Extension of the energy range accessible with a TES using bath temperature variations

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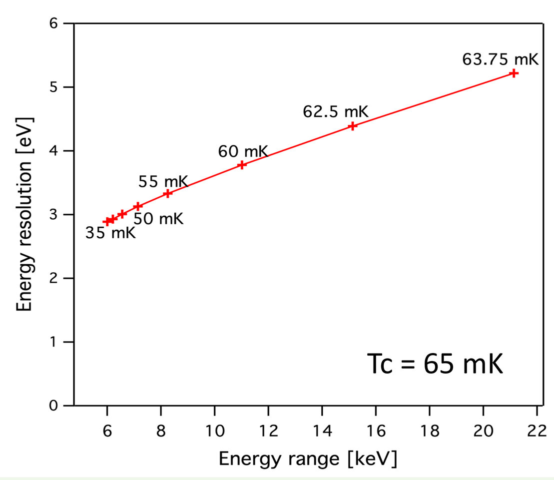
Abstract

The energy range of transition-edge-sensor (TES) X-ray microcalorimeters with a multiplexed read-out depends upon the width and shape of the TES superconducting transition, and also on the dynamic range of the read-out. In many detector systems, the multiplexed read-out slew rate capability will be the limiting factor for the energy range. In these cases, if we are willing to accept some energy resolution degradation, we can significantly extend the energy range by increasing the bath temperature of operation, essentially creating a second "extended energy range" mode of operation. For example, if we require the very highest energy resolution up to 7 keV, and wish to optimize the design up to this energy, for some measurements it could be very beneficial to have a mode where we can extend the energy range to 15-20 keV even if some energy resolution is sacrificed. Science measurements where this could be useful include improving black hole spin measurements and expanding our understanding of the X-ray-emitting corona associated with accreting black holes. In this paper we explore the trade-off between dynamic range and energy resolution from changing the bath temperature of the TES. We present measurements of TES resolution and slew-rate as a function of bath temperature and compare to numerical simulations.

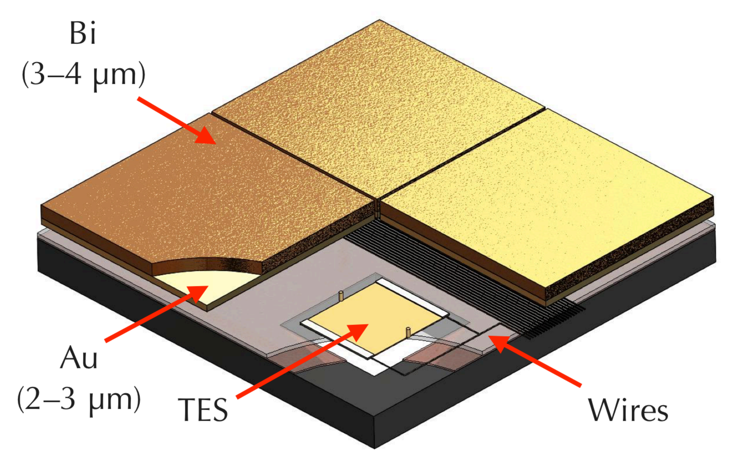
1 Concept

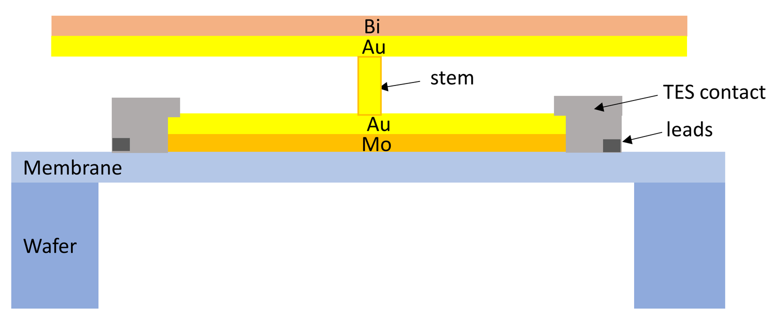
- TES detectors are currently at the heart of x-ray imaging spectroscopy, with the Athena mission for which they've been selected and the also for the Lynx mission being proposed to the NASA 2020 decadal survey
- The energy range of our pixel designs depends on 2 factors:
  - the width and shape of the TES superconducting transition
  - the slew rate of the read-out
- Slew rate : maximum of the derivative of the current over time
- A simulation was done in S.R. Bandler[(1)] in order to estimate how the estimate energy resolution might change as a function of the bath temperature.
- This showed that, by accepting a degradation in resolution, one could extend the accessible energy range
- In this work we perform lab measurements in order the assess the feasibility and potential of this method



2 Measurement

- This experiment was performed using microcalorimeters with 100 µm square TESs. The absorbers are ~5.5 µm thick and ~240 µm wide, consisting of a bilayer of Au/Bi. The absorbers are attached to the TES sensor (Au/Mo) via 2 dotted stems.

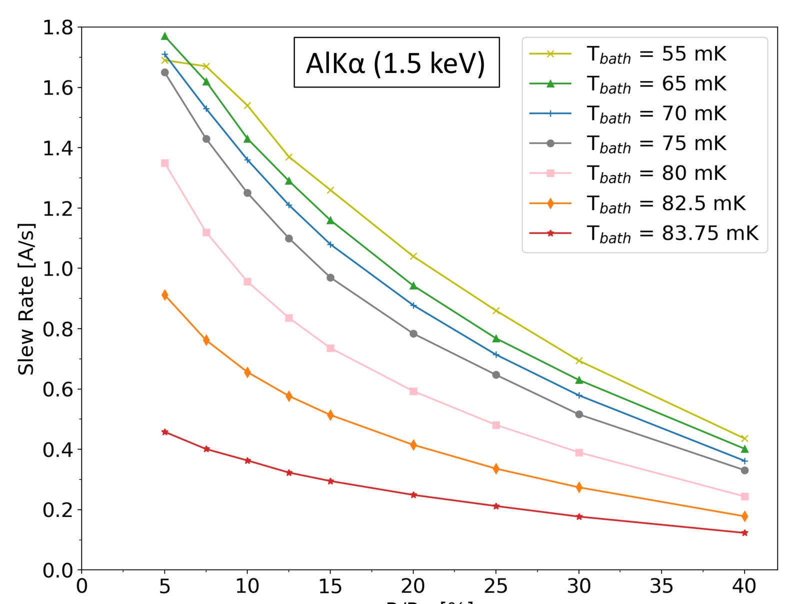


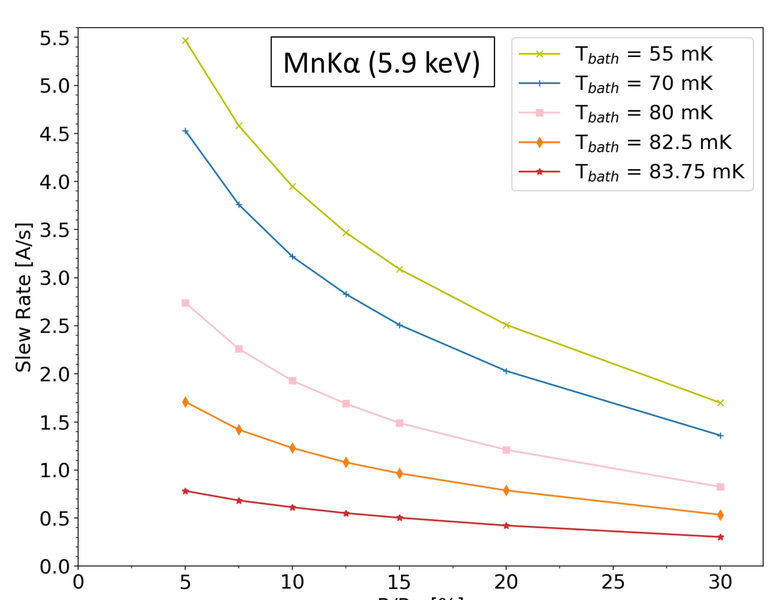


- We measured a critical temperature Tc of 86.5 mK, a thermal conductance of 1.0 W/K at Tc and a heat capacity of 1.2 pJ/K
- In this experiment, we vary the temperature of the bath T_{bath} from 55 mK - which is our usual temperature of operation for this kind of detectors - up to 83.75 mK – in order to get as close as possible to Tc while still being able to measure a reasonable level of signal to noise ratio.
- We used 2 different sources of x-rays : Al, producing x-rays at 1.5 keV (AlKα line), and Fe^{55}, producing x-rays at 5.9 keV (MnKα line)

3 Impact of T_{bath} on slew-rate

- As we increase the bath temperature, we observed a decrease in the slew rate.

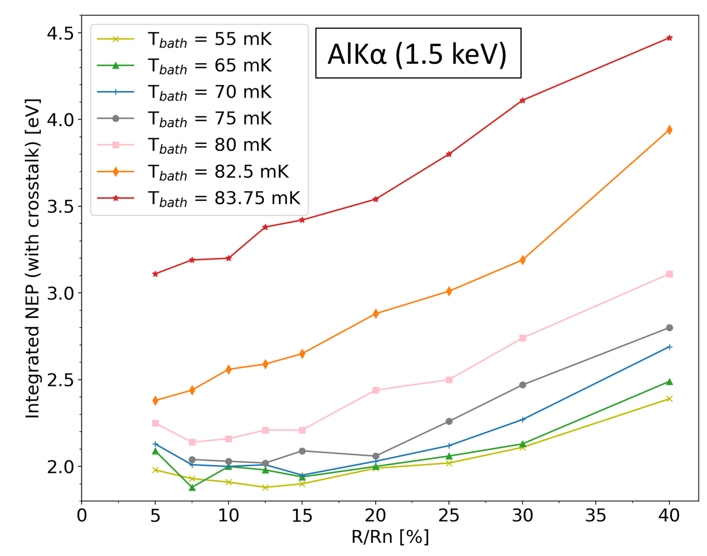


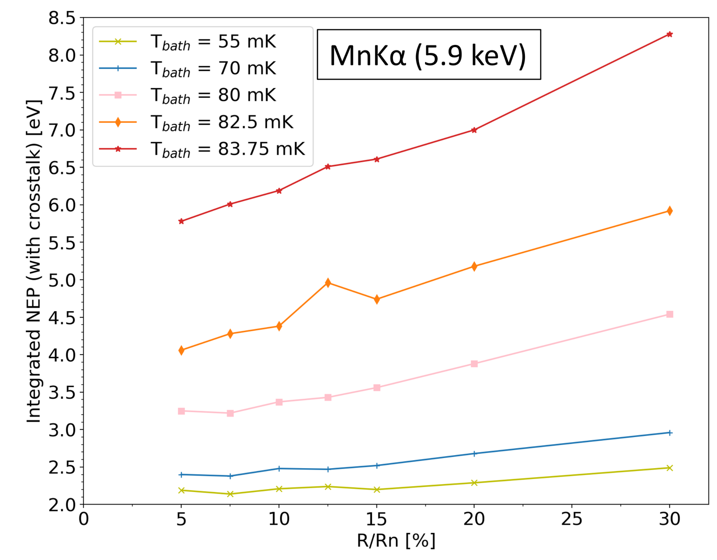


- At 1.5 keV we observe a decrease of a factor ~4 in slew rate between bath temperatures of 55 mK and 83.75 mK. At 5.9 keV, this factor becomes closer to a factor ~8
- This difference is likely due to the change in non-linear shapes for different bath temperatures.

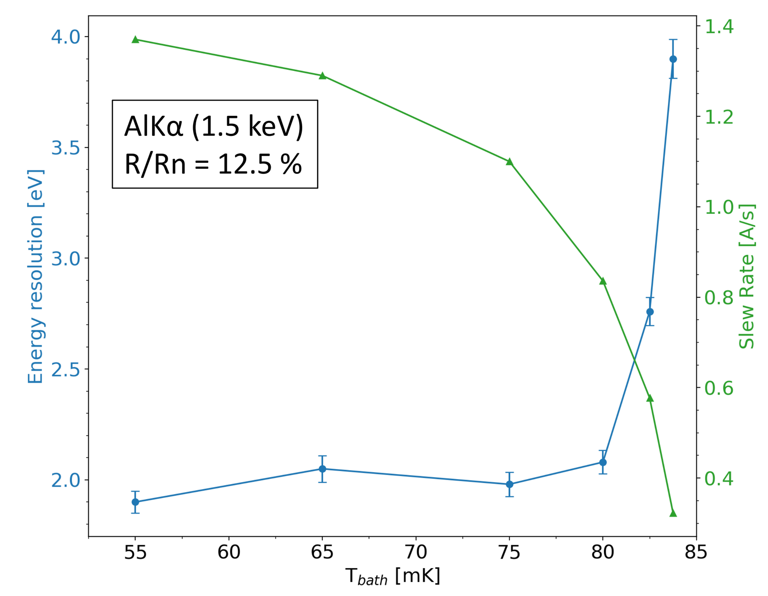
4 Impact of T_{bath} on resolution

- As we increase the bath temperature, we also observed an increase in the integrated NEP. This is expected as our signal to noise decreases.
- We measure of degradation in the integrated NEP of 70% at 12.5% in the transition at 1.5 keV, and of almost a factor 3 at 5.9 keV

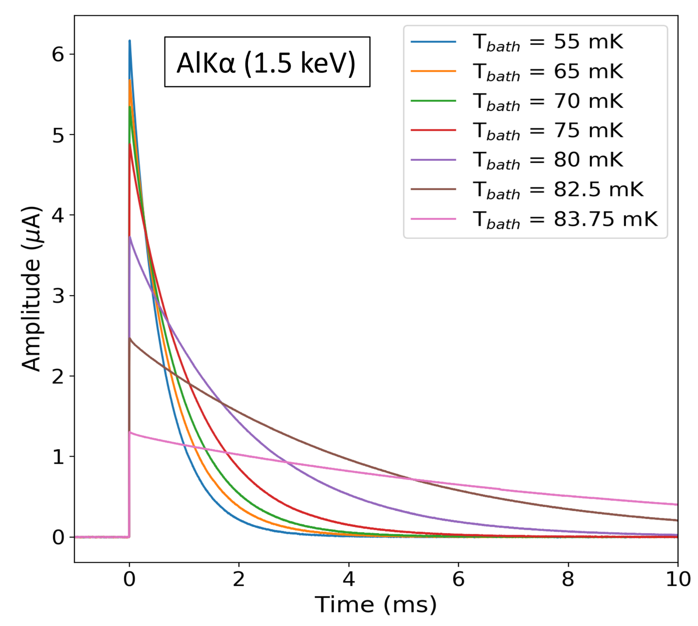


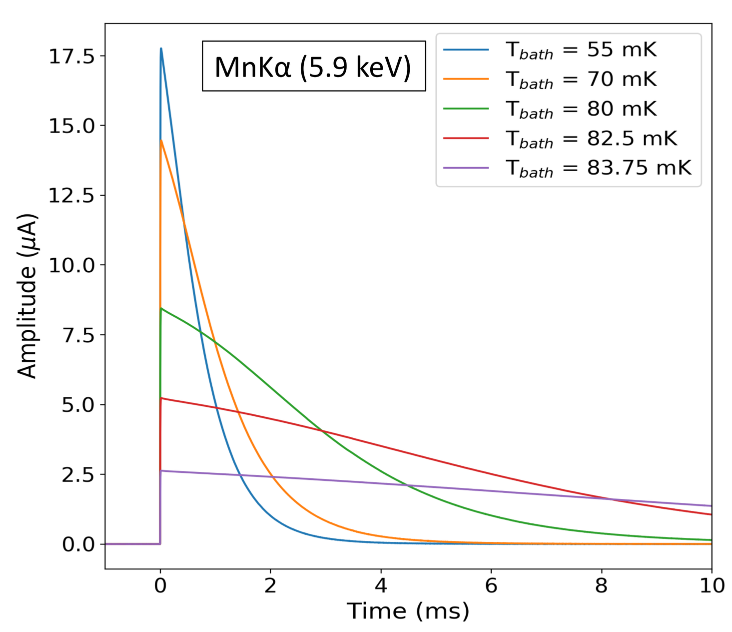


- Looking into the energy resolution for the aluminum source as a function of T_{bath} and together with the measured slew rate, it appears clearly that this extended energy range mode could be used, but finding a tradeoff of how much the slew rate could be relaxed vs. the degradation in energy



- The energy resolution degradation has not yet been measured at 5.9 keV but based upon the integrated nep, we would expect the deterioration to be larger than that observed at 1.5 keV.
- As we go higher in energy and also higher in temperature, the shape of the pulses change as we get more and more saturation, as can clearly be seen below





- In the future, TESs designed slightly differently, for instance having slightly broader transitions, could be useful in order to be less affected by saturation effects

Conclusions

- This experiment confirmed that the energy range can be extended by operating at higher temperature, at the cost of a degradation of the energy resolution
- The trade-off between the slew rate reduction and degradation in energy resolution has been observed for one particular pixel design.
- Further studies will investigate the possible effects of increased susceptibility to bath temperature fluctuations and the impact of increased multiplexed readout noise.

References

(1) S.R. Bandler et al., "Lynx x-ray microcalorimeter", JATIS, 2019