wide-band parametric amplifier readout for optical microwave kinetic inductance detectors

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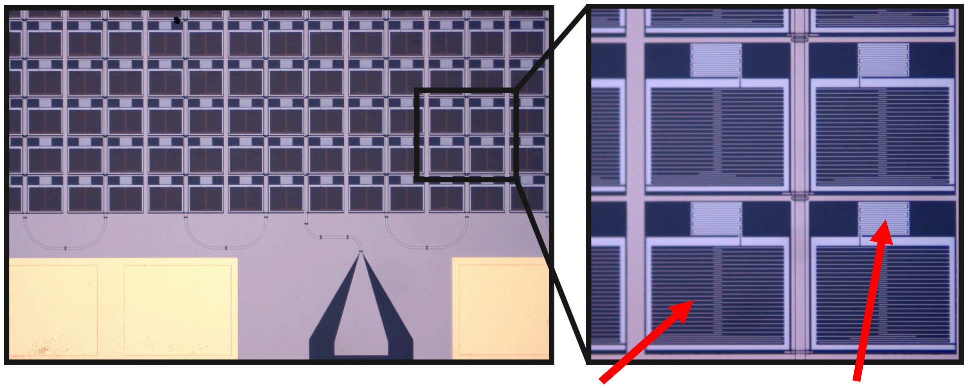
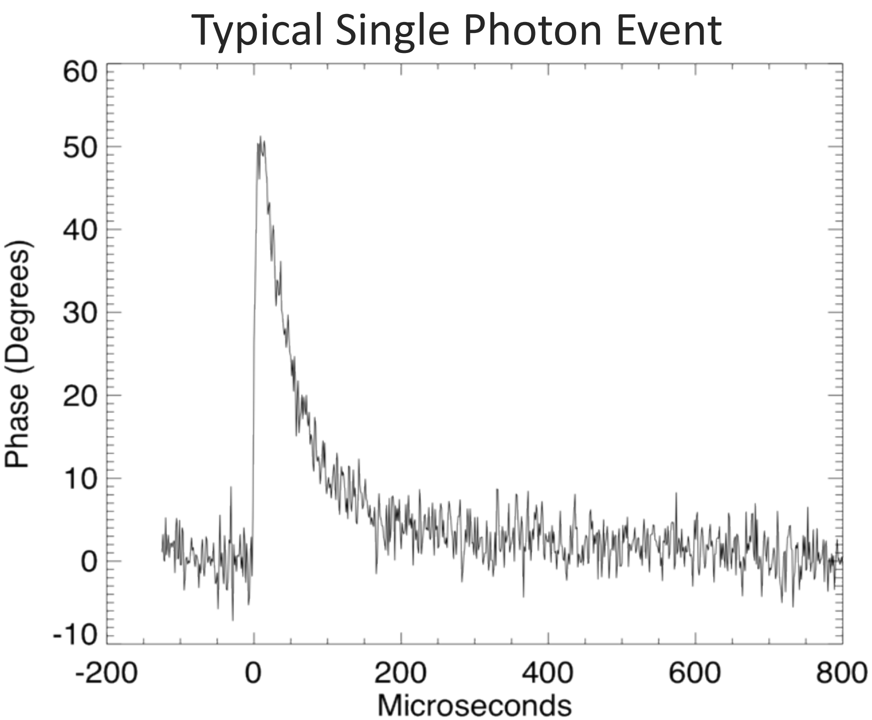
optical lumped element MKIDs

- Optimized for single photon detection at wavelengths between 1500 nm and 400 nm

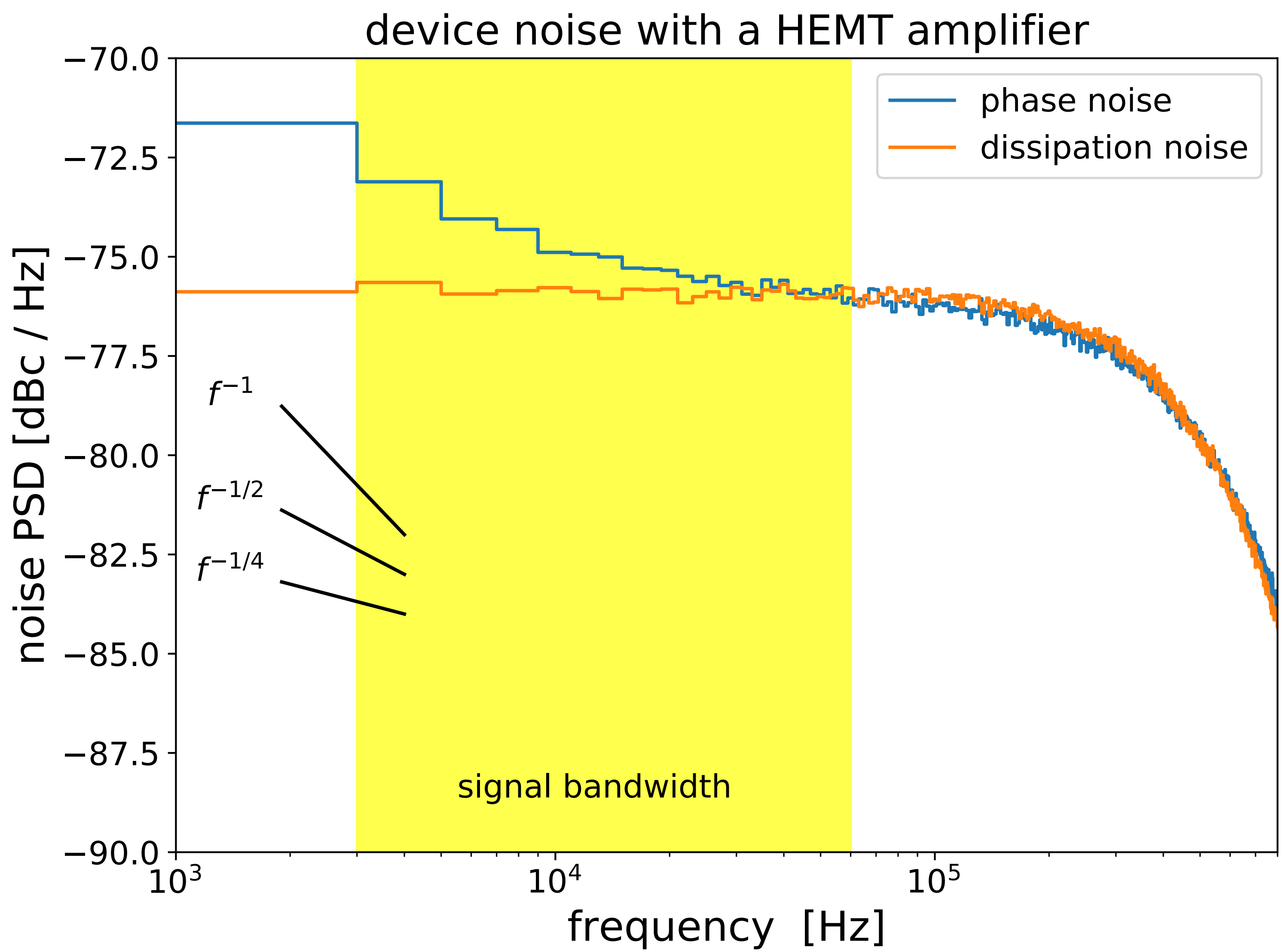
- Current state-of-the-art detectors use PtSi, a high surface impedance superconductor, in arrays of up to 20,000 pixels

- Technology has been deployed in three science instruments to date: ARCONS, DARKNESS, and MEC





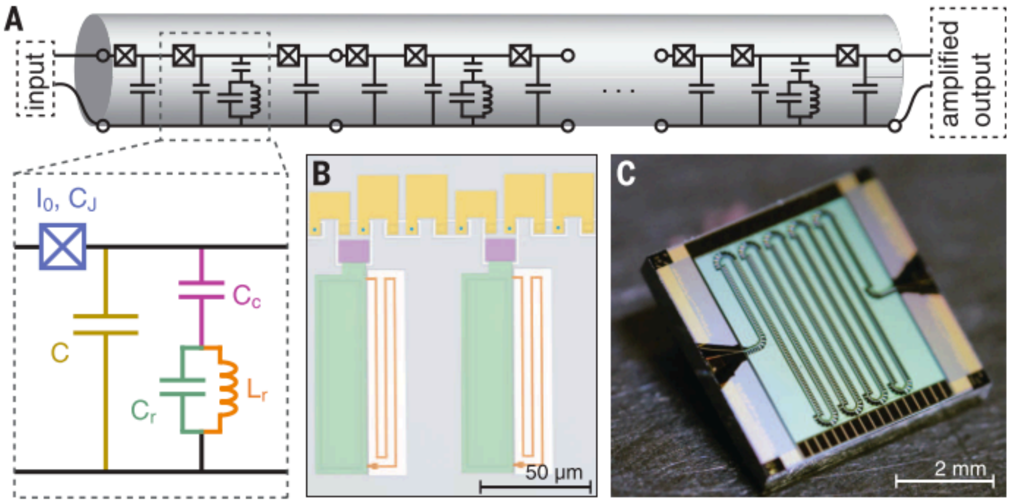
standard noise performance



parametric amplifiers

Josephson parametric amplifiers

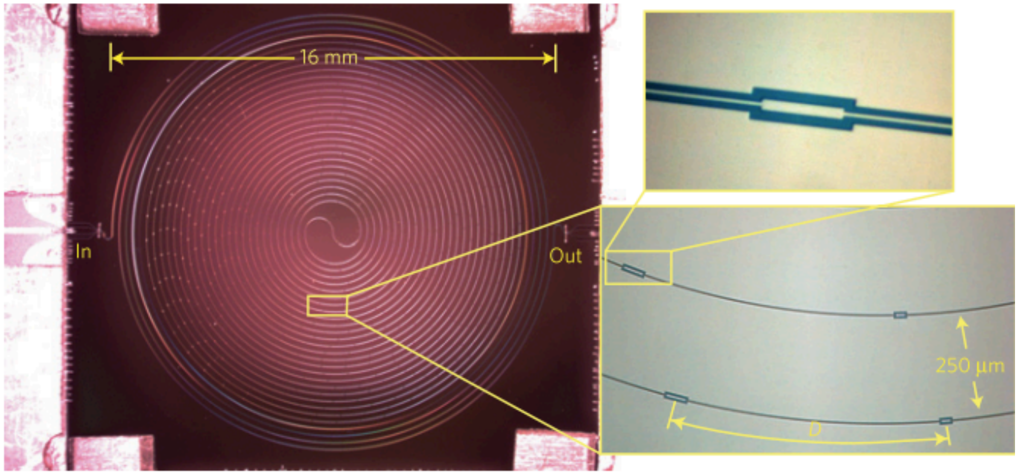
- Amplifier compression at low powers (about -100 dBm)
- Nulling tones required for high power signals



C. Macklin et al. Science. 350, 307-310 (2015).

Kinetic inductance based parametric amplifiers

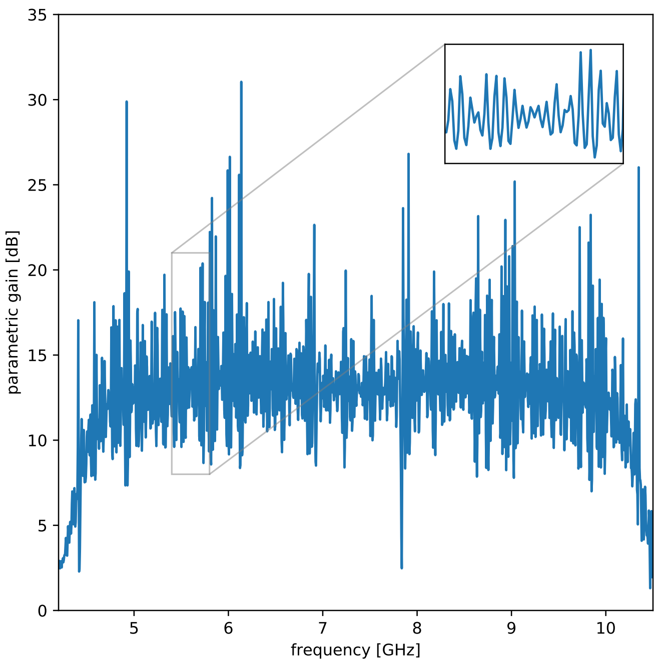
- Amplifier compression at higher powers (about -50 dBm)
- Compatible with single photon detection and large arrays

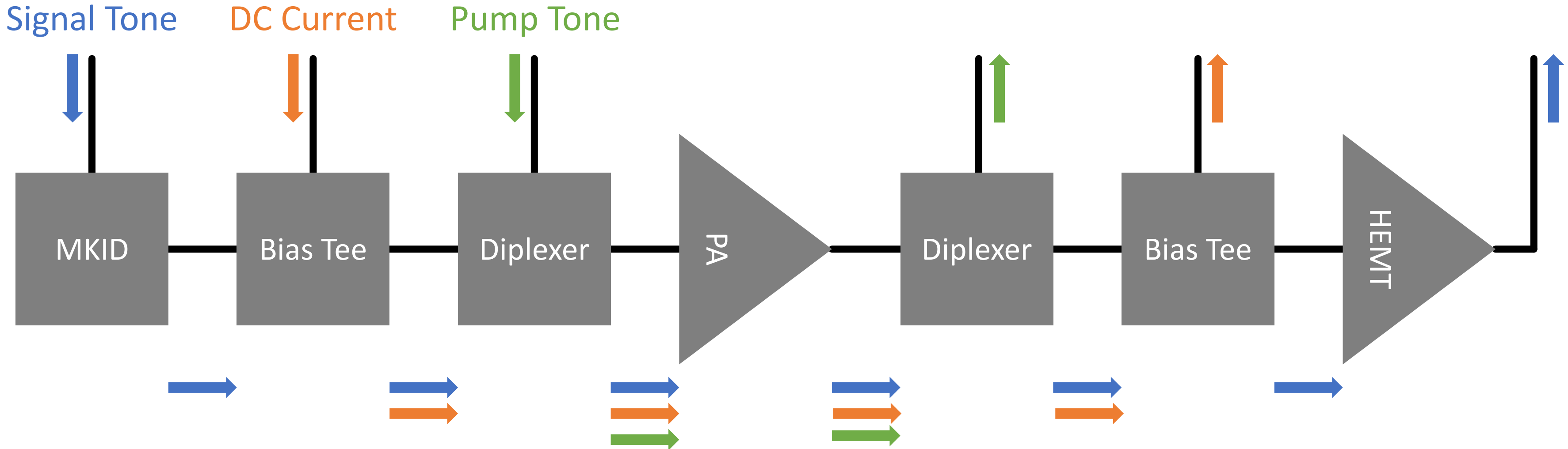


B. H. Eom et al. Nat. Phys. 8, 623–627 (2012).

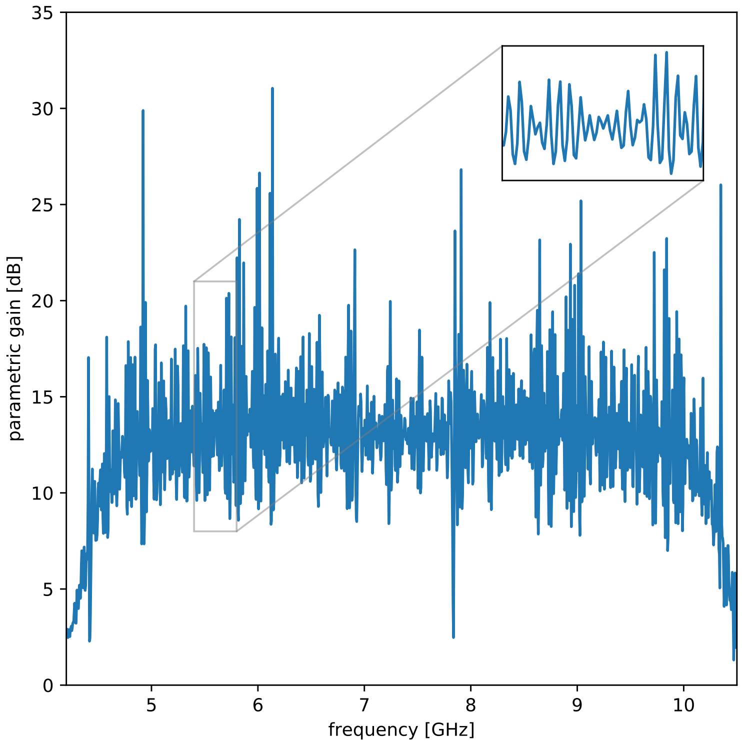
MKID readout chain

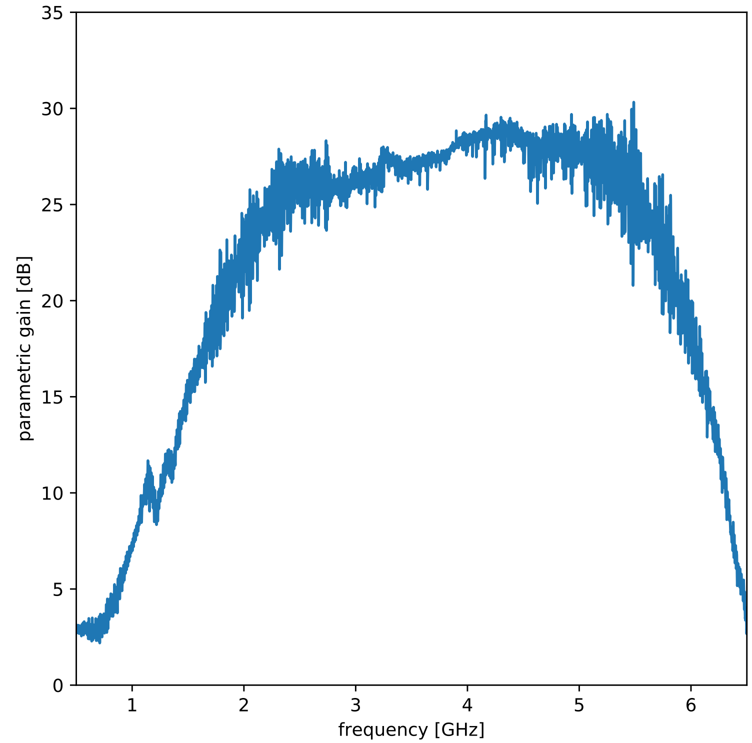
- 13 dB of gain over 5 GHz bandwidth
- -53 dBm amplifier compression point
- Unity transmission when unpowered
- Quantum limited noise performance





parametric amplifier improvements

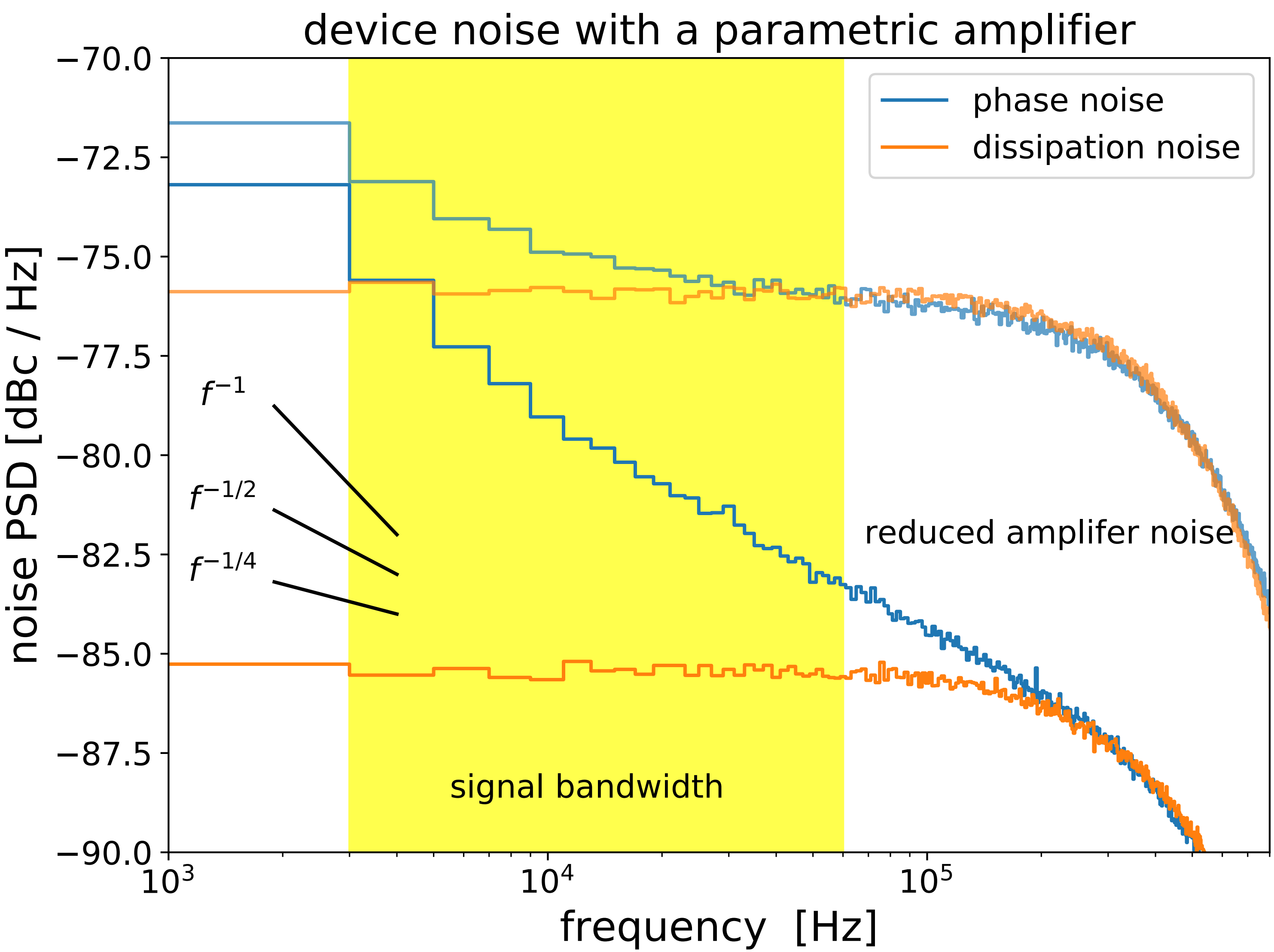




Improvements have lead to increased gain and better gain uniformity

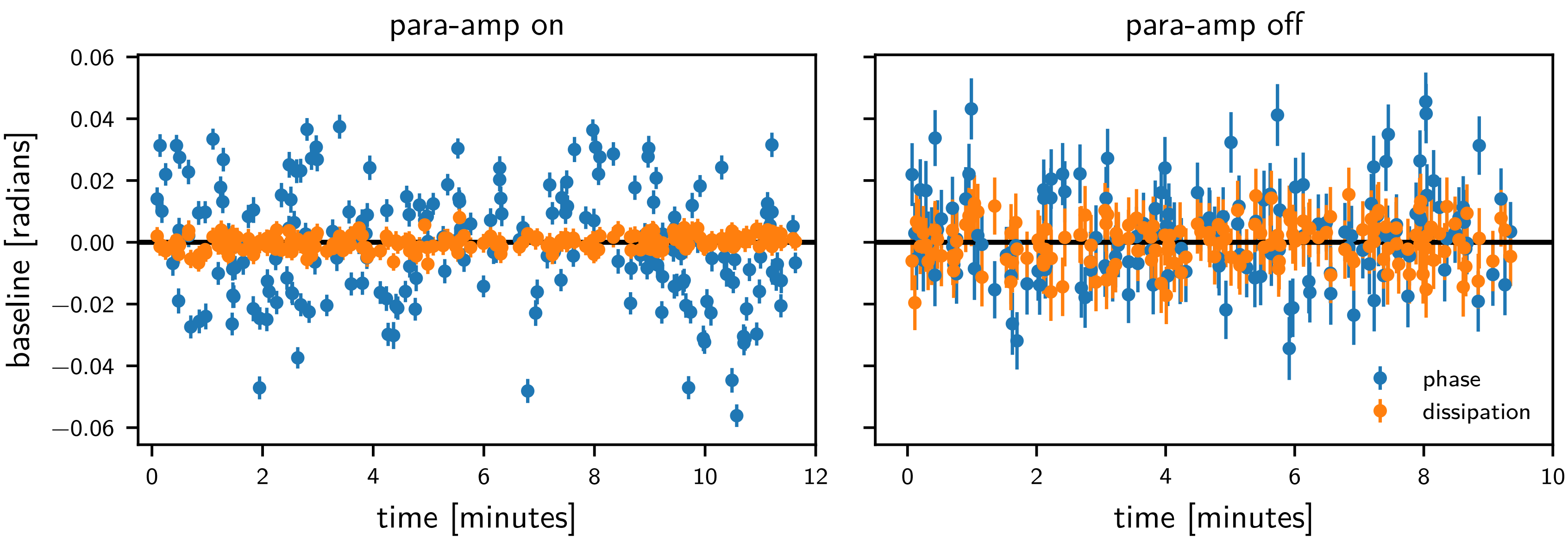
See the poster by Peter Day et al. for more details (ID:306)

improved noise performance



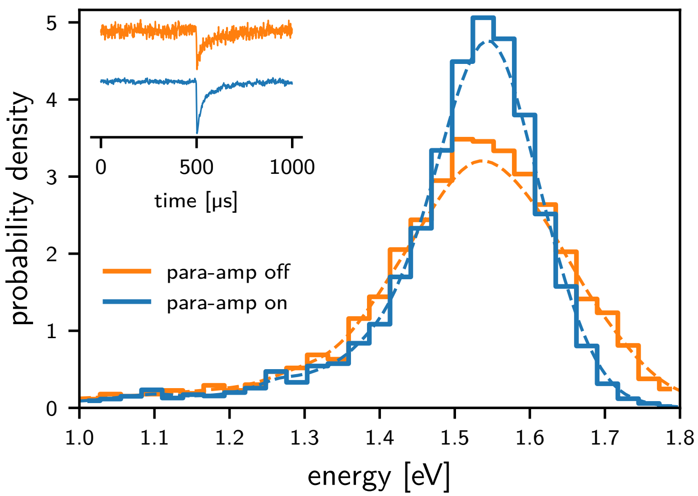
Measurement Stability

- The gain from the para-amp is sufficiently stable for measurements on the order of 10 minutes.
- The low frequency two-level system noise introduces a baseline uncertainty that does not improve with lower amplifier noise.
- The photon energy estimation is insensitive to TLS baseline drifts.



photon energy measurements

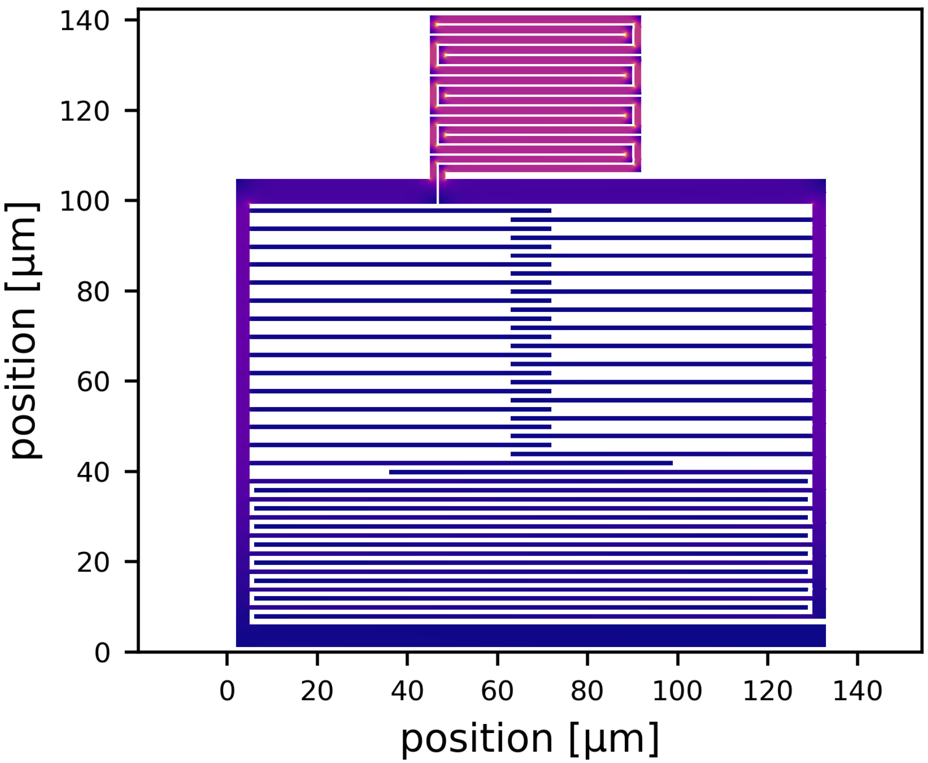
- The reduced noise improves the resolving power from about 7 to 9
- Noise measurements predict a resolving power of up to 25
- An unknown process is limiting the resolving power at $R \sim 10$

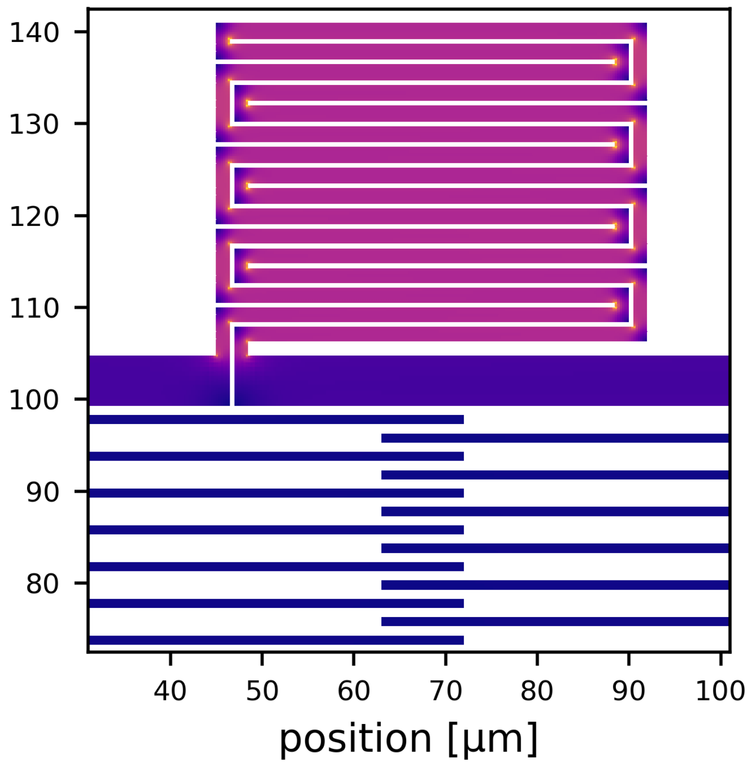


Energy [eV]	Resolving Power [$E/\Delta E$]	
	Measured	Expected
1.53 (808 nm)	$5.8 \rightarrow 8.9$	$9.5 \rightarrow 23$
1.35 (920 nm)	$7.4 \rightarrow 9.4$	$10 \rightarrow 24$
1.27 (980 nm)	$7.5 \rightarrow 9.6$	$11 \rightarrow 25$
1.11 (1120 nm)	$6.6 \rightarrow 9.6$	$9.3 \rightarrow 24$
0.946 (1310 nm)	$6.0 \rightarrow 9.2$	$8.7 \rightarrow 23$

current density uniformity

$$\text{response} \propto \int J^2(\vec{r})\, \delta n_{qp}(\vec{r}) d^3\vec{r}$$

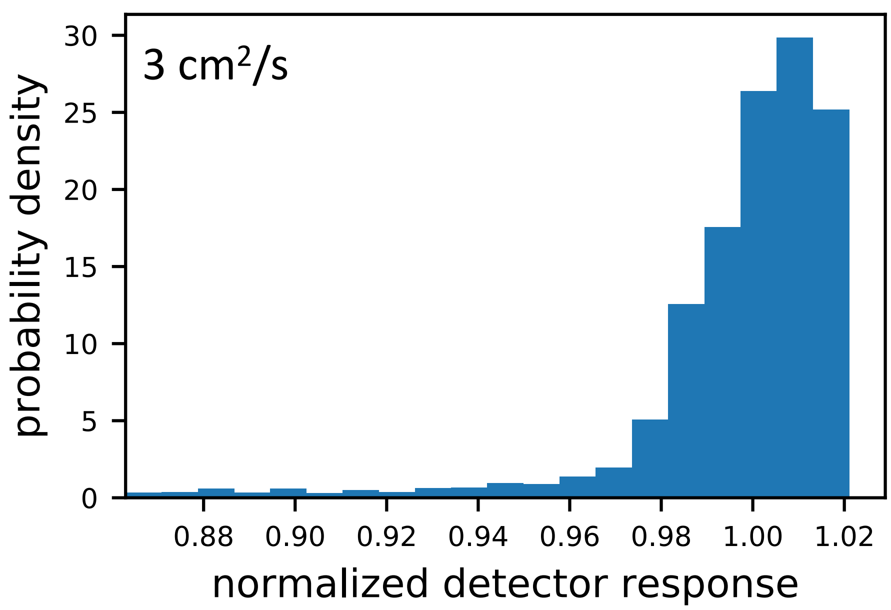


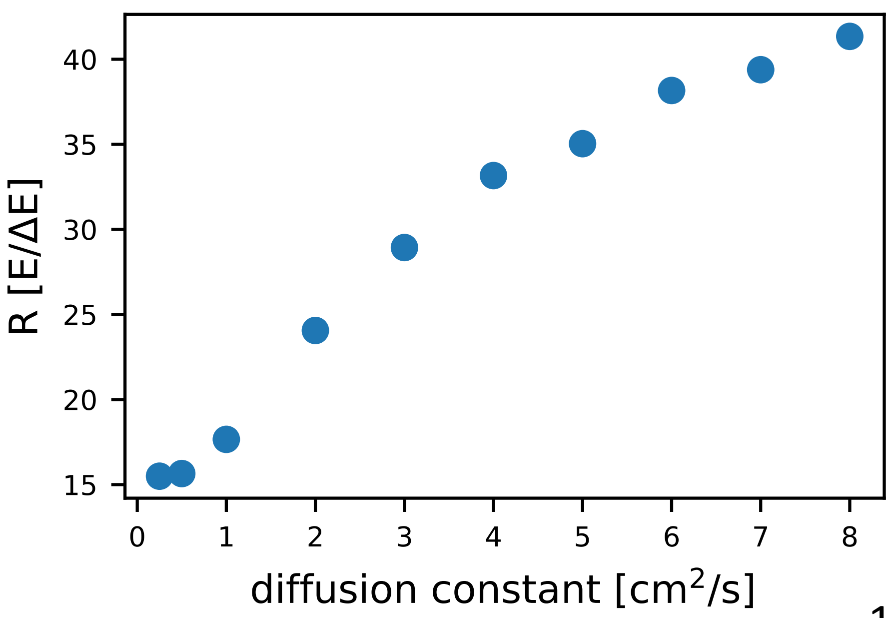


current density uniformity

$$\text{response} \propto \int J^2(\vec{r})\, \delta n_{qp}(\vec{r}) d^3\vec{r}$$

$R \sim 20$ to 40 for different diffusion constants





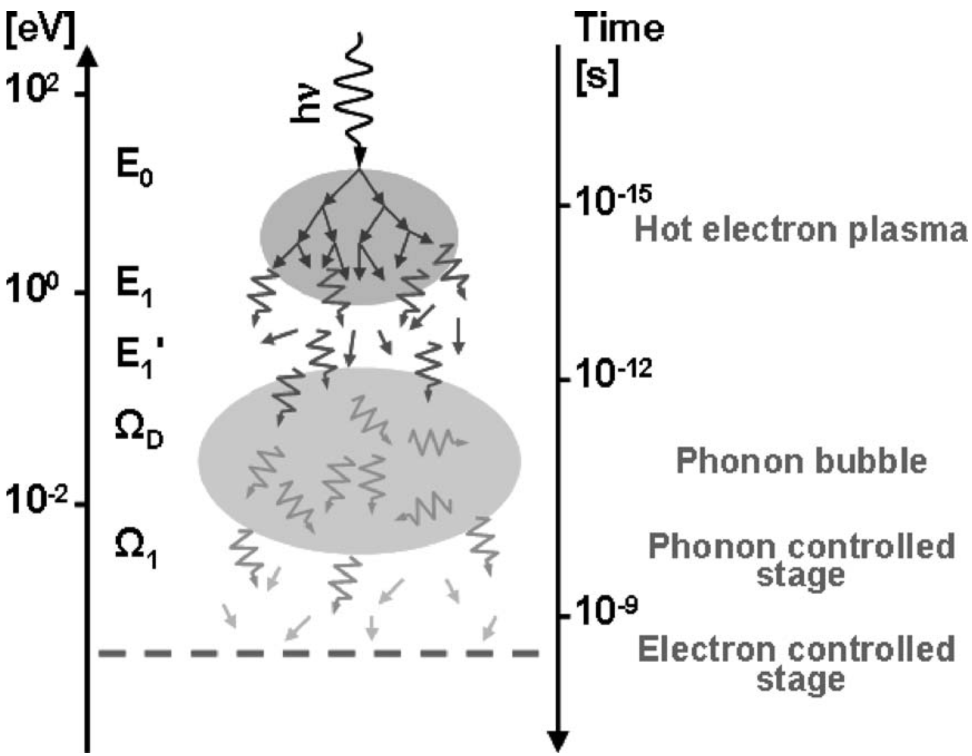
electron-phonon coupling effects

$$R \approx \frac{1}{2.355}\sqrt{\frac{\eta\, E}{(F+J)\Delta}}$$

Phonons that are created in the initial energy down conversion can escape to the substrate.

This process creates an extra variability in the detected pulse height.

For PtSi, $R \sim 13$ to 30 at 800 nm.



A. Kozorezov et al. Phys. Rev. B. 75, 094513 (2007).

Wide-band parametric amplifier readout and resolution of optical microwave kinetic inductance detectors

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ABSTRACT

The energy resolution of a single photon counting microwave kinetic inductance detector can be degraded by noise coming from the primary low temperature amplifier in the detector's readout system. Until recently, quantum limited amplifiers have been incompatible with these detectors due to the dynamic range, power, and bandwidth constraints. However, we show that a kinetic inductance based traveling-wave parametric amplifier can be used for this application and reaches the quantum limit. The total system noise for this readout scheme was equal to ∼2.1 in units of quanta. For incident photons in the 800–1300 nm range, the amplifier increased the average resolving power of the detector from ∼6.7 to 9.3 at which point the resolution becomes limited by noise on the pulse height of the signal. Noise measurements suggest that a resolving power of up to 25 is possible if the redesigned detectors can remove this additional noise source.

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