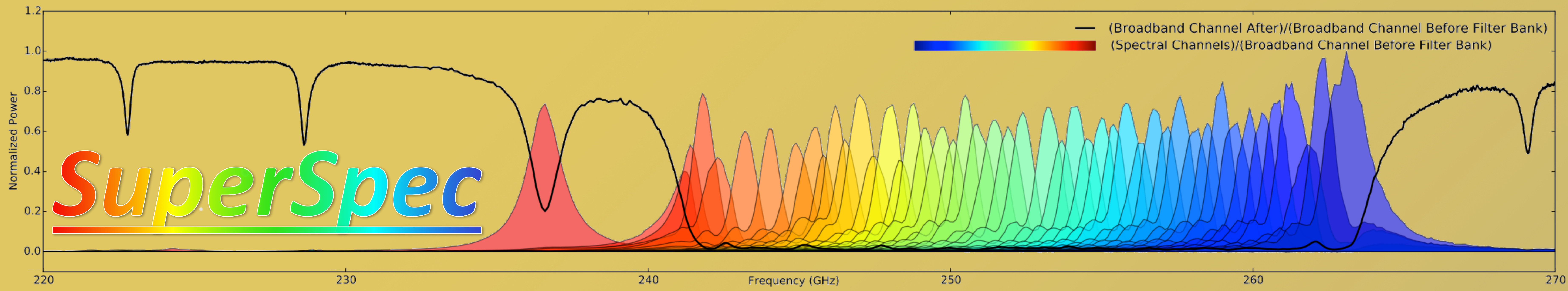

Noise Properties of SuperSpec's (an On-Chip Spectrometer) Extremely Low Volume Titanium Nitride Kinetic Inductance Detectors

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Introduction

SuperSpec is a new technology for millimeter and submillimeter spectroscopy. It is an on-chip spectrometer being developed for multi-object, moderate resolution (R = 300), large bandwidth survey spectroscopy of high-redshift galaxies for the 1 mm atmospheric window. SuperSpec targets the CO ladder in the redshift range of z = 0 to 4, the [CII] 158 um line from z = 5 to 9, and the [NII] 205 um line from z = 4 to 7. SuperSpec employs a novel architecture in which detectors are coupled to a series of resonant filters along a single microwave feedline, creating a full spectrometer occupying only ~10 cm^2 of silicon. SuperSpec plans to field a demonstration instrument on the Large Millimeter Telescope this year.

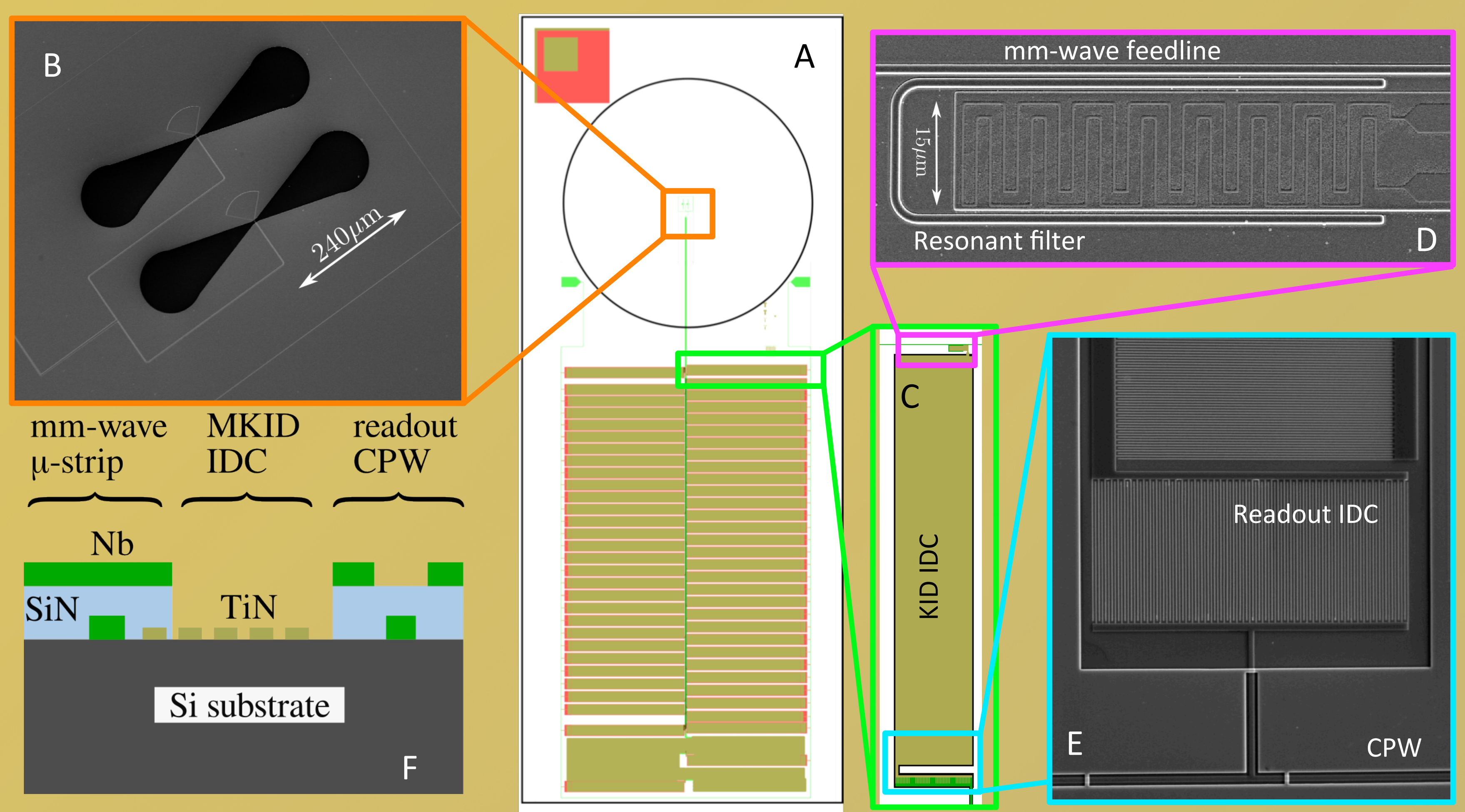

Fig 1: SuperSpec test device. (A) A mask with dual bowtie-slot antenna and lens footprint at the top, and feedline running vertically past an array of filters. (B) Dual bowtie-slot antenna. (C) A single mm-wave filter and KID (KID resonant frequencies are from ~100-500 MHz). (D) The millimeter-wave resonator and 250 nm line width inductor. (E) The lower portion of the large IDC, coupling IDC, and readout CPW. (F) Cross-section showing the device layers.

Detector NEP

SuperSpec utilizes extremely low volume (2.6 μm^3 inductors) titanium nitride KIDs. Low volume is achieved via 20 nm thick and 250 nm linewidth inductors. This low volume design allows for extremely responsive detectors (responsivity ∝ volume^{-1}) enabling very low NEPs.

- 3 x 10^{-18} W/Hz$^{0.5}$ is obtained at a detector temperature of 210 mK for a Tc = 0.9 K device (Wheeler et al. 2017 LTD Proceedings).
- 7 x 10^{-19} W/Hz$^{0.5}$ is obtained for a detector temperature of less than 100 mK for the same device (McGeehan et al. 2017 LTD Proceedings).

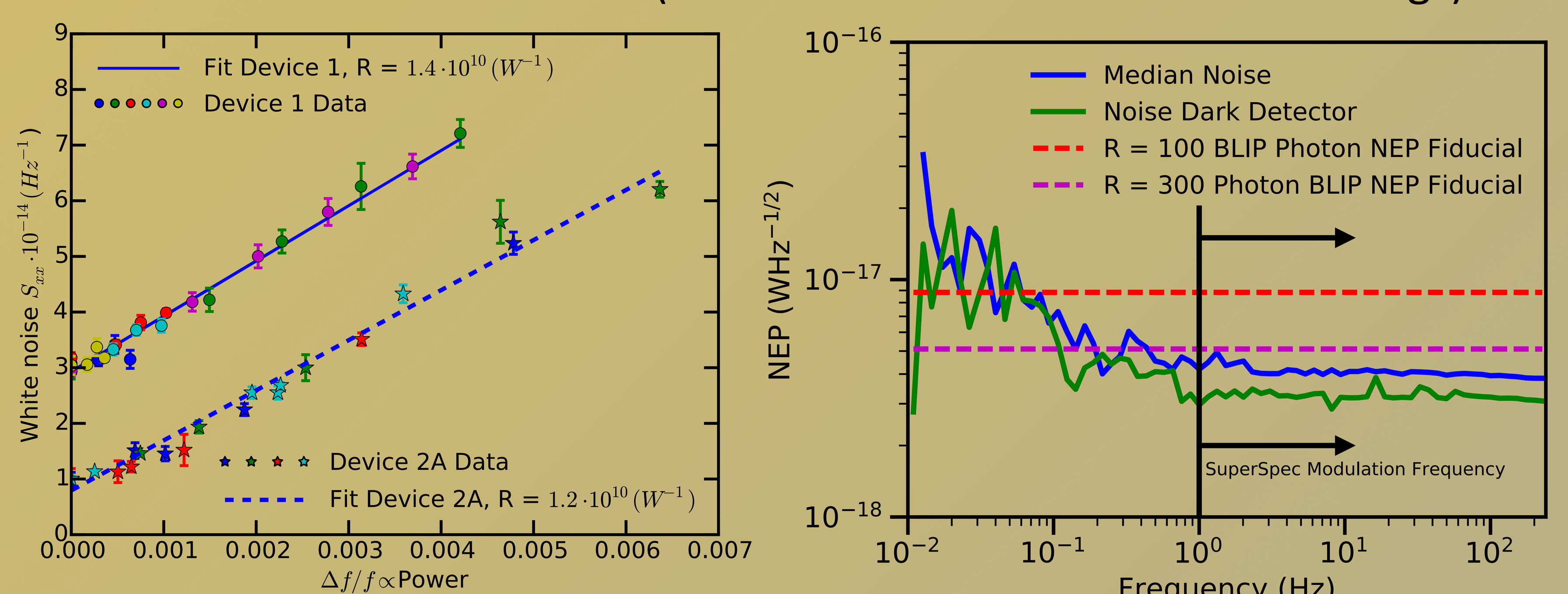

Fig 2: Left: Measured responsivities for two spectrometers using coherent source method (Hailey-Dunsheath et al. 2015 LTD Proceedings). Each different color symbol represents a different detector. Right: NEP PSDs for SuperSpec detectors.

Detector 1/f NEP Versus Tc

SuperSpec detectors have 1/f noise, low frequency noise, that is not dependent on the superconducting transition temperature, Tc. Improved NEP is expected to be obtained by decreasing the target Tc. This results in increased responsivity without an increase in 1/f noise levels, yielding improved NEP performance at low frequencies.

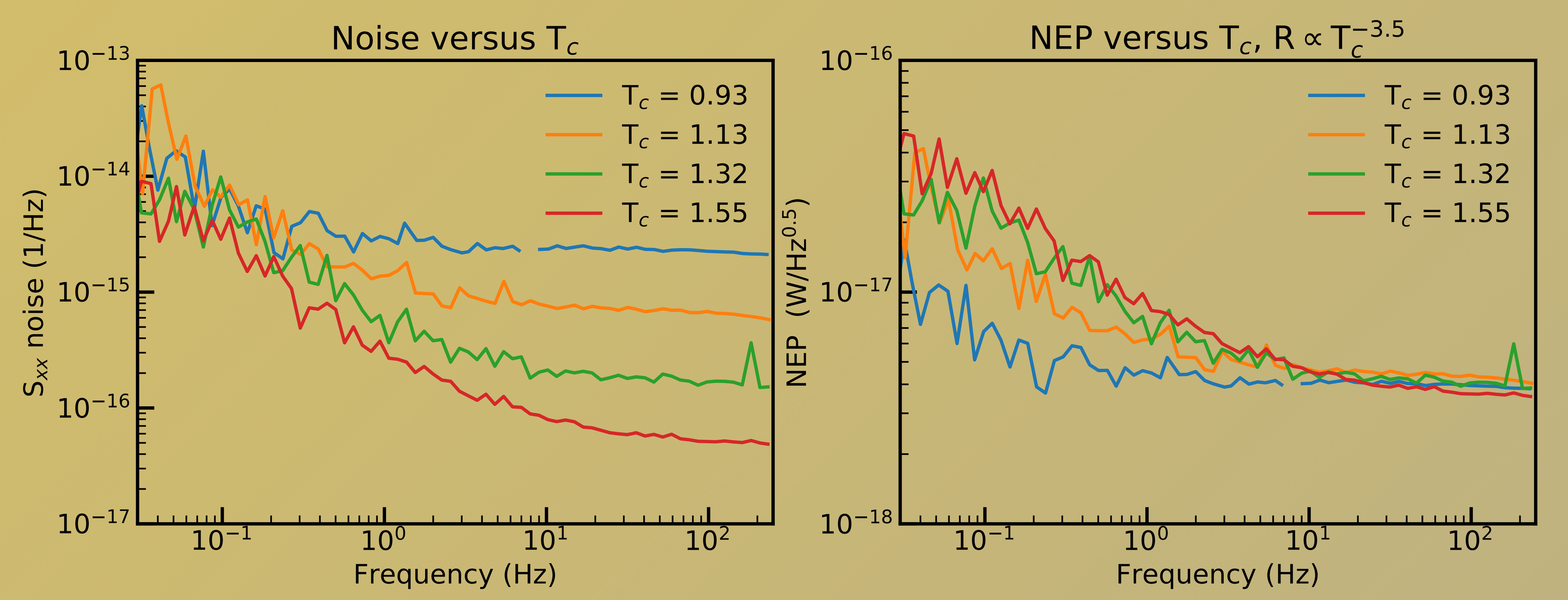

Fig 3: Plots showing the effect of Tc on the 1/f noise level for SuperSpec detectors. Left: The raw noise data in Sxx units. Right: Hypothetical NEP achieved assuming that the responsivity of the detectors goes as Tc$^{-3.5}$ (empirically observed).

Detector 1/f NEP Versus Loading

For SuperSpec detectors we find that the 1/f noise has a dependence on photon loading levels. This results in decreased low frequency performance with increased loading. However, 1/f noise is still insignificant for SuperSpec modulation speeds at telescope loading levels.

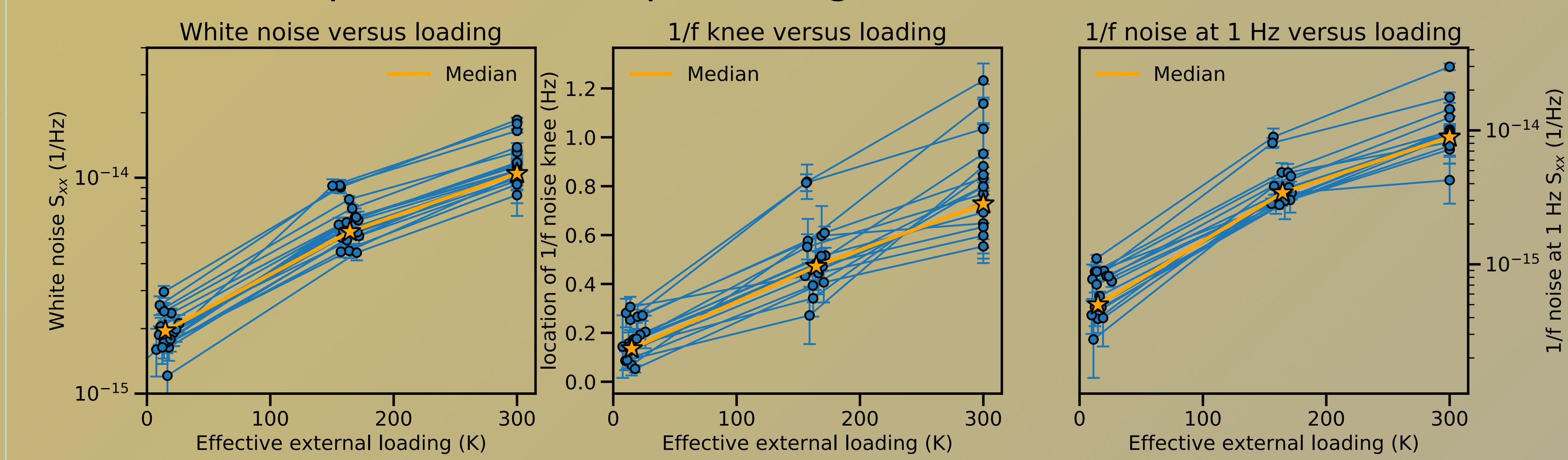

Fig 4: Noise versus loading for 37 SuperSpec detectors. 1/f knee is the frequency at which half of the noise is 1/f and half is white, frequency independent, noise. Principle component analysis has been performed to remove common mode noise.

TiN Time Constants

SuperSpec spectrometers contain a low quality factor (Q ~3000) high frequency (500 MHz) KID for measuring time constants. Time constants are found to be approximately 10 μs.

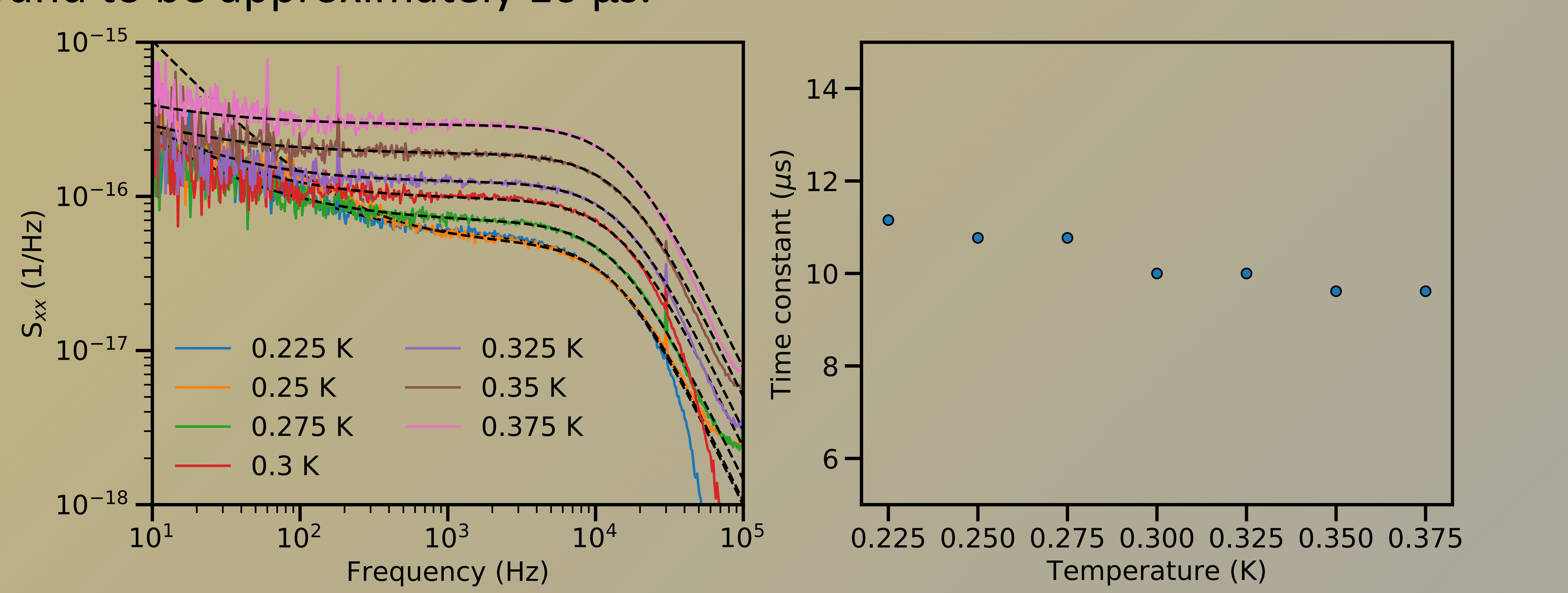

Fig 5: Left: Fits to the noise spectrum of a SuperSpec detector (Tc = 1.5). Right: The extracted τ_{qp} as a function of array temperature. τ_{qp} is found to be roughly independent of the array temperature for the temperatures measured here. Ringdown time is 1.7 μs.

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