A liquid nitrogen-cooled cryostat for multichannel HTS magnetoencephalography

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2. 7-channel HTS MEG System
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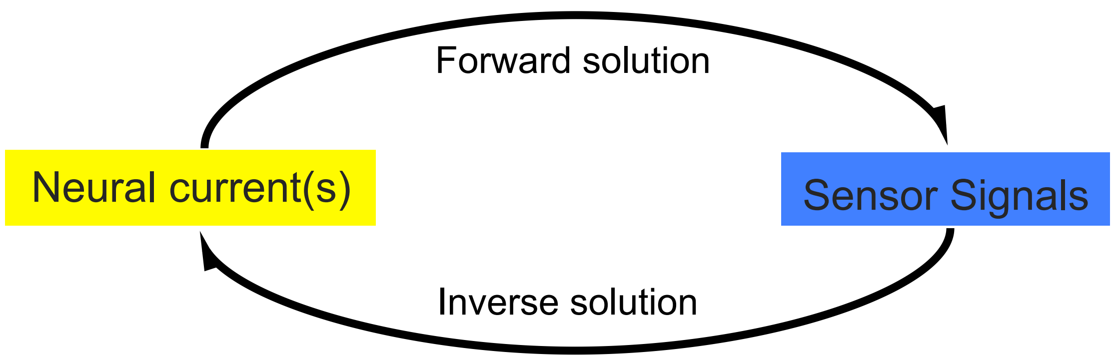
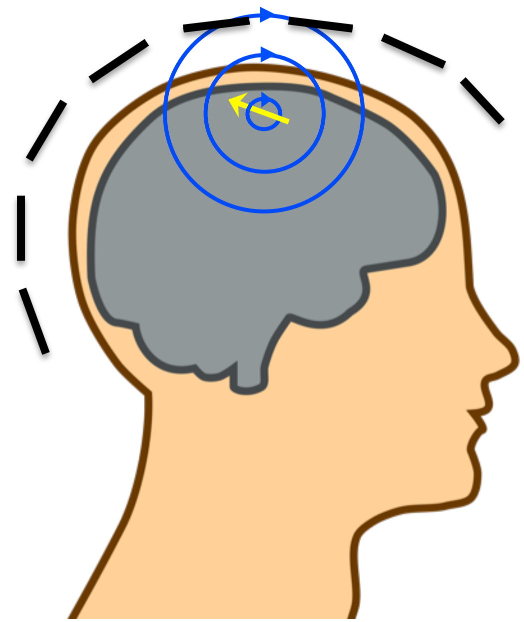
1. Introduction

1.1. MEG

- **M**agnetoencephalo**g**raphy
  = Recording of brain activity through measurement of magnetic fields
- Neural currents generate weak magnetic fields (typ.: 10 – 1000 fT)
- Magnetically shielded room + highly sensitive magnetometers

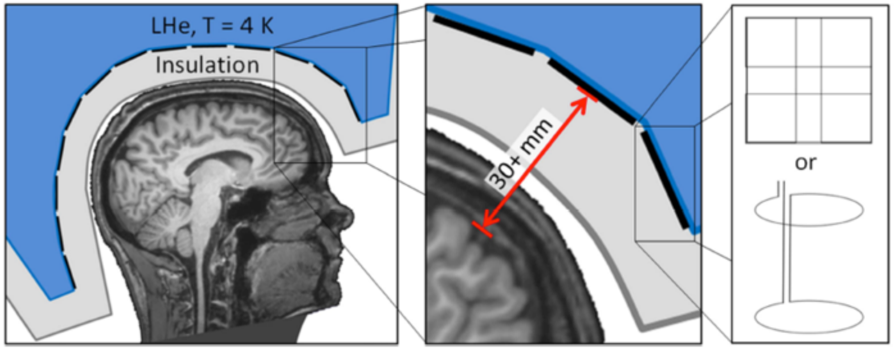




1.1. MEG

- Commercial systems:
  - Hundreds of low-T_c SQUIDs
  - Liquid helium-cooled
  - Fixed helmet cryostat (≈20 mm insulation)
  - Resolution: ≈1 ms, ≈5 mm
  - Applications:
    - Neuroscience
    - Diagnosing neural disorders (e.g. ASD)
    - Clinical guiding of brain surgeries (e.g. Epilepsy)

Elekta Neuromag® TRIUX™



Körber et al., *Supercond. Sci. Technol* **29** (2016)

1.2. On-scalp MEG

- Alternative sensor technologies operating at higher temperatures (e.g. high-T_c SQUIDs, OPMs, …)

Singe-channel high-T_c SQUID cryostat (ILK Dresden)

Boto et al., *NeuroImage* (2017)

1.2. On-scalp MEG

- Alternative sensor technologies operating at higher temperatures (e.g. high-T_c SQUIDs, OPMs, …)
  - Simpler cryogenics → flexible arrays

Singe-channel high-T_c SQUID cryostat (ILK Dresden)

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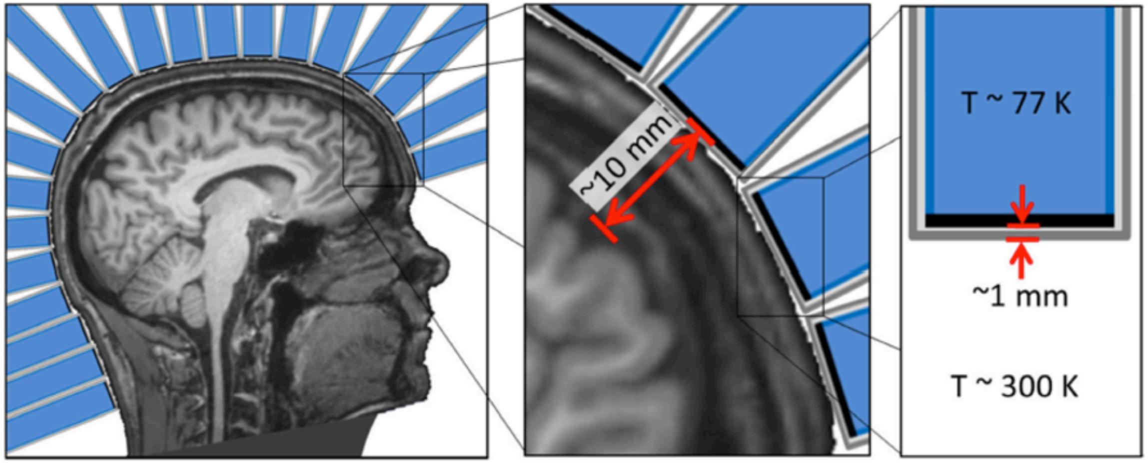


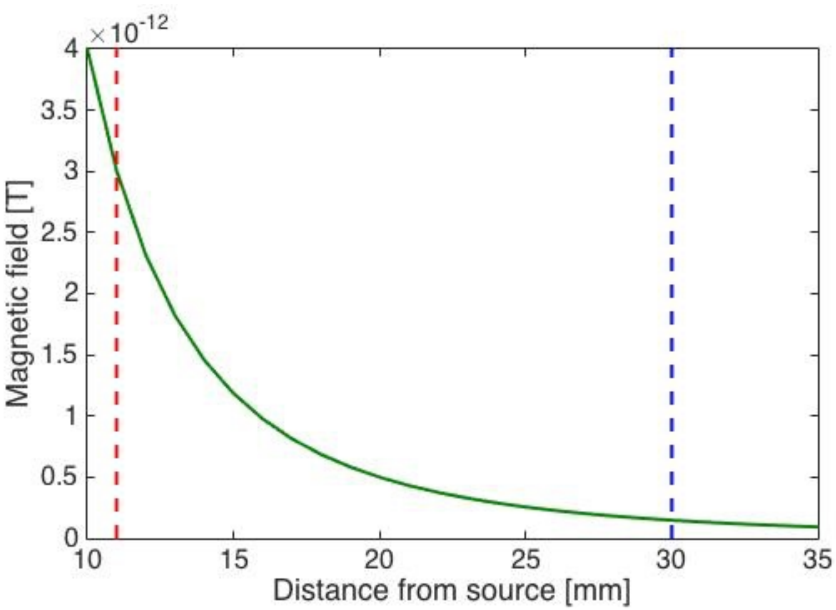
Körber et al., *Supercond. Sci. Technol* **29** (2016)

1.2. On-scalp MEG

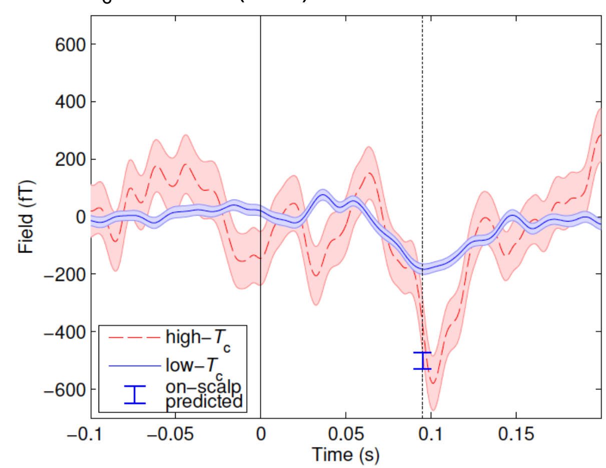
- Alternative sensor technologies operating at higher temperatures (e.g. high-T_c SQUIDs, OPMs, …)
  - Simpler cryogenics → flexible arrays
  - **Closer proximity** → higher signals

Singe-channel high-T_c SQUID cryostat (ILK Dresden)

Boto et al., *NeuroImage* (2017)

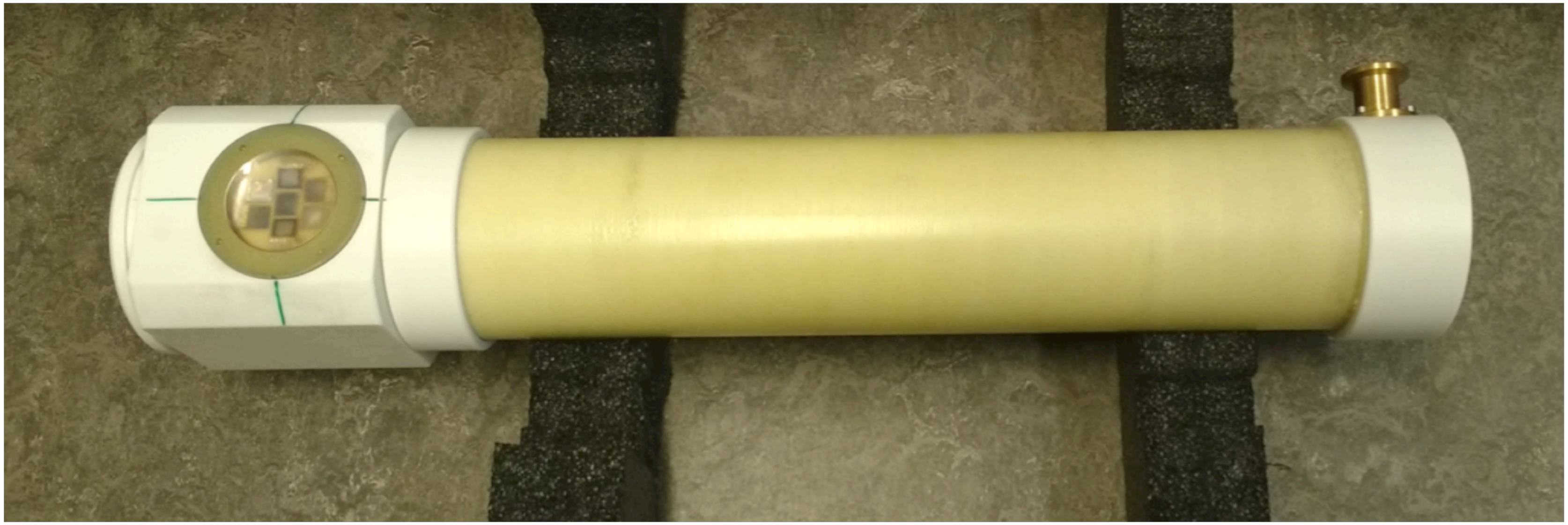


AEF N100m peak measured with high-T_c (red) at 3 mm and low-T_c SQUIDs (blue) at 20 mm distance of the head

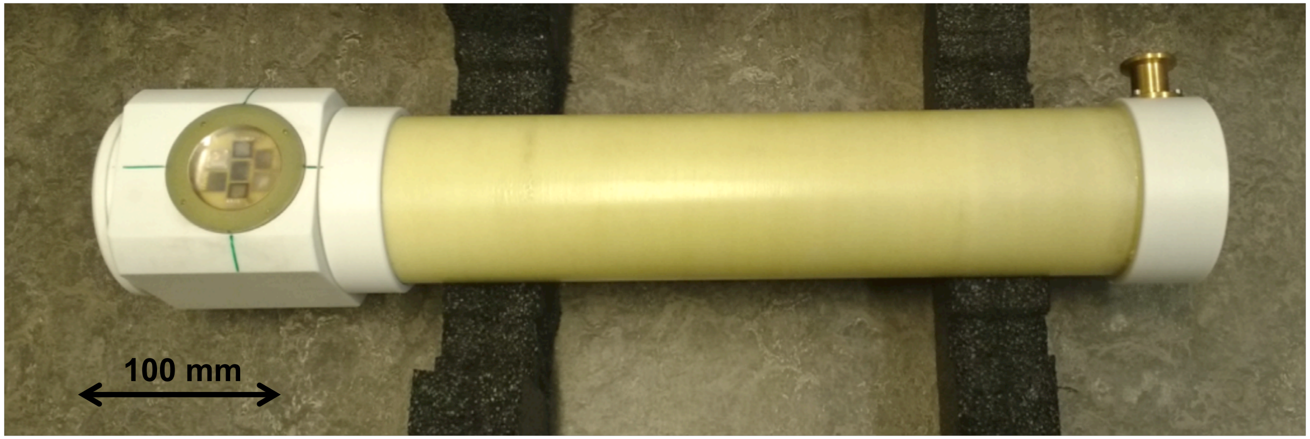


M. Xie et al., *IEEE Trans. Biomed. Eng.* **PP**, 99 (2016)

2. 7-channel HTS MEG System

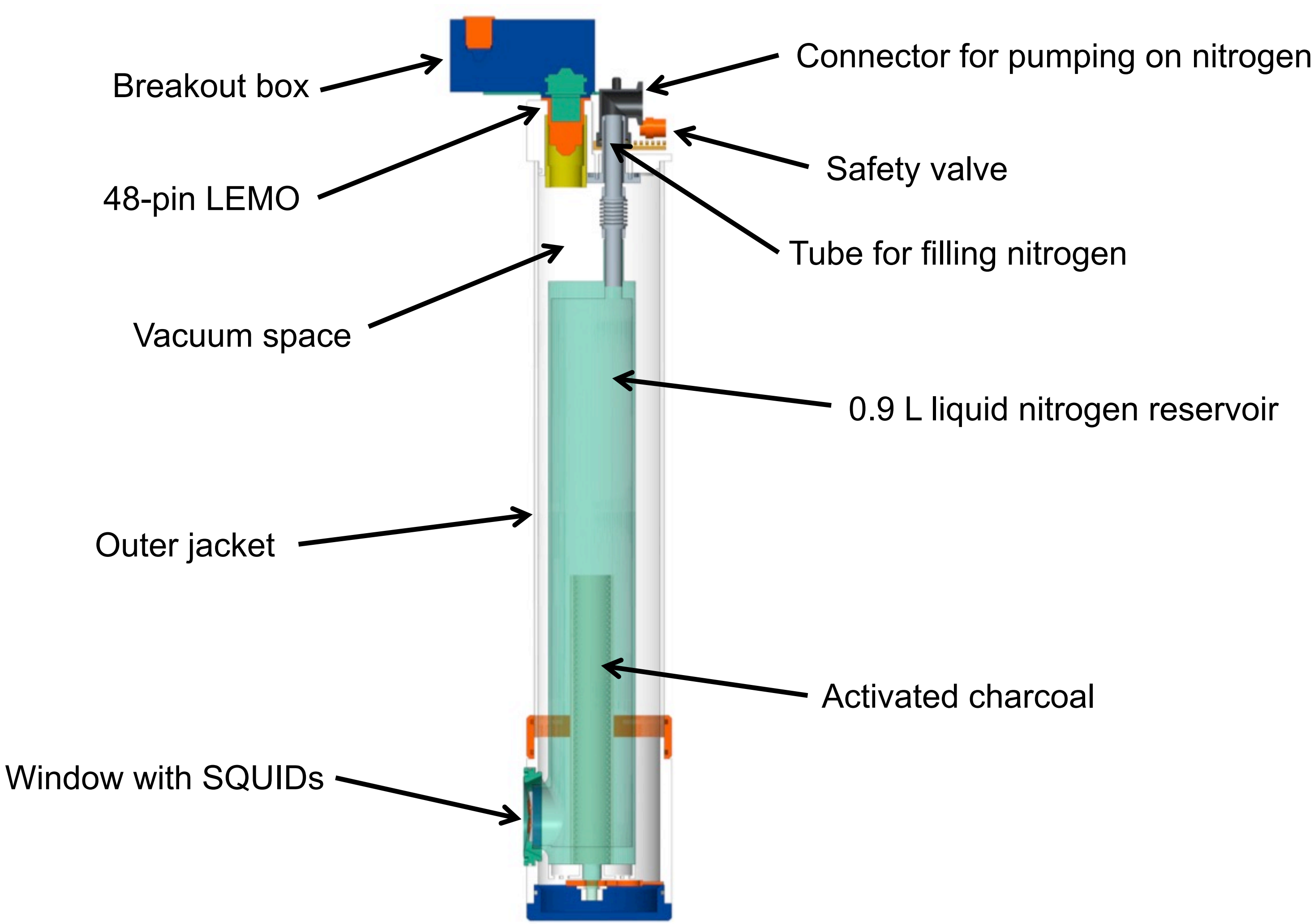


2. 7-channel HTS MEG System

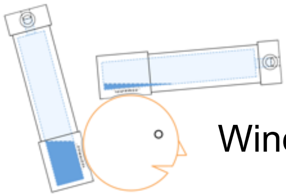


- First step towards full-head system
- Features:
  - Minimal sensor-to-room temperature distance (< 3 mm)
  - 7-channel high-T_c SQUID array
  - “Head- aligned”
  - Dense spatial sampling
  - Low noise

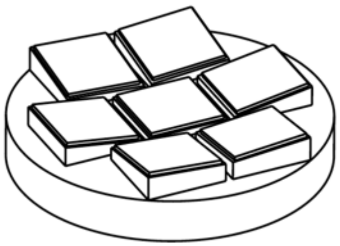
2.1. Cryostat


Breakout box
48-pin LEMO
Vacuum space
Outer jacket
Window with SQUIDs
Connector for pumping on nitrogen
Safety valve
Tube for filling nitrogen
0.9 L liquid nitrogen reservoir
Activated charcoal

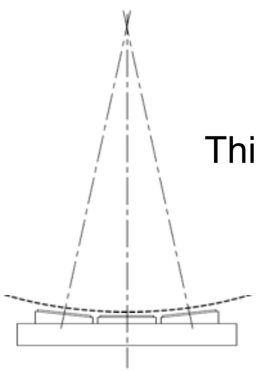
2.1. Cryostat



Window in liquid nitrogen reservoir

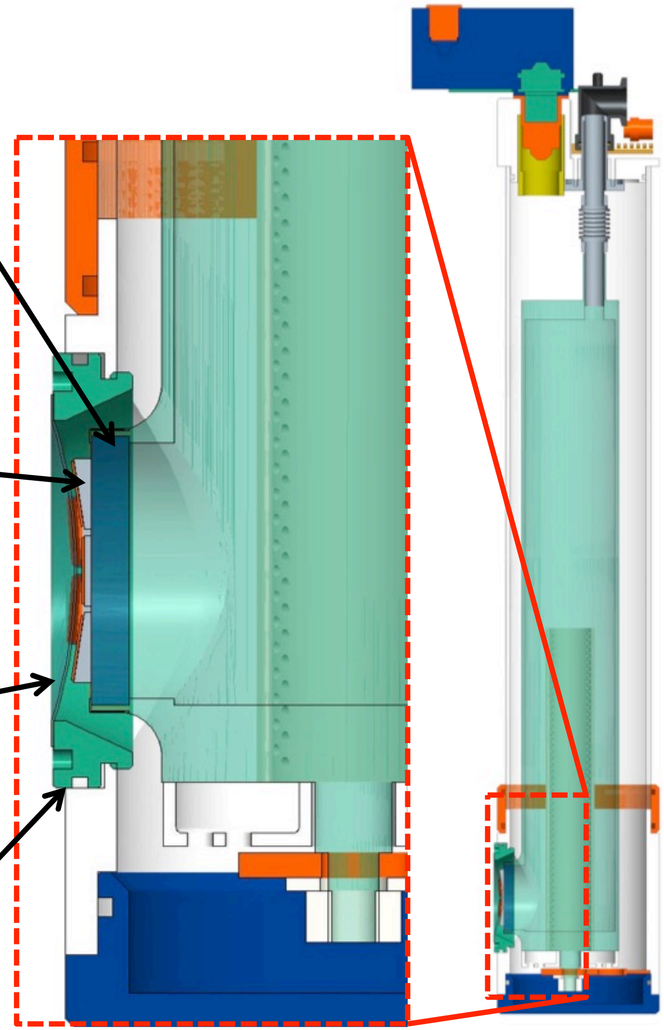


Wedges holding SQUIDs
(2 mm edge-to-edge)



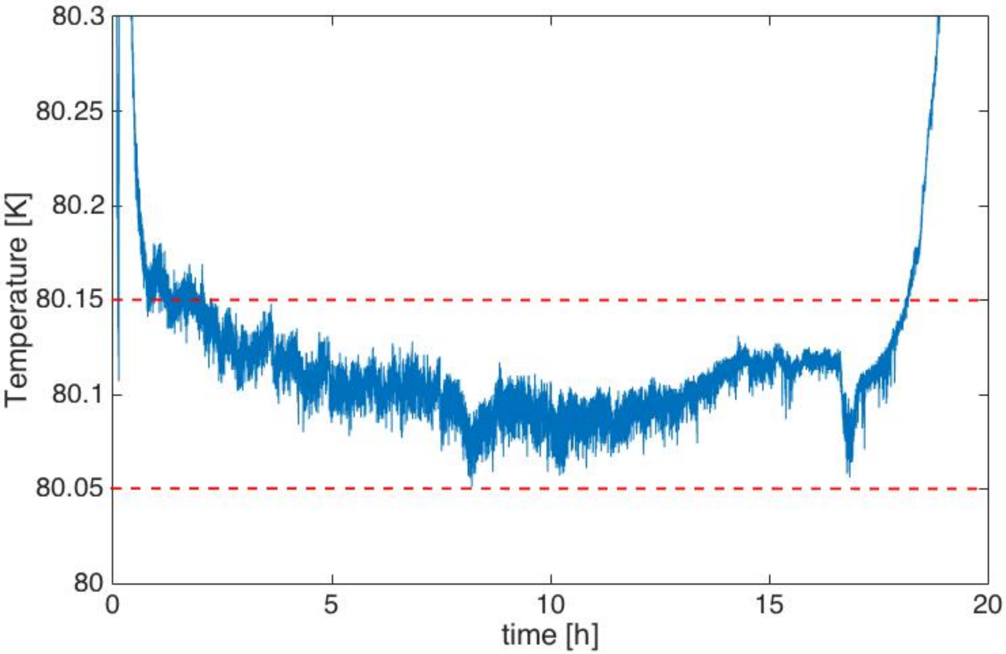
Thin (0.4 mm), concave window

Screw-connection window holder



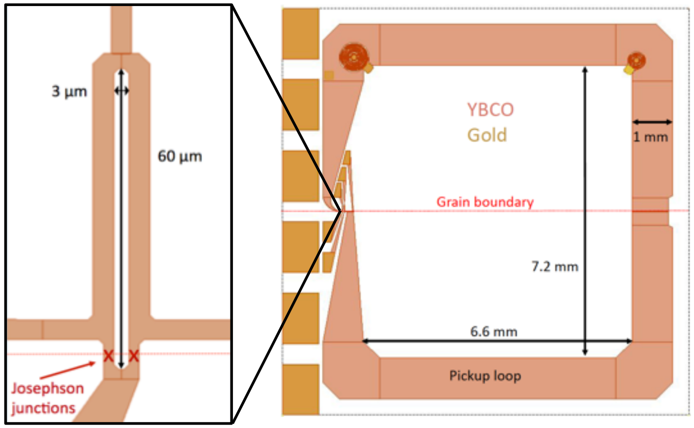
2.1. Cryostat

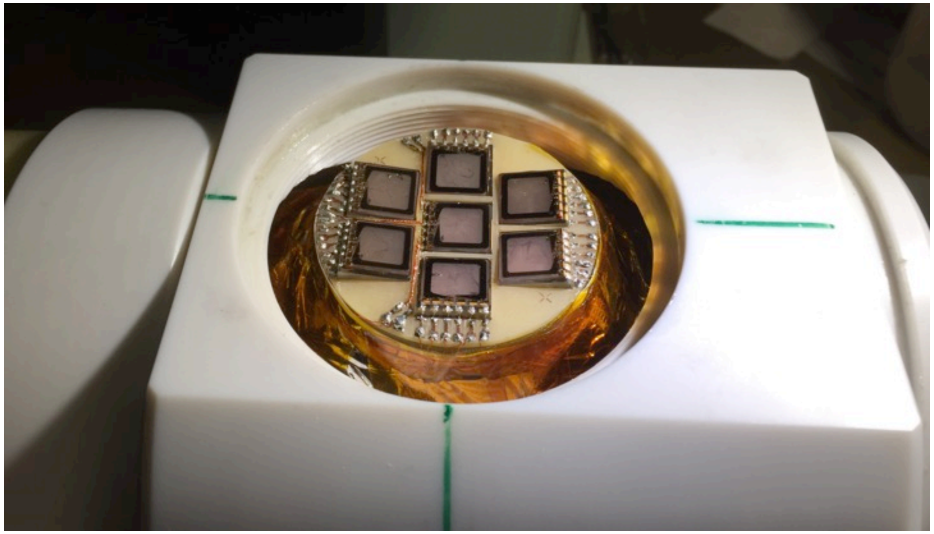
- Hold time (T < 81 K)
  - t_{hold} > 19 h
- Temperature stability
  - ΔT < 100 mK (for >16 h)
- Base temperature
  - T_{base} = 80.1 K
  - With pumping: $T_{base, pump}$ = 70.6 K



2.2. SQUID magnetometers

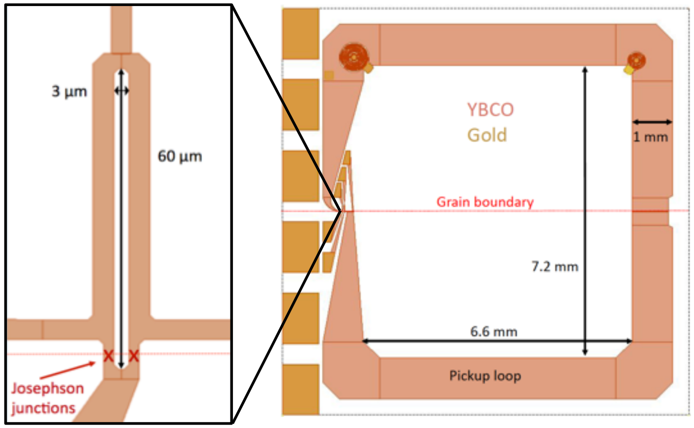
- $YBa_2Cu_3O_{7-x}$ on $SrTiO_3$ (10 mm x 10 mm)
- Bicrystal grain boundary junctions
- Directly coupled
- Direct injection feedback



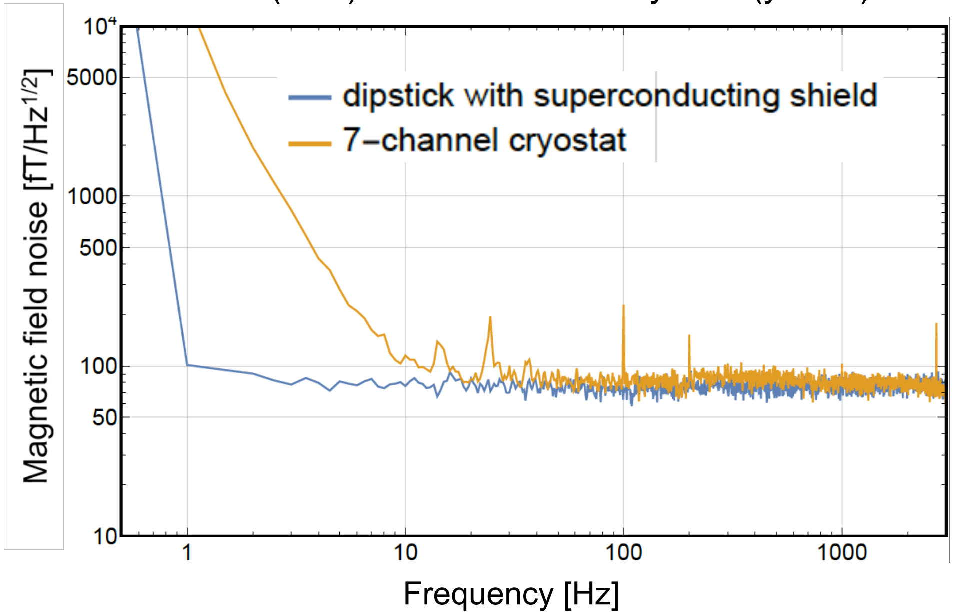


2.2. SQUID magnetometers

- $YBa_2Cu_3O_{7-x}$ on $SrTiO_3$ (10 mm x 10 mm)
- Bicrystal grain boundary junctions
- Directly coupled
- Direct injection feedback
- White noise level
  - Flux: $S_\Phi^{1/2} = 10\ \mu\Phi_0/Hz^{1/2}$
  - Field: $S_B^{1/2} = 80\ fT/Hz^{1/2}$



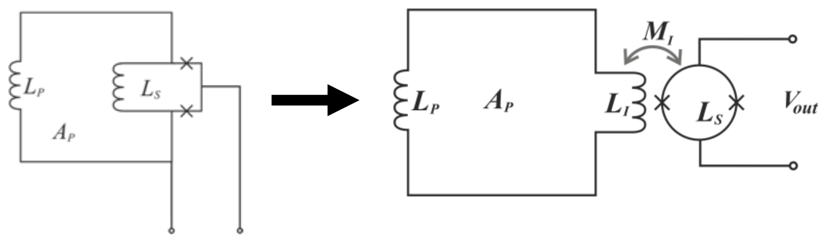
Magnetic field noise in dipstick with superconducting shield (blue) vs. in 7-channel cryostat (yellow)

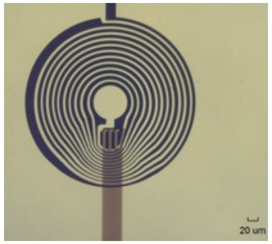


2.2. SQUID magnetometers

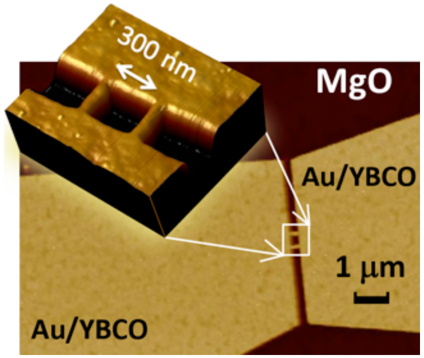
Sensor development

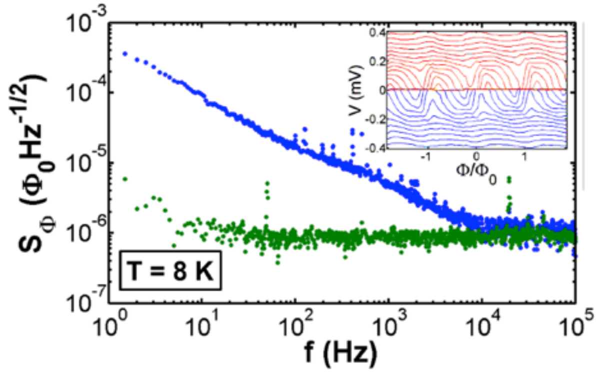
- Flux transformers





- NanoSQUIDs

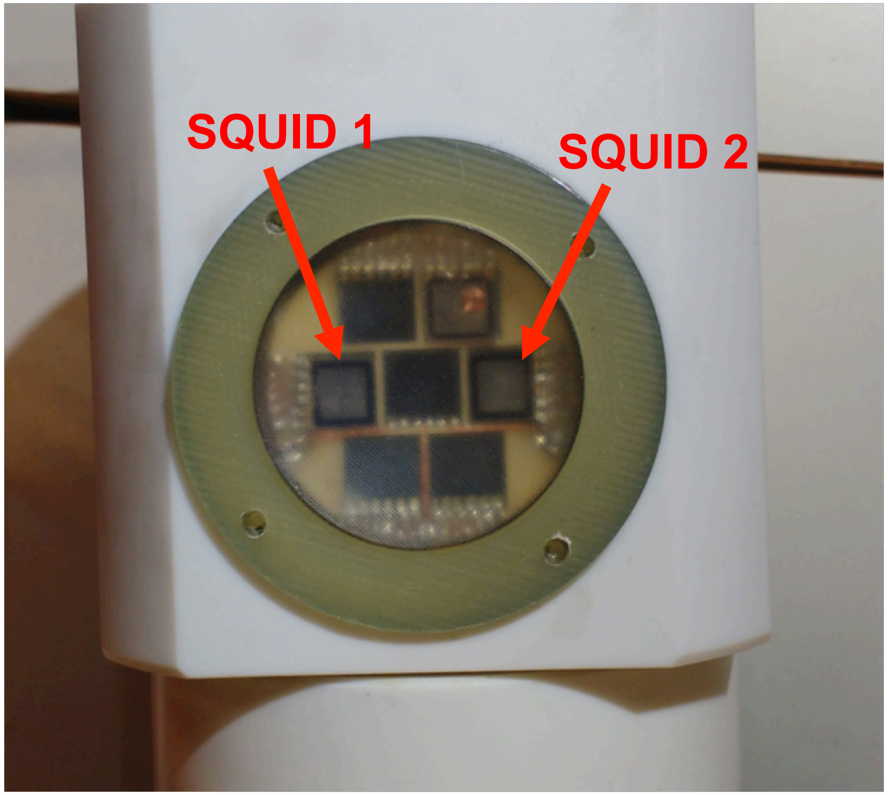




R. Arpaia et al., *Appl. Phys. Lett.* **104,** 7 (2014)

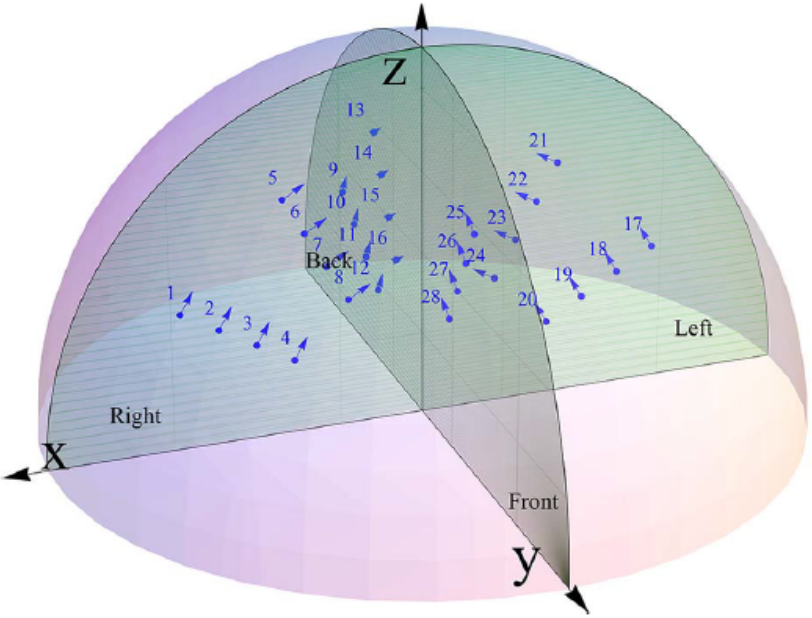
2.3. Measurement on head phantom

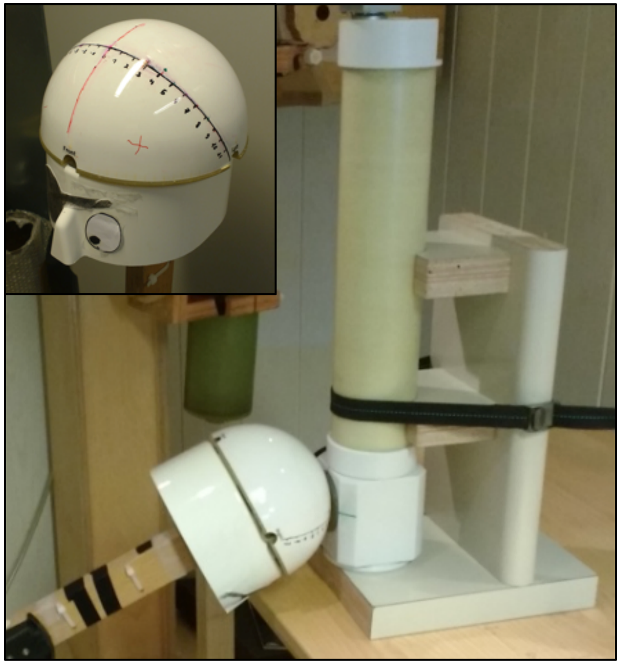
- Setup for first verification



2.3. Measurement on head phantom

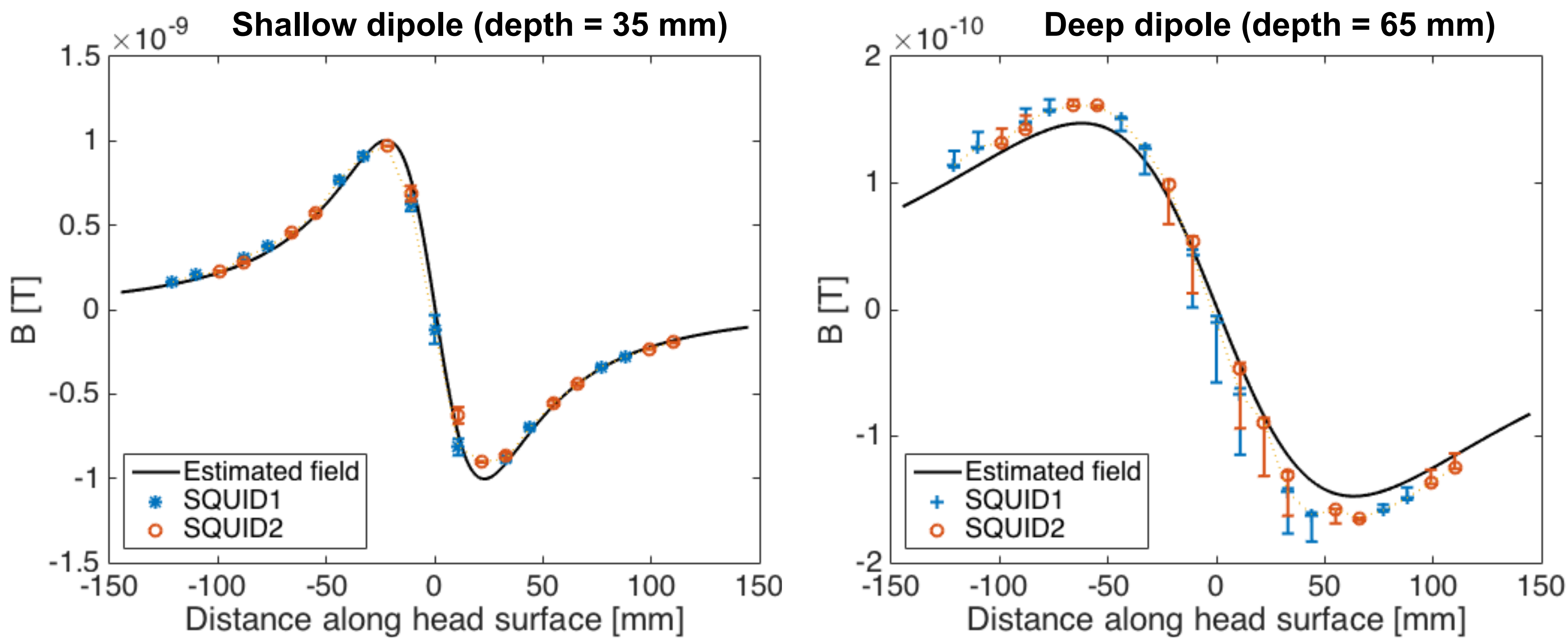
- Verification using head phantom with 28 dipoles
- Measurement of magnetic field distribution on head surface for dipoles at different depths





Location and orientation of dipoles in head phantom (courtesy of Elekta Neuromag®)

2.3. Measurement on head phantom



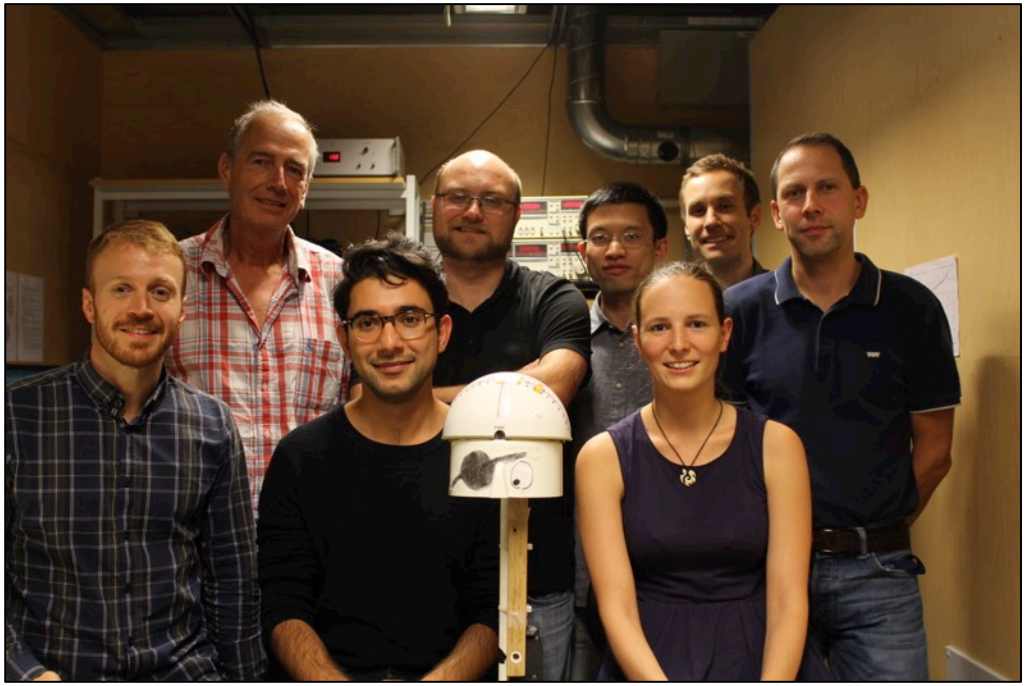
Comparison of measured and estimated magnetic field for dipole 25 and 28

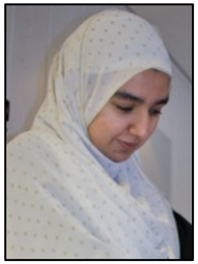
3. Conclusion and outlook

- 7-channel HTS MEG system with sensor-to-head distance ≈ 1 mm, long hold time (19 h) and tightly packed, head-aligned sensor array
- First verification measurement with head phantom: measurements in good agreement with simulations

- Outlook:
  - Phantom measurement with all sensors
  - Benchmarking with low-T_c SQUID MEG (in collaboration with NatMEG center at Karolinska Institute (KI), Stockholm, Sweden)
  - MEG measurements (in collaboration with NatMEG center and neurophysiologists at the University of Gothenburg and KI)
  - Next generation multichannel HTS system

Thanks





CHALMERS

Knut och Alice Wallenbergs Stiftelse

GÖTEBORGS UNIVERSITET

MedTech West

NatMEG

Karolinska Institutet

2.2. SQUID magnetometers

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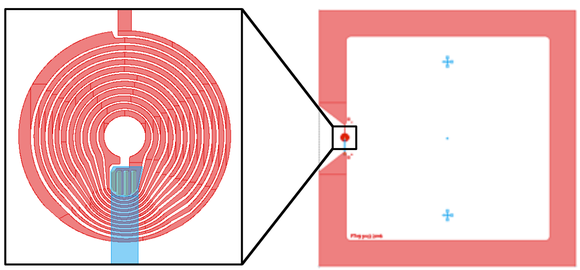
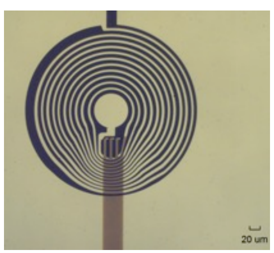
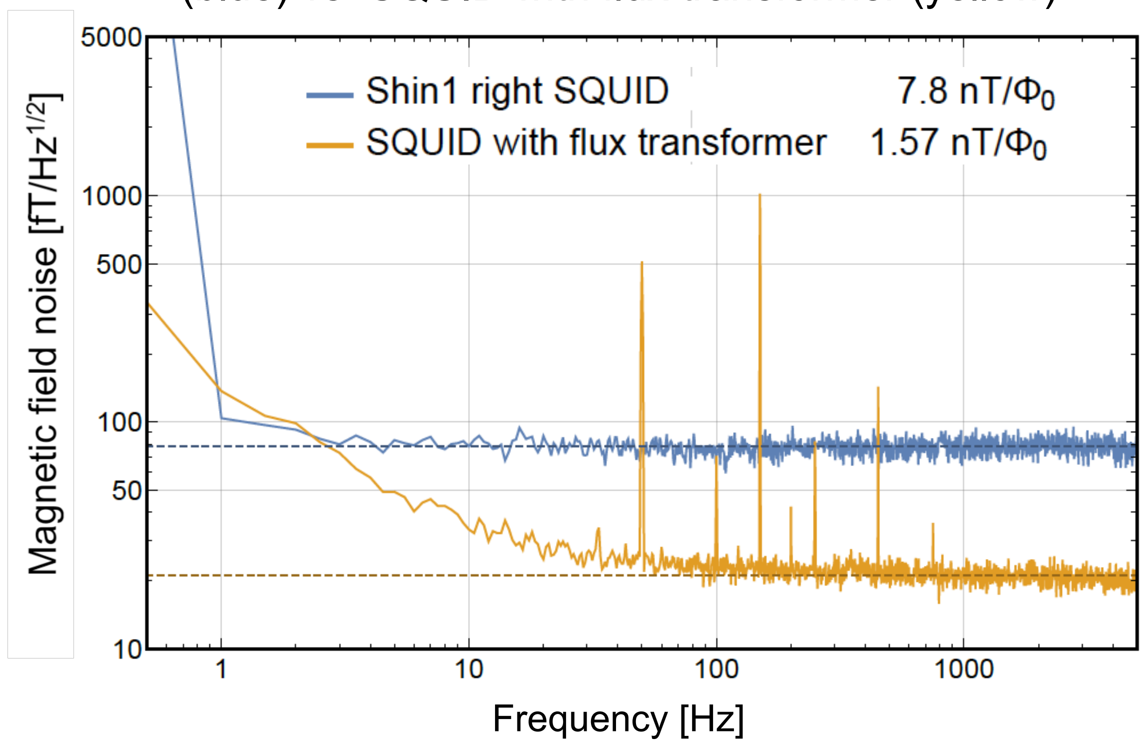
- Flux transformers





Magnetic field noise with previously described SQUID (blue) vs. SQUID with flux transformer (yellow)



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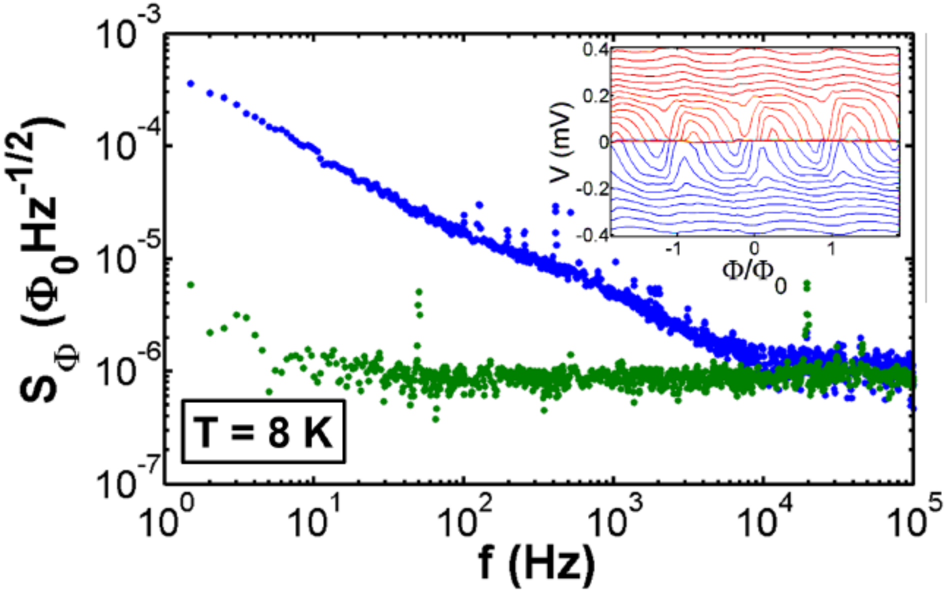

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