

LTD-10, Genova, Italy, 9 July 2003



Performance of Resistive Microcalorimeters and Bolometers



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Summary

What we understand

Ideal model

Non-ideal effects

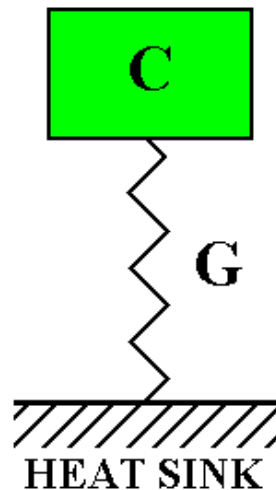
What we don't understand yet

Excess noise

The ideal model

- J. C. Mather, Appl. Opt. **21**, 1125 (1982).
(several hundred citations?)
- S. H. Moseley, J. C. Mather, and D. McCammon,
J. Appl. Phys. **56**, 1257 (1984).
(177 of citations)

The ideal model

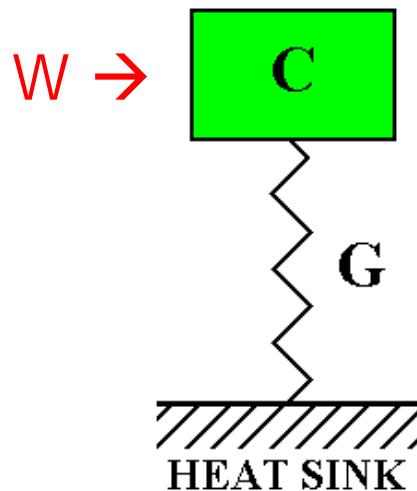


Small signal theory
($\Delta T \ll T$)

- First order approximation
- Linear detector

The ideal model

Theoretical description

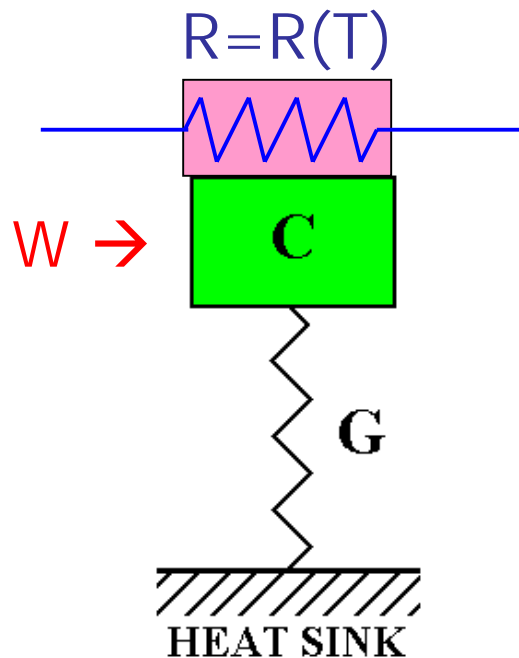


$$C \frac{d(\Delta T)}{dt} + G\Delta T = \Delta P + W$$

Power stored In heat capacity (points to $C \frac{d(\Delta T)}{dt}$)
 Power flowing through the thermal conductivity (points to $G\Delta T$)
 Electro-thermal feedback (points to ΔP)
 $\Delta P = -G_{ETF} \Delta T$
 Measured Power/Energy (points to W)

1 pole low-pass system with $\tau = C/(G + G_{ETF})$

The ideal model



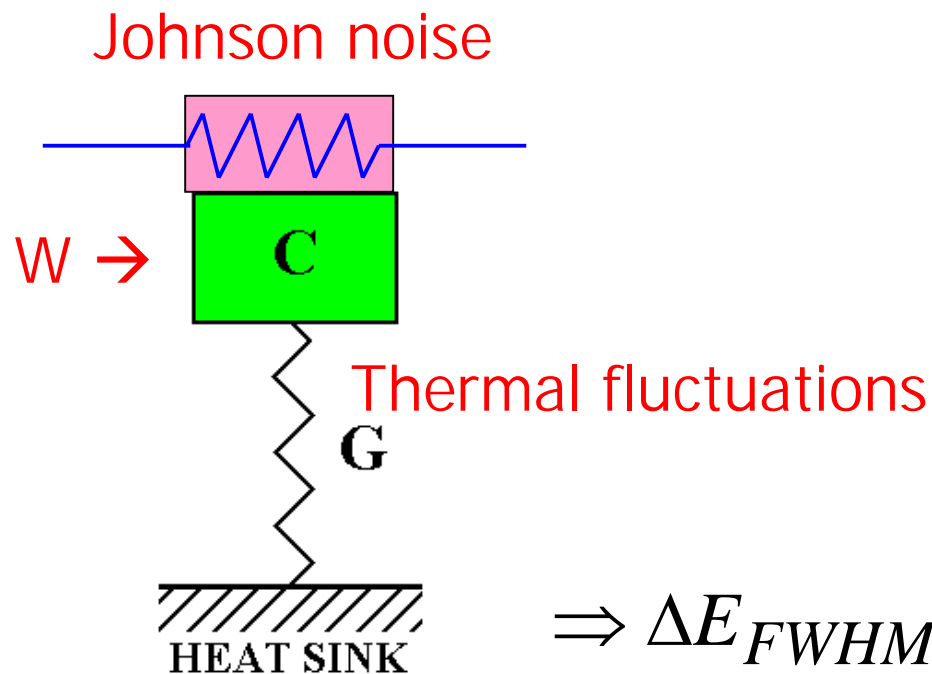
Sensitivity

$$\alpha = \frac{T}{R} \frac{dR}{dT}$$

Resistance Change

$$\Rightarrow \Delta R = \frac{R \cdot \alpha}{T} \Delta T$$

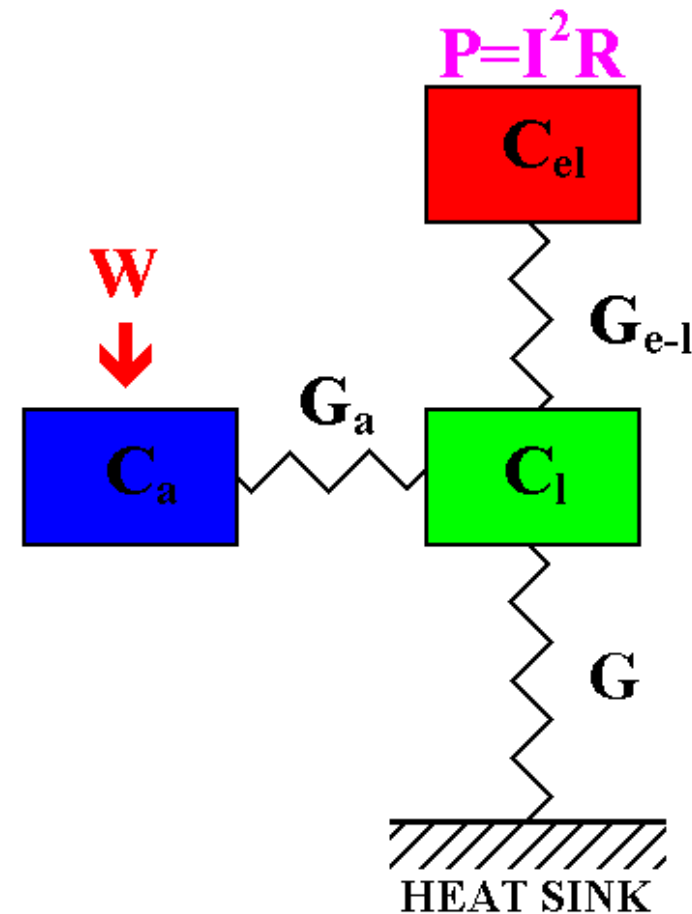
U Noise



$$\Rightarrow \Delta E_{FWHM} = 2.35 \cdot \xi \sqrt{kCT^2}$$

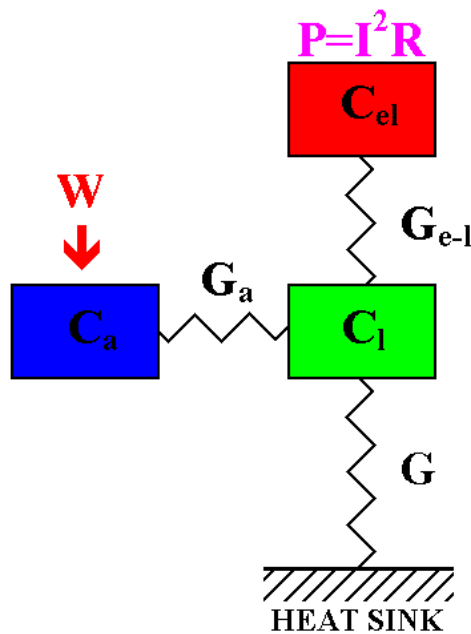
Non ideal effects

- Thermal decoupling between electrons and phonon in the thermometer
- Thermal decoupling between absorber and thermometer



Consequences

- Reduction in the detector responsivity (smaller pulses)



$$C_{el} \frac{d(\Delta T_e)}{dt} + G_{e-l}(T_e) \Delta T_e = G_{e-l}(T_l) \Delta T_l - G_{ETF} \Delta T_e$$

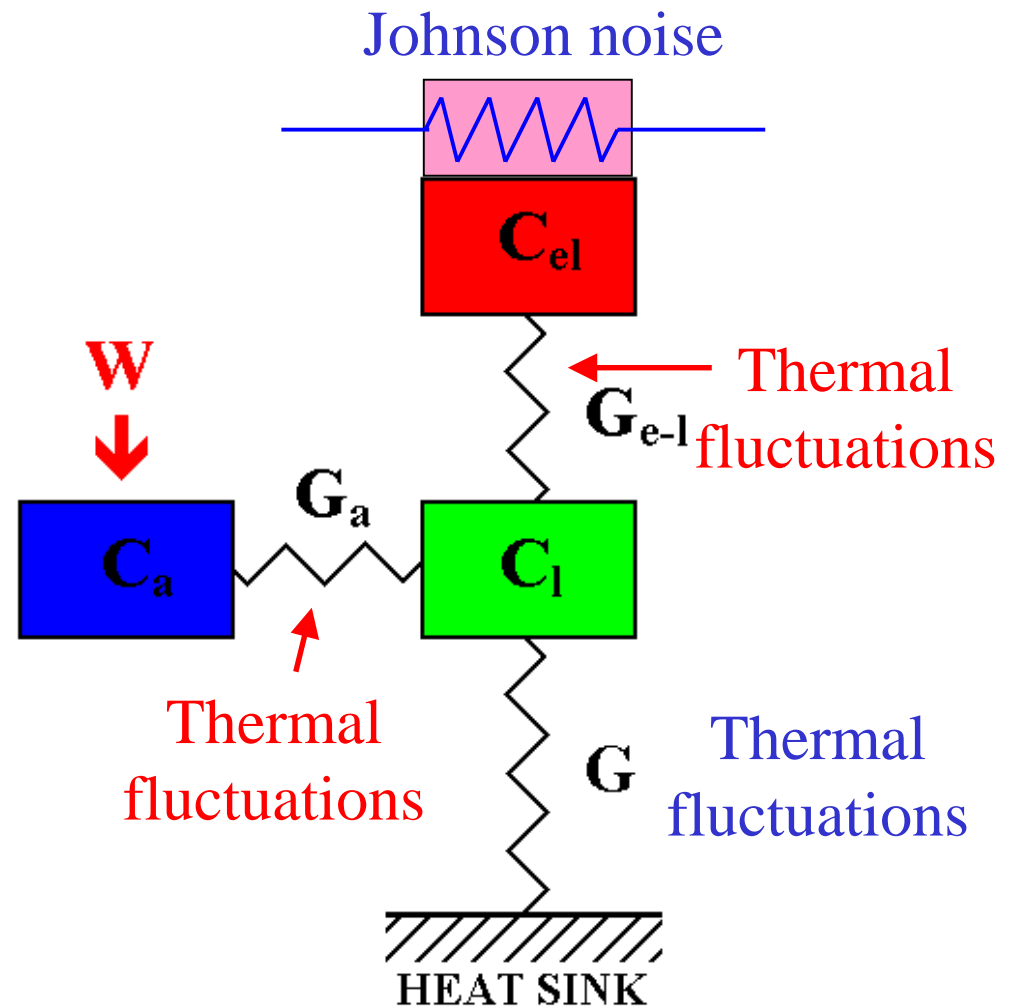
$$C_l \frac{d(\Delta T_l)}{dt} + G \Delta T_l = G_{e-l}(T_e) \Delta T_e - G_{e-l}(T_l) \Delta T_l + G_a \Delta T_a - G_a \Delta T_l$$

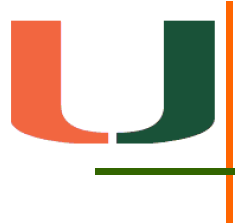
$$C_{el} \frac{d(\Delta T_a)}{dt} + G_a \Delta T_a = W + G_a \Delta T_l$$

$$\Rightarrow \Delta T_e < \Delta T_a$$

Consequences

- Reduction in the detector responsivity (smaller pulses)
- Additional noise sources





Thermometer non-ohmic behavior

Ideal thermometer:

$$R=R(T)$$

$$dR = \frac{R \cdot \alpha}{T} dT$$

$$\alpha = \frac{T}{R} \frac{dR}{dT}$$

Non-ohmic thermometer:

$$R=R(T,I)$$

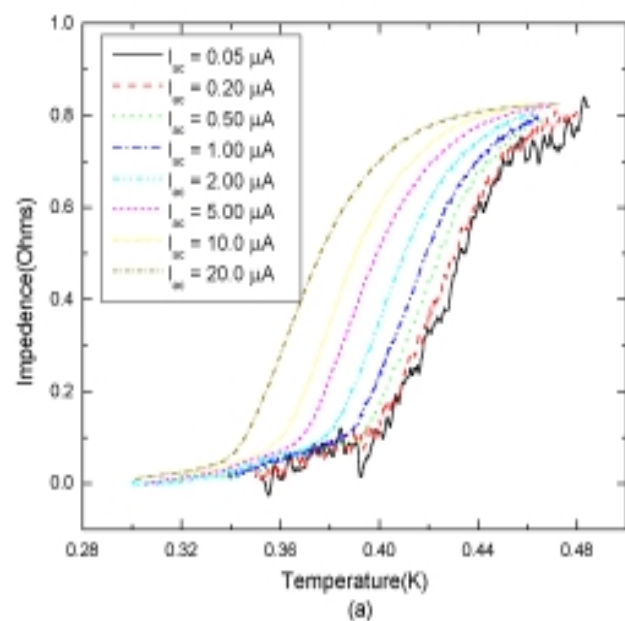
$$dR = \frac{R \cdot \alpha_I}{T} dT + \frac{R \cdot \beta_I}{I} dI$$

$$\alpha_I = \left. \frac{T}{R} \frac{\partial R}{\partial T} \right|_I$$

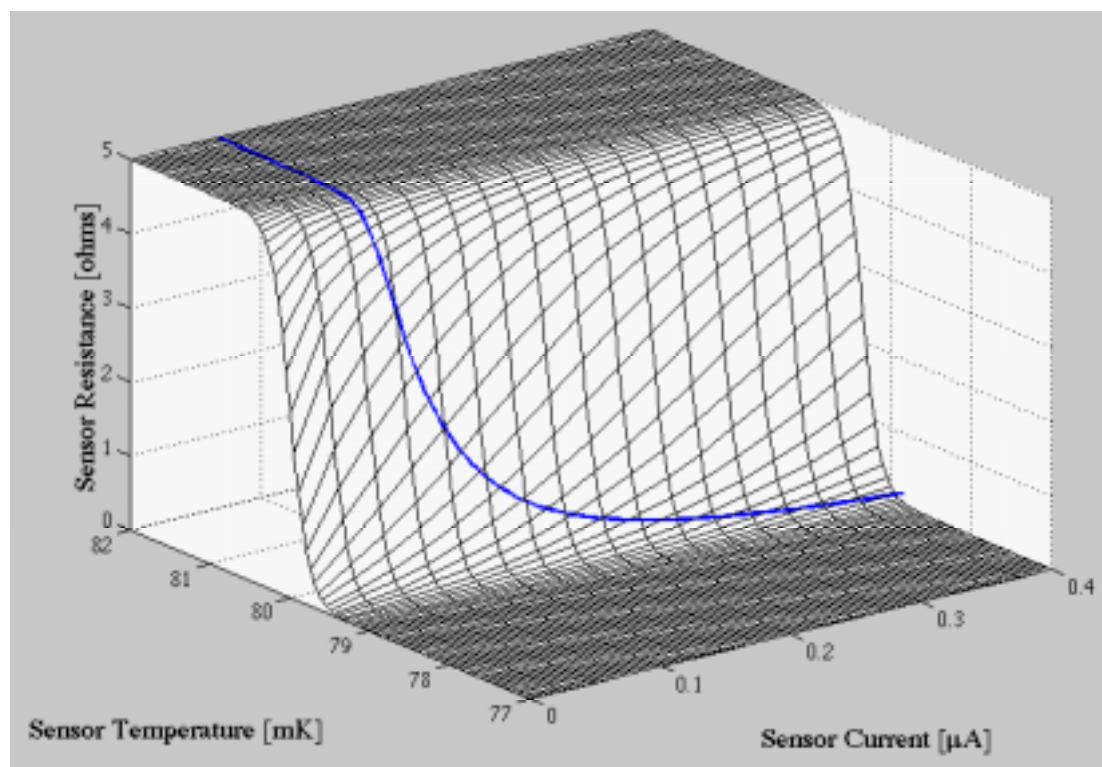
$$\beta_I = \left. \frac{I}{R} \frac{\partial R}{\partial I} \right|_T$$



Thermometer non-ohmic behavior



Tan et al. – LTD9



Cabrera et al.

Non-linear model

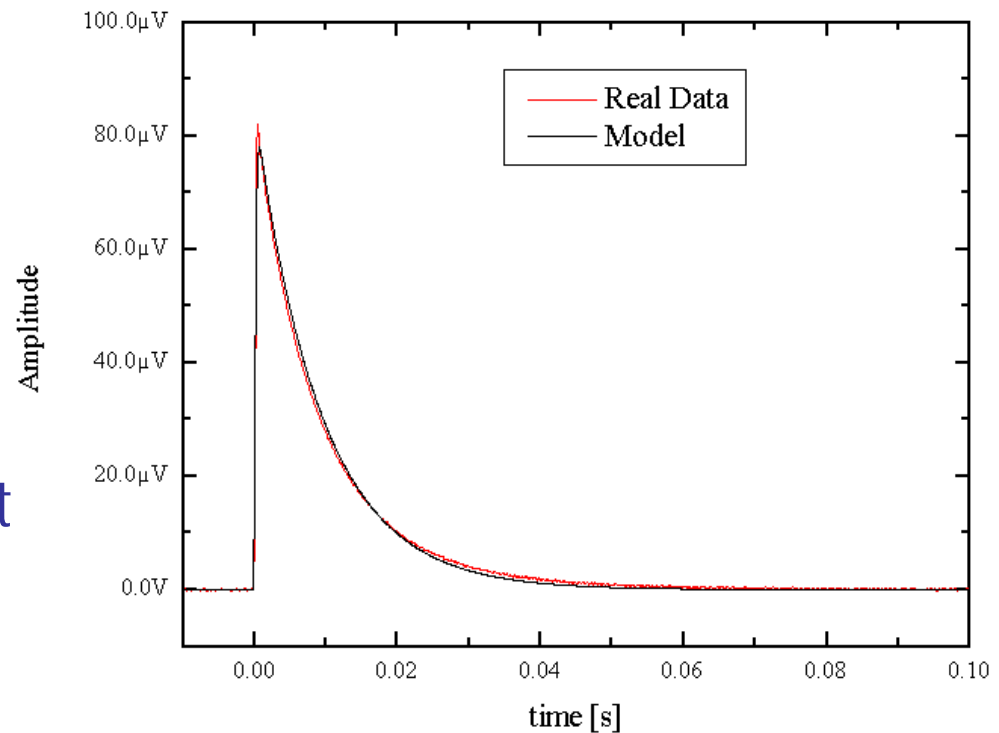
$$C = C_1 \cdot T + C_3 \cdot T^3$$

$$G = G_0 \cdot T^\beta$$

$$\alpha = \alpha(T)$$

→ Linear approximation cannot be used to predict pulse shape

→ Non linear models



Design Optimization

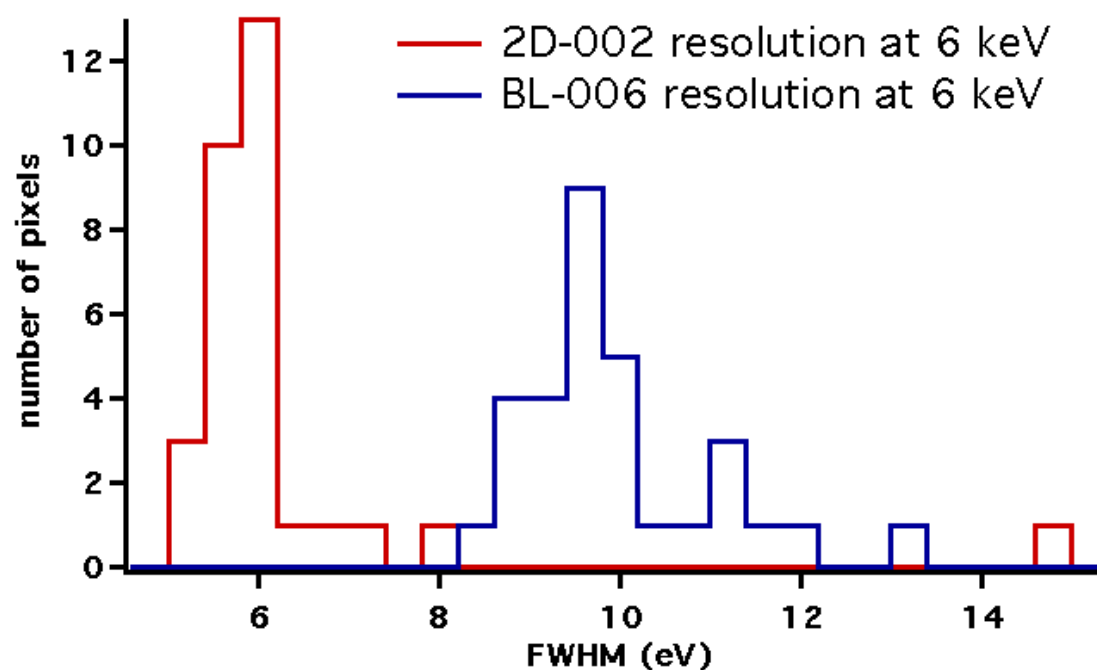
Optimization of the XRS detector on Astro-E2 Energy resolution

Inputs:

Pulse recovery time
Absorber size
Thermistor characteristics
Properties of components

Outputs:

Thermal conductance
Thermistor volume
Energy resolution



Is that all?

YES

- Responsivity
- Noise in semiconductor thermistors

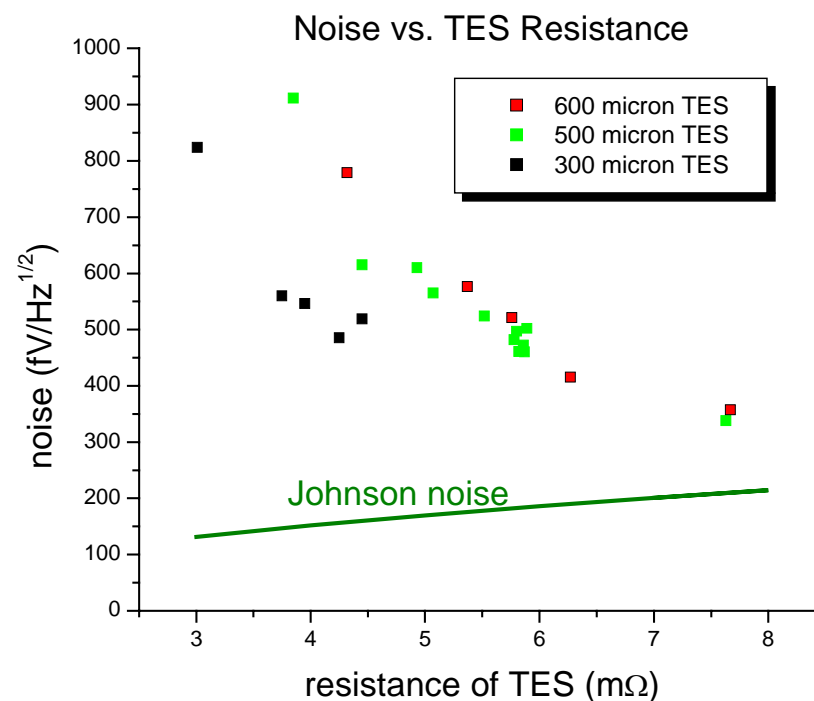
NO

- Absorber thermalization → Paper H03 – Chapellier
- Excess noise in TES → Paper C03 – Vaillancourt

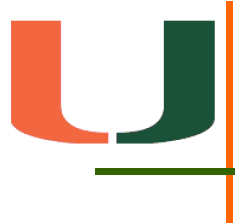
TES Excess noise

LTD-9

- Most groups (except Wisconsin) reported the presence of a significant level of noise of unknown origin in their TES devices
- The characteristics of the excess noise for devices fabricated by different groups didn't seem to agree



Lindeman et al. – LTD9



What has been done since LTD-9?

3 main directions

- Understanding of fundamental noise sources in superconductors (can they explain the excess noise?)
- Fabrication of devices with excess noise of known origin
- Empirical attenuation of the excess noise



Fundamental noise sources in superconductors

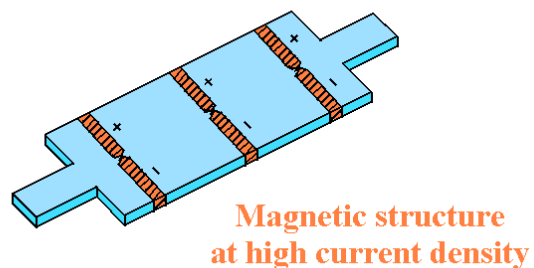
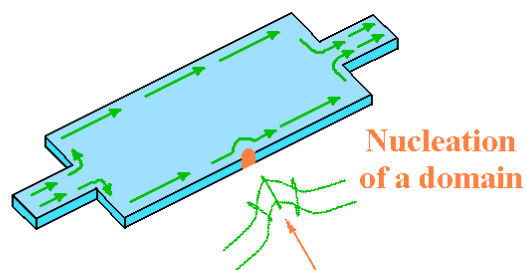
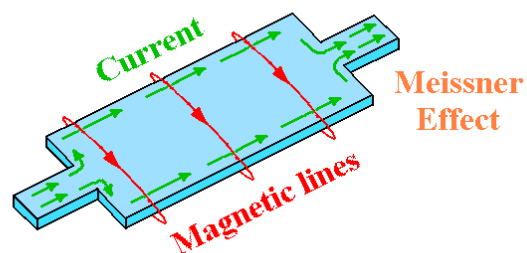


- **Fluctuations in the order parameter**
Paper R02 – Seidel (next talk)
Paper R08 – Galeazzi
- **Fluctuations due to magnetic flux penetration**
Paper R08 – Galeazzi



Magnetic Flux penetration in TES

Type I superconductor



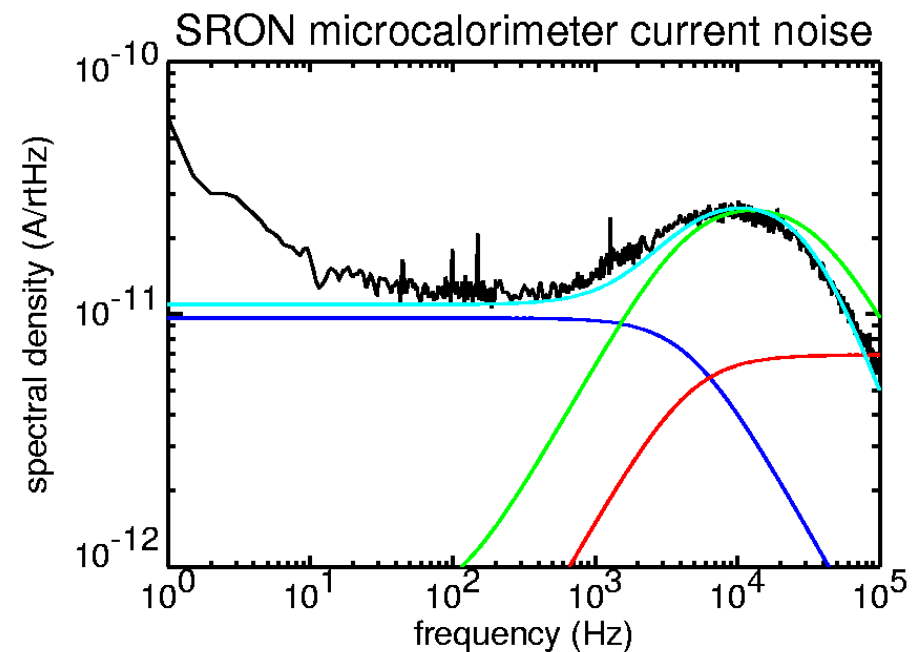
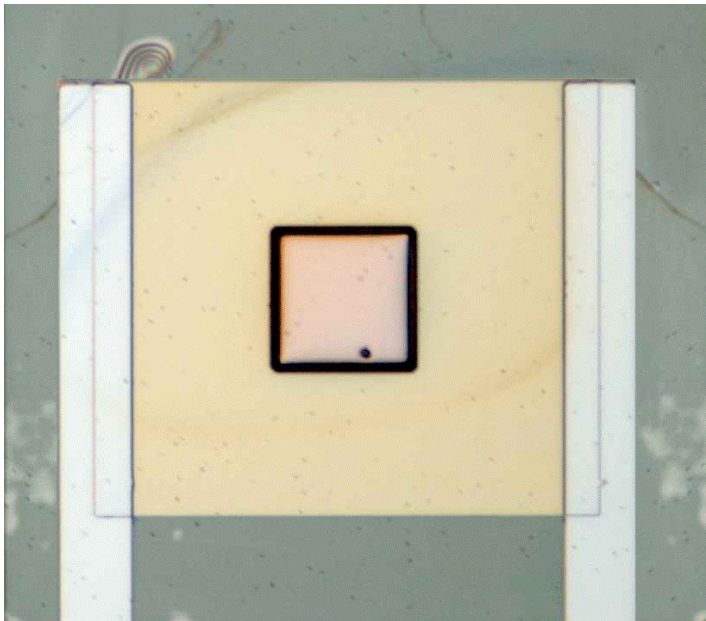


Device with fully characterized excess noise



Devices with higher resistance and central absorber (SRON)

Internal thermal fluctuations



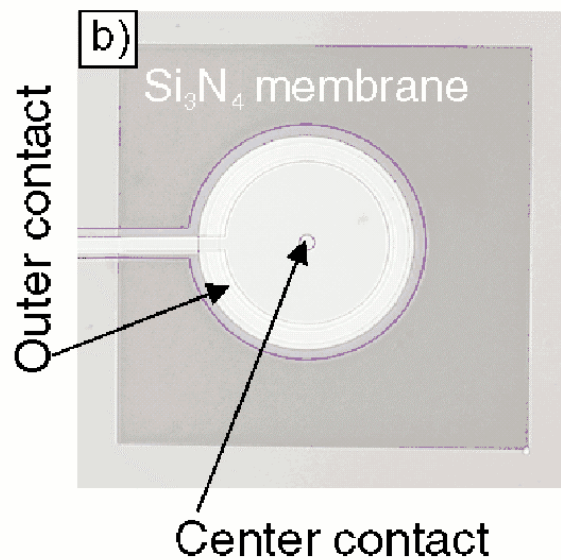
Paper R03 – Bergmann Tiest



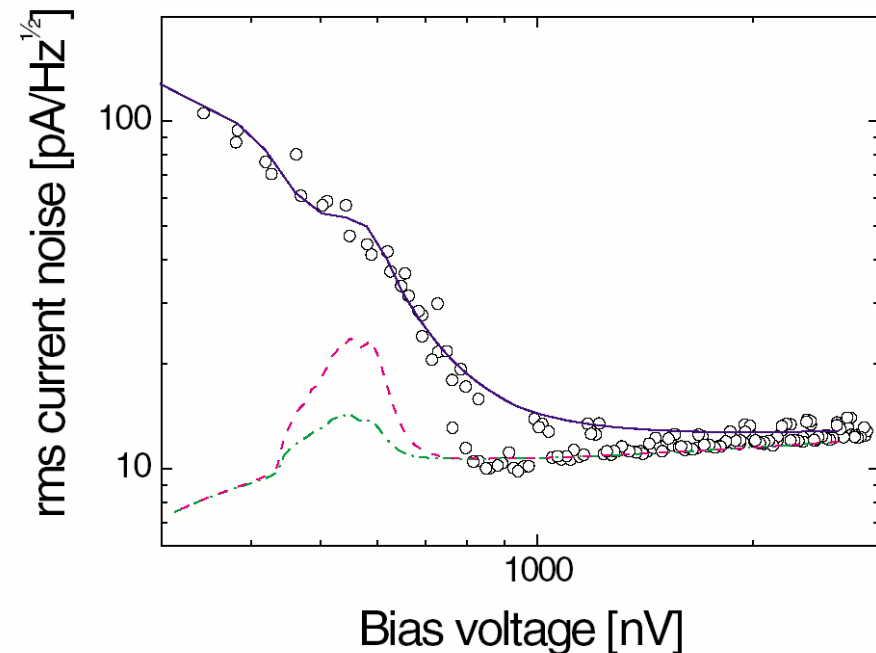
Device with fully characterized excess noise



Corbino Geometry (U. Jyväskylä + SRON)



Critical fluctuations as a source of excess noise



Paper R06 – Luukanen

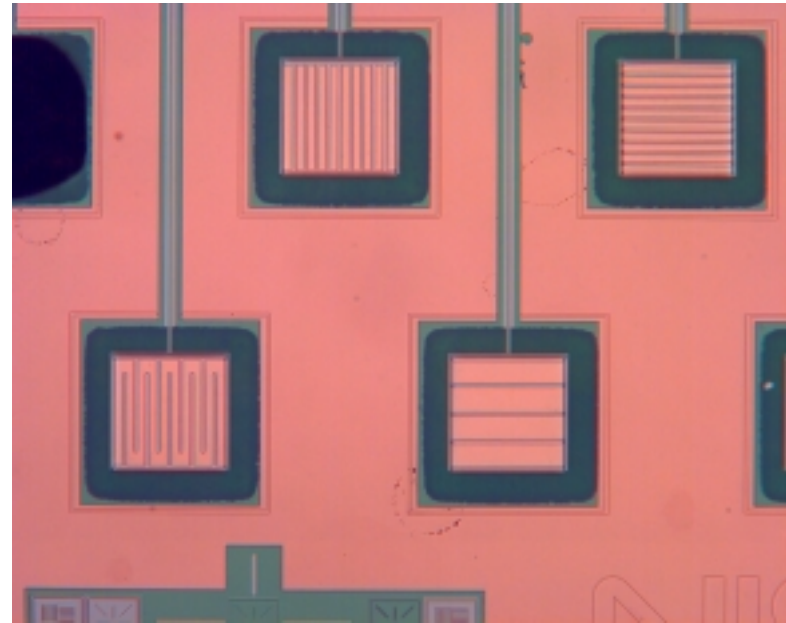
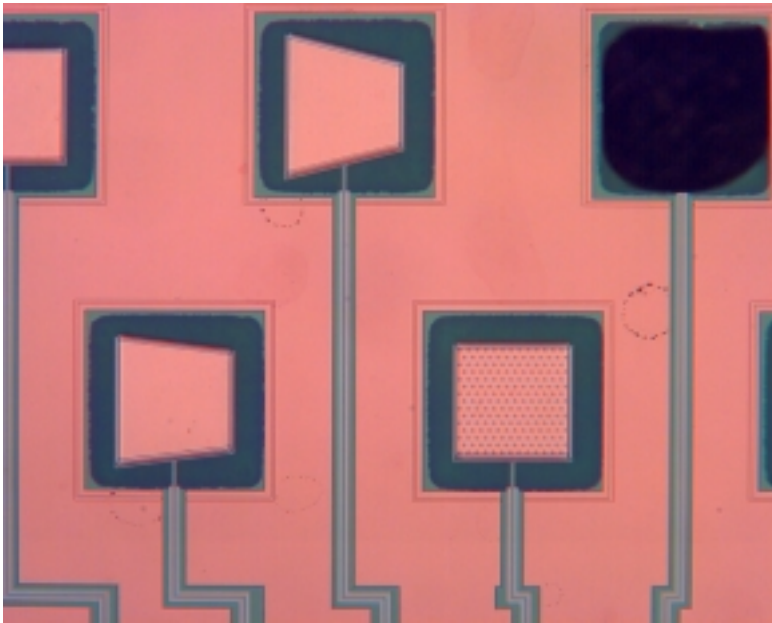
“Empirical” removal of excess noise

- Device Engineering
- Magnetic field modulation

SRON – Paper R03

NIST – Paper R04

NASA/GSFC – Paper R09
Paper T02

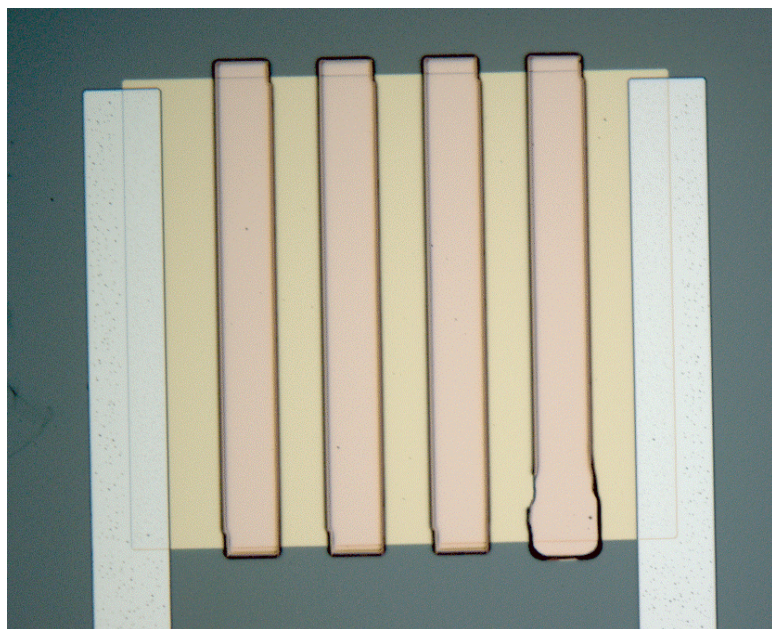


Courtesy of NIST

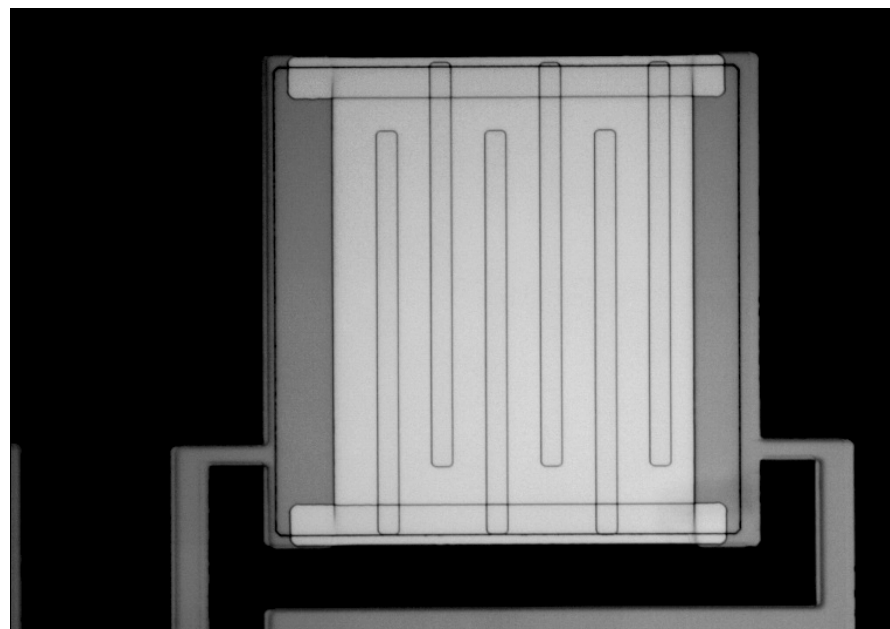


Empirical removal of excess noise

“Zebra” Geometry



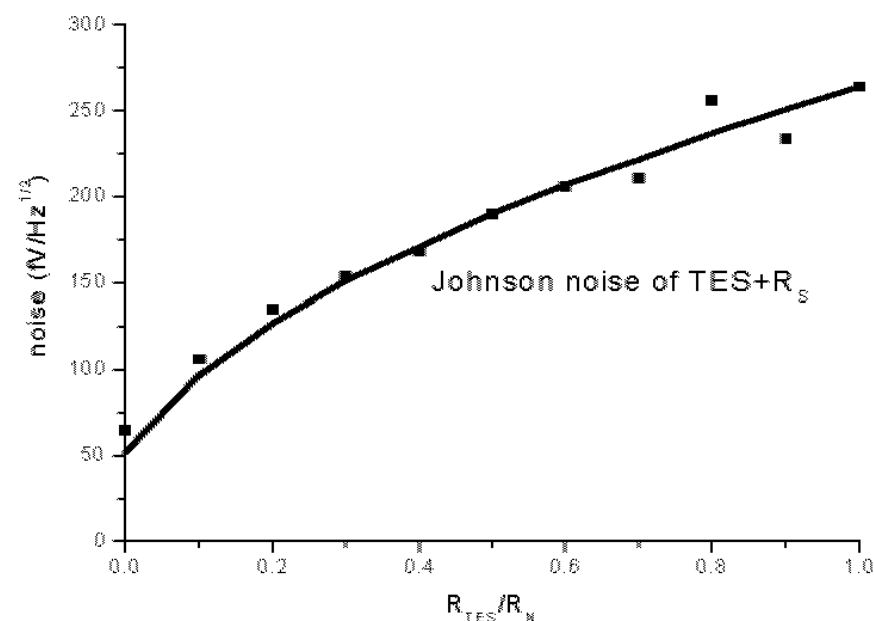
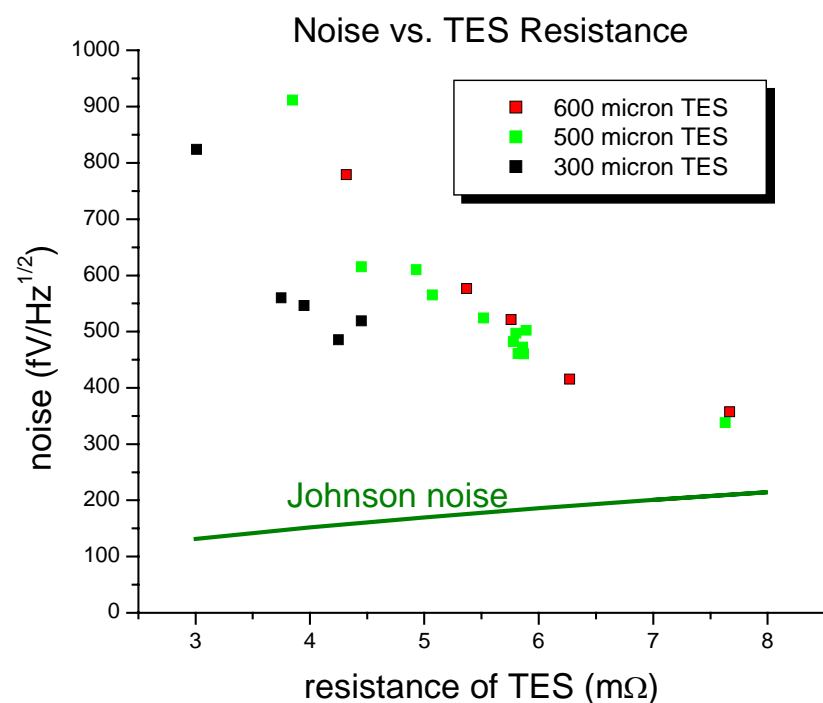
SRON



NASA/GSFC



Empirical removal of excess noise



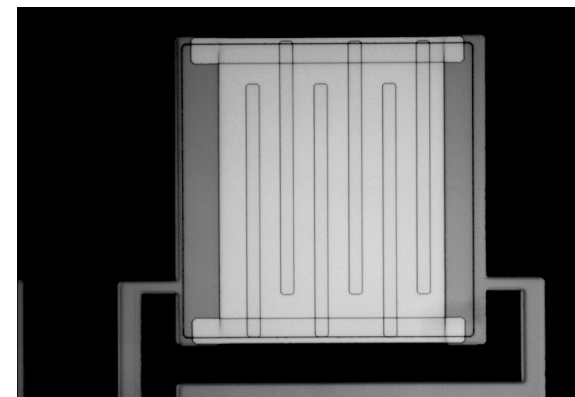
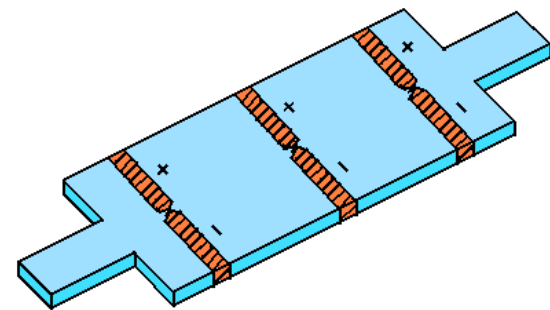


Empirical removal of excess noise

Why is noise reduced with “zebra” design?

- SRON: reduced internal thermal fluctuations – **Paper R03**
- It should reduce the fluctuations in the order parameter – **Paper R02**
- It should also reduce fluctuations in magnetic flux penetration

(perpendicular vs. parallel stripes)

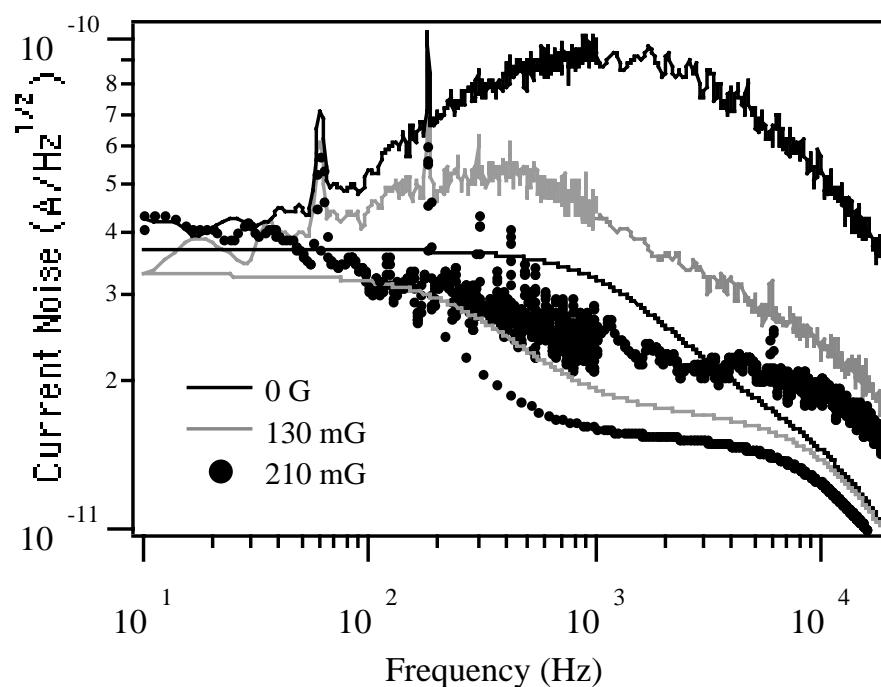


Paper R08 – Galeazzi



Empirical removal of excess noise

Reduction in the excess noise by applying a small external magnetic field



Considerations

- **Type I or Type II?** (the physics is quite different)
- **Better characterization of the excess noise**
(noise vs. power, voltage, T , T_C , etc.)
- **Is there agreement between theoretical models and data?**
(Magnetic flux penetration vs. changes in order parameter)
- **Why noise is reduced in “zebra” geometry?**
SRON results vs. NIST & NASA/GSFC results
(Internal thermal noise vs. order parameter fluctuations vs. magnetic flux penetration)
bars all across vs. interrupted bars

LTD-11?

Conclusions

Is that all we need?

YES

- Responsivity
- Noise in semiconductor thermistors

NO

- Absorber thermalization
- Excess noise in TES

- In the past few years our understanding of the behavior of microcalorimeters and bolometers has drastically improved
- This resulted in a significant improvement in device performance due to a better detector optimization
- Semiconductor thermistors are now a mature, reliable technology, with very high performance that can be predicted by models
- We still need to improve our understanding of TES behavior and absorber thermalization
- This could potentially lead to another drastic improvement in detector performance