Scanning SQUID Microscopy

Physikalisches Institut – Experimentalphysik II (Festkörperphysik)

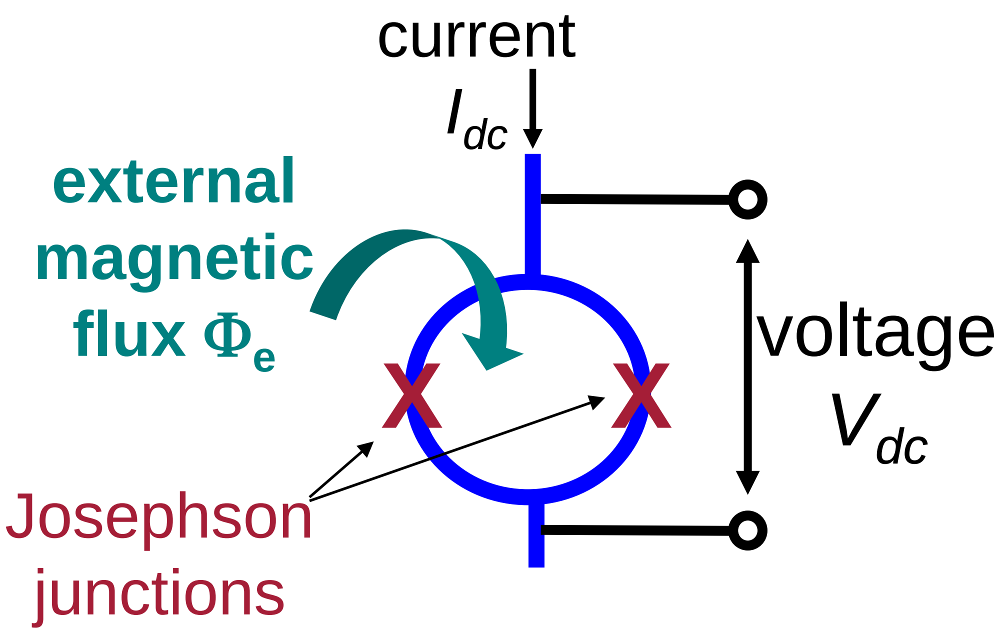
Prof. Dr. Dieter Kölle & Prof. Dr. Reinhold Kleiner

SFB initiative *Imaging in Inflammation*

Methodological Meeting – July 2014

Superconducting Quantum Interference Device (SQUID)

„direct current“ (dc) SQUID



flux quantization

in a superconducting ring

+

Josephson effect

Josephson junction
= two weakly coupled superconductors („weak link“)

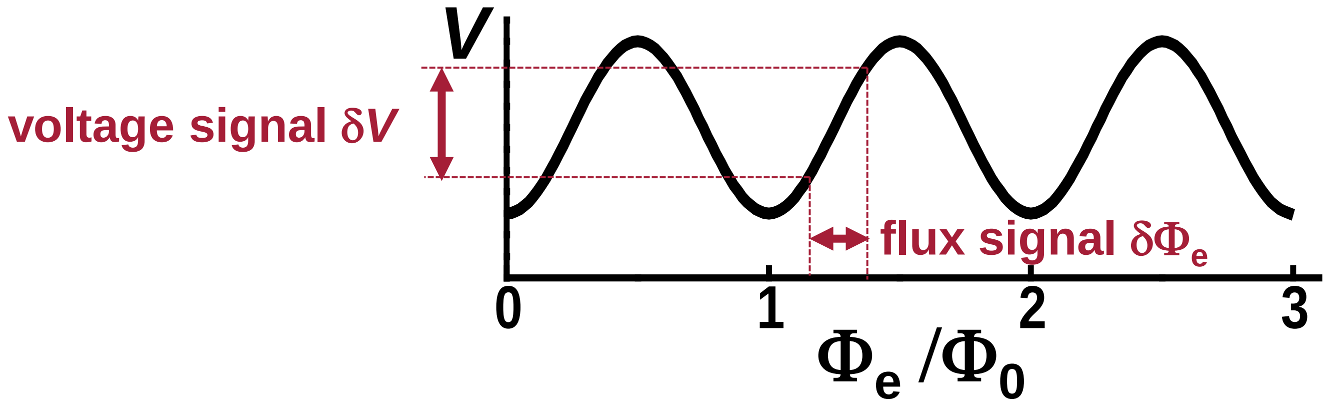
periodic response to external flux Φ_e

period: $\Phi_0 = h/2e \approx 2.07 \times 10^{-15}$ Vs (magnetic flux quantum)

magnetic flux of the earth‘s field: $3 \cdot 10^6\ \Phi_0$ per cm^2

dc SQUID: flux-to-voltage transducer

periodic voltage-flux characteristics



flux feedback electronics → linear voltage-to-flux response up to frequency *f* ~20 MHz

magnetic flux noise:

$\Phi_n \sim 1\ \mu\Phi_0 \cdot (\Delta f/\mathrm{Hz})^{1/2}$

Δf: measurement bandwidth

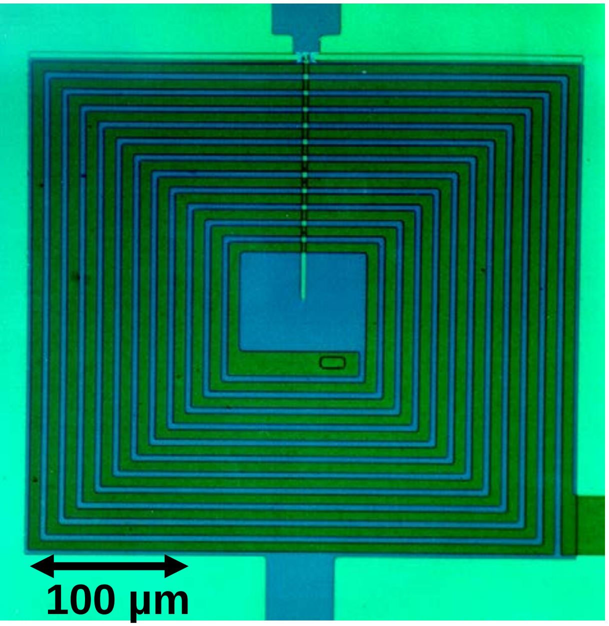
→ **most sensitive detector for magnetic flux**

operation temperatures: ~4 K (liquid Helium) or ~77 K (liquid Nitrogen)

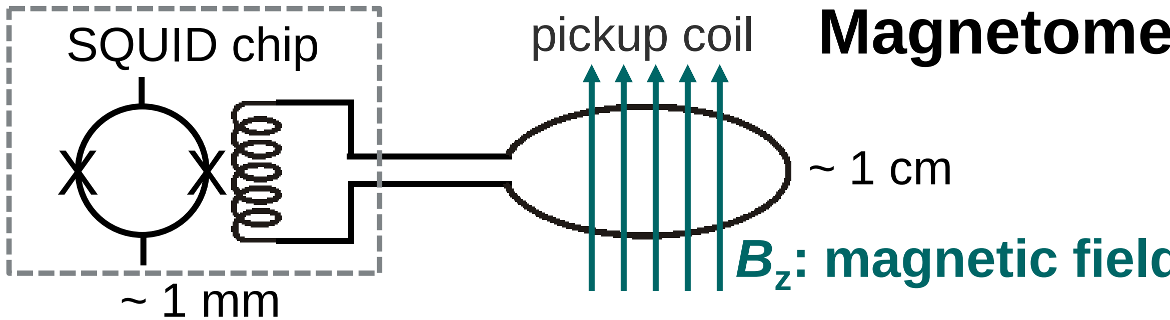
SQUID Performance & Applications

typical designs:

- thin film structures (~100 nm thick)
- lateral structures by micro-/nano-patterning



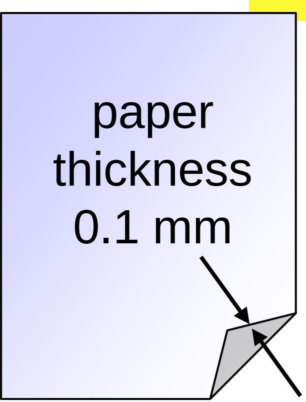
Magnetometer



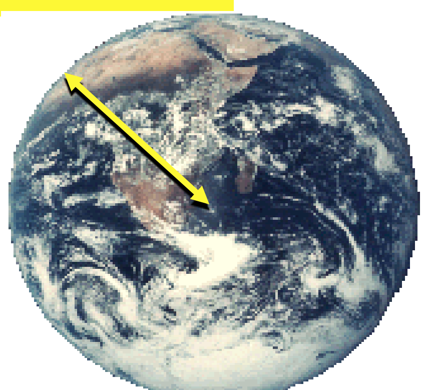
field noise: $\Phi_n / A_{eff} = B_n \sim 1\ \mathrm{fT} \cdot (\Delta f/\mathrm{Hz})^{1/2}$

A_{eff} = effective sensor area @ f > 1 Hz

1 fT x 6•10^9 = earth magnetic field



x 6•10^9 = radius of the earth



Important application:
Magnetoencephalopgraphy (MEG)

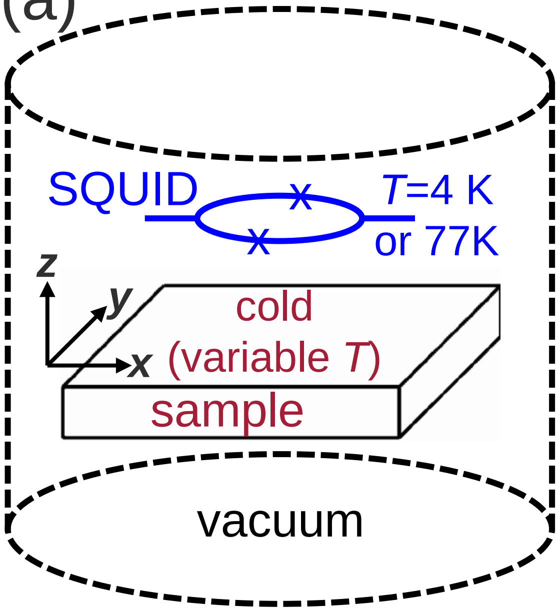
SQUID Microscopy = scanning probe technique

sample is scanned relative to SQUID (or vice versa)

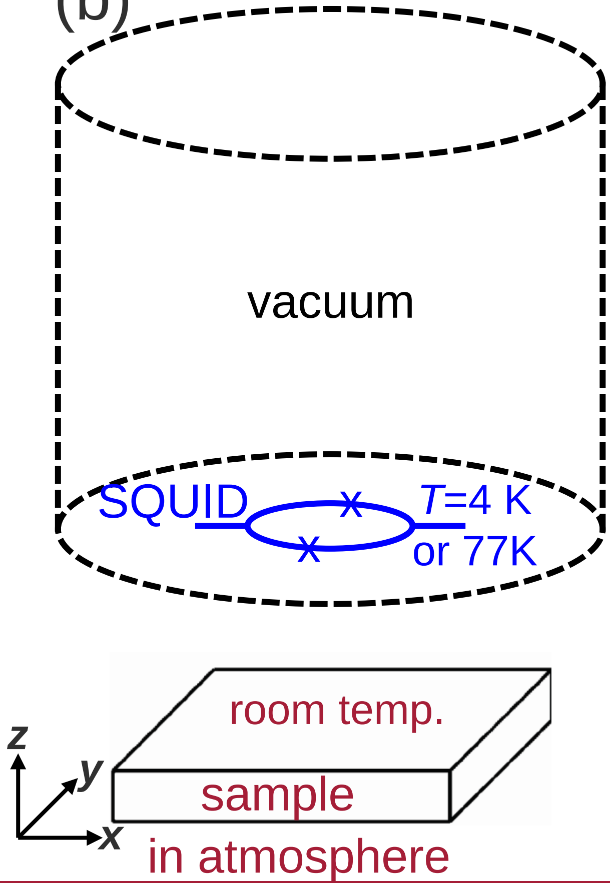
→ SQUID detects local magnetic field distribution

→ combines high flux sensitivity with spatial resolution

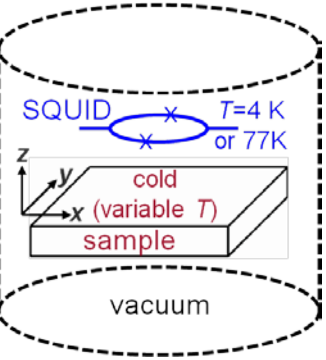
(a)



(b)



SQUID Microscopy: Sample in vauum @ variable temperature

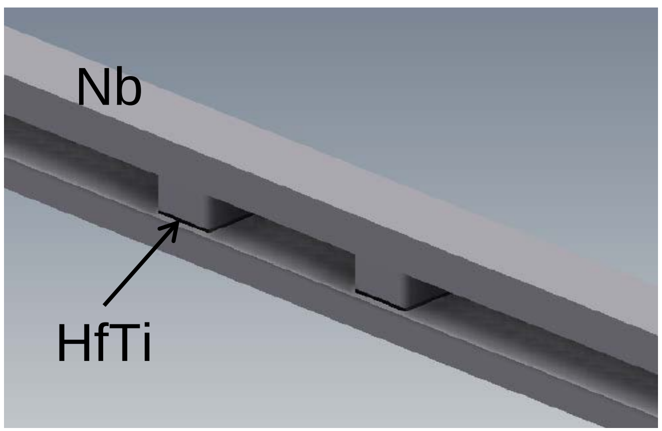


→ small sample-to-SQUID distance possible

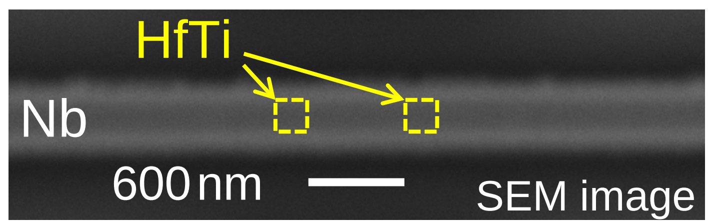
spatial resolution determined by:

- sample-to-SQUID distance
- SQUID size

→spatial resolution ~ 1 µm (~100 nm feasible → „nanoSQUID“)



Nb nanoSQUID:



junction area: 200 x 200 nm^2

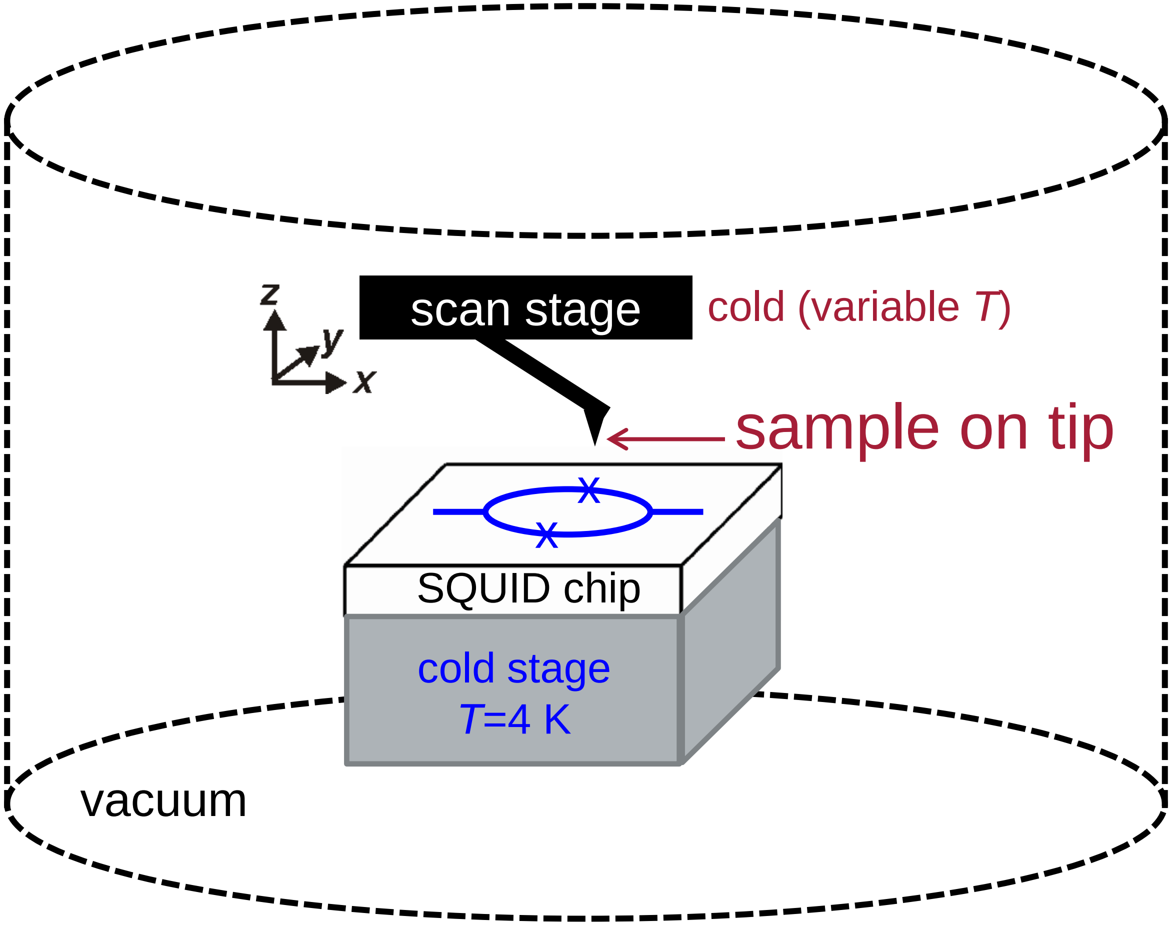
spin noise: $\mu_n \sim 10\ \mu_B \cdot (\Delta f/\mathrm{Hz})^{1/2}$

flux noise: $\Phi_n \sim 100\ \mathrm{n}\Phi_0 \cdot (\Delta f/\mathrm{Hz})^{1/2}$

field noise: $B_n \sim 1\ \mathrm{nT} \cdot (\Delta f/\mathrm{Hz})^{1/2}$

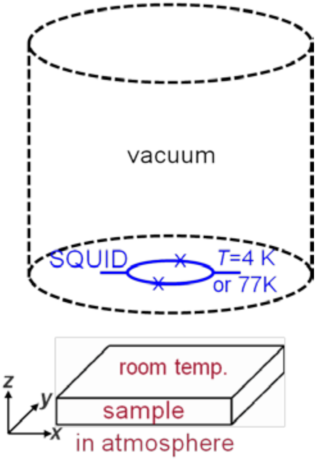
μ_B = Bohr magneton

SQUID Microscopy: Sample in vauum @ variable temperature



→ setup under construction

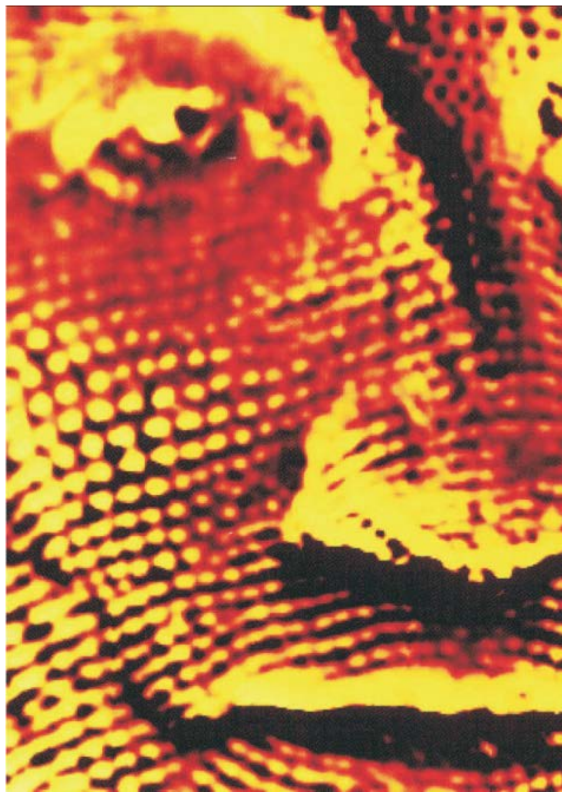
SQUID Microscopy
Sample in atmosphere @ room temperature



→ large sample-to-SQUID distance

determined by SQUID-to-window gap + window thickness

→ spatial resolution > 100 µm

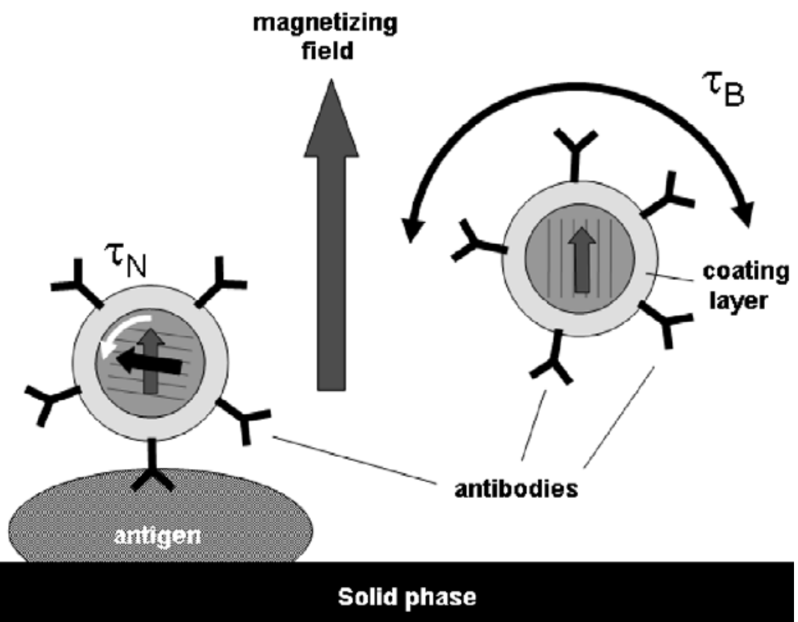


1 Dollar bill
→ magnetic ink

J. Clarke, Scientific American 08/1994

Magnetic Relaxation ImmunoAssay (MARIA)

antibodies linked to magnetic labels (nanoparticles)

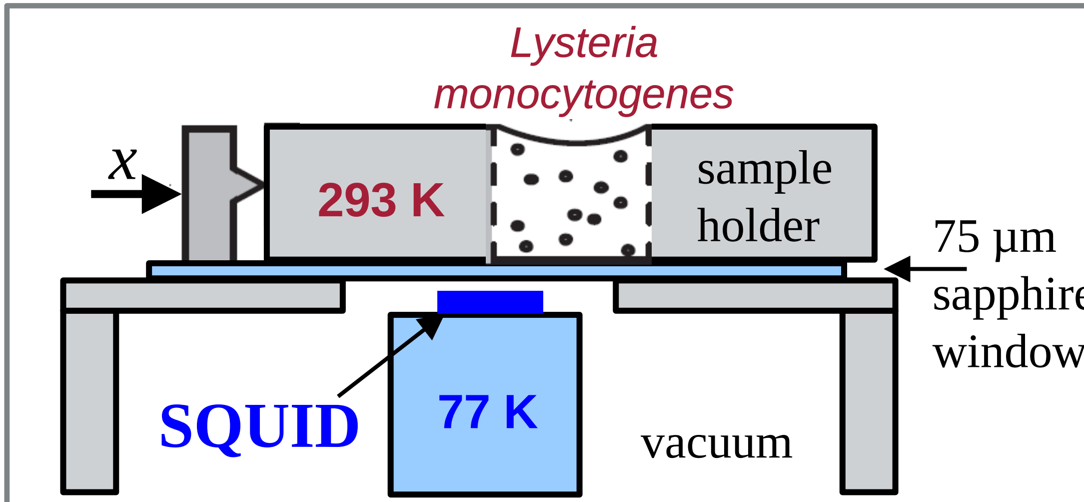


J. Vrba, „The SQUID Handbook“, vol.II

relaxation time for bound particles

$\tau_N >> \tau_B$ (unbound)

magnetic relaxation measured by SQUID



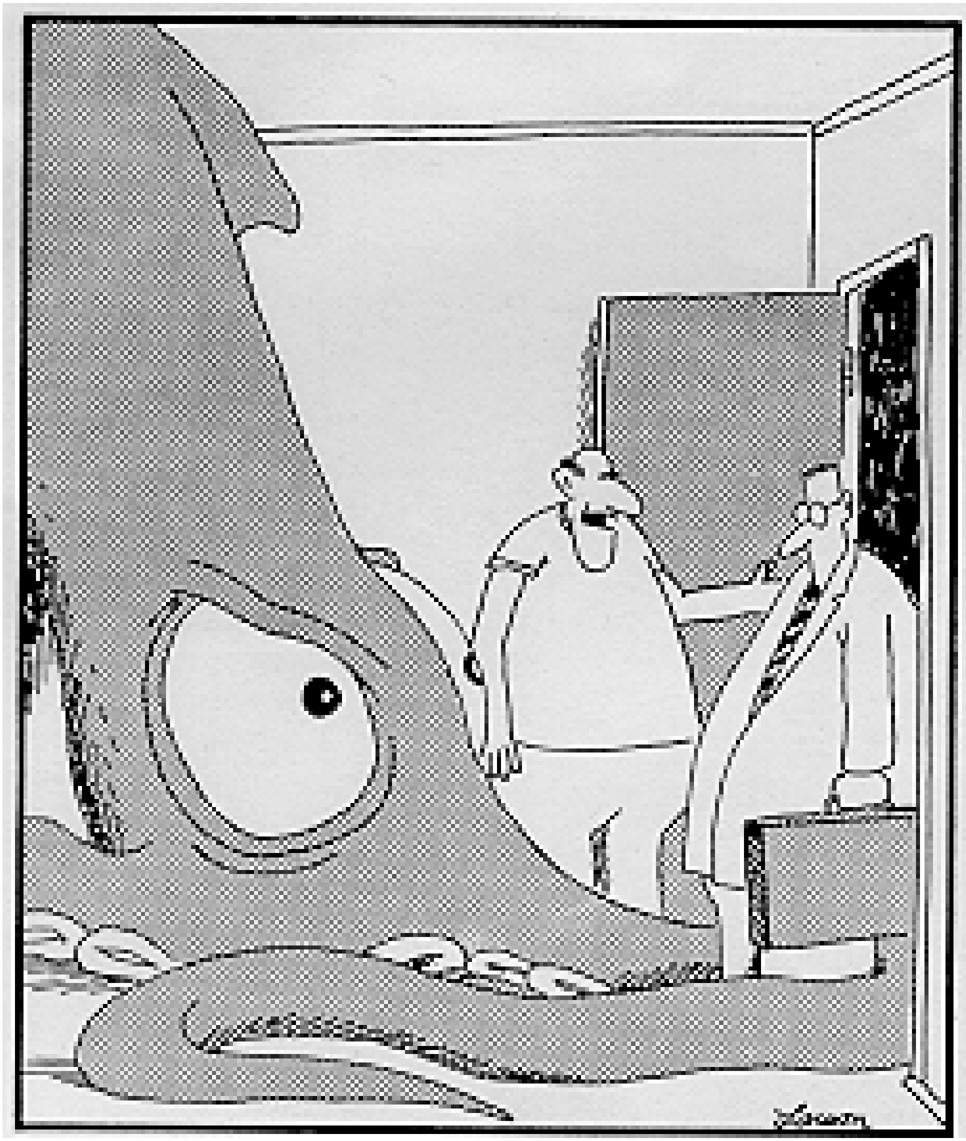
Detection of bacteria in suspension by using a superconducting quantum interference device

Grossman *et* al., PNAS **101**, 129 (2004)

→ study of binding reactions between bio-molecules

no need for
- immobilization of targets
- separation of unbound tags

EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN



„Oh, no, he's quite harmless. ...

Just don't show any fear. ...

SQUIDs can **sense** fear."