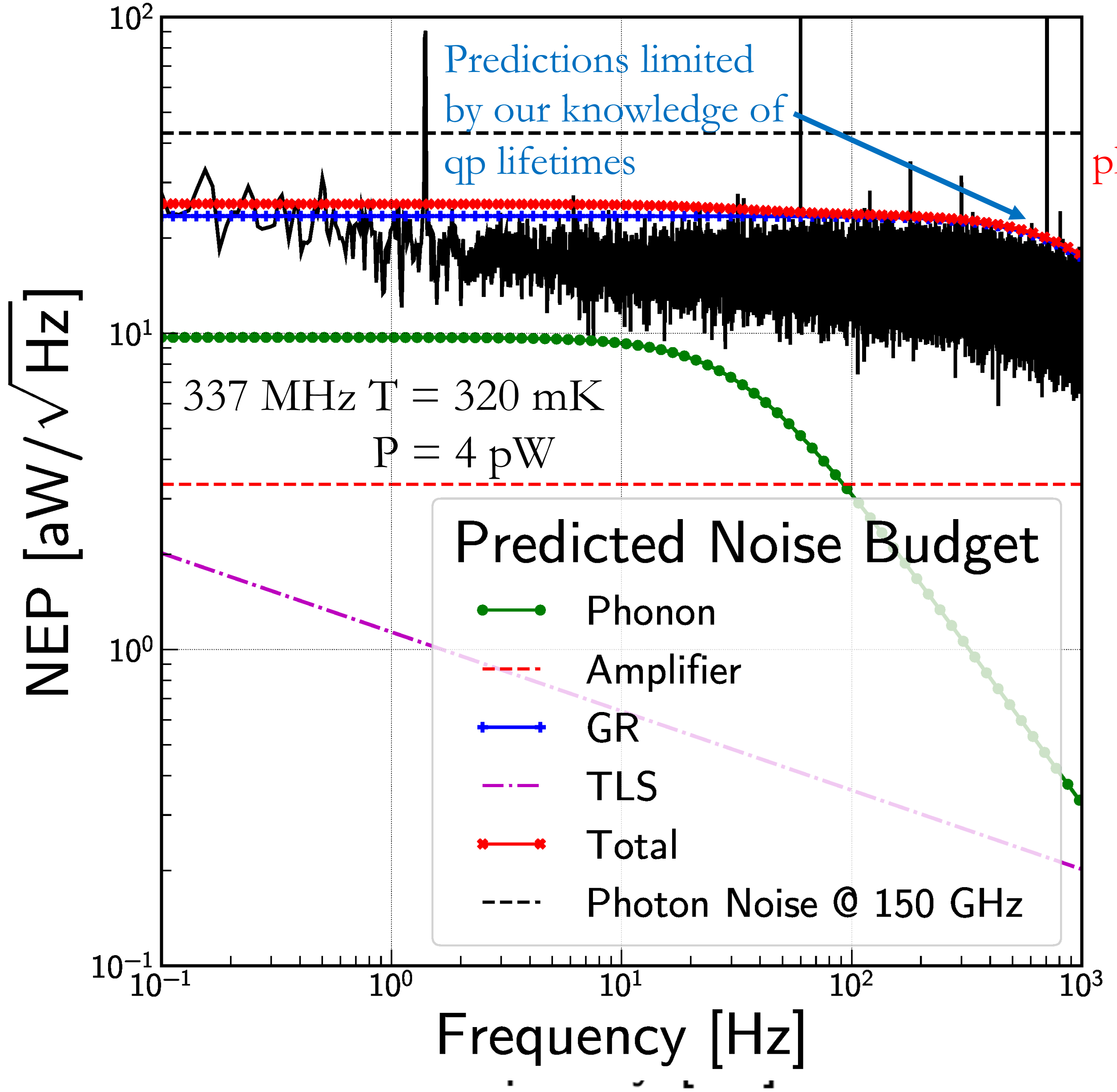
Noise performance

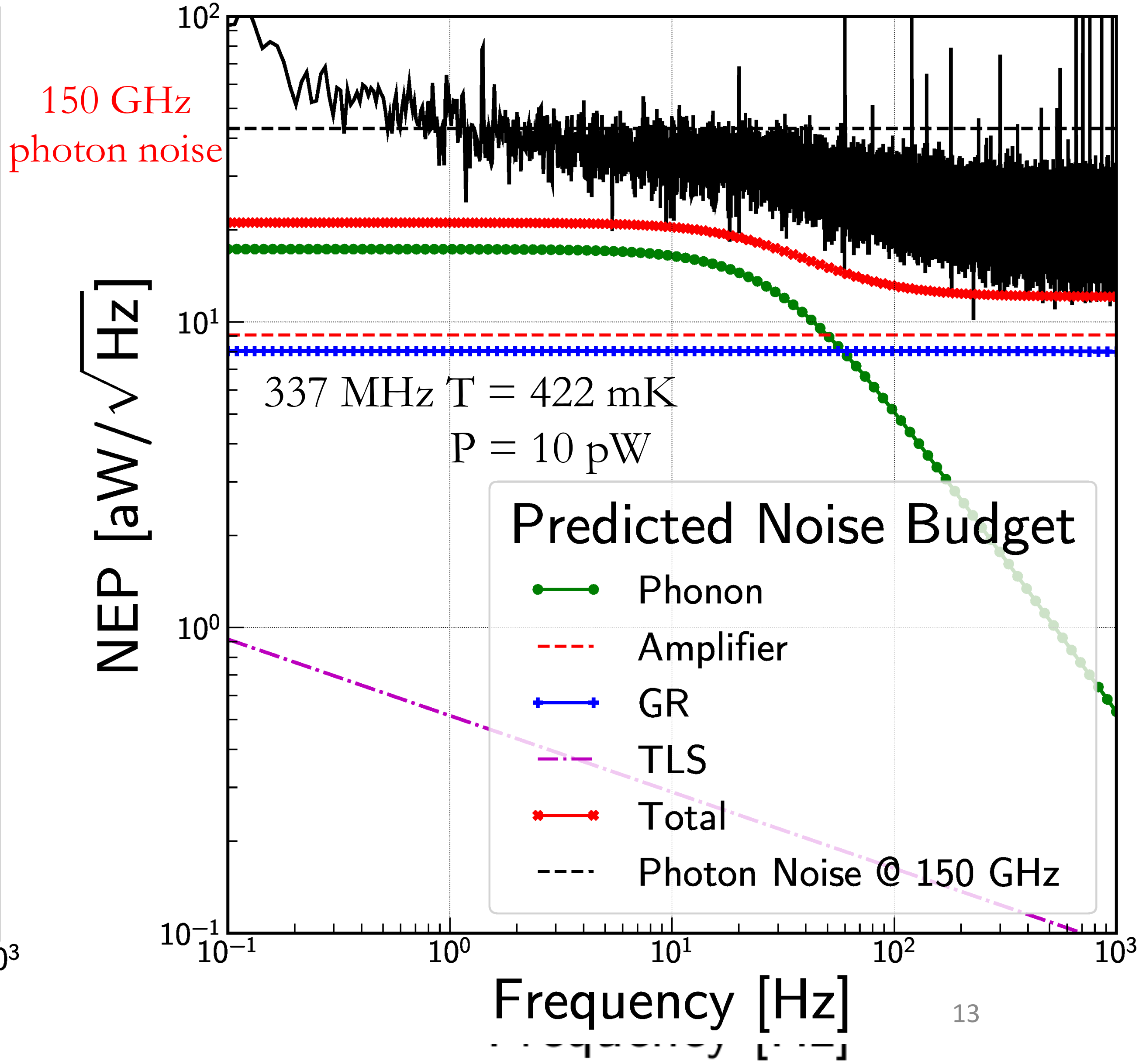


- Measurements done at 90 mK bath temperature
- Use common mode noise rejection
- Little 1/f noise in the devices themselves
- Useful for photon-noise limited measurements

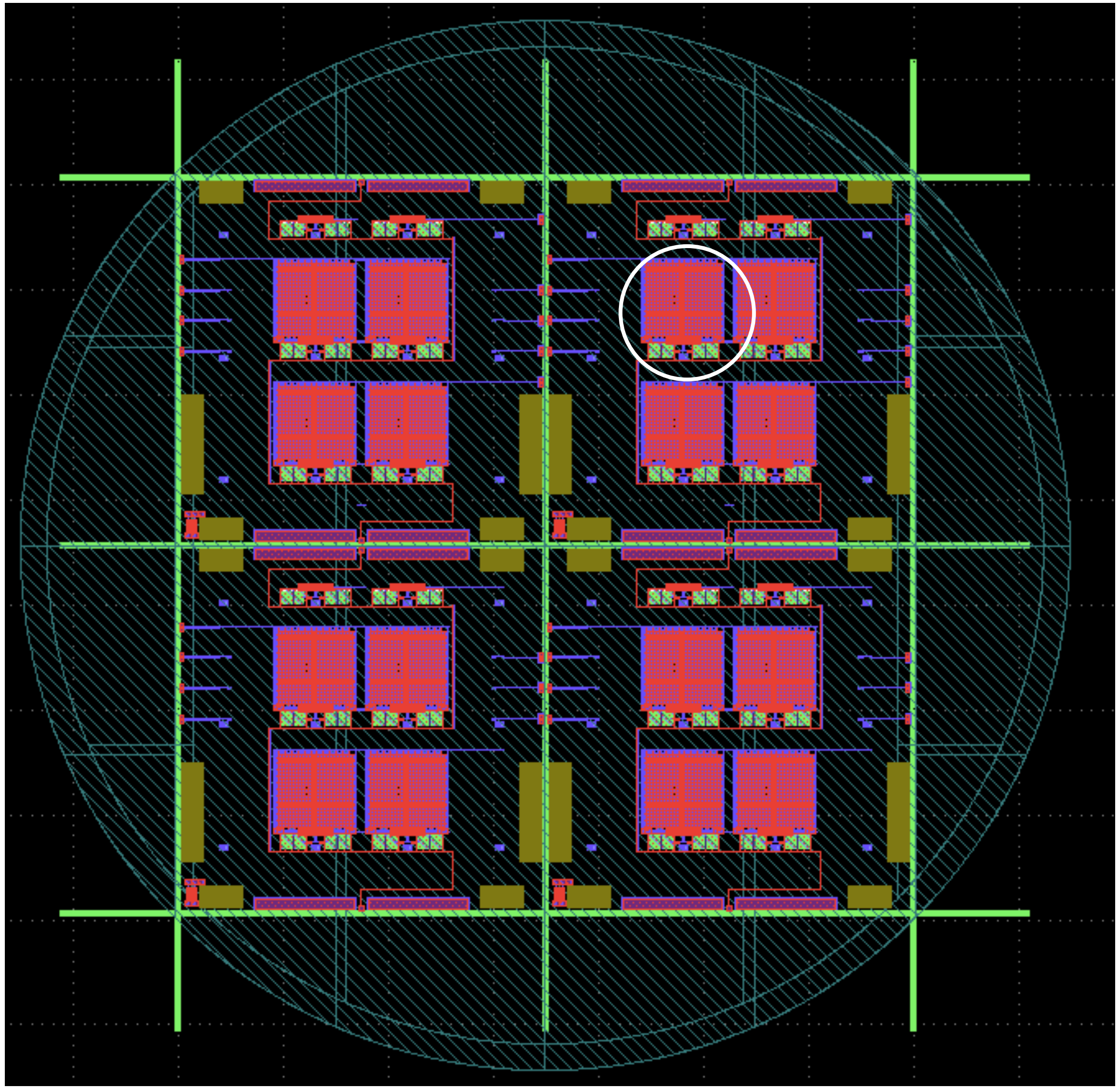


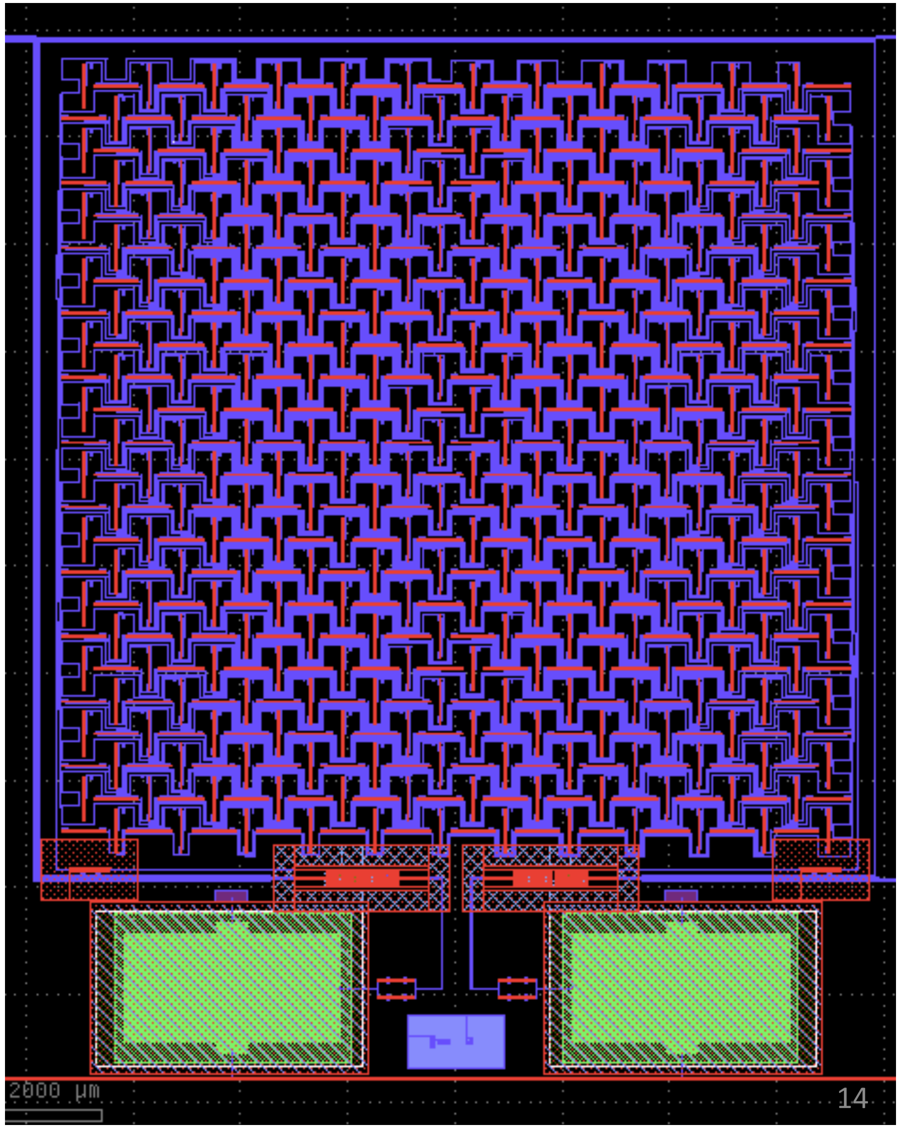
Measured Noise vs. Predictions





Antenna Coupled TKID design





Conclusions

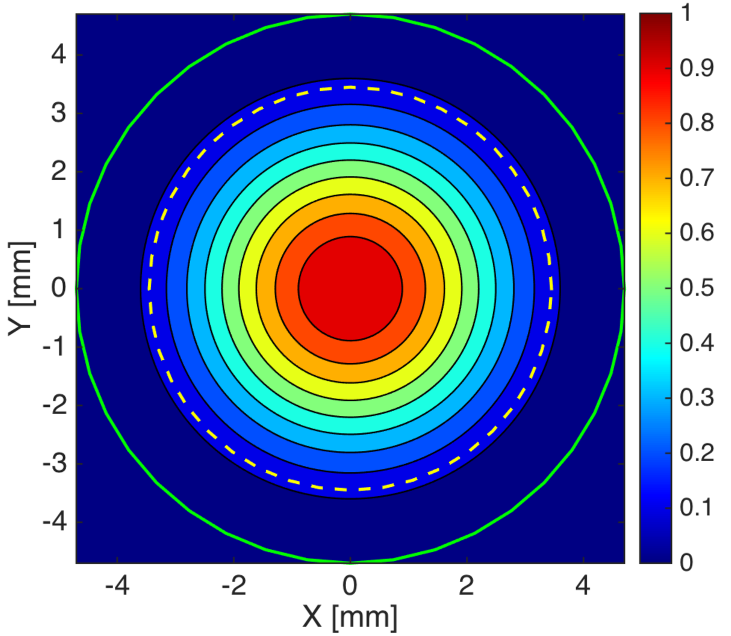
- TKIDs offer simple integration, but much needed design flexibility
- Dark but heater loaded measurements demonstrate background limited performance suitable for 150, 250GHz ground observing
- Detectors stable to 0.1 Hz
- Time constant low enough for simple transfer functions
- Clear pathway to antenna coupled designs- currently under fabrication

Why Antenna Arrays?

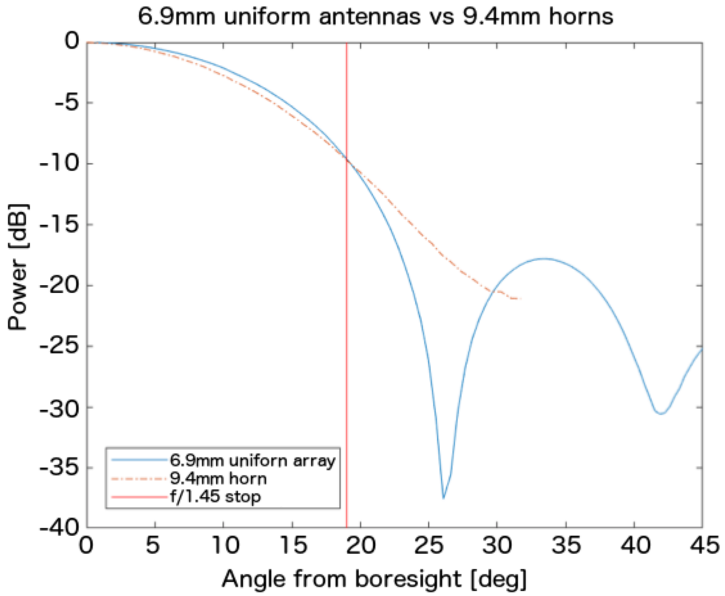
Analysis by Lorenzo Moncelsi, Roger O'Brient, Corwin Shiu, John Kovac

- Future antennas will have circular footprint, hex-packed in focal planes.
- With the same target beam, uniform illumination allows pixels to be ~90% smaller than gaussian illuminated, so could nearly double the pixels count
- Bolometers and bias lines reduce this advantage: conservative estimate is 50-60% increase in detector count.

Solid- outline of Gaussian feed
Dashed- outline of Tophat feed



Similar gain and edge taper in resultant beams



Thank you!!!