# Review:
# Metallic Magnetic Calorimeters for X-ray Spectroscopy

L. Fleischmann and etc., *IEEE/CSC & ESAS EUROPEAN SUPERCONDUCTIVITY NEWS FORUM (ESNF),* No. 7, January 2009

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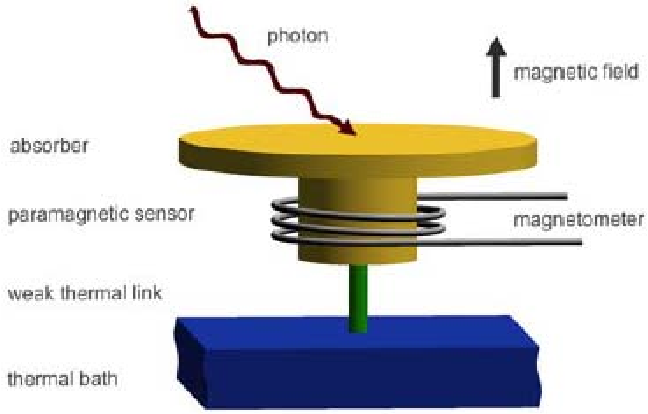
# Introduction

- Metallic Magnetic Calorimeters

$$\Delta\Phi \propto \frac{\partial M}{\partial T}\Delta T = \frac{\partial M}{\partial T}\frac{E}{C} = \frac{\partial M}{\partial T}\frac{E}{C_a + C_s}$$

  - Higher temperature, lower magnetization
  - A low noise high bandwidth SQUID magnetometer



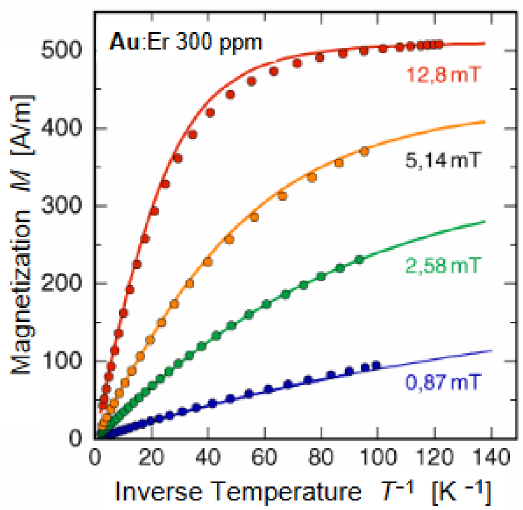
# Background

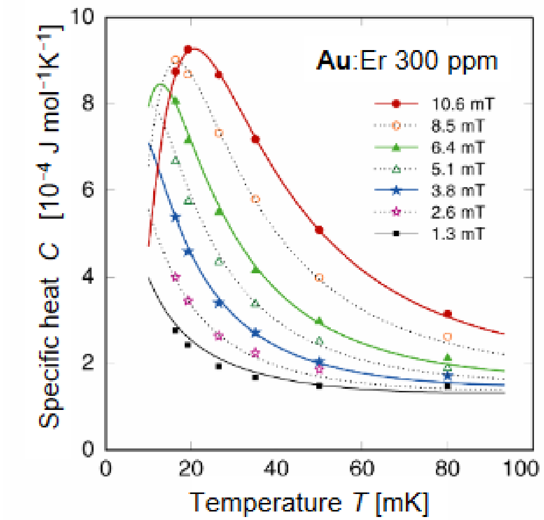
1. Sensor Metal
   A. Response time
      - Use of metal or semi-metal as the host-metal
      - The strong coupling between conduction electrons and localized spins leads to rapid thermalization
      - Well below microseconds
   B. Signal size
      - The Ruderman-Kittel-Kasuja-Yoshida (RKKY) interaction
        - An enhanced interaction between the localized magnetic moments
        - Reduces the temperature dependence of the magnetization
        - Increases the heat capacity of the sensor

➢(Au:Er) – gold doped with erbium

# Introduction

- Properties of (Au:Er)



# Background

## 2. Noise sources

A. The thermal fluctuations of energy between the subsystems of the detector and the thermal

- Independent of the readout techniques
- The fundamental limit of the energy resolution

$$\Delta E_{\mathrm{FWHM}} = 2.35\sqrt{4k_{\mathrm{B}}C_{\mathrm{a}}T^2}\left(\frac{1}{\beta(1-\beta)}\frac{\tau_0}{\tau_1}\right)^{1/4}$$

- $\beta$: the fraction of the heat capacity due to the spin system

$C_{\mathrm{a}} = C_{\mathrm{s}} = 0.2$ pJ/K $\quad \tau_0 = 1$ μs $\quad \tau_1 = 1$ ms

T= 50 mK

➢ $\Delta E_{\mathrm{FWHM}} = 0.62$ eV

# Background

## 2. Noise sources

B. The magnetic Johnson noise

$$S_{\Phi} \propto \sigma k_B T$$

- Very small

C. The flux noise of the SQUID

$$S_{\Phi} = S_{\Phi,1} + \frac{4k_{\mathrm{B}}TR_{\mathrm{g}}}{(\partial V_1 / \partial \Phi_1)^2_{R_g}} + \frac{S_{\Phi,2}}{G_{\Phi}^2} + \frac{S_{V,\mathrm{el}}}{(\partial V_1 / \partial \Phi_1)^2 G_{\Phi}^2}$$

D. 1/f noise contribution

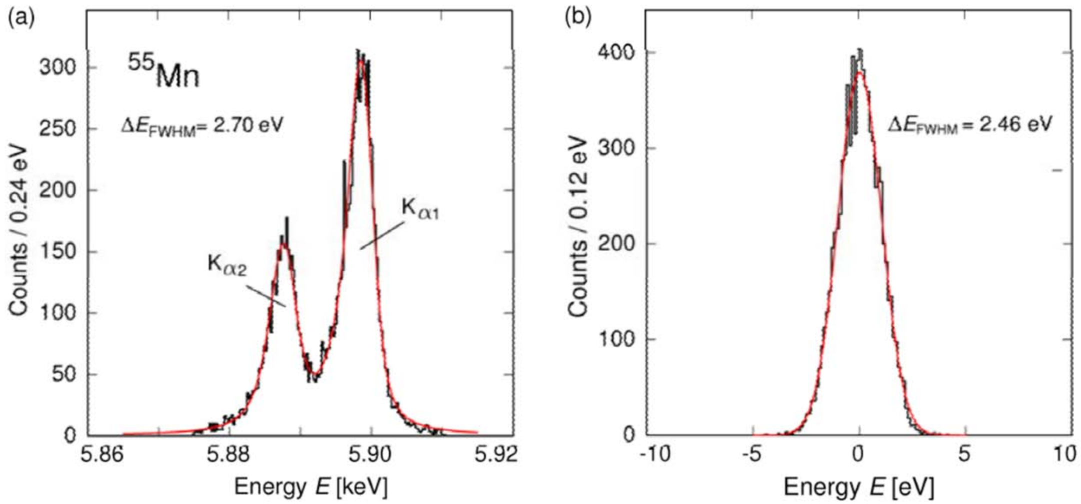
- seems to be caused by the magnetic moments of the sensor and to be independent of the temperature

➢ Degradation by C & D - $\Delta E_{\mathrm{FWHM}} = 0.95\ \mathrm{eV}$

# Test

- The x-ray fluorescence spectrum of manganese emitted by an external $^{55}Fe$-source
- Magnetic field $= 3$ mT
- A bath temperature of 23 mK $\pm$ 15 μK
- The temperature of the calorimeter of about 35 mK
  - Due to heat dissipation from SQUID chip

# Result




Energy spectrum of the Ka line of manganese

Energy spectrum obtained by applying the optimal filtering algorithm to untriggered noise traces

$$\Delta E_{\mathrm{FWHM}} = 2.5\ \mathrm{eV}$$

## Discussion

- Assuming noise-free readout and only thermodynamic fluctuation noise: $\Delta E_{\mathrm{FWHM}} = 0.4\ \mathrm{eV}$
- + SQUID flux noise and 1/f noise: $\Delta E_{\mathrm{FWHM}} = 1.6\ \mathrm{eV}$

- Actual value = 1.6 times designed value

➢ Seems to be caused by the fluctuation of SQUID chip heat dissipation