SQUIDs – From ideas to instruments

R. Stolz[1], and the teams of the

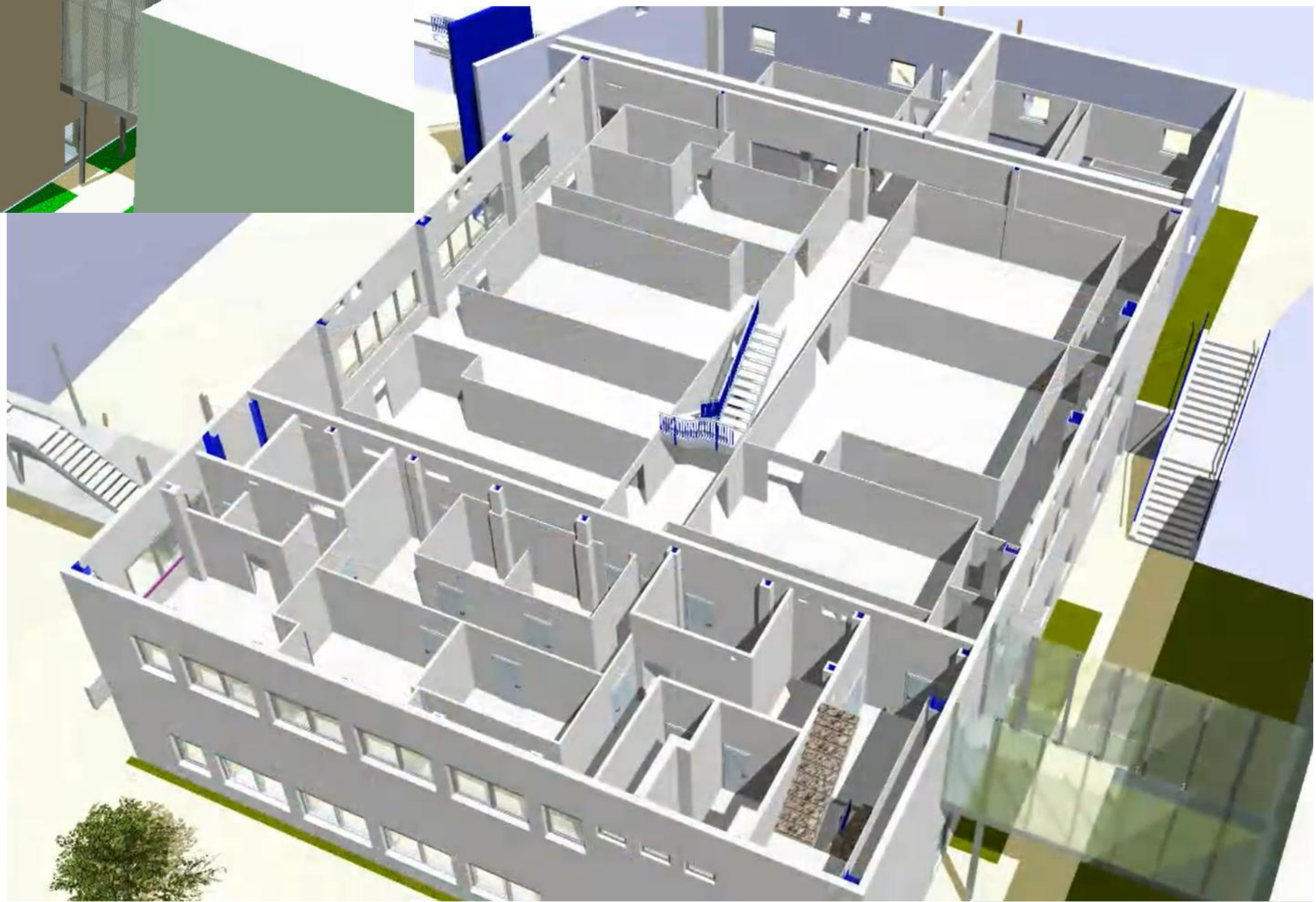
Leibniz Institute of Photonic Technology [1] and

Supracon AG , Jena (Germany)

Development of technologies

IPHT/IAP clean room

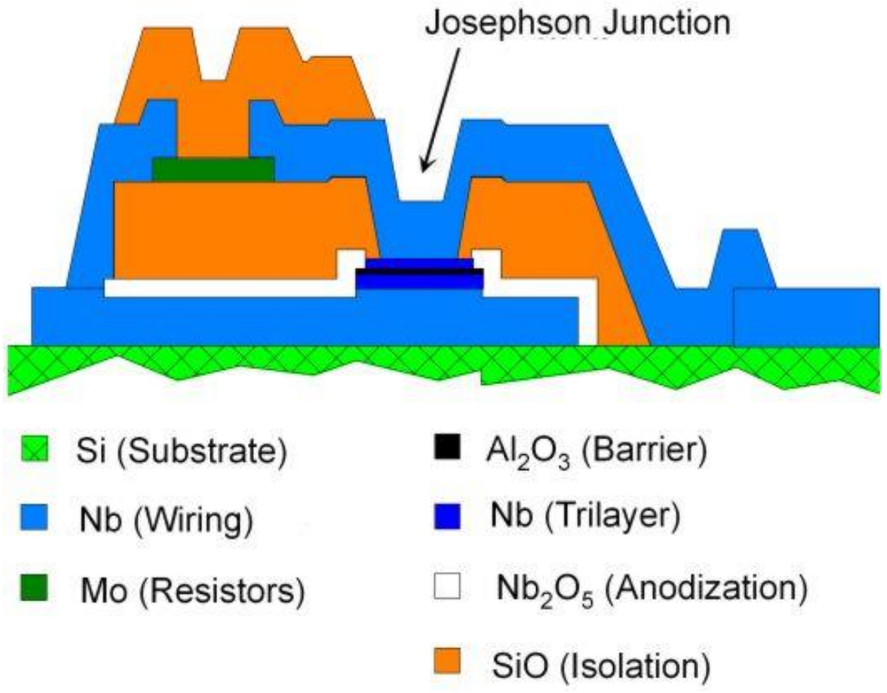
ISO class 4 clean room on 2 floors



Start in technology development in 1994,

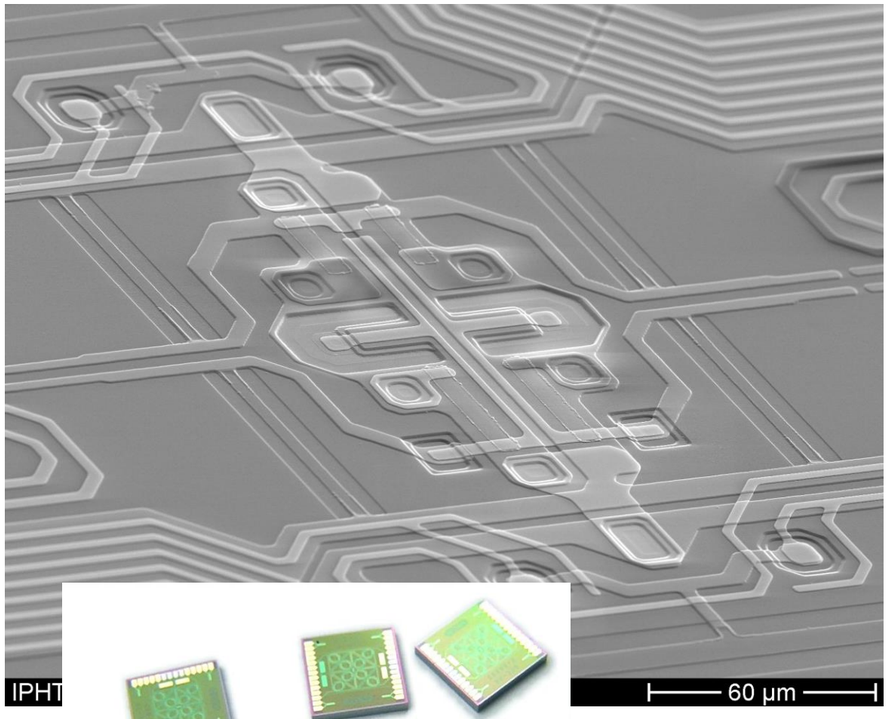
Various clean room technol. available:
Window type LTS JJ
Cross-type LTS JJ
HTS,
RSFQ,
Mixed variants.

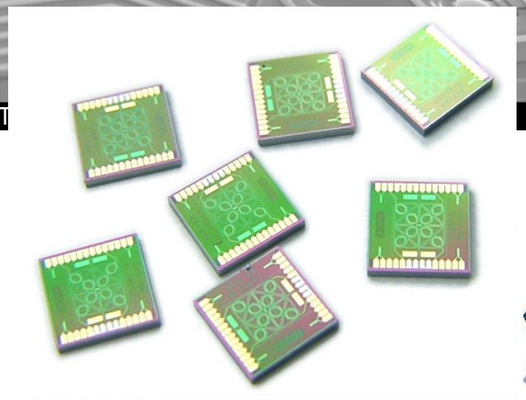
Standard „Window-type“ LTS SQUID technology

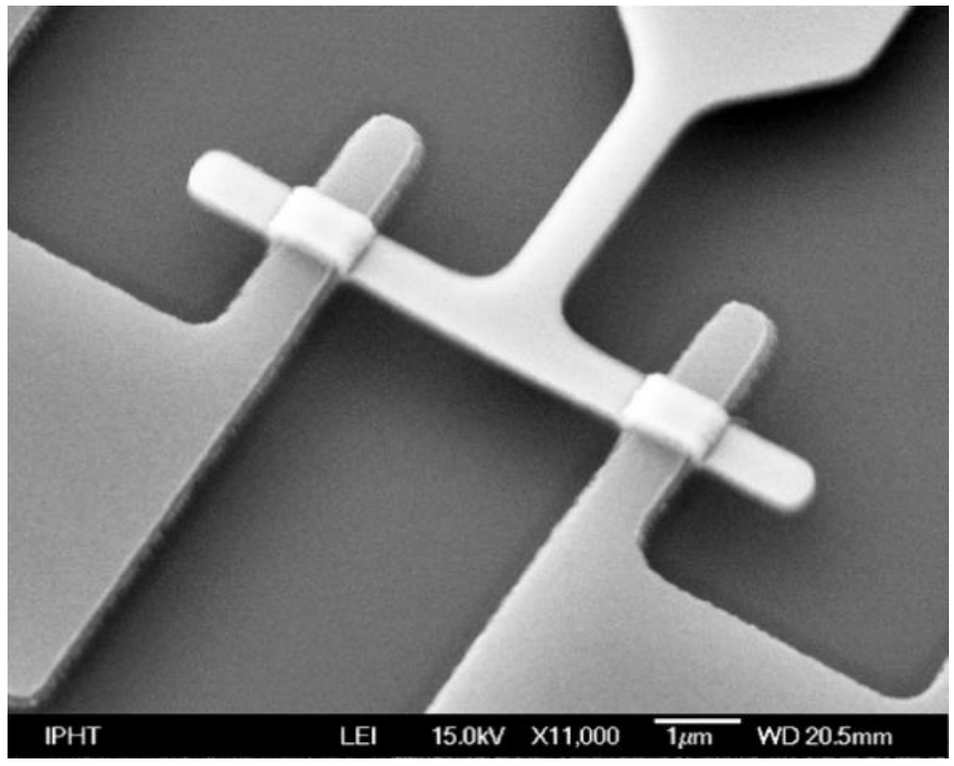


Window-type: up to 9 layers; 3 metal layers; 3µm JJ,

Cross-type: JJ size down to 0.25µm, high voltage swings >100µV, low intrinsic noise, high magnetic field operation, lower flux trapping probability.

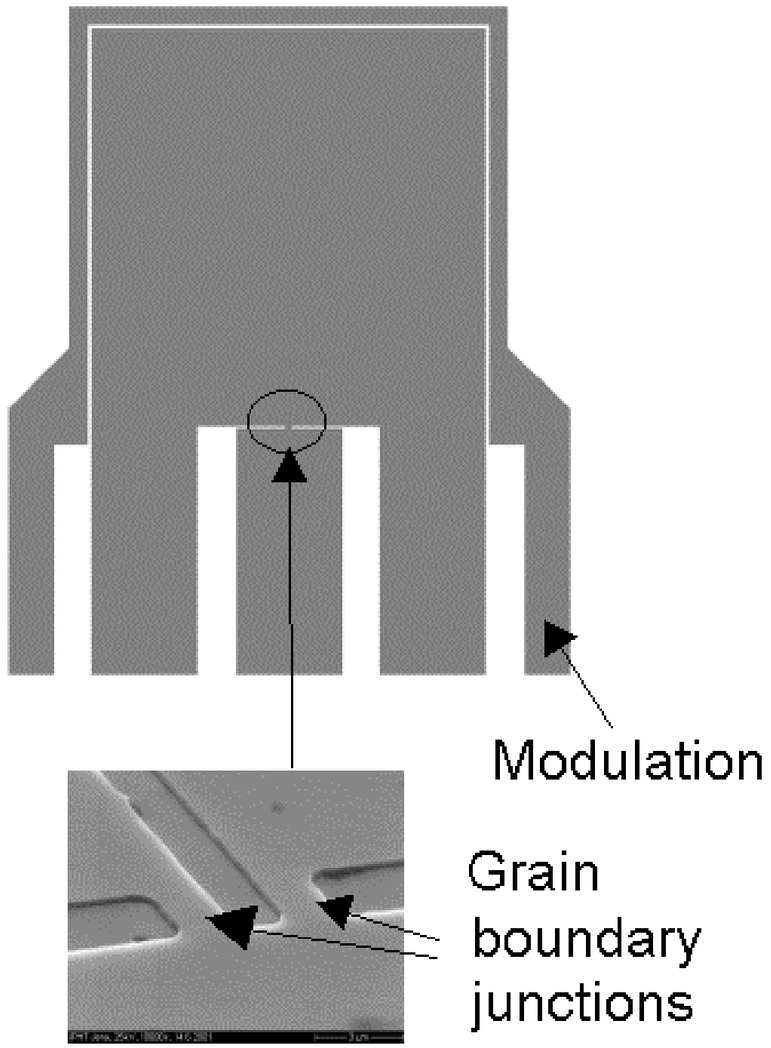


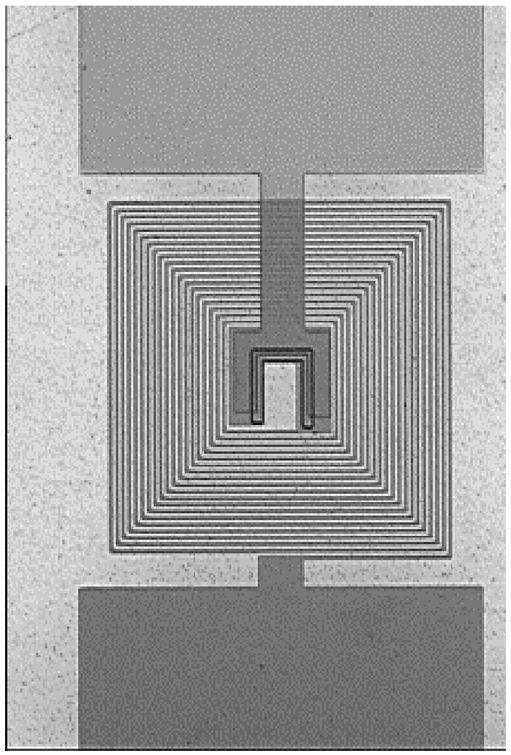




supracon®
SQUID and Microfabrication Technologies

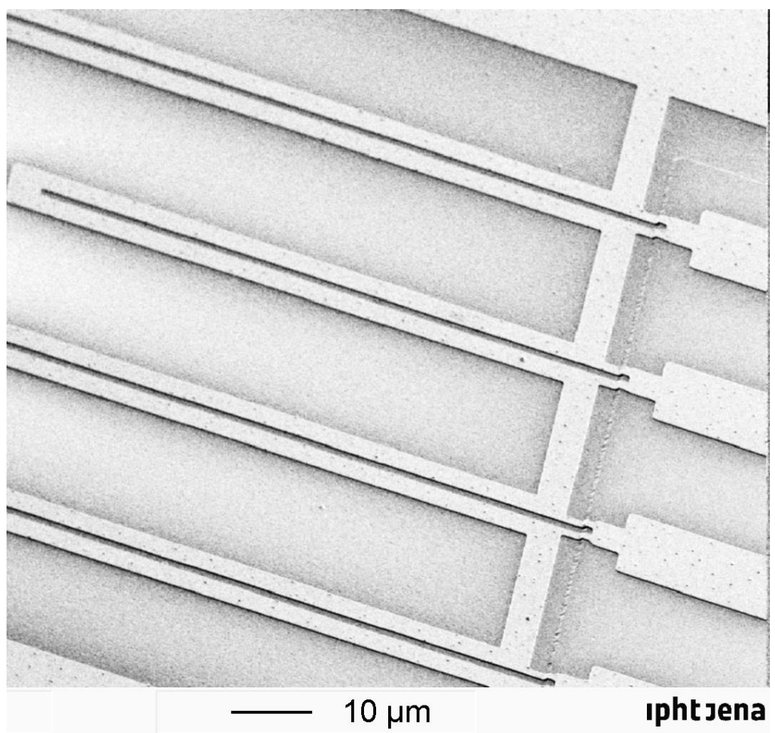
HTS SQUIDs





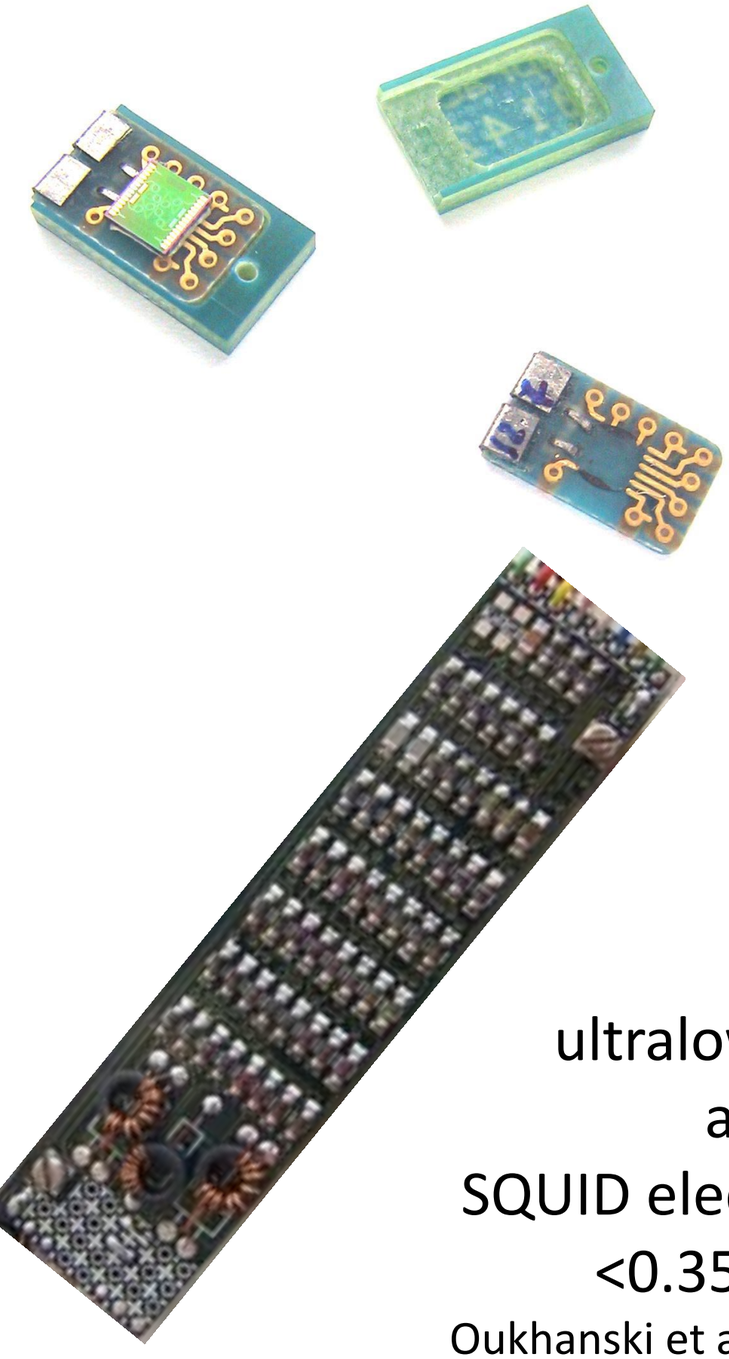
- bicrystalline JJ,
- 1 up to 3 layers,
- typ. in liquid nitrogen 77K,
- until today: challenging process,
  → no wafer-scale process,
  → no multilayer process,
  → no reliable JJ technology.

- step-edge JJ,
- single layer,
- cover layers to improve reliability and life time,
- reduction in fabrication time,
  → urgent need for increased number of instruments.



Other technologies

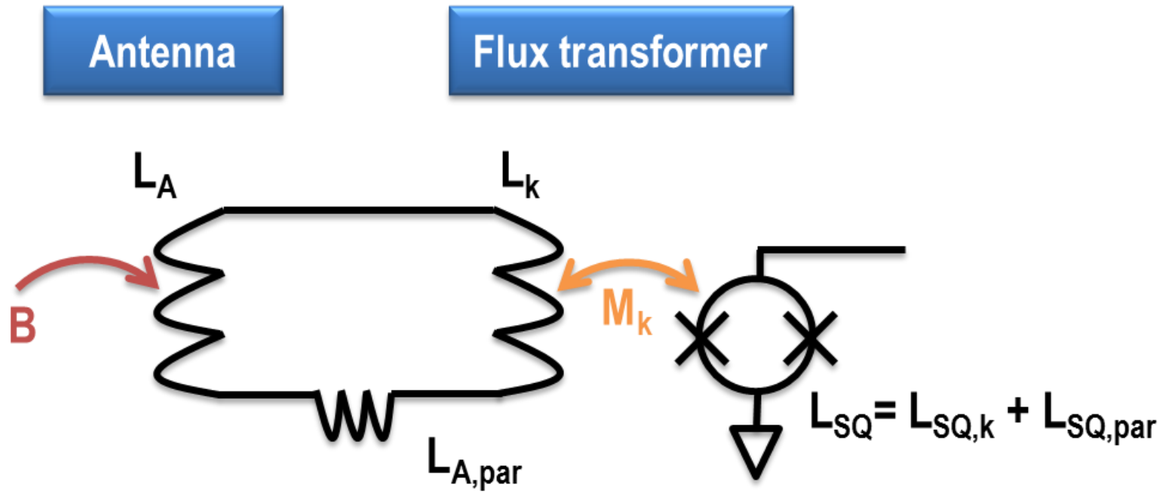
- MEMS type technologies,
- Assembling and interconnection techniques,
- Packaging technologies,
- Electronics development,
- Software development,
- Data processing tools,
- System integration technologies.



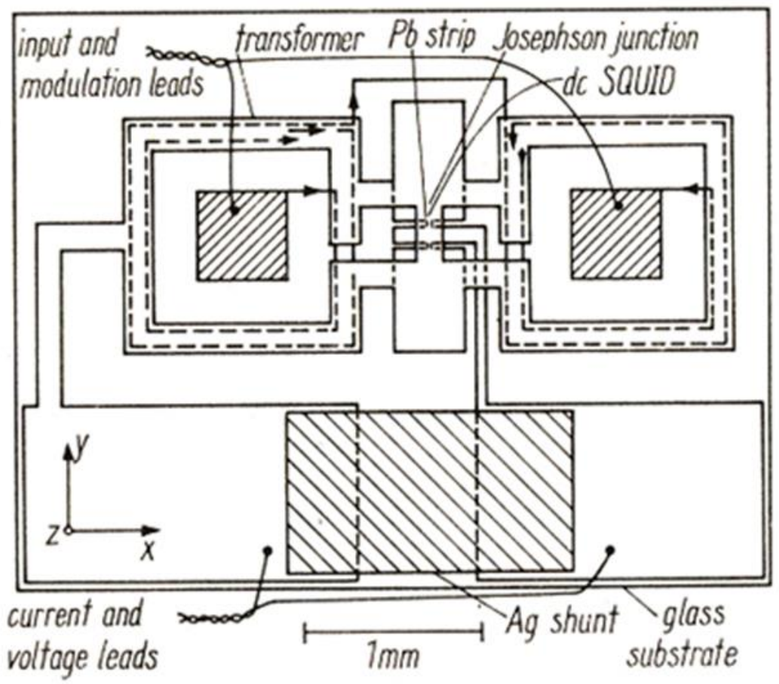
ultralow-noise
and drift
SQUID electronics
<0.35nV/√Hz
Oukhanski et al., APL 89, 2006

SQUIDs from Jena (Germany)

SQUID history in Jena



- first planar-type SQUID with flux transformer & pickup loop in Jena (Dettmann und Richter 1977)
  famous UJ111 in Nb/PbAuIn-technology

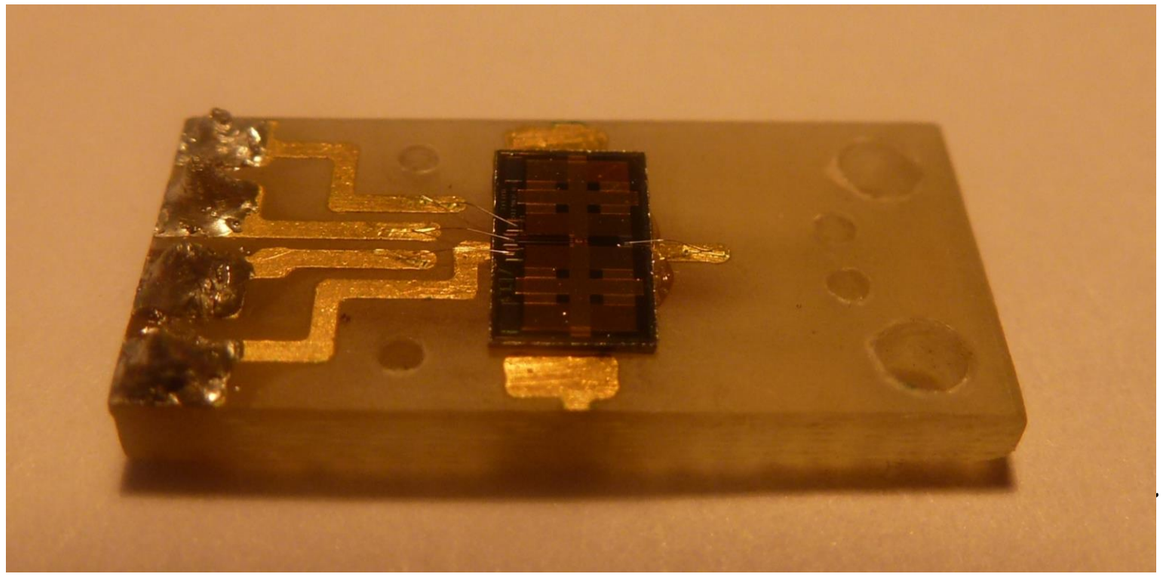


- Setup of Nb-technologies between 1994-1996 at IPHT Jena,

- first SQUID design and fabrication in 1995,

- first published results on LTS SQUIDs in 1999 in SUST (“LTS SQUID sensor with a new configuration”)

and now…

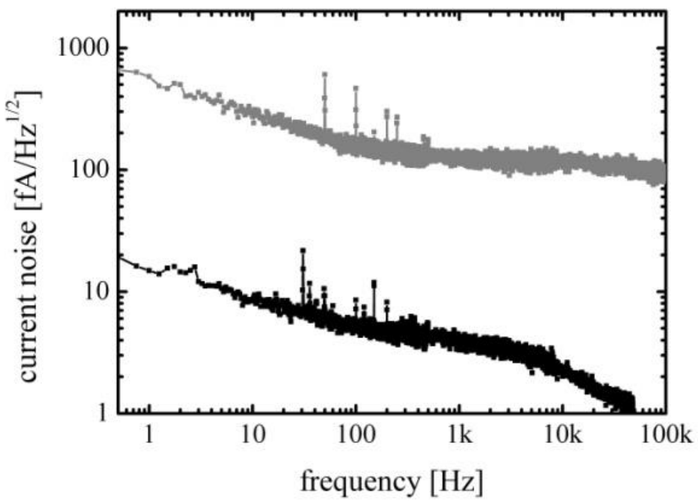


SQUID sensor applications

SQUID itself as gradiometer and coupling of signal via integrated thin-film input coil

Current sensors

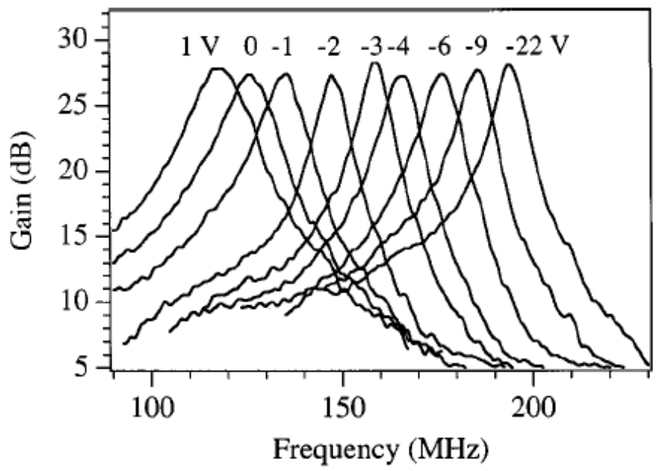
- detector readout (TES, MMC, gravi,...),
- measurement of beam profiles,
- $\sqrt{S_I}$ few $fA/\sqrt{Hz}$



V. Zakosarenko et al., SUST 25, 2012.

Single SQUID amplifiers

- rf-amplifiers - quantum limited sensitivity (100 MHz … 10 GHz),
- voltmeter,
- displacement sensors,…

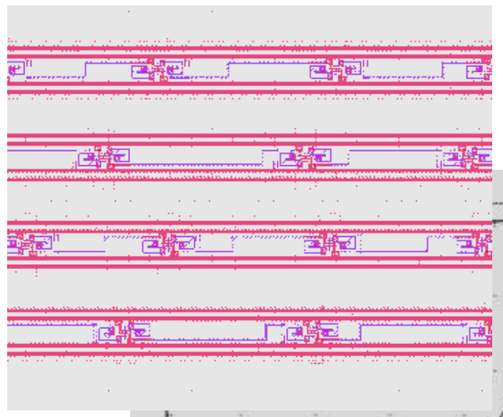


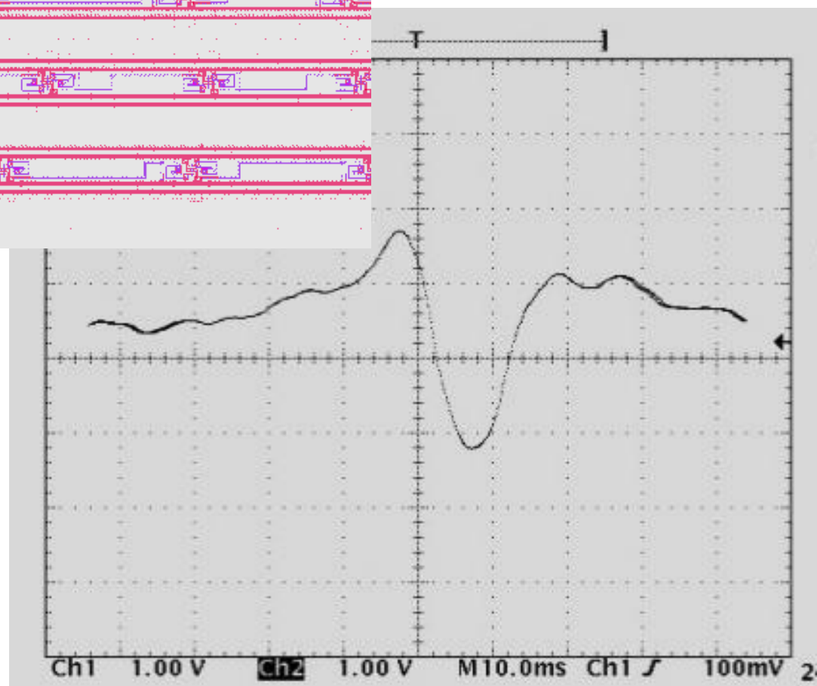
M. Mück et al., APL 75, 1999.

SQUID amplifiers

- SQUID arrays
- SQIFs as output stage

e.g. for multiplexers, …





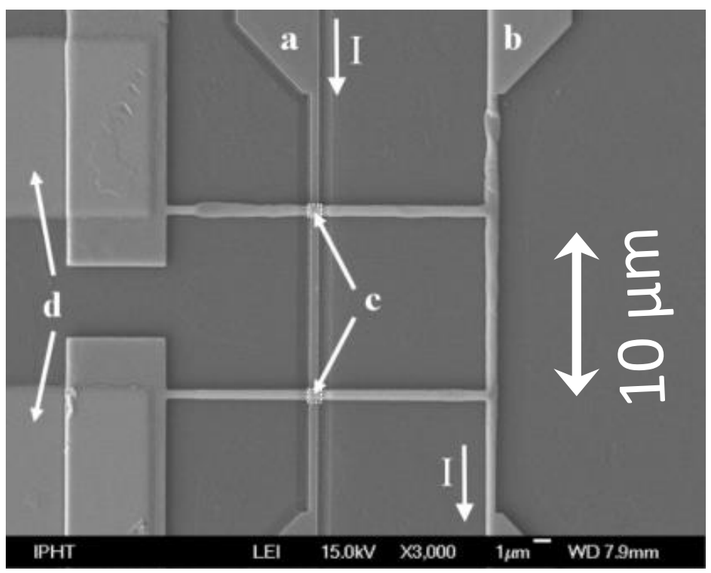
Magnetic field measurements using SQUIDs

spatial resolution ⟵ **optimization** ⟶ **field resolution**

$\approx 0.1\mu m$ | **typ. loop diameter** | **several mm…cm**

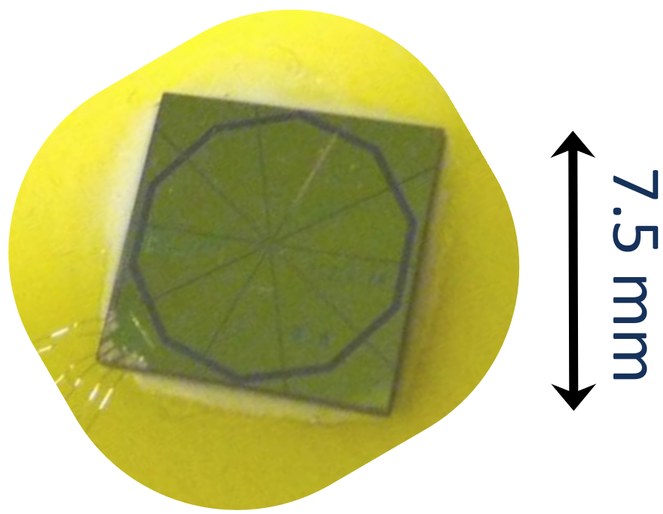
Nano-SQUIDs

- investigation of small spin systems,
- detection of single electron spin flips,



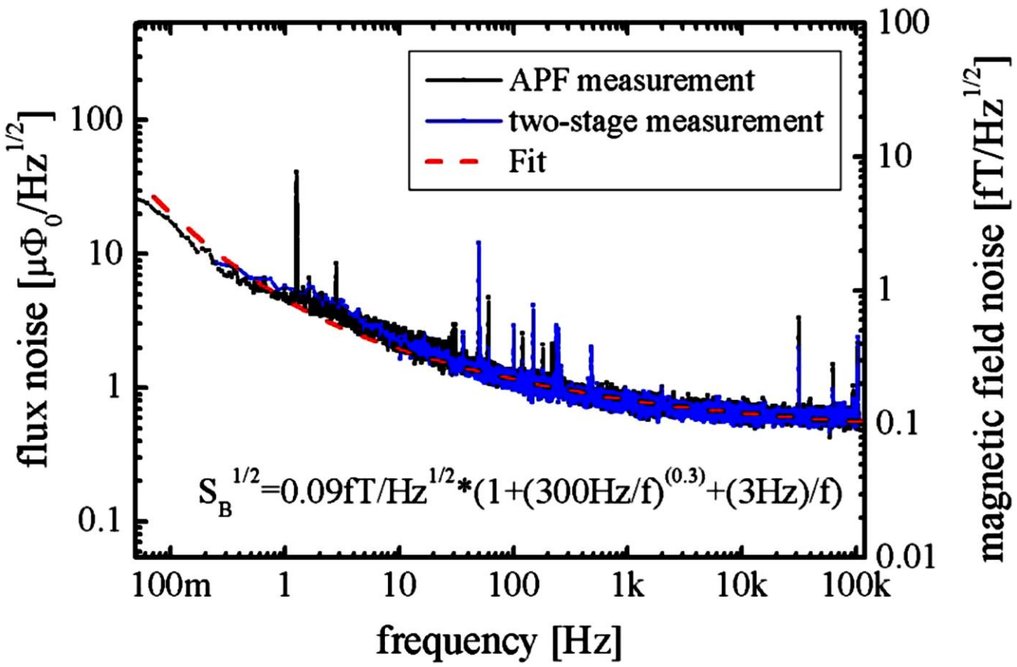
Magnetic properties

- biomagnetism,
- SQUID microscopy,
- susceptometry,
- …,



Magnetometry

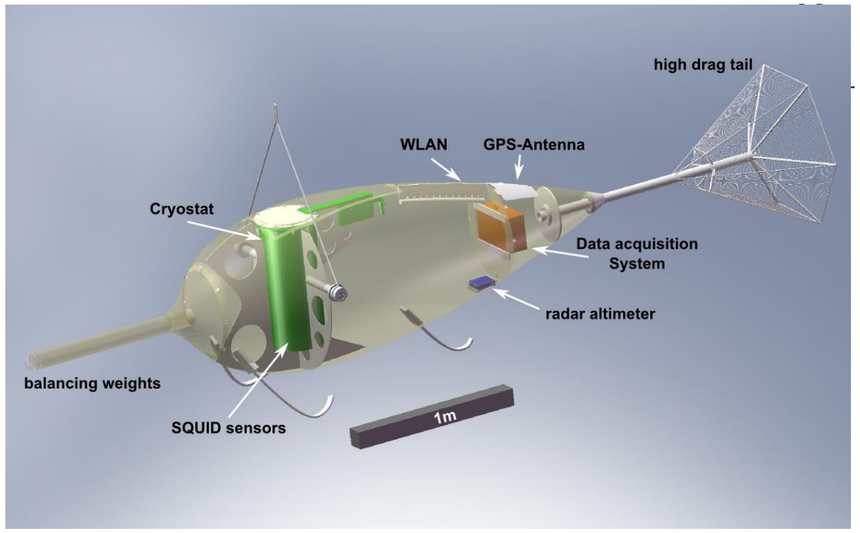
- geophysics,
- biomagnetism,
- $\sqrt{S_B} \approx 0.1 fT/\sqrt{Hz}$ or $\sqrt{S_G} \approx 15 fT/(m \cdot \sqrt{Hz})$.



Systems and Platforms

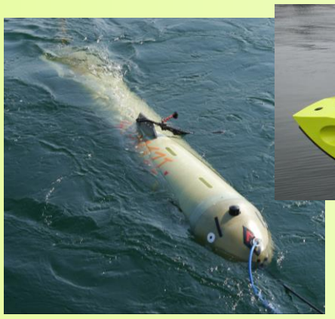
JeSSY STAR – FTMG instrument and platforms

Airborne



Ground based

Marine



Sub-marine

Under ground

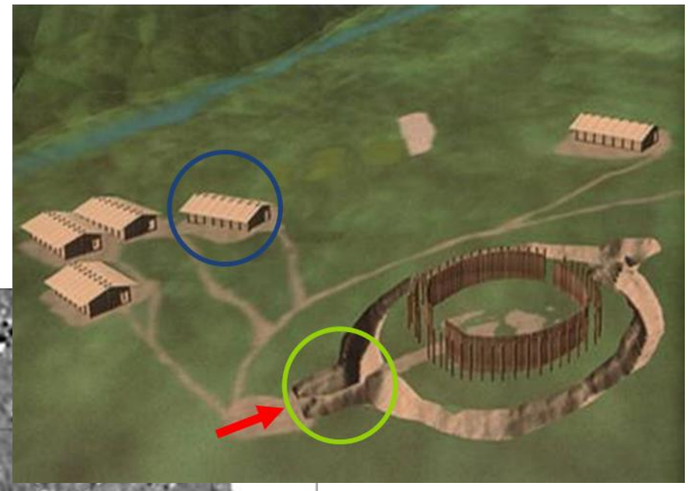
Down hole

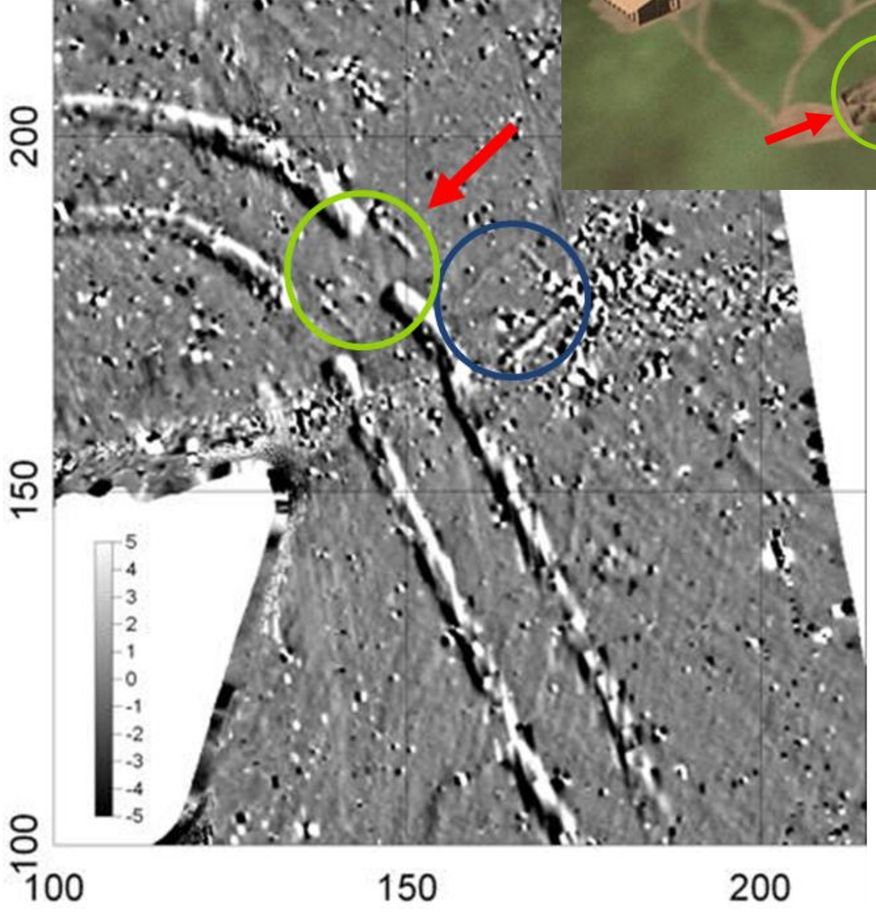
Status full tensor gradiometry

FTMG instruments already accepted by industry; successful case studies.

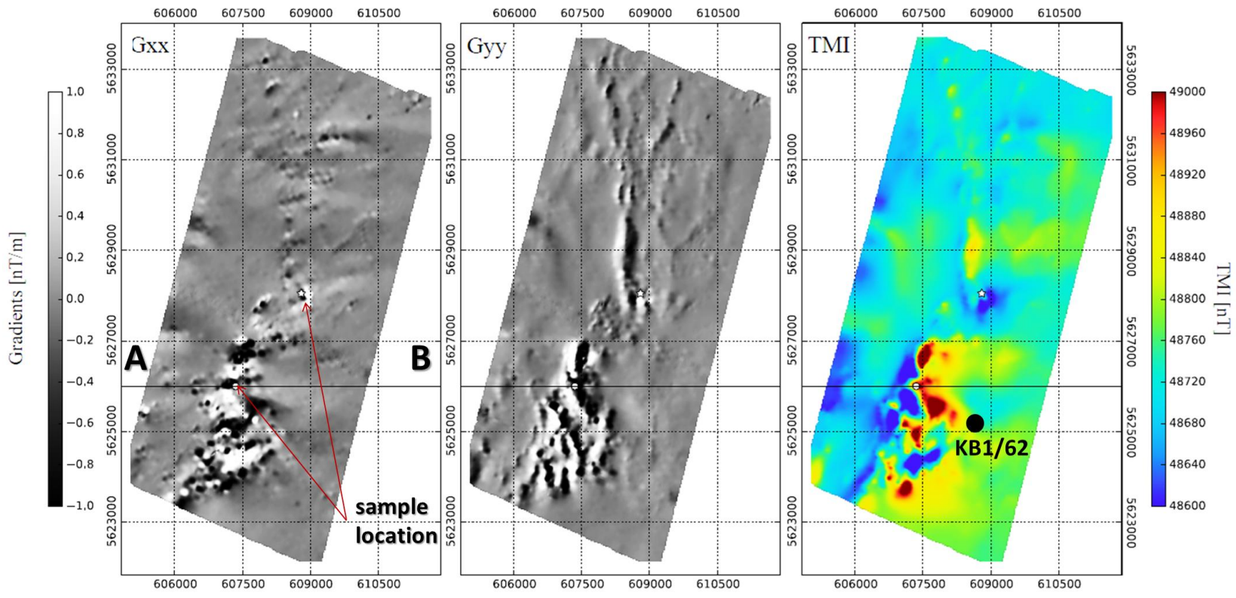
[A. Rompel SAGA 2009, A. Vorster SAGA 2013, R. Stolz SAGA 2015]

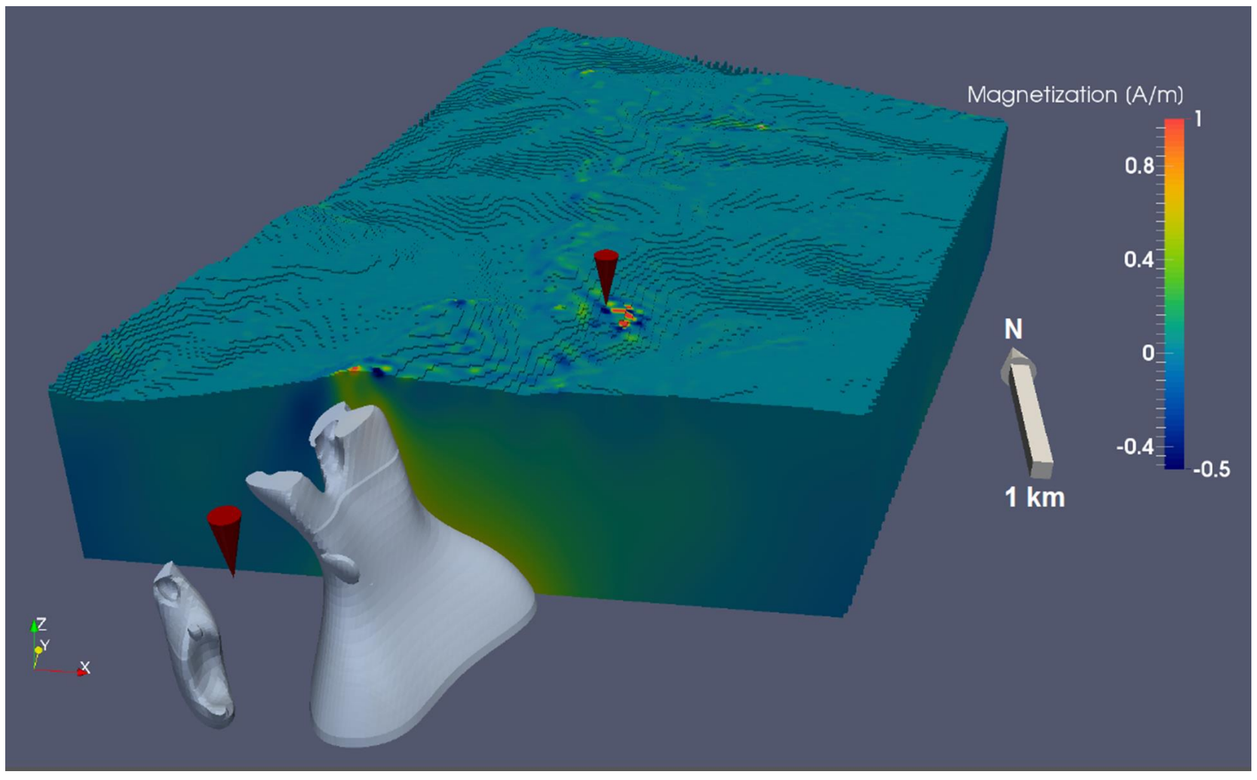
Archaeometry





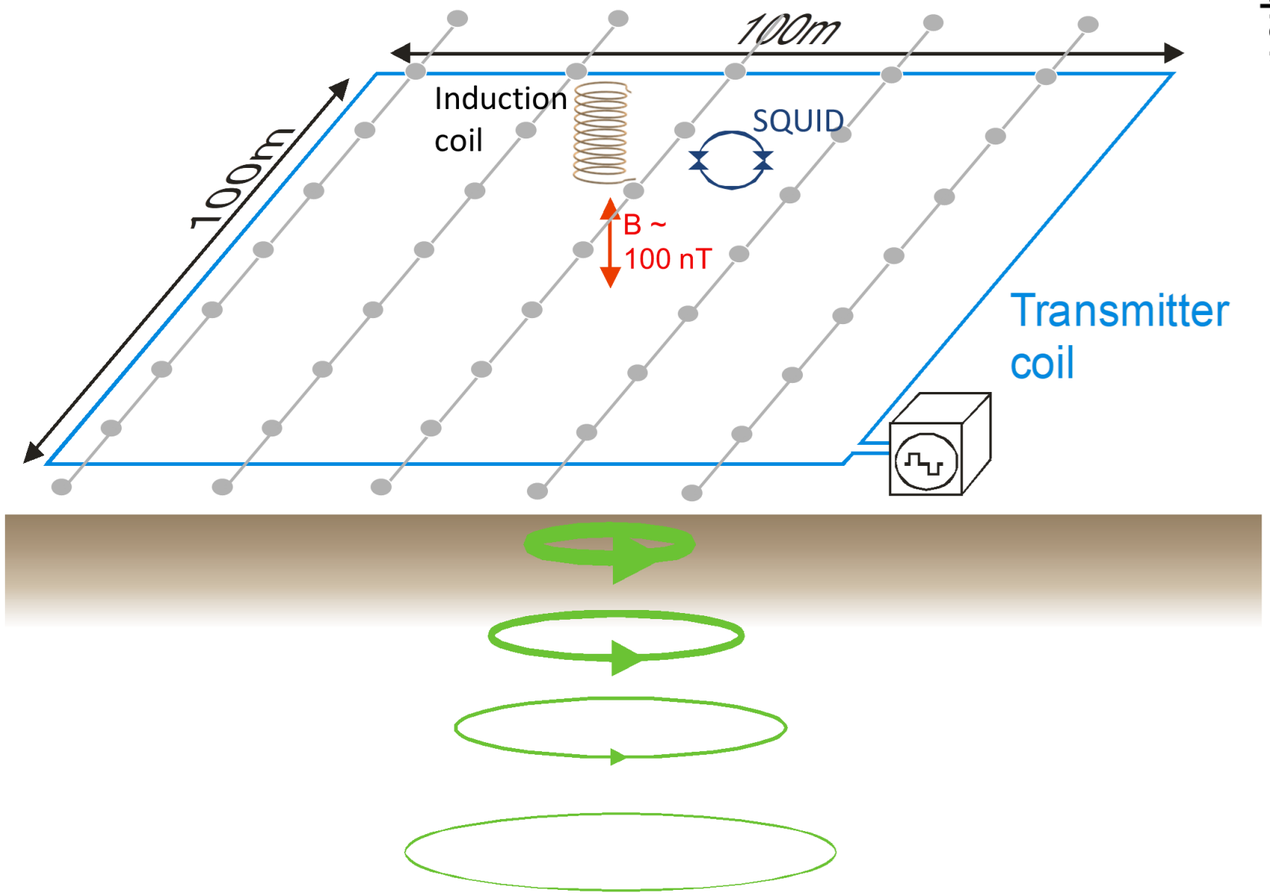
Mineral exploration





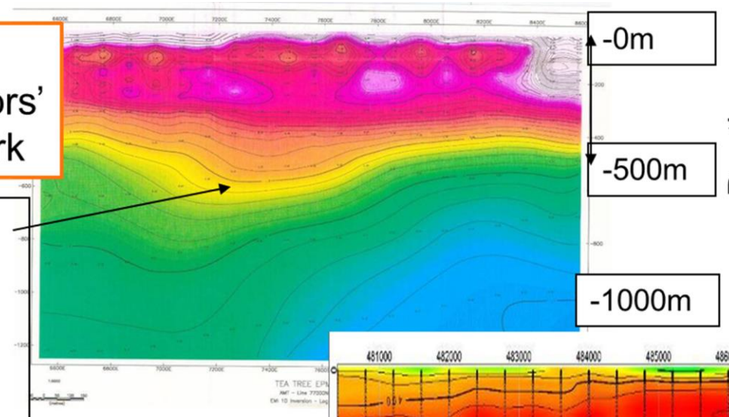
Transient electromagnetics (TEM) – JESSY DEEP

LeRoux et al., SAGA2009

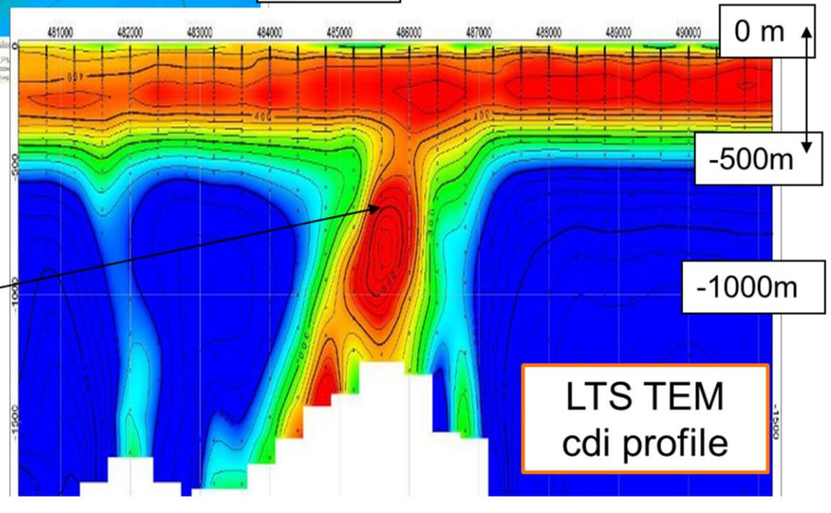


Earlier competitors' AMT work

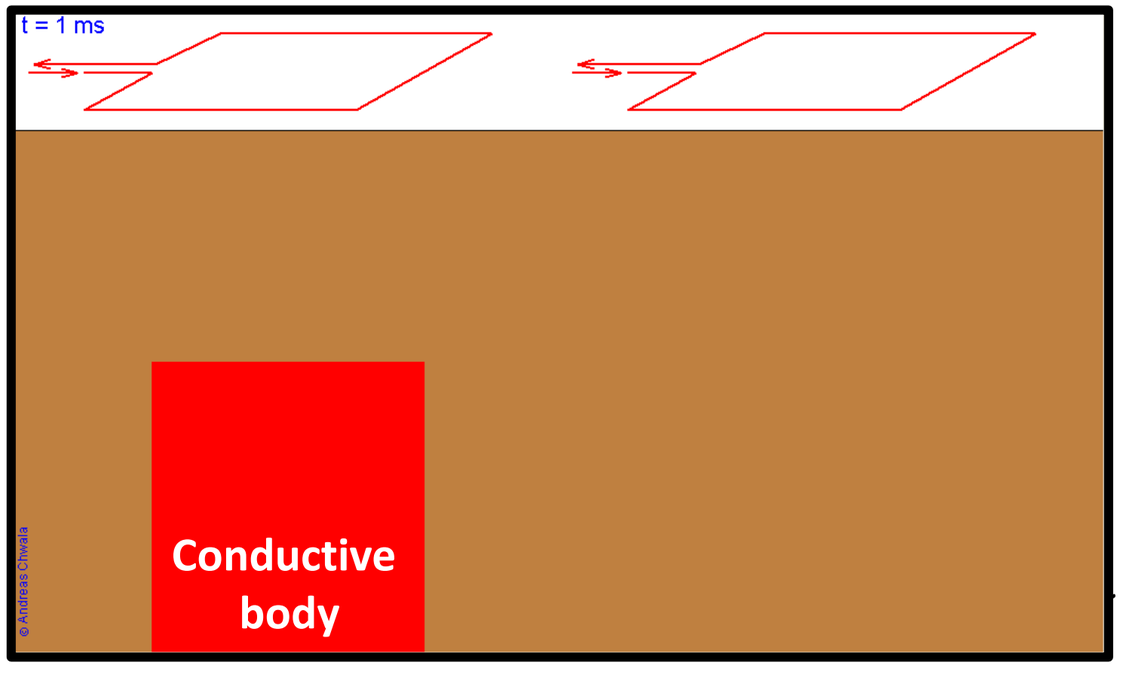
MT response thought to be due to a faulty remote reference station



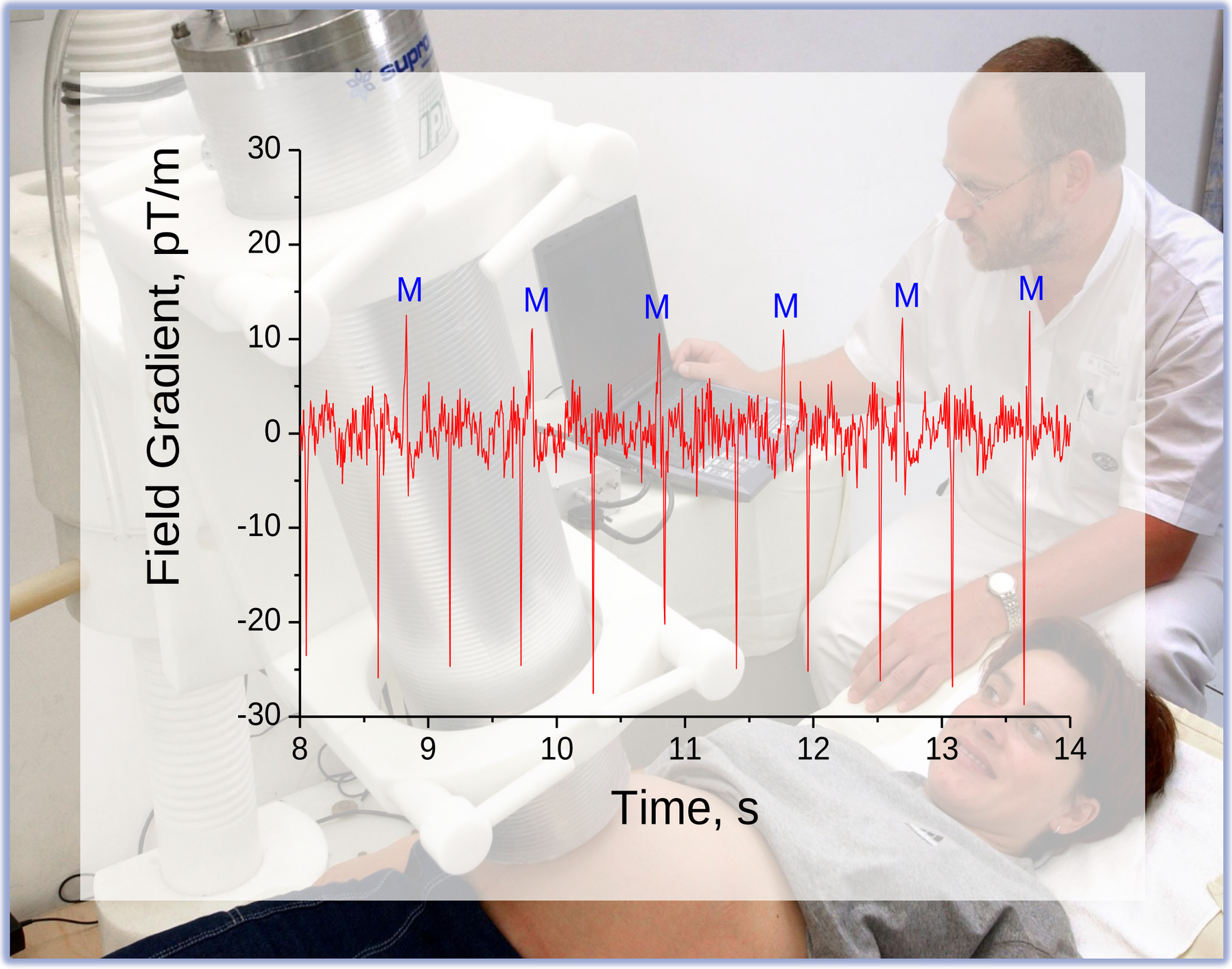
LTS TEM clearly detecting strong bedrock conductor



Data courtesy of Falcon Minerals and Anglo Exploration JV, Australia



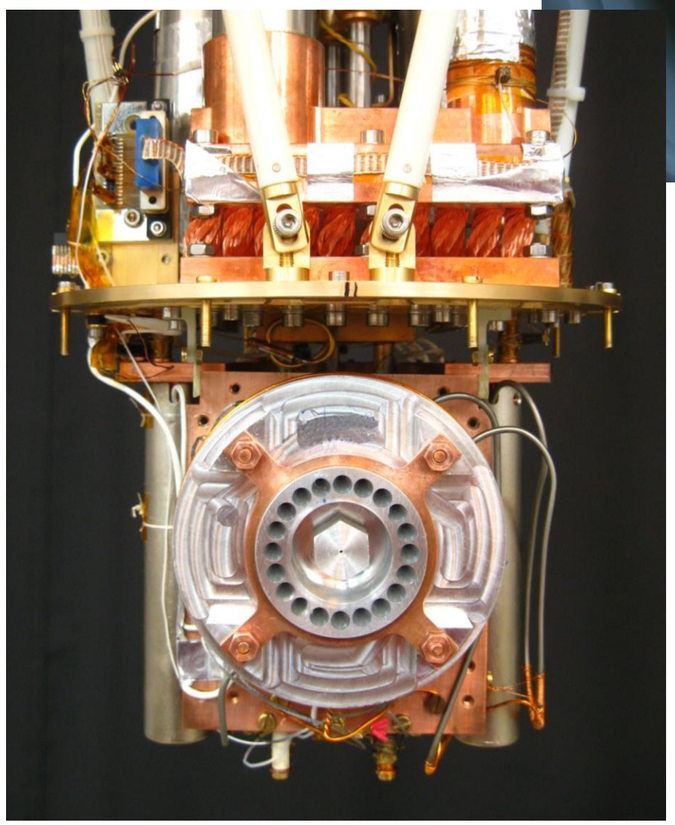
Biomagnetic instruments

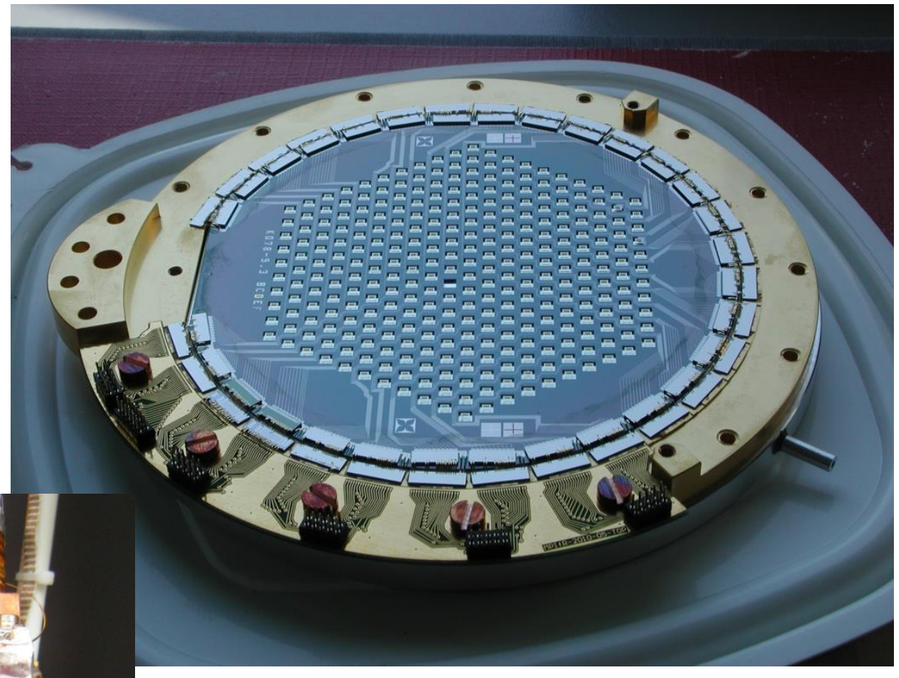


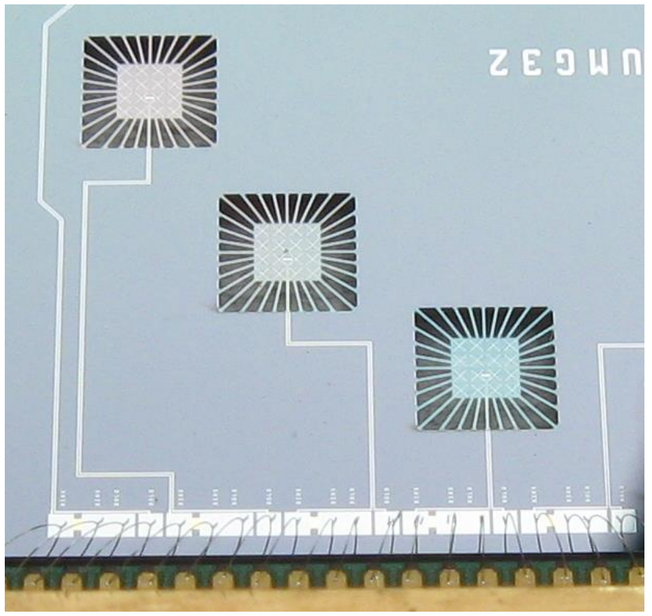
Real-time fetal MCG measured without magnetic shielding

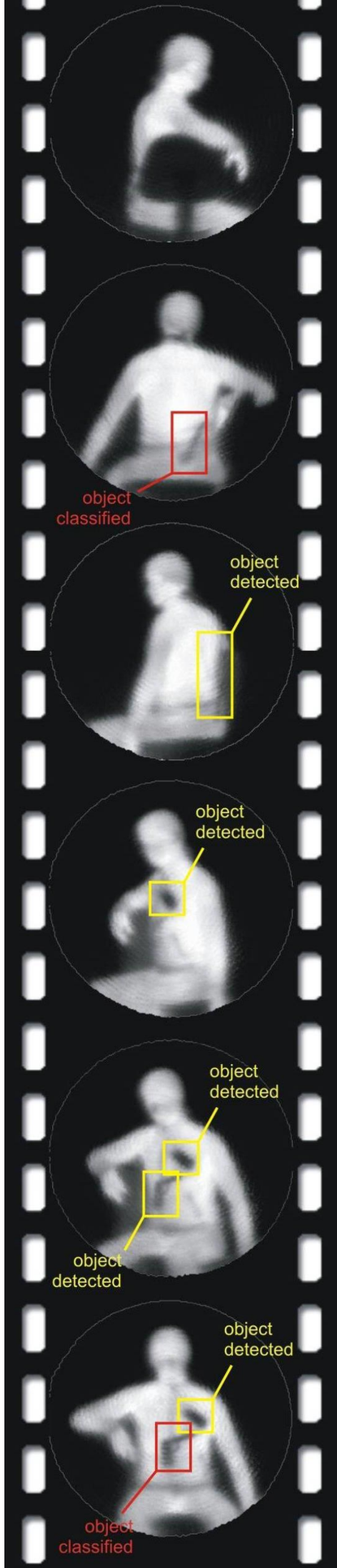
36th week of gestation. Fetal MCG with signal-to-noise ratio (SNR) of about 2.

THz-Safety and sub-mm astrophysical cameras





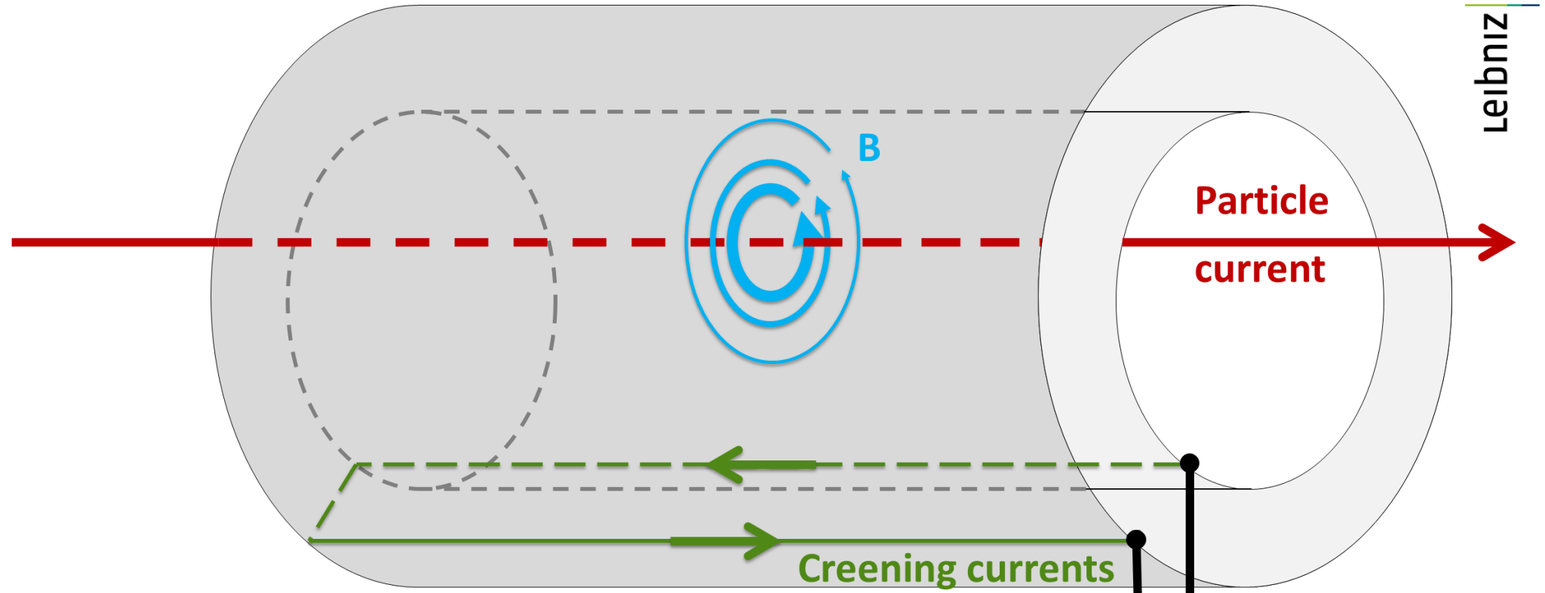


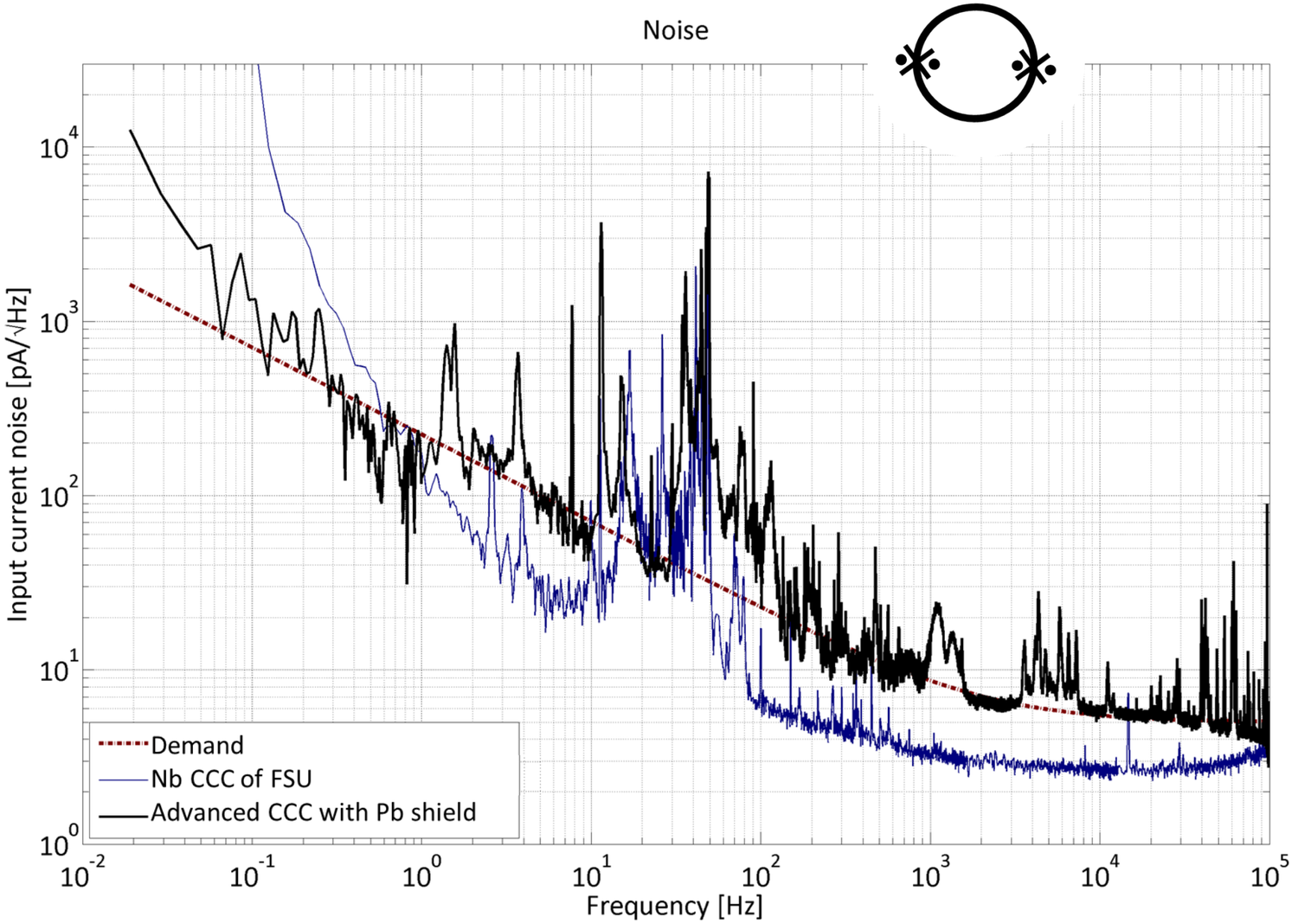


SQUID readout and Multiplexer for superconducting transition edge bolometers.

New beam current sensors for advanced accelerators

Joint development efforts
with FSU Jena (Seidel group),
Helmholtz-Institute Jena
(Stoehlker group),
GSI and CERN





Thanks to

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& Alex Braginski

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Thank you. Questions?

Thanks to my family!