MEG Instrumentation Lecture

MEG Core Facility
NIMH

SQUID Sensors

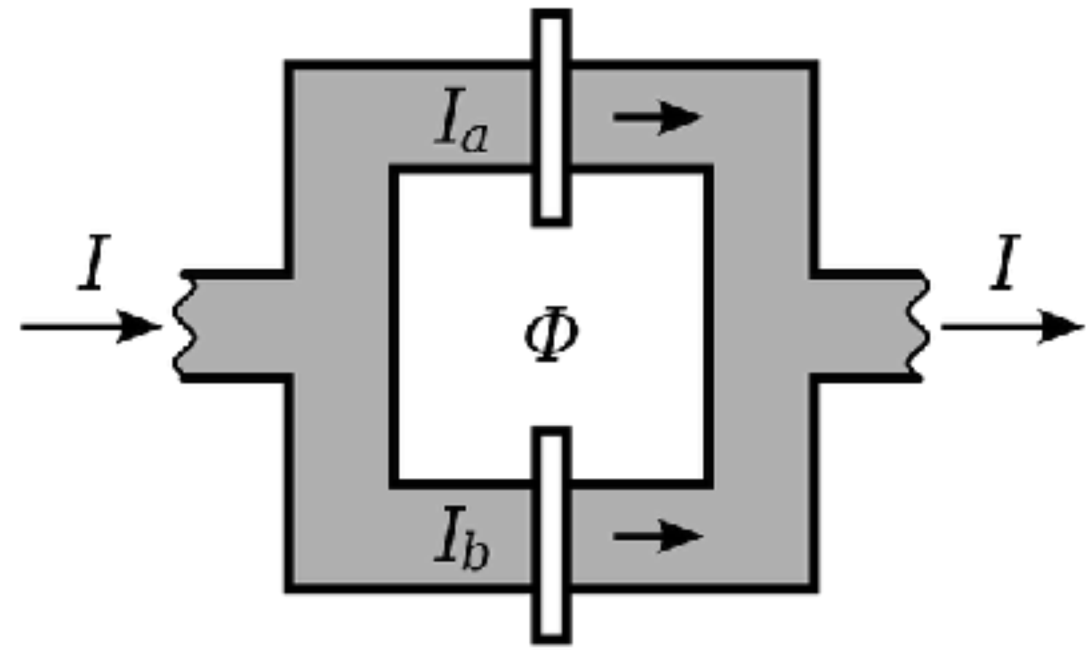
- SQUID is an acronym for “Superconducting Quantum Interference Device”
- Based upon theoretical work of Brian Josephson (1962, and Nobel Prize in 1973)
- Superconductivity is mediated by formation of Cooper pairs (electron pairs)
- SQUIDs are based on the “dc Josephson effect”: small supercurrents can flow unimpeded through an insulating barrier, whereas large currents cannot
- Low temperature superconductors, using Niobium ($T_c = 9.3K$), are designed to operate at 4.2 degrees Kelvin in a liquid helium bath!
- dc-SQUID has two Josephson junctions
- SQUIDs can detect changes in magnetic flux of ~10^{-6} of a flux quantum
- SQUID sensors can detect magnetic fields from dc to several kiloHertz

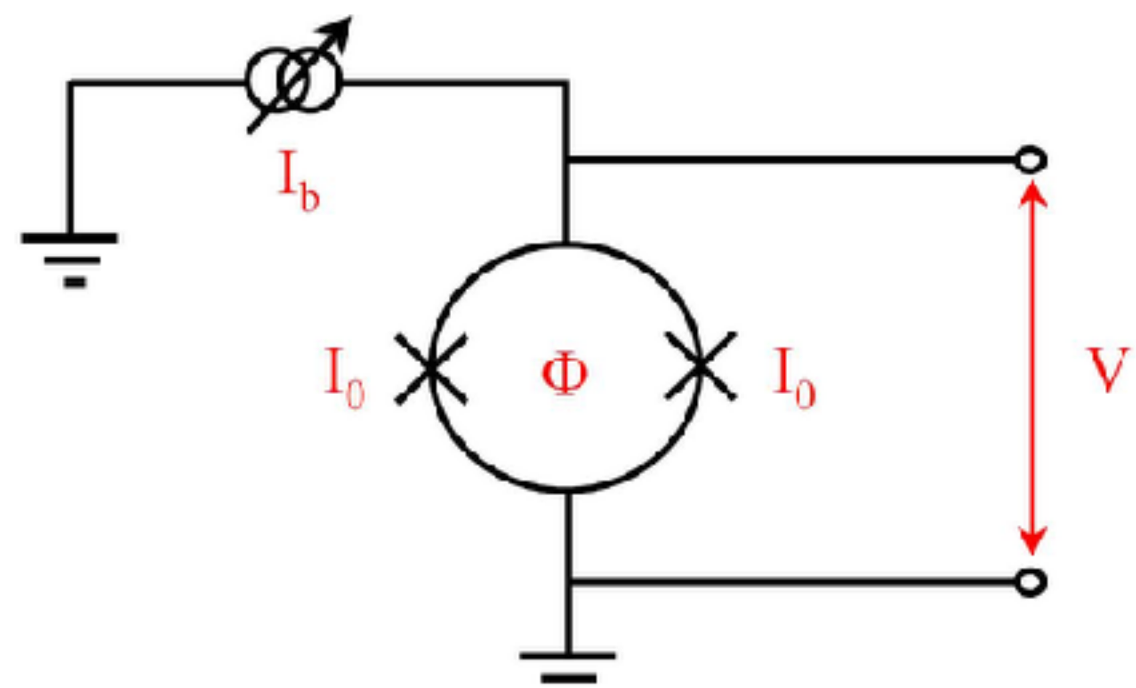
DC-SQUID

- dc-SQUID consists of a ring of superconducting material with two symmetrical insulating barriers - “weak links”

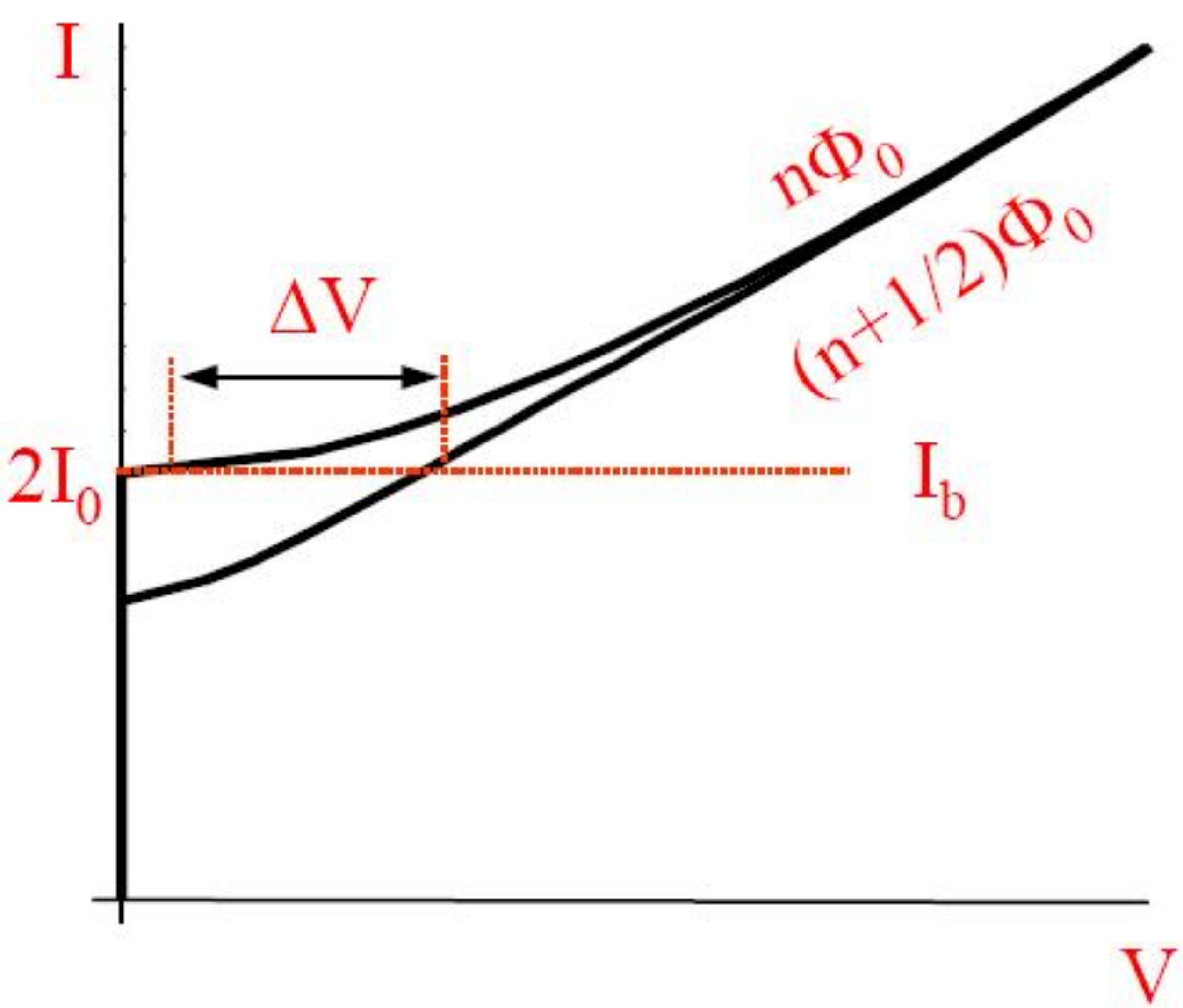
- At very low currents, a super-current can flow through the weak links with no voltage difference

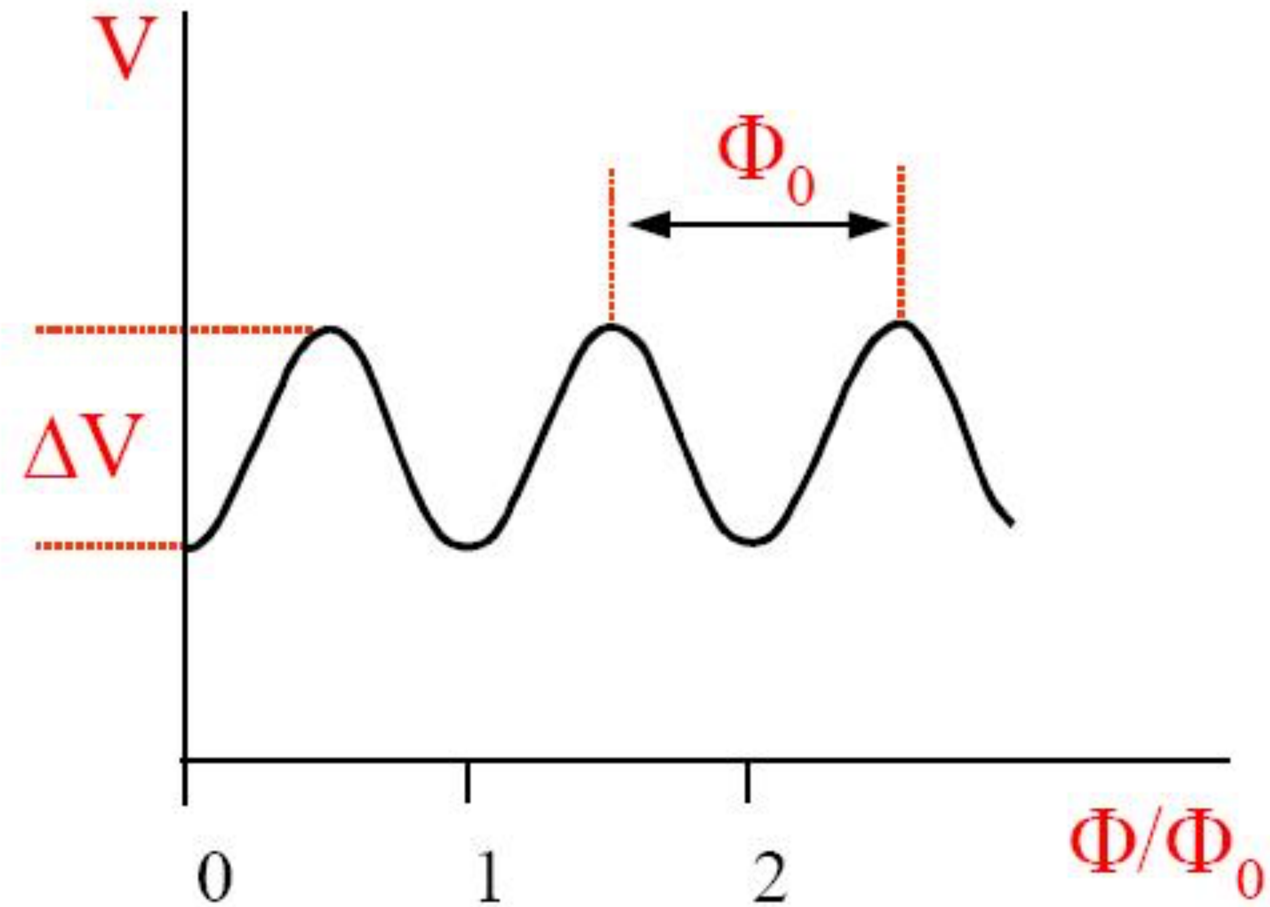
- At higher currents, the junctions no longer support superconductivity and a voltage appears across them





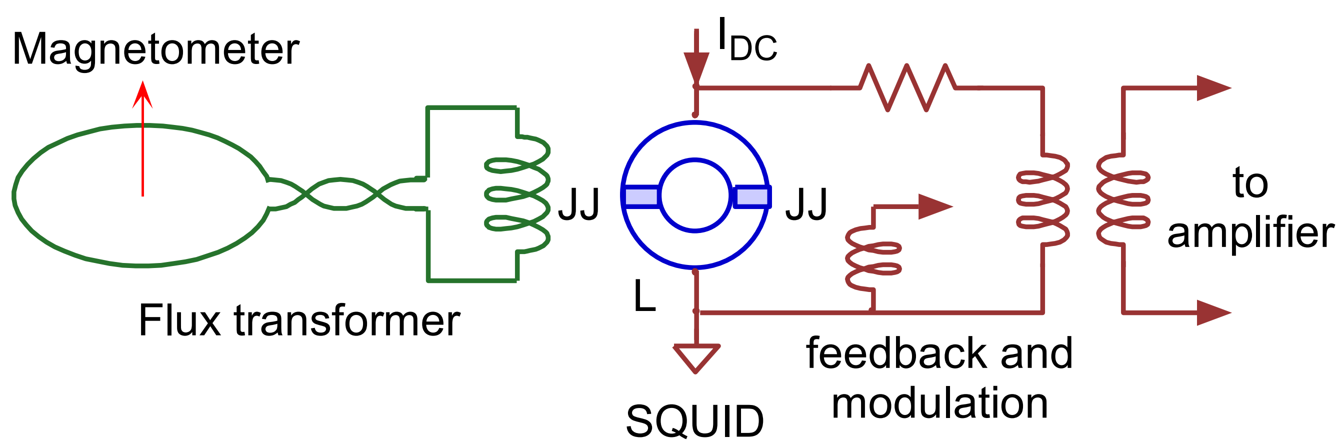
Current vs Voltage &
Voltage vs Magnetic Flux

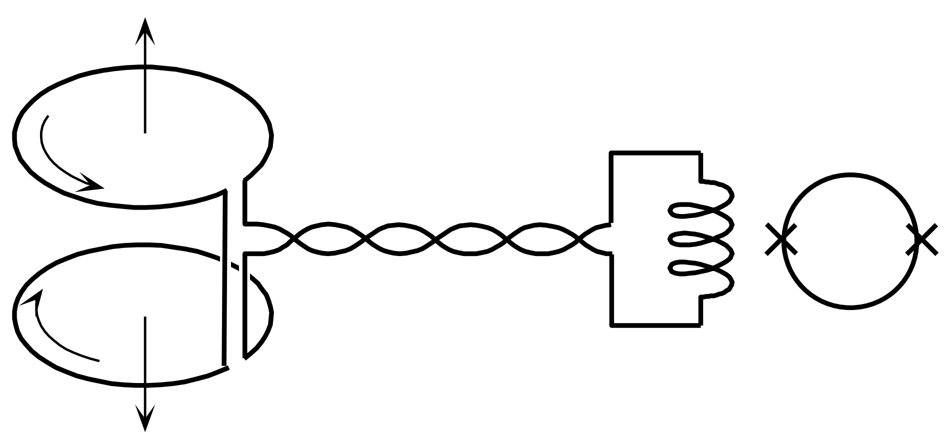




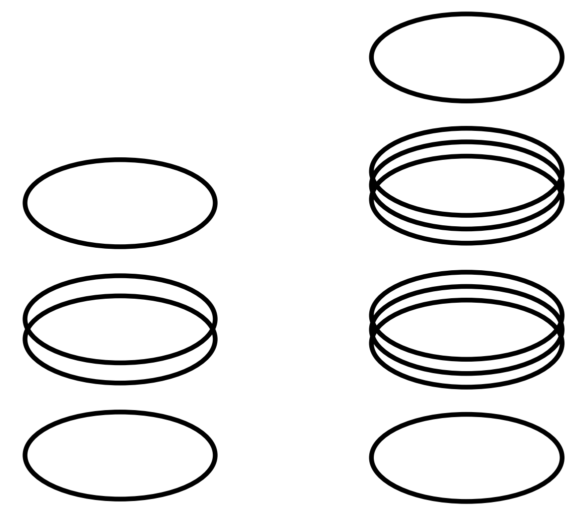
SQUID Sensors & Flux Transformers

DC SQUID Magnetometer





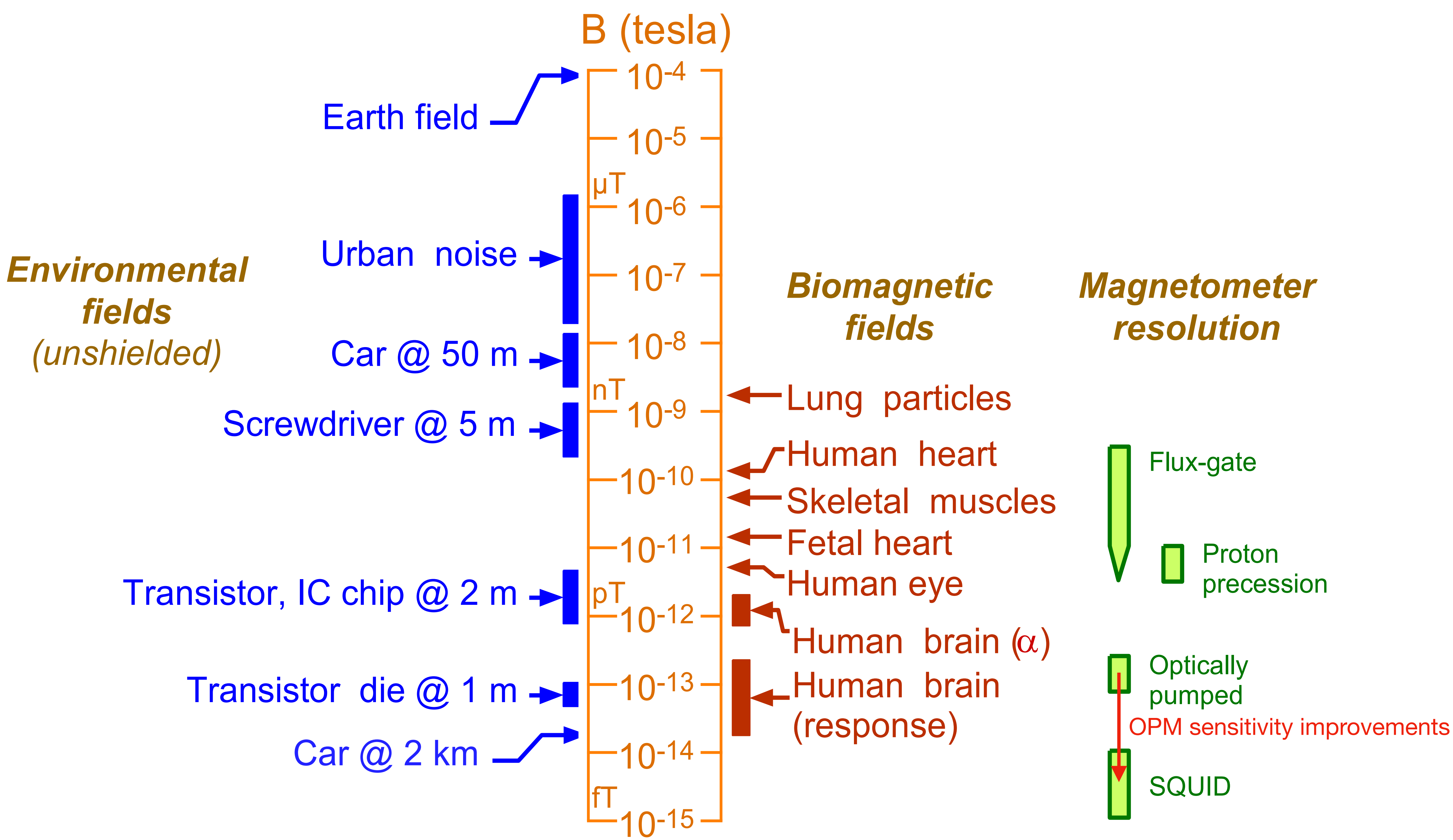
1st order gradiometer



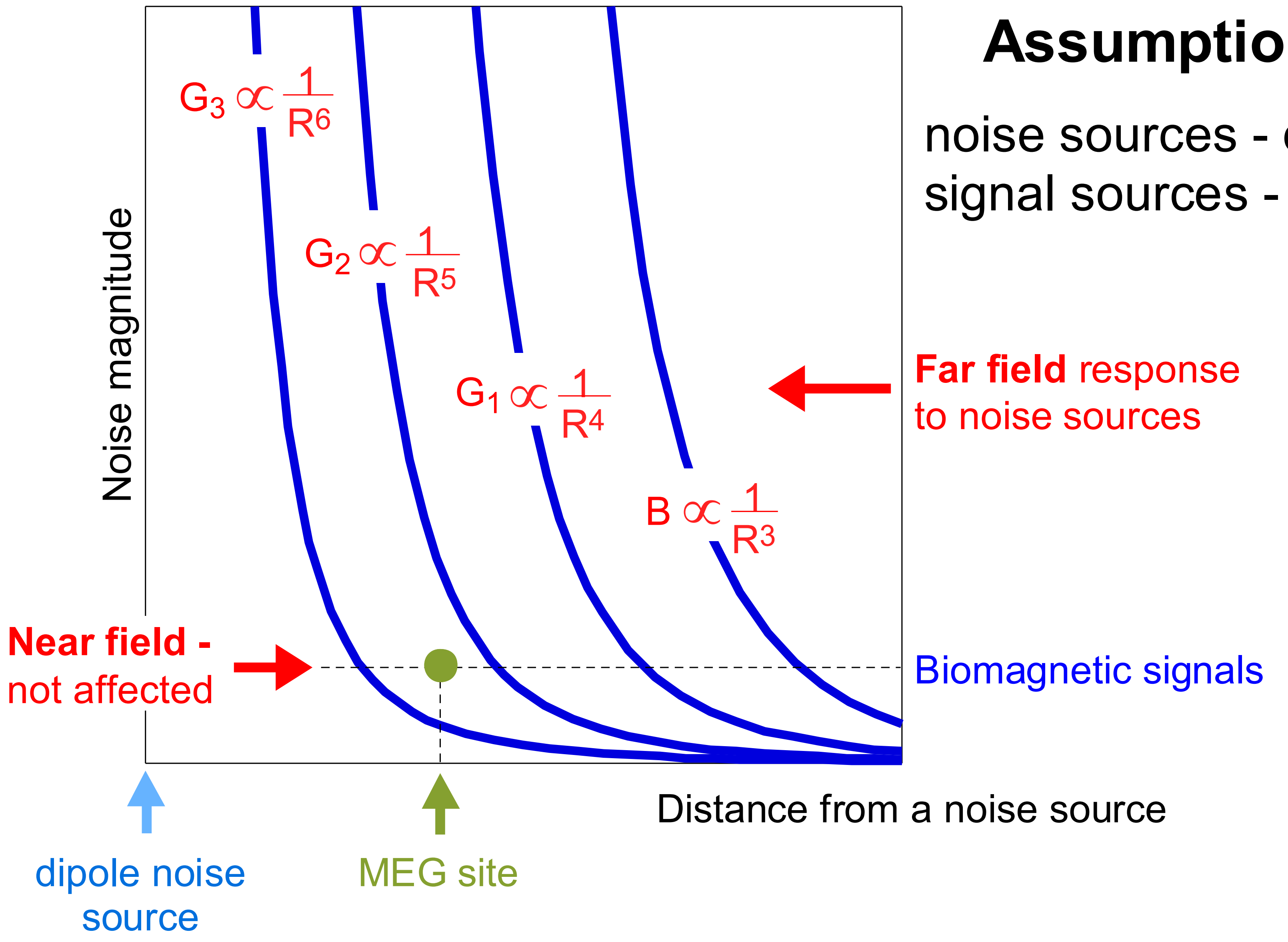
2nd order gradiometer

3rd order gradiometer

Comparison of Magnetic Fields: Why We Need Shielding & Gradiometers



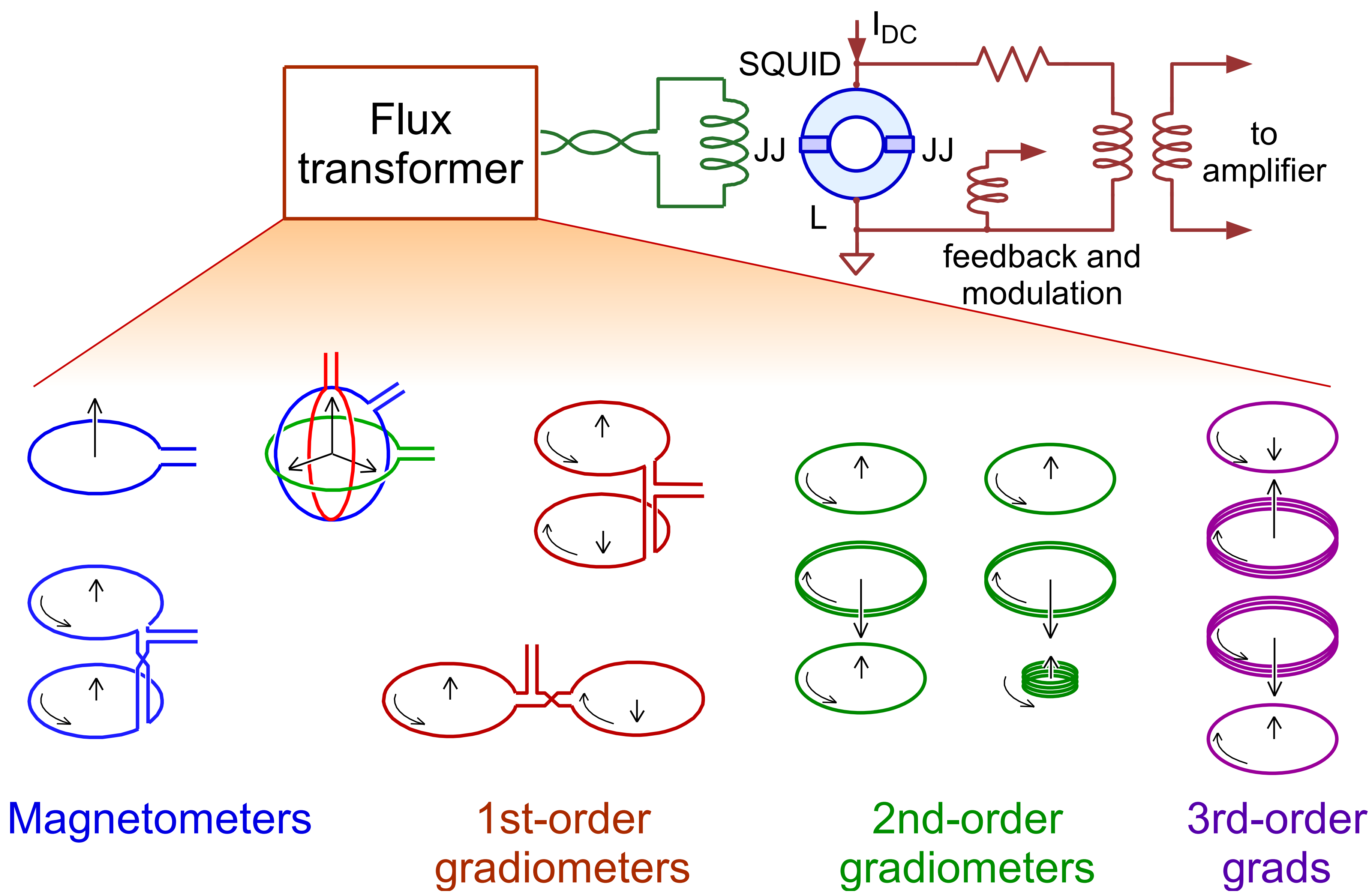
Detection of MEG Signals Requires Attenuation of Interfering Magnetic Fields



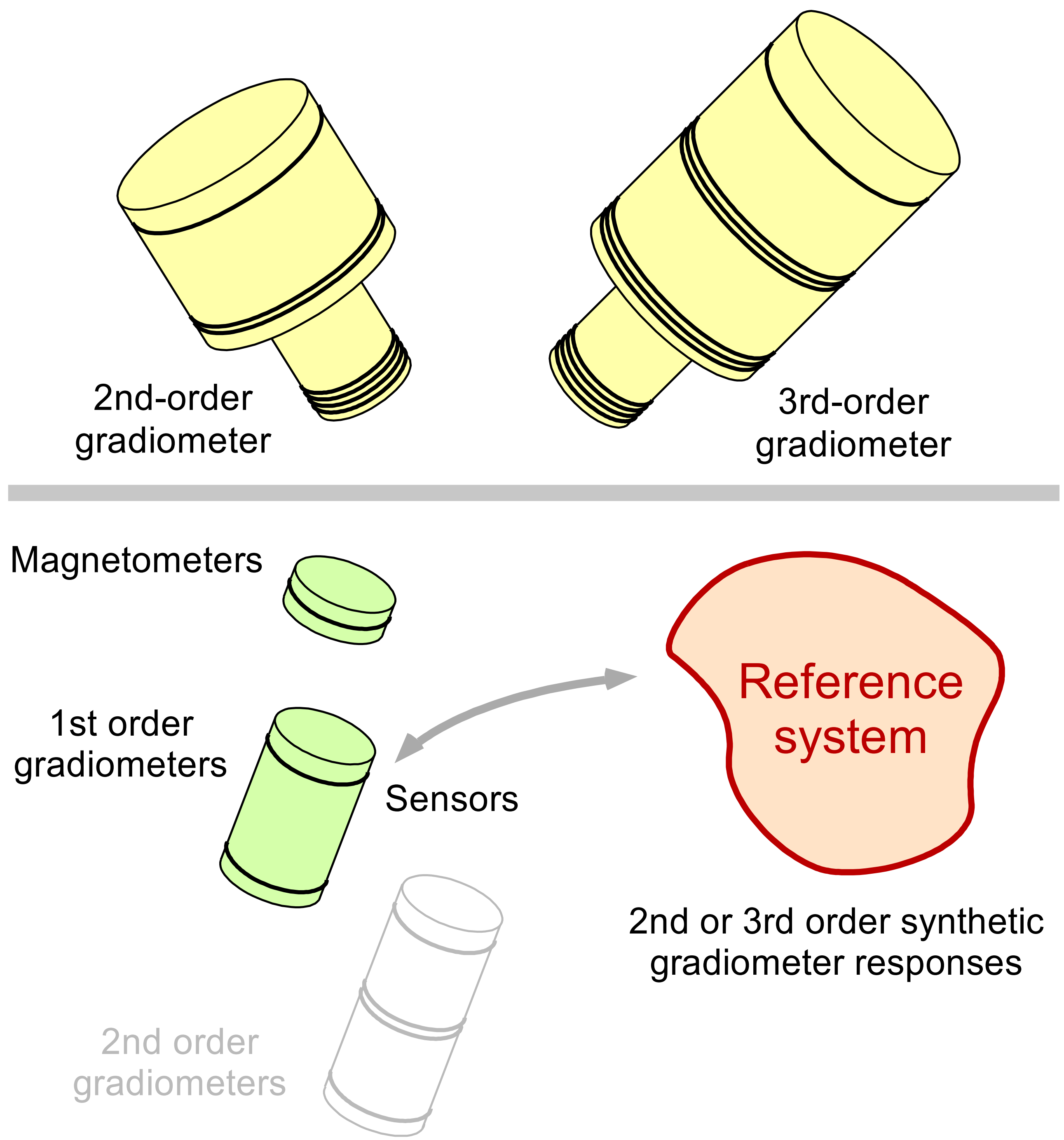
Assumptions:

noise sources - distant
signal sources - near

SQUIDs are Coupled to Flux Transformers



Synthetic High-Order Gradiometer Have Advantages Over Hardware Gradiometers



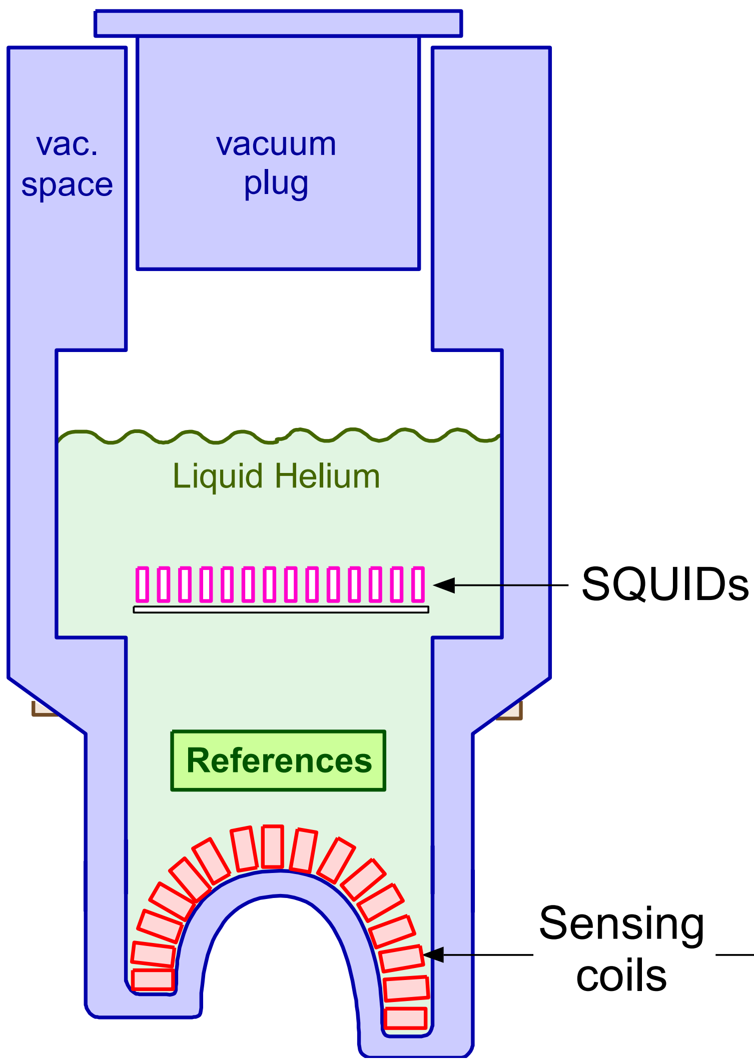
Hardware higher-order gradiometers

Synthetic higher-order gradiometers

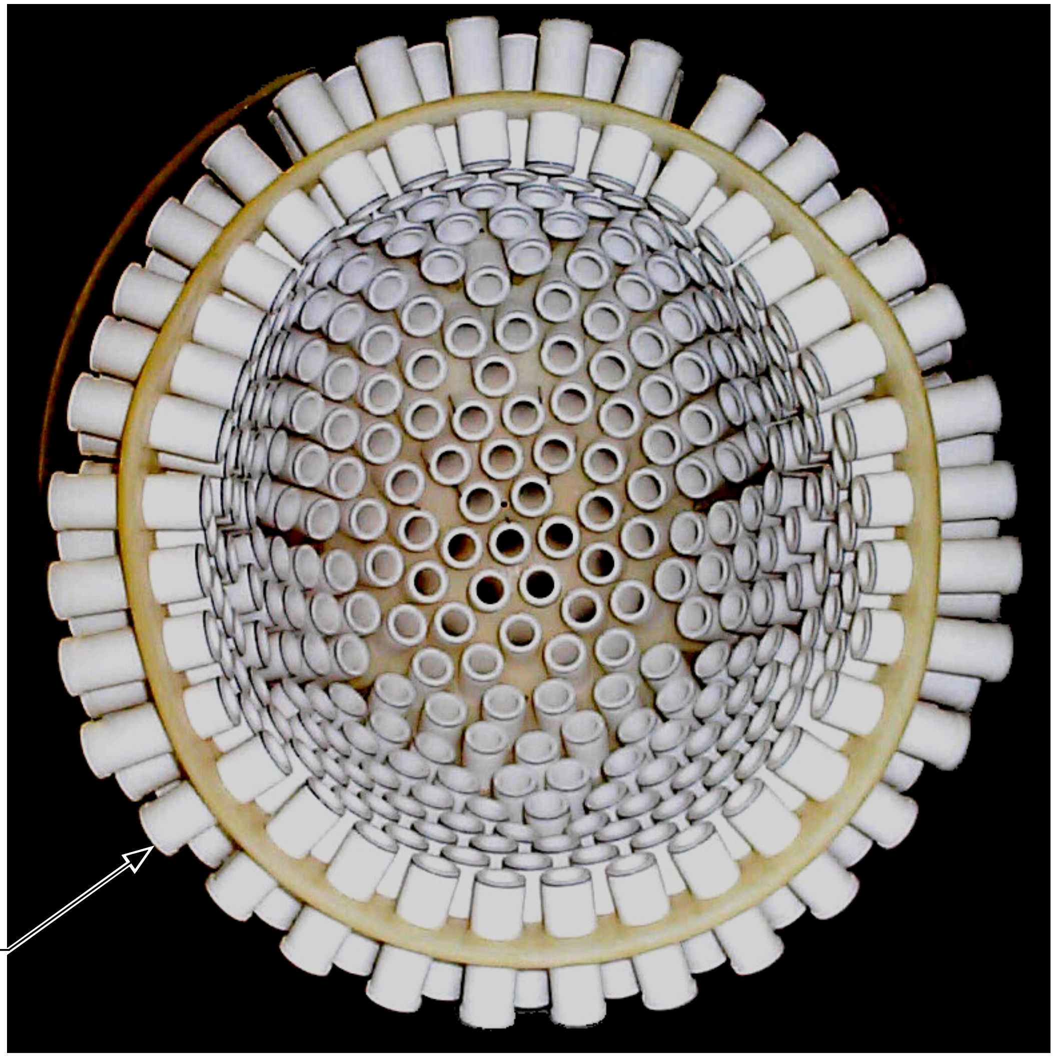
1509-JV, Nov 94

CTF MEG Has 275 Primary Sensors and 29 Reference Sensors

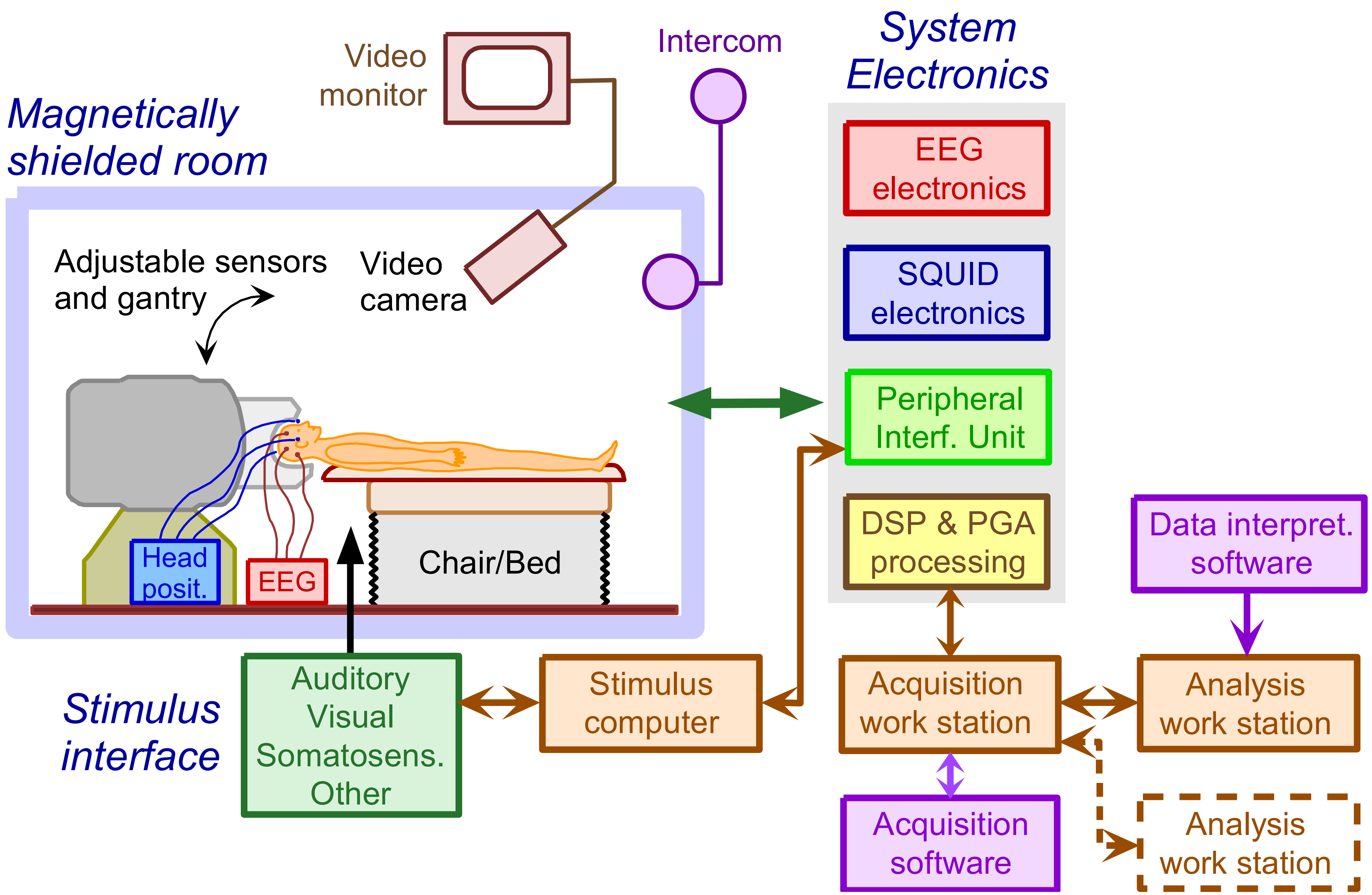
MEG sensor system



CTF275 channel MEG sensor array

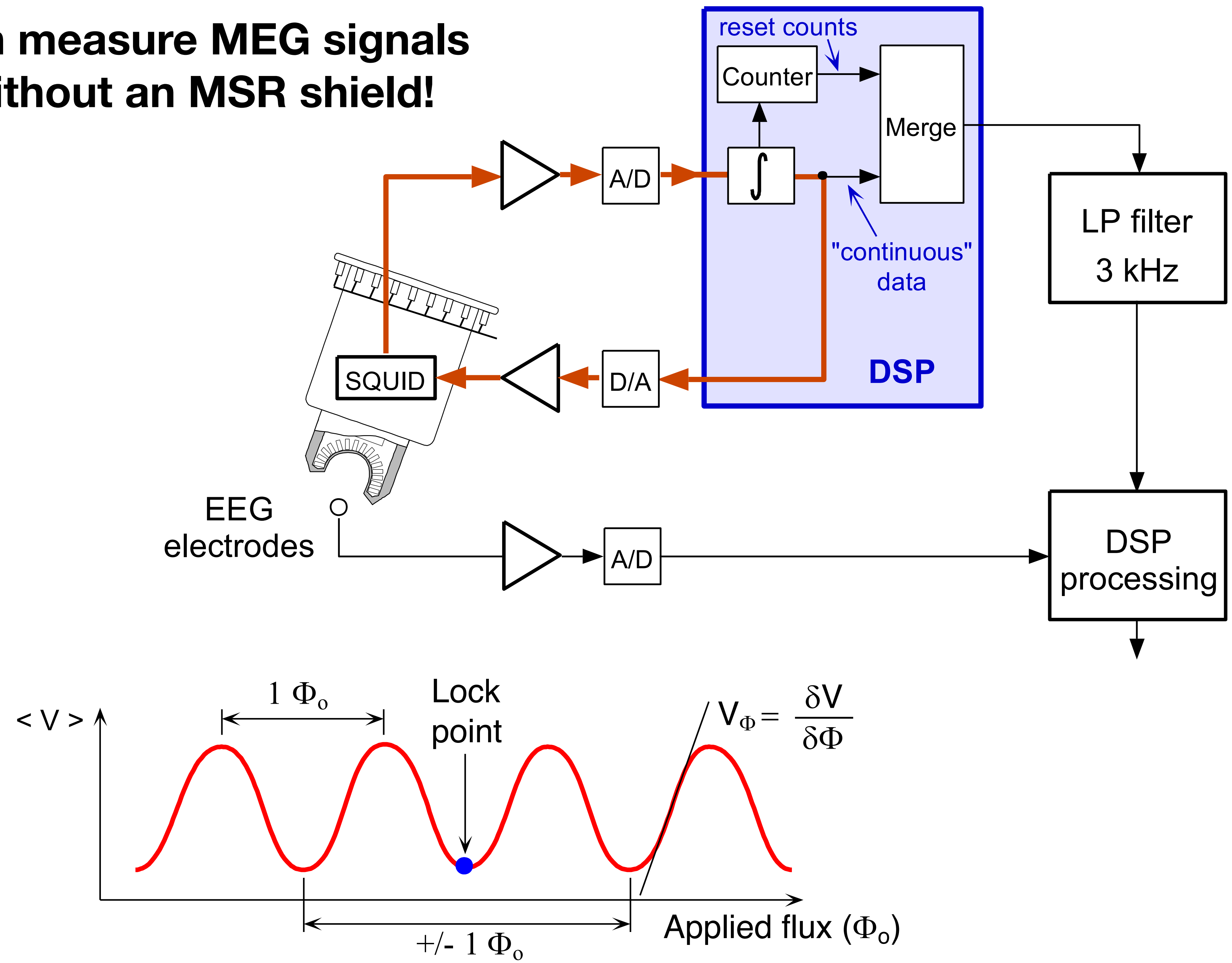


NIMH MEG System Diagram



CTF SQUID Electronics Have 192 dB (32-bit) Dynamic Range

Can measure MEG signals without an MSR shield!



Head Localization Coils Determine Coordinate Frame of the Head Relative to the Sensors

Special-Purpose Instruments Include Fetal and Pediatric MEG

Future Alternatives to Low Temperature MEG SQUID Sensors

- SQUIDs can be fabricated from high-temperature superconductors such as YBCO
- High-Tc SQUID Advantage: can operate at 77 degrees Kelvin in liquid Nitrogen
- High-Tc SQUID Disadvantages: higher noise levels and chemical instability
- Optically pumped magnetometers (OPMs)
- OPM Advantages: Operation at room temperature, can be placed closer to the head for better S/N, can measure total field or vector field, and lower cost sensors and electronics
- OPM Disadvantages: Currently noisier than low-Tc SQUIDs, no hardware gradiometers, requires high-quality shielded room and noise cancellation, limited bandwidth, and no commercially-available MEG systems, so far

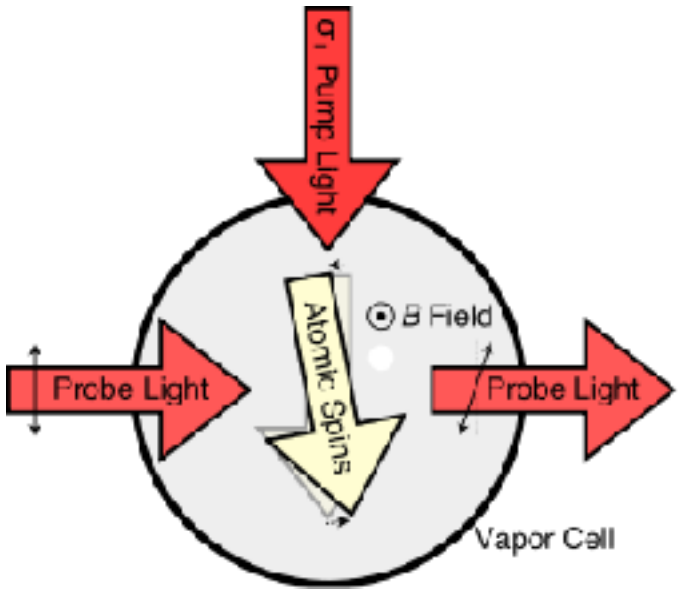
Optically Pumped Magnetometers (OPMs)

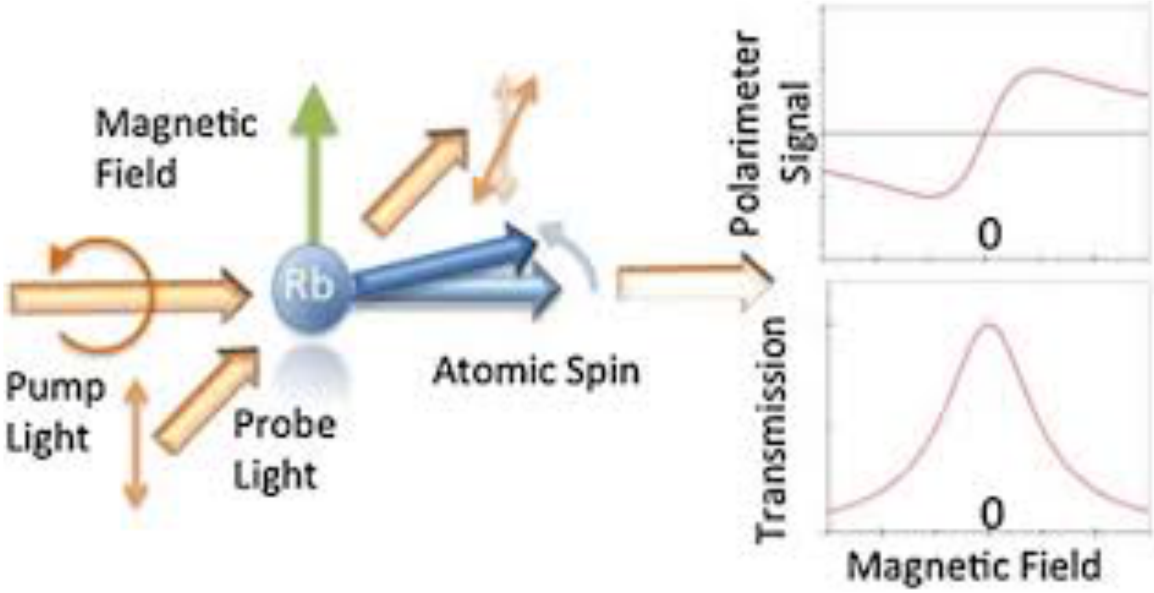
- A small transparent glass cell contains an alkali metal vapor such as potassium, cesium, or rubidium

- A laser is used to “pump” the vapor into an excited state

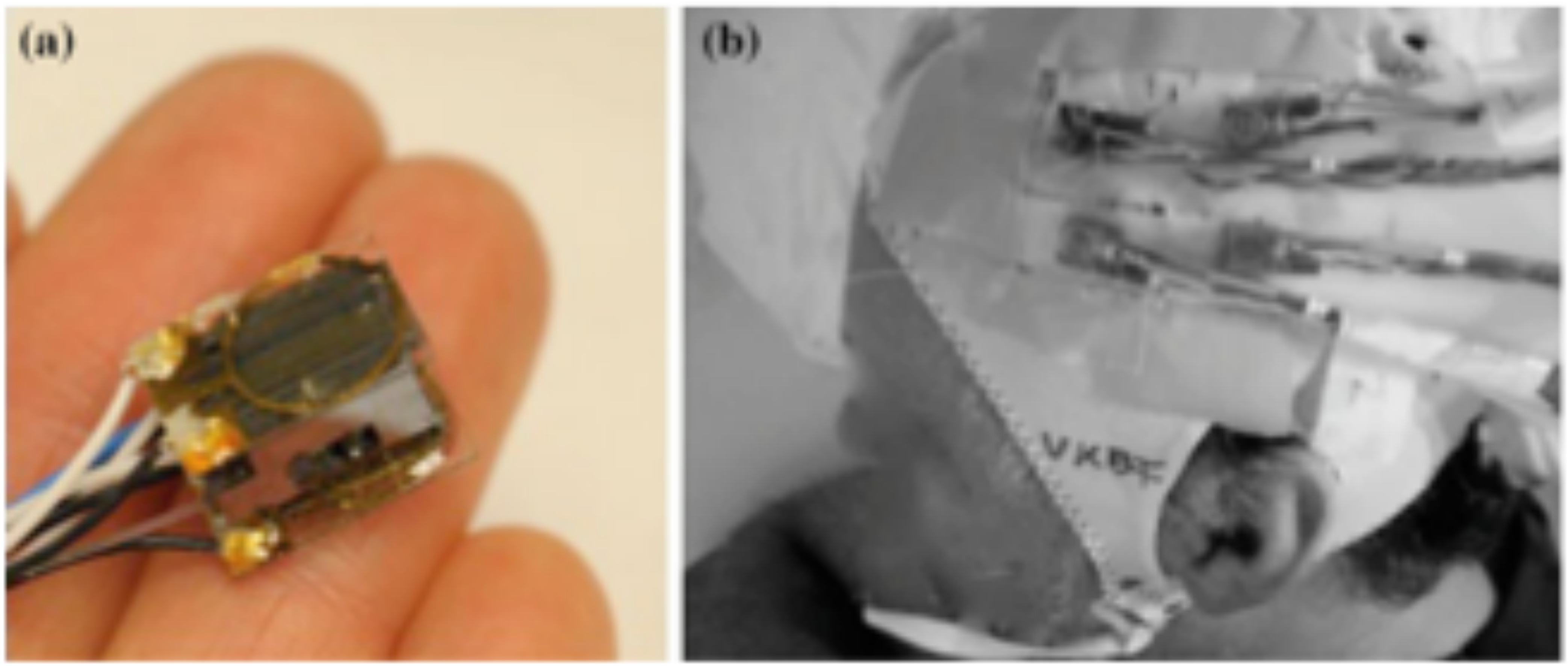
- A second laser and photodetector are used to measure the optical transparency of the vapor

- Optical transparency is lowest at zero magnetic field



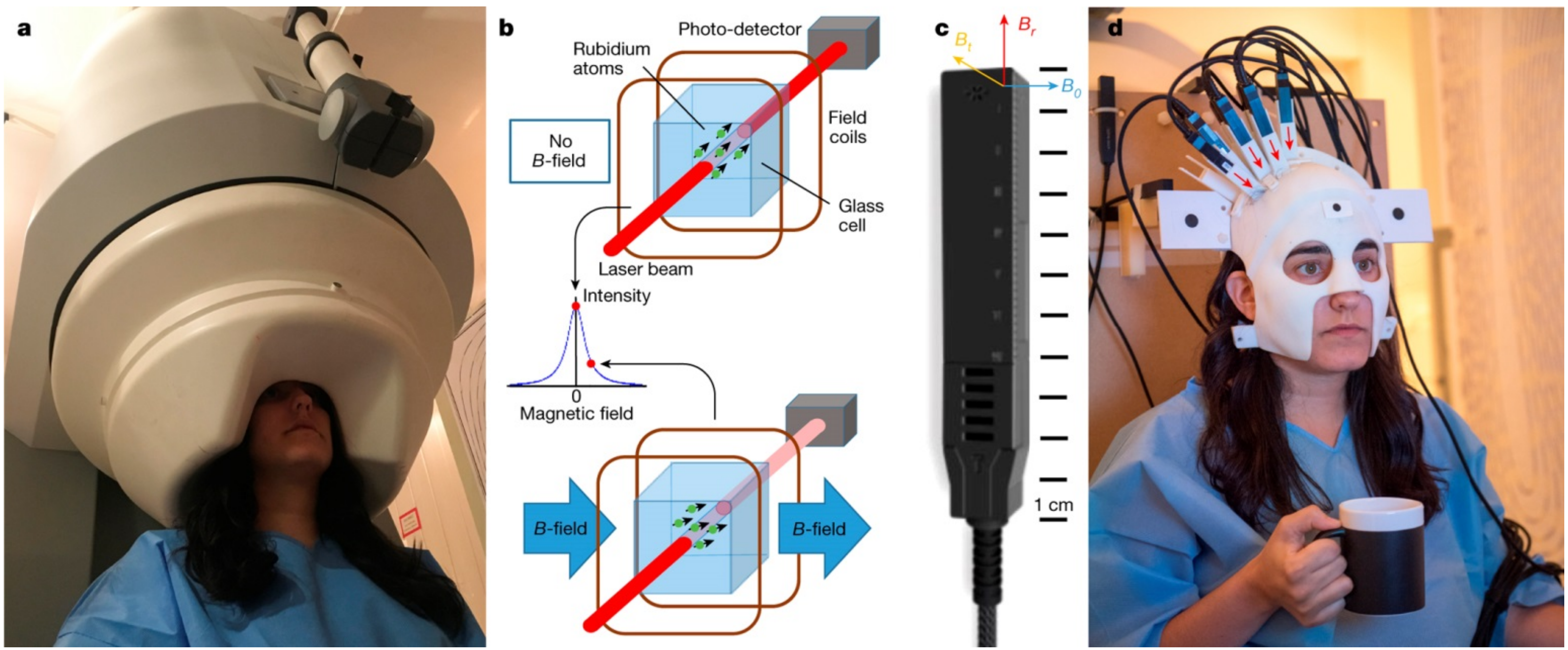


Chip-Scale OPM Size



A New Generation MEG System

E Boto *et al.* *Nature* **555**, 657–661 (2018) doi:10.1038/nature26147



University of Colorado Prototype MEG using OPMs