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

\[ P_{\text{opt}} + P_{\text{read}} = P_{\text{leg}} \]

\[ P_{\text{read}} \ll P_{\text{opt}} \]

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

\[ P \approx 5 \text{ pW} \]

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

Suppression in GR and TLS noise due to increase in responsivity

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

\[ S = \frac{\delta f_r}{\delta P} = f_r(T) \cdot \frac{\beta(\omega, T)\kappa(T)}{2Q_i G(T)T} \]
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://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? XeF₂ contamination?
- Consistent with our experience from TES bolometers
Responsivity

Over an elevation nod
\[ \delta P_{\text{atm}} < 0.1 \text{ pW} \]

150 GHz loading

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

337 MHz: $T = 422 \text{ mK}$
$P = 10 \text{ pW}$

337 MHz: $T = 320 \text{ mK}$
$P = 4 \text{ pW}$
Measured Noise vs. Predictions

Predictions limited by our knowledge of qp lifetimes

337 MHz $T = 320$ mK
$P = 4$ pW

150 GHz photon noise

337 MHz $T = 422$ mK
$P = 10$ pW

Predicted Noise Budget

- Phonon
- Amplifier
- GR
- TLS
- Total
- Photon Noise @ 150 GHz

NEP [aW/√Hz]

Frequency [Hz]
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!!!