

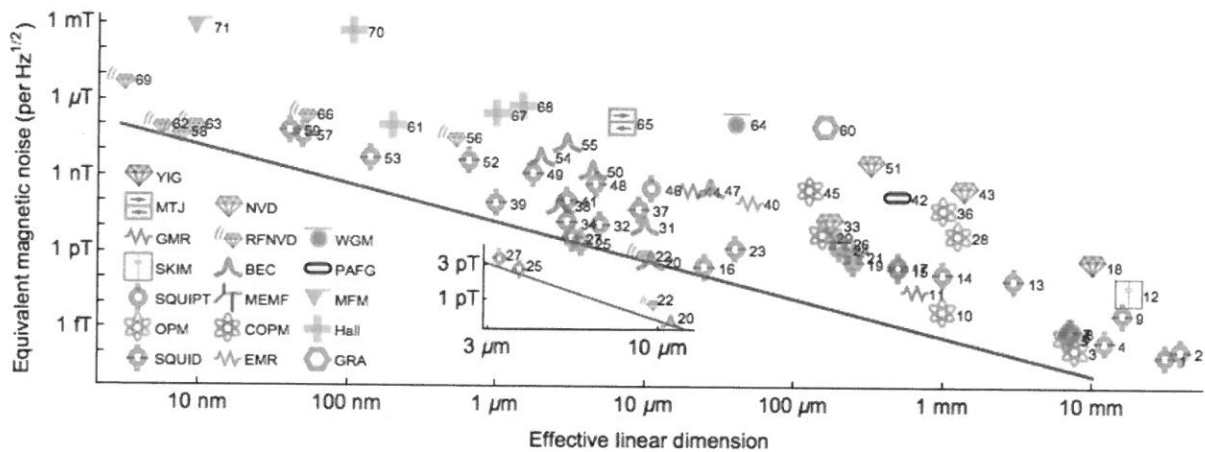
# On energy resolution limits in magnetic field sensing

Morgan W. Mitchell<sup>1,2</sup>

<sup>1</sup> ICFO-Institut de Ciències Fòniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain.

<sup>2</sup>ICREA -- Institució Catalana de Recerca i Estudis Avançats, 08010 Barcelona, Spain.

We describe a class of quantum sensing limits that – unlike the standard quantum limit and Heisenberg limit – make no reference to particle number [1]. Rather, these “energy resolution limits” constrain  $E_R$ , the *energy resolution per bandwidth*, a figure of merit that combines the measurement noise, duration or bandwidth, and size of the sensed region. Technology-specific energy resolution limits have been derived for a number of important sensing modalities [2,3] and seem to converge near a limiting value of  $E_R = \hbar$ . We review the state of knowledge about such limits, and consider the possibility that a more general, technology-spanning limit constrains energy resolution. Possible sources include the Margolus-Levitin bound on the speed of quantum evolution and the Bremermann-Beckenstein bound on the entropy of a space-time region of given energy and volume.



**Figure 1.** Reported low-frequency magnetic sensitivity versus size of the sensed region for several high-performance magnetic sensor types. MTJ - magnetic tunnel junction; GMR - giant magneto-resistance; SKIM - superconducting kinetic impedance magnetometer; SQUIPT - superconducting quantum interference proximity transistor; SQUID superconducting quantum interference device; OPM optically-pumped magnetometer; NVD - nitrogen-vacancy center in diamond (including RF sensors below 10  $\mu\text{m}$ ); BEC Bose-Einstein condensate; MEMF - magnetolectric multiferroic; COPM - cold-atom OPM; EMR extraordinary magneto-resistance; YIG yttrium-aluminum-garnet; GRA - graphene, MFM - magnetic force microscope, PAFG - parallel gating fluxgate, WGM - whispering-gallery mode magnetostrictive. Green line shows an energy resolution per bandwidth of  $\hbar$ .

[1] M. W. Mitchell, “Number-Unconstrained Quantum Sensing” *Quantum Science and Technology* 2, 044005 (2017).

[2] M. W. Mitchell, “Sensor self-interaction, scale-invariant spin dynamics, and the  $\hbar$  limit of magnetic field sensing” [arXiv:1904.01528](https://arxiv.org/abs/1904.01528) (2019).

[3] M. W. Mitchell and S. Palacios “Quantum limits to the energy resolution of magnetic field sensors” [arXiv:1905.00618](https://arxiv.org/abs/1905.00618) (2019).