

Axion searches *with magnetometers*

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Axion(-like) Dark Matter

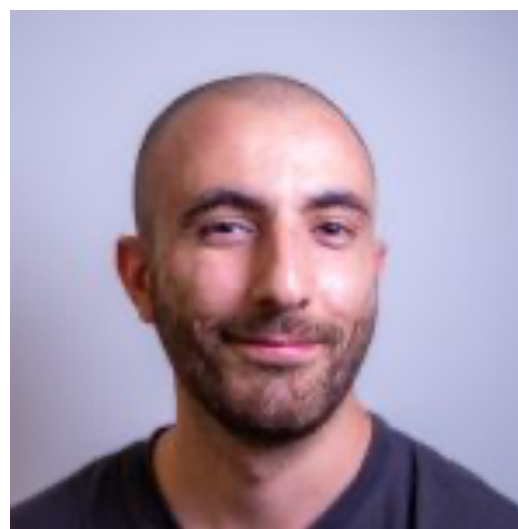
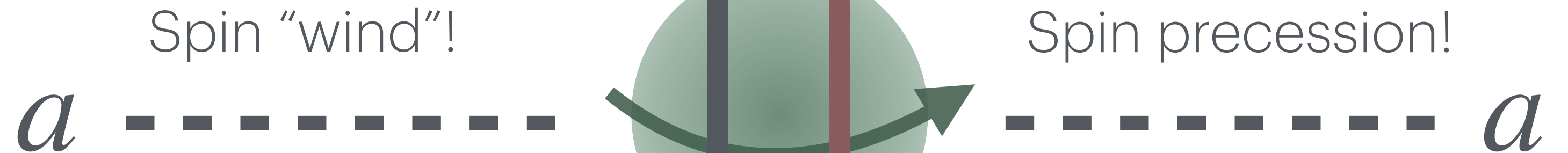
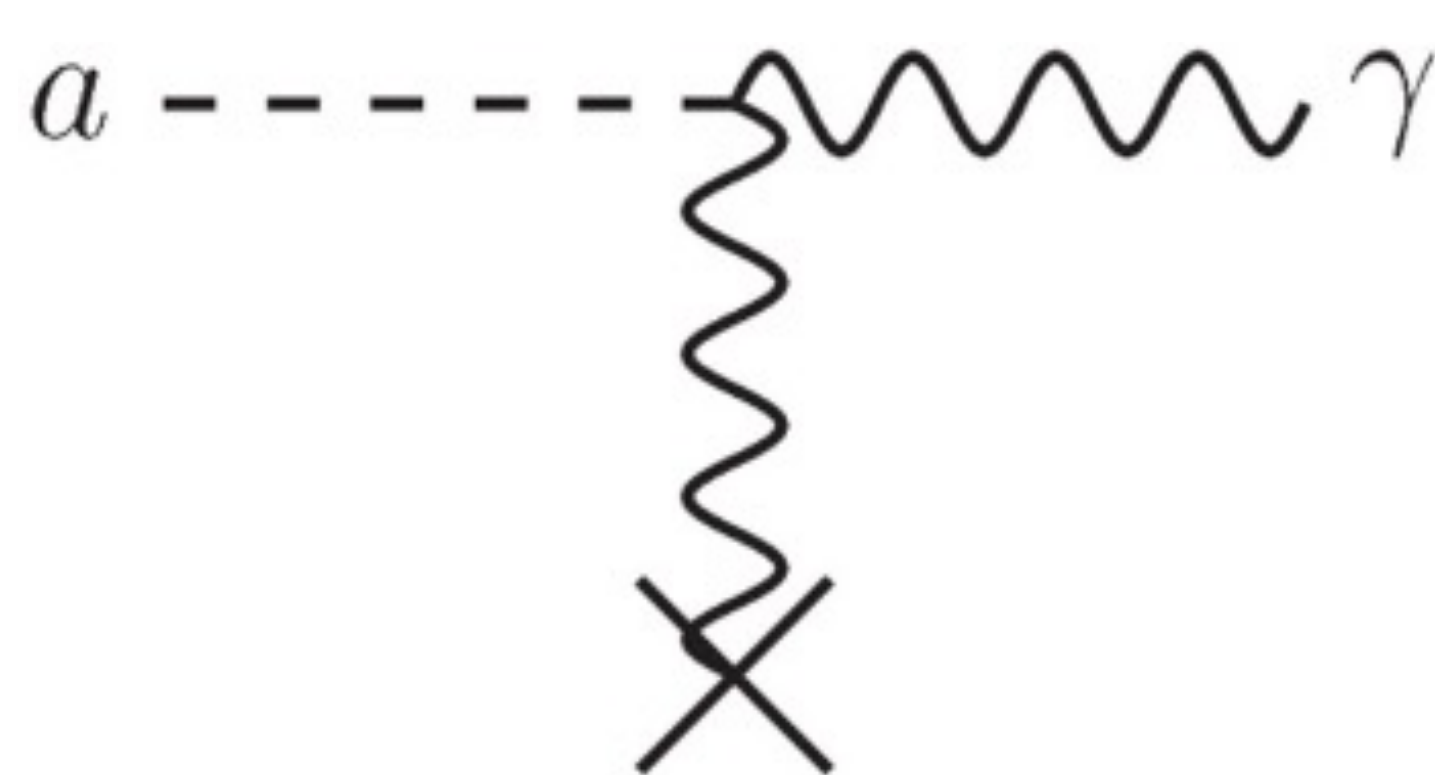
Couplings to known fields

$$a(t) \propto \sqrt{\rho_{DM}} \cos\left(\frac{m_a c^2}{\hbar} t\right) \propto a_0 \cos(\omega_a t)$$

$$H \propto a \vec{E} \cdot \vec{B}$$

$$H \propto \vec{\sigma} \cdot \vec{\nabla} a$$

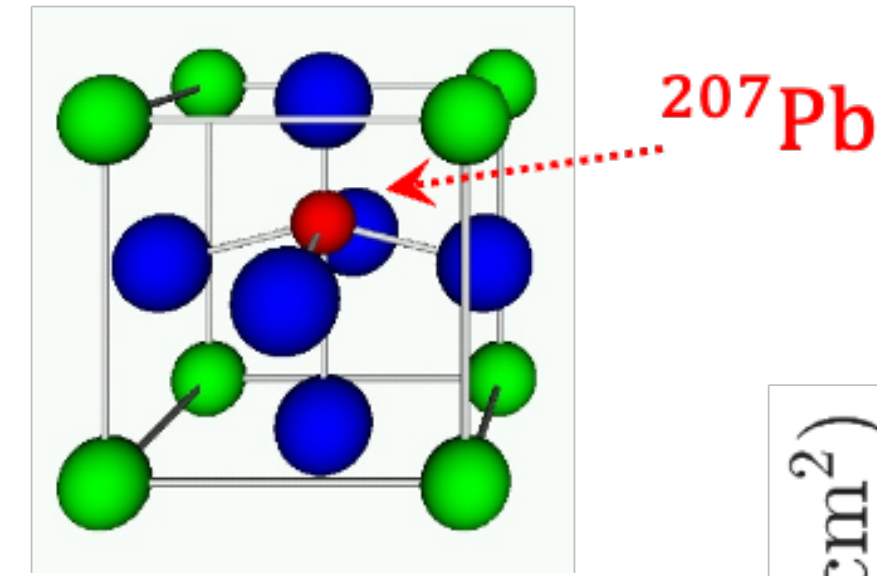
$$H \propto a \vec{\sigma} \cdot \vec{E}^*$$



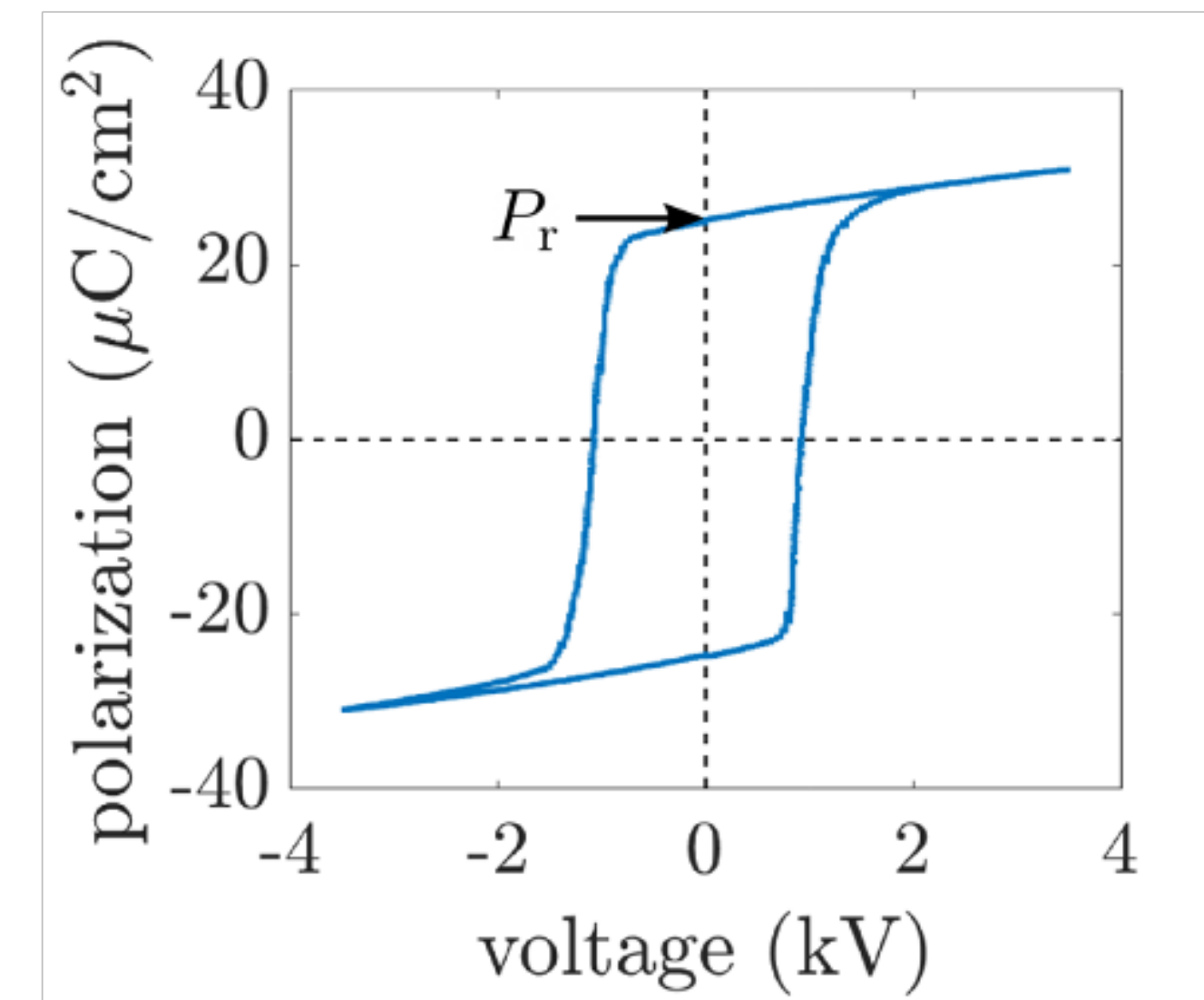
Arian Dogan's talk!

Magnetic Sensors

Inductive detection



$$P(t) = \frac{1}{\pi r^2} \int_0^t I(t') dt'$$



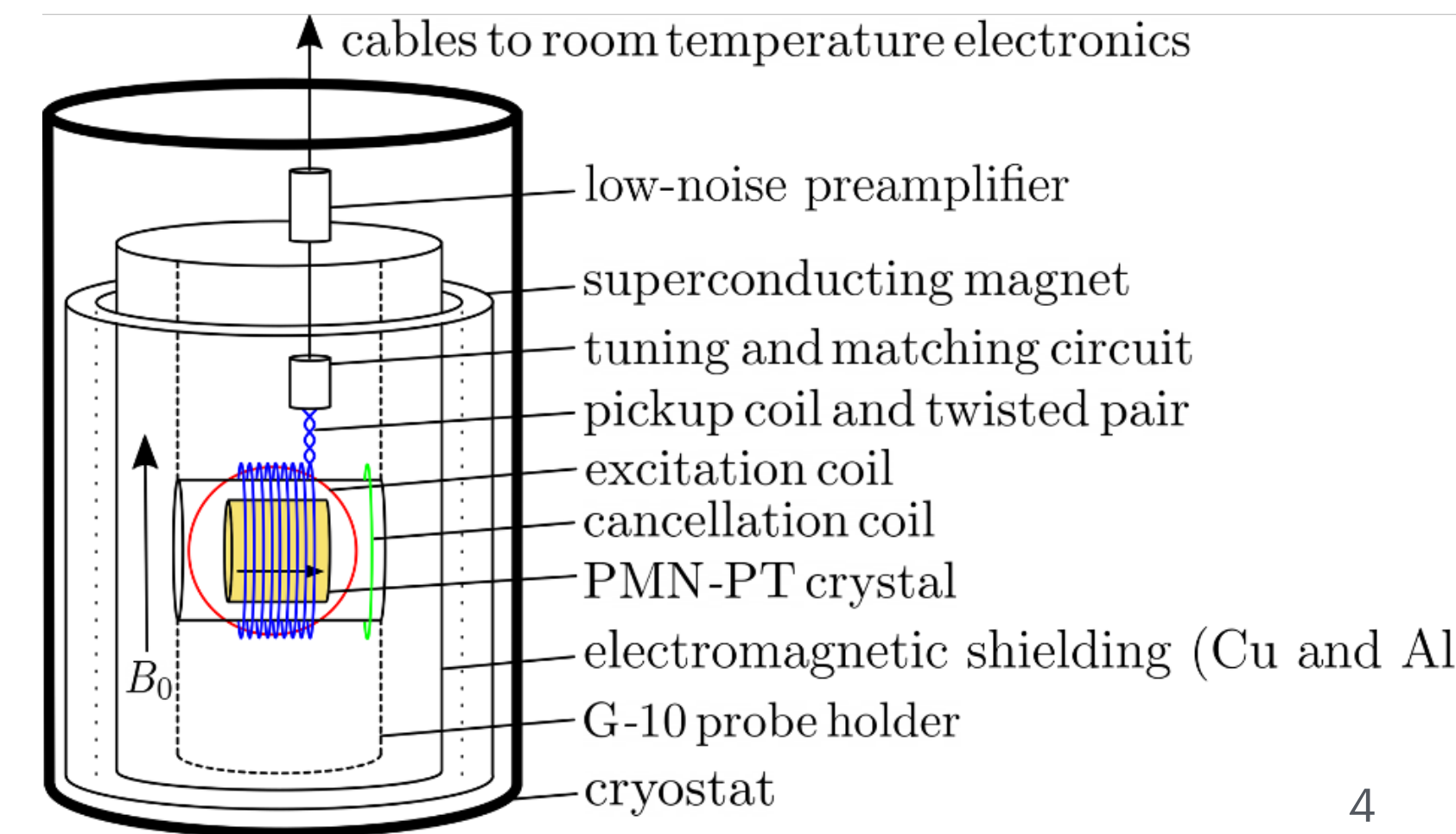
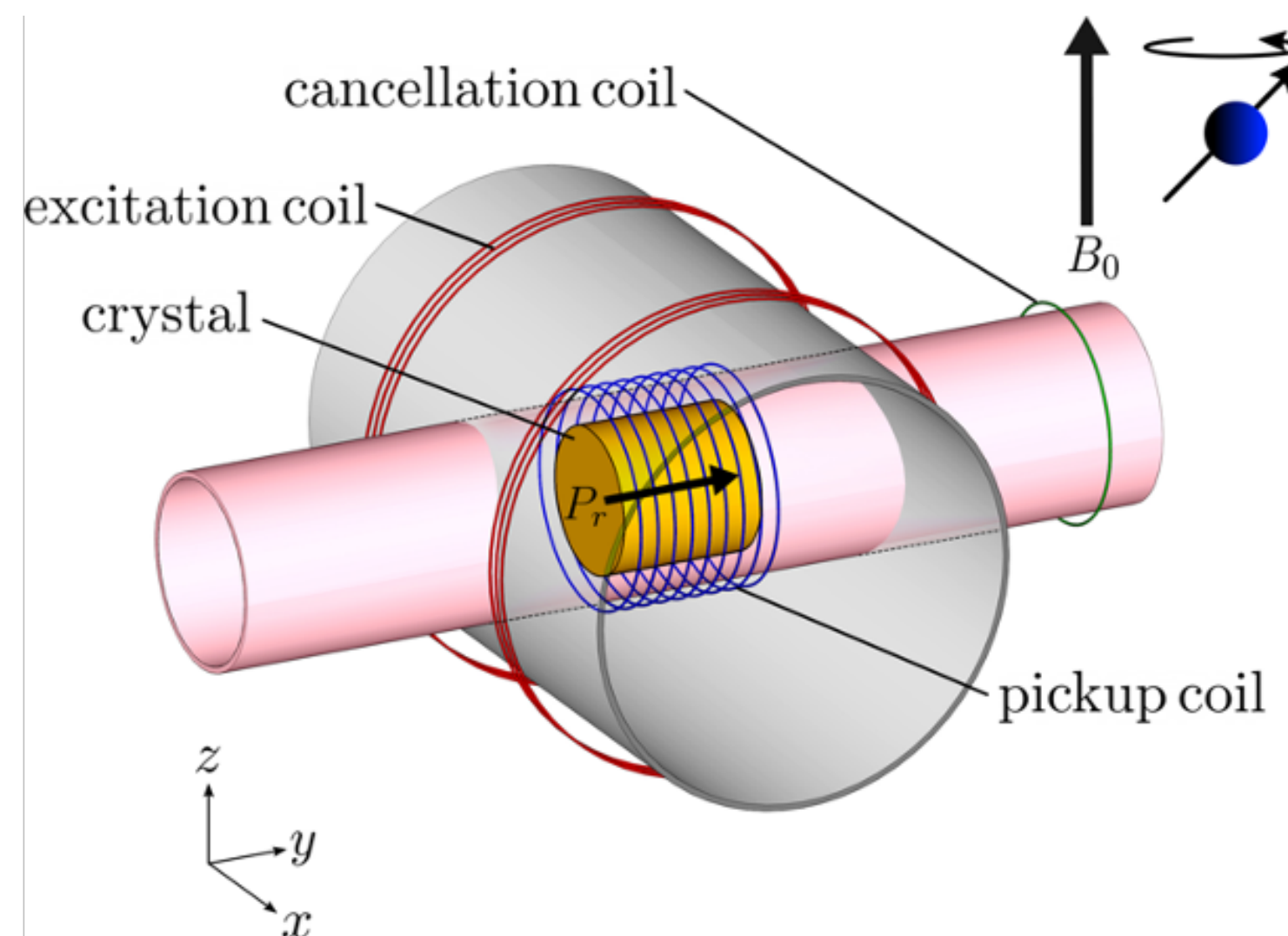
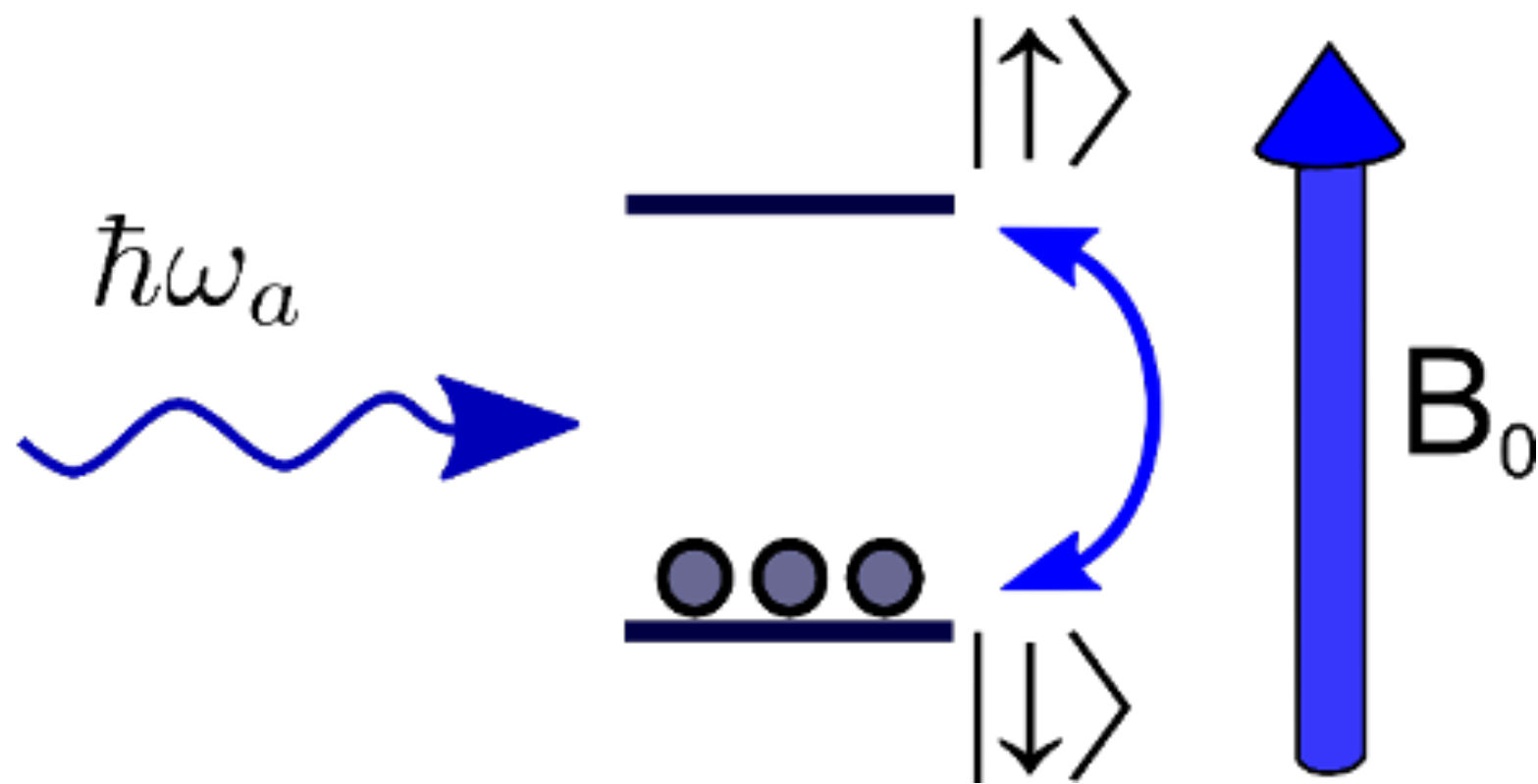
$$a(t) \propto a_0 \cos(\omega_a t)$$



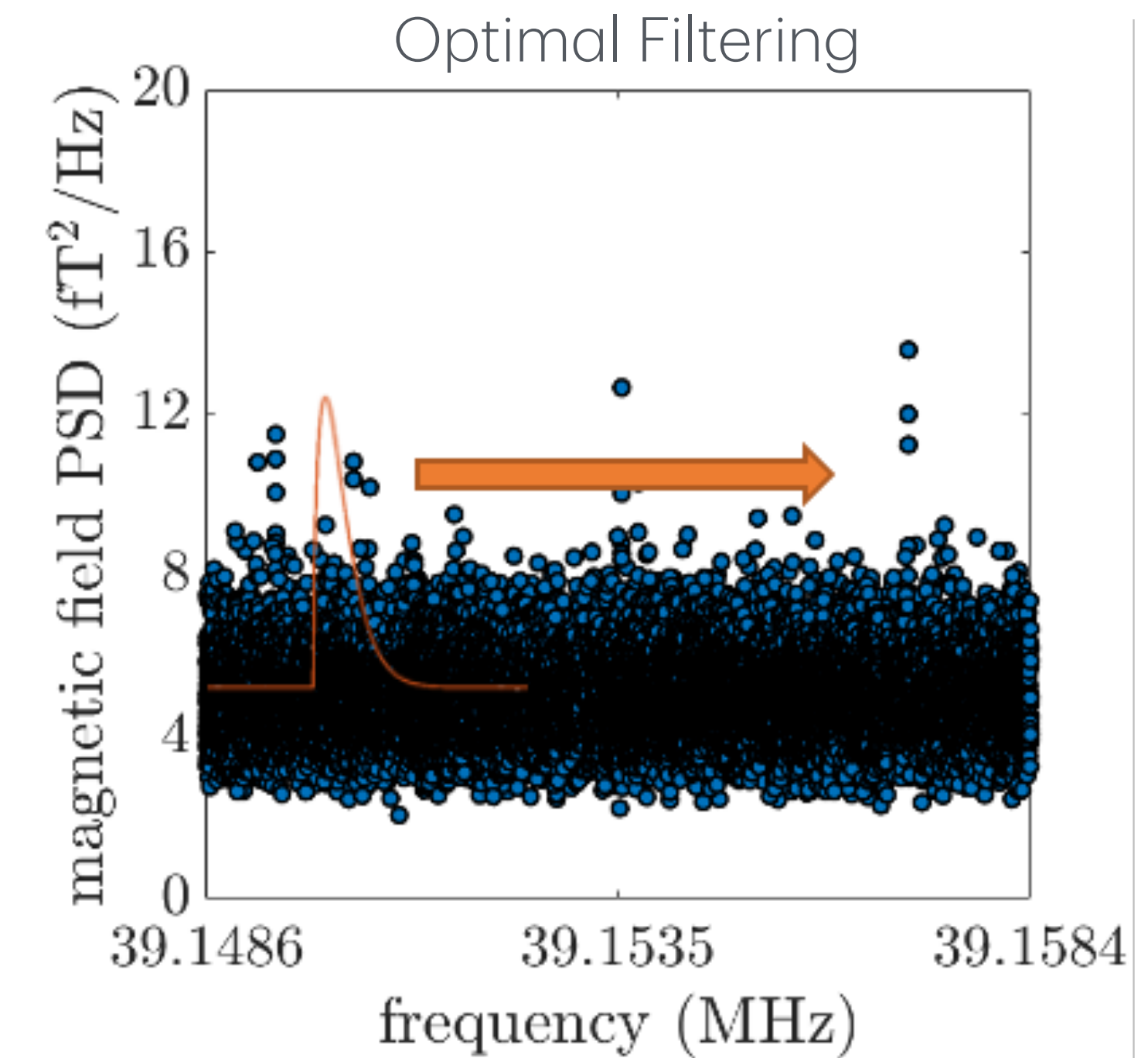
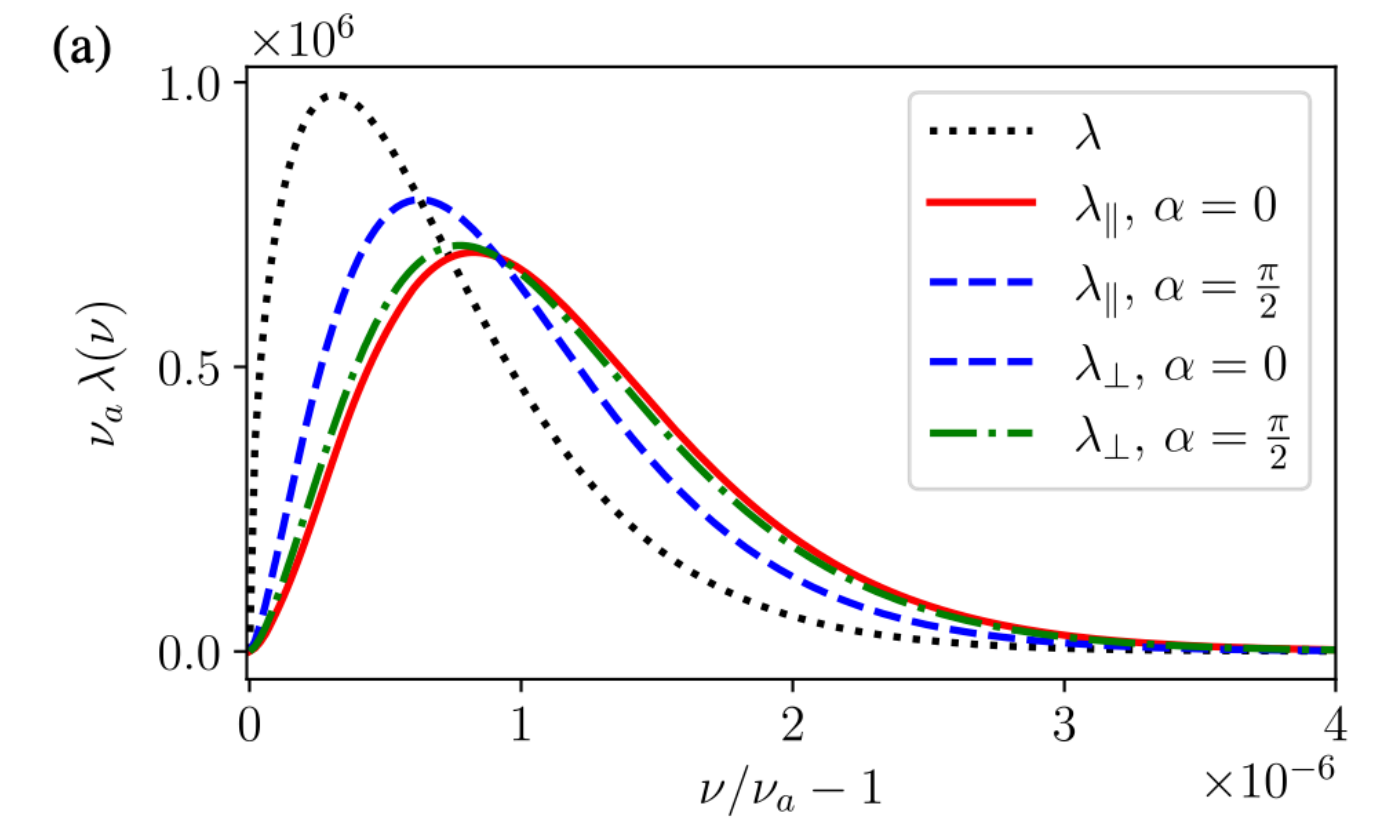
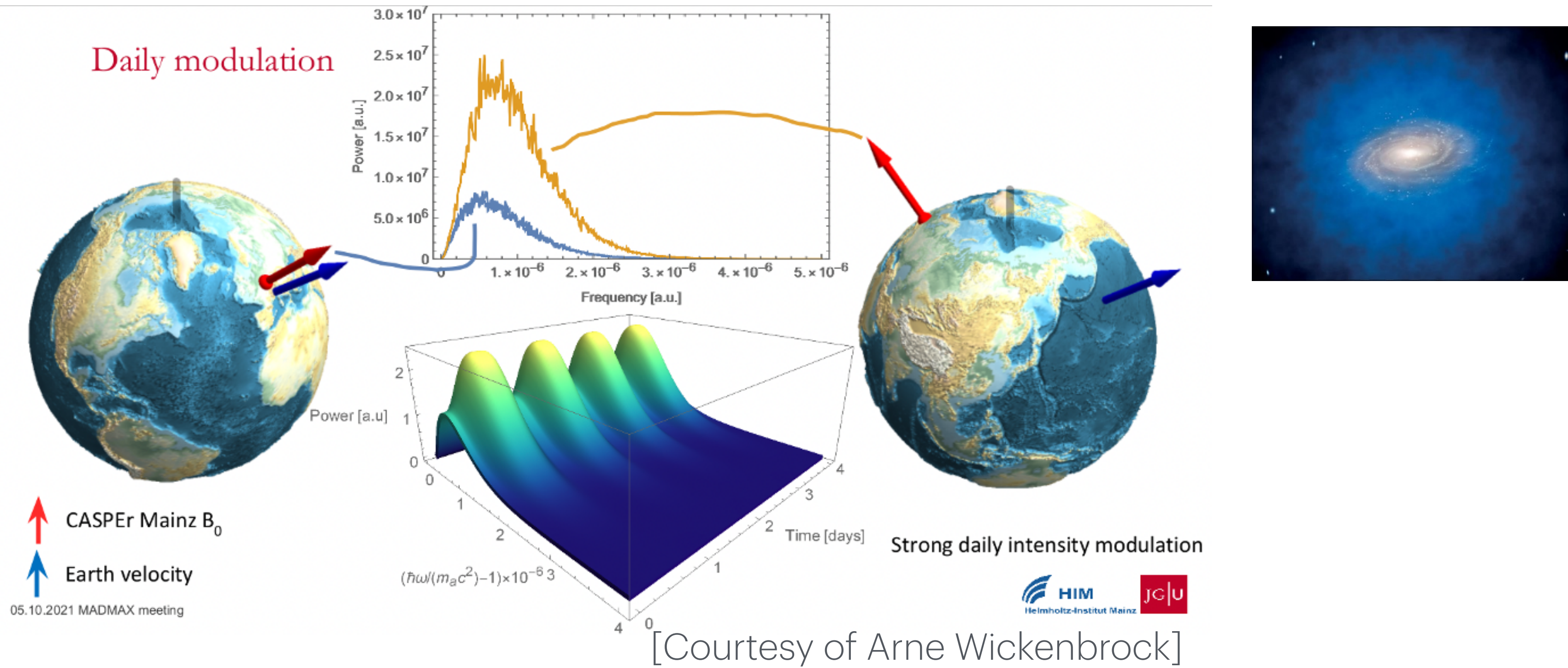
$$H \propto (\vec{\sigma} \cdot \vec{\nabla} a_0) \cos(\omega_a t)$$

$$H \propto (a_0 \vec{\sigma} \cdot \vec{E}^*) \cos(\omega_a t)$$

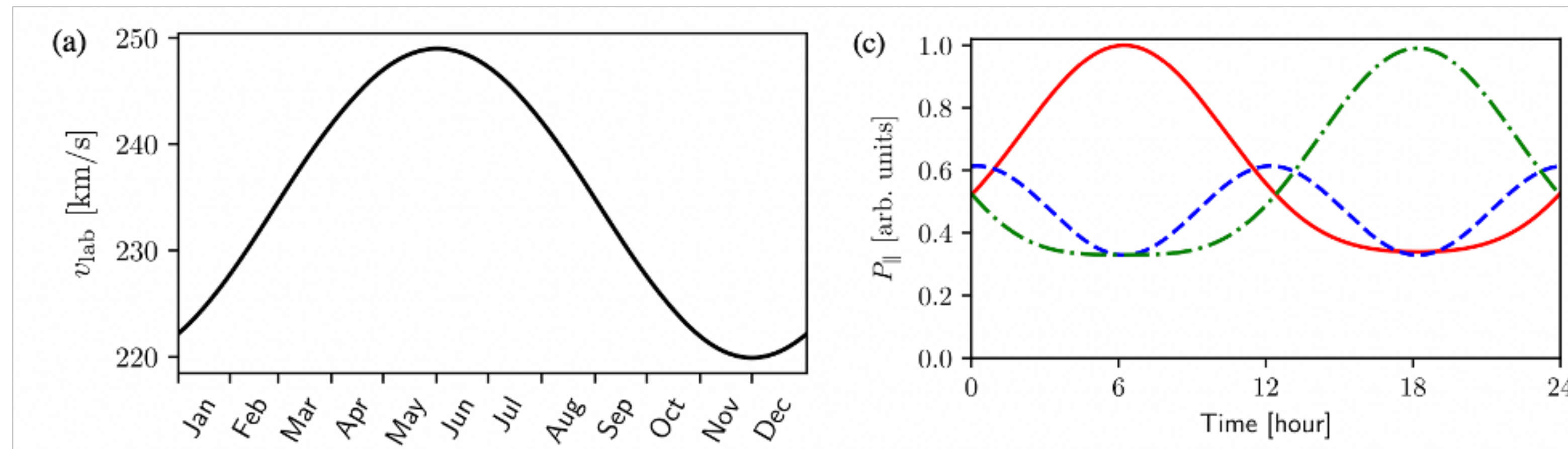
$$H \propto (\vec{\sigma} \cdot \vec{B}^*) \cos(\omega_a t)$$



Expected Line-shapes from Axion Couplings



[Gramolin et al., PRD 105, 035029 (2022)]



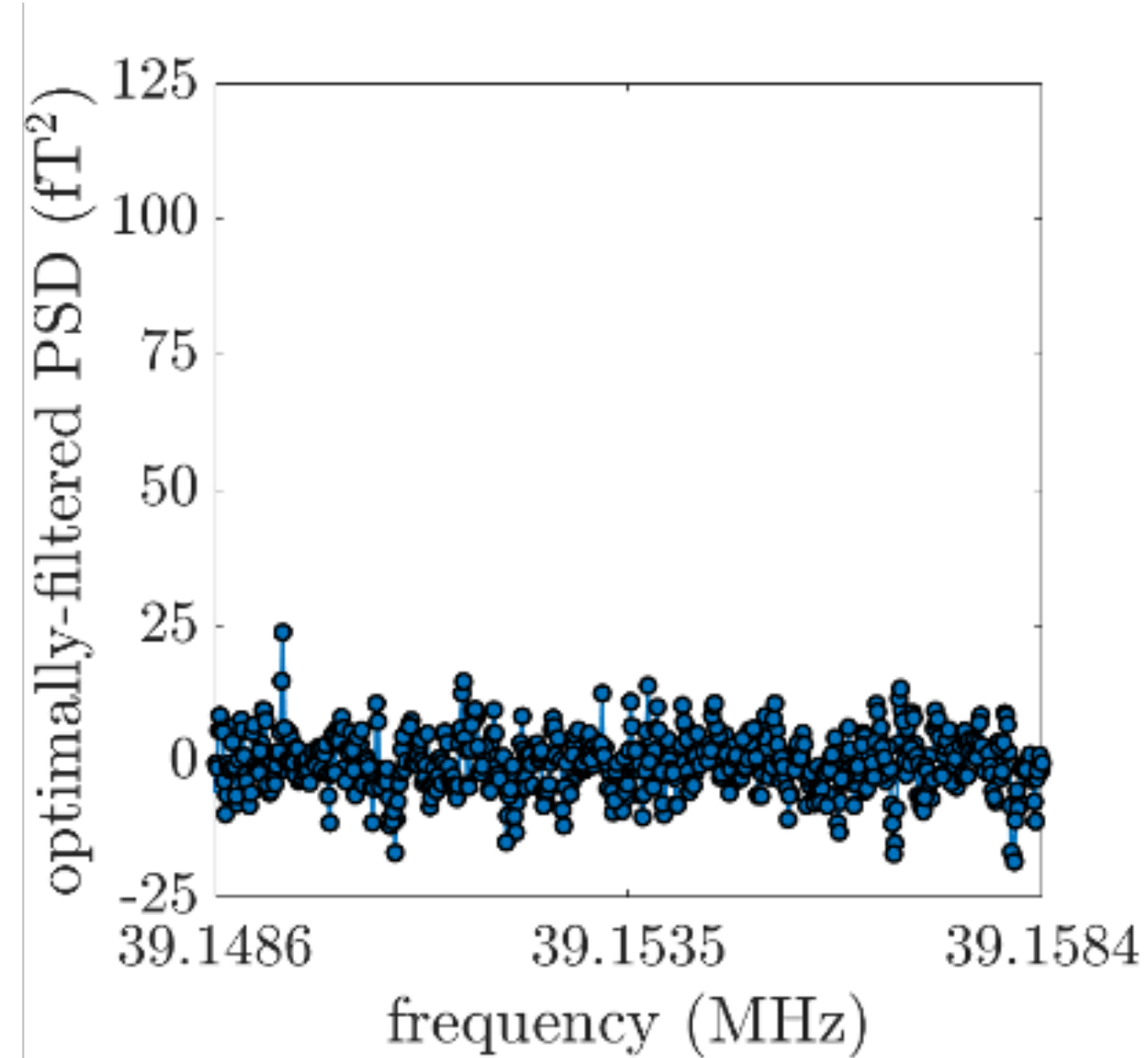
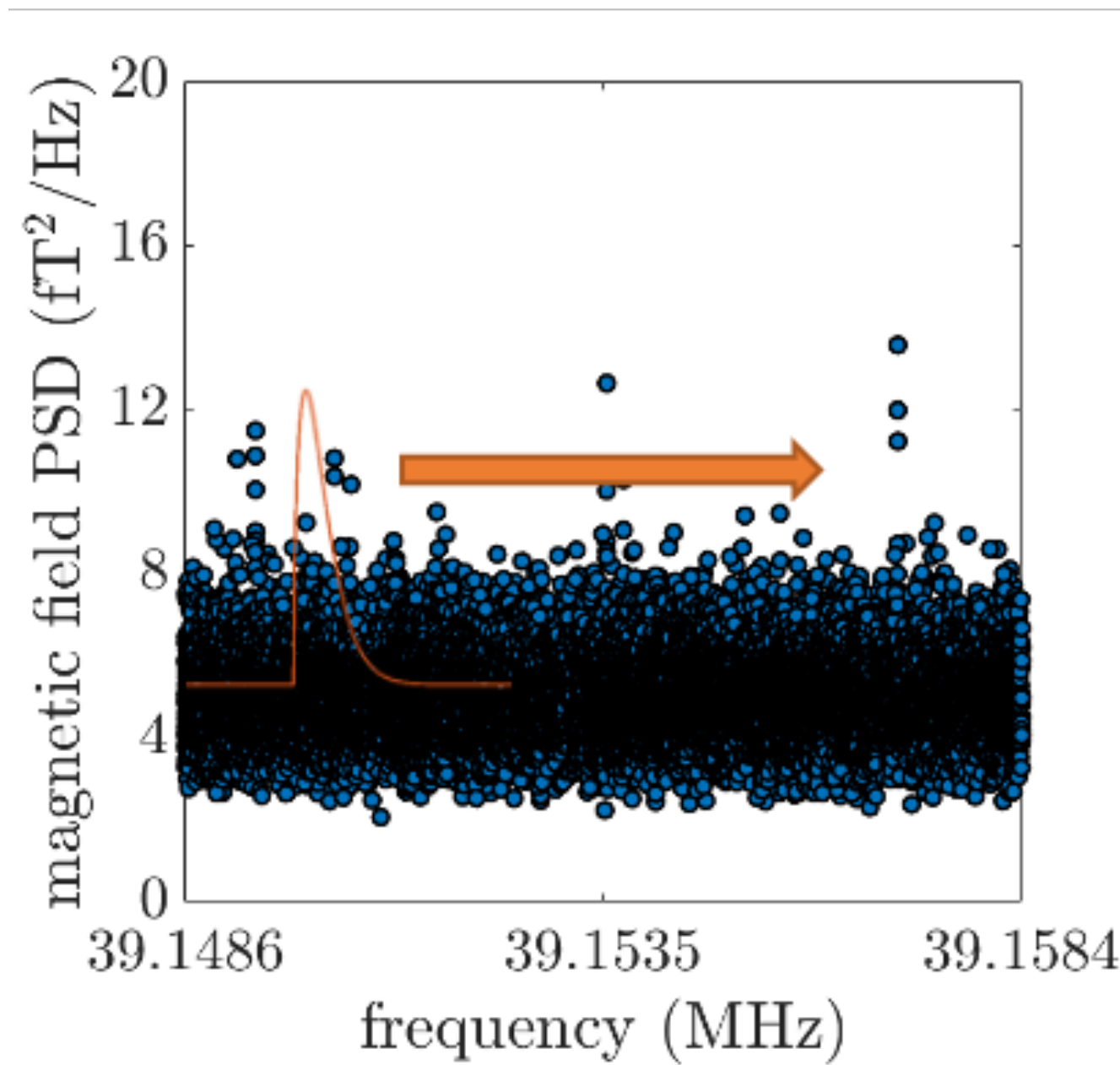
Magnetic Sensors

Data analysis with CASPEr-Electric



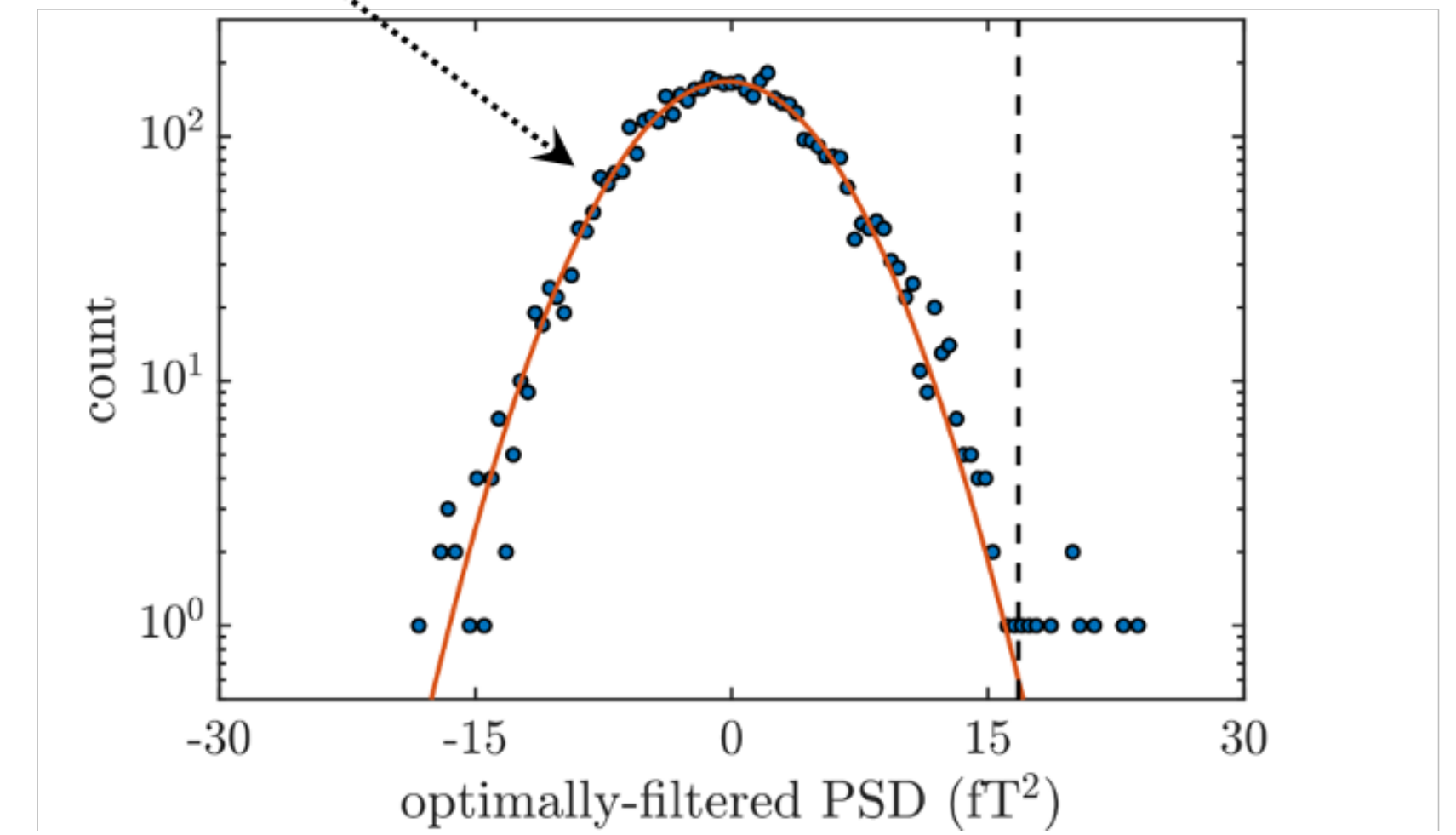
Alex Sushkov

$$S_{\text{measurement}} = S_{\text{signal}} + S_{\text{noise}}$$

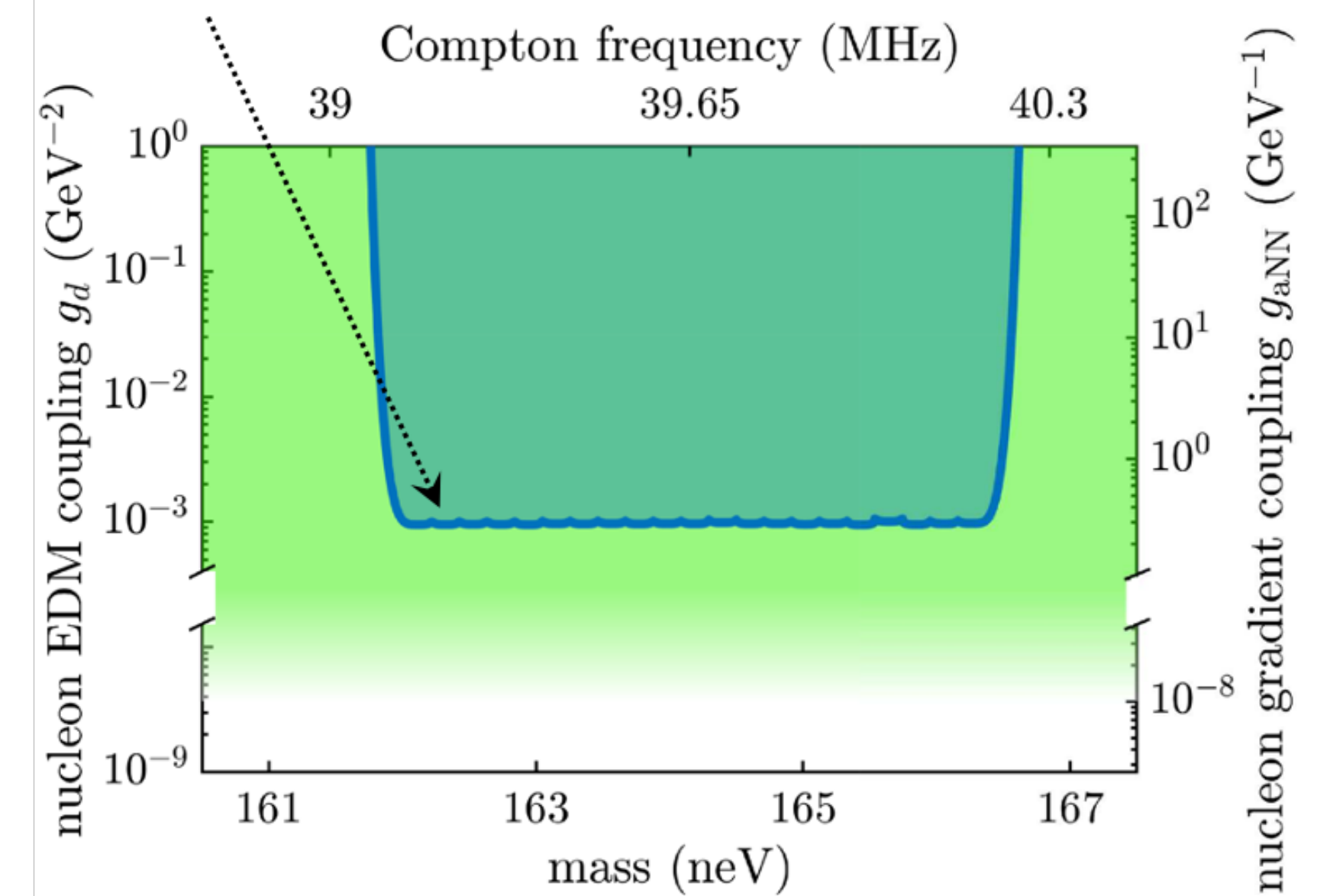


3.355 σ detection threshold

histogram of data points



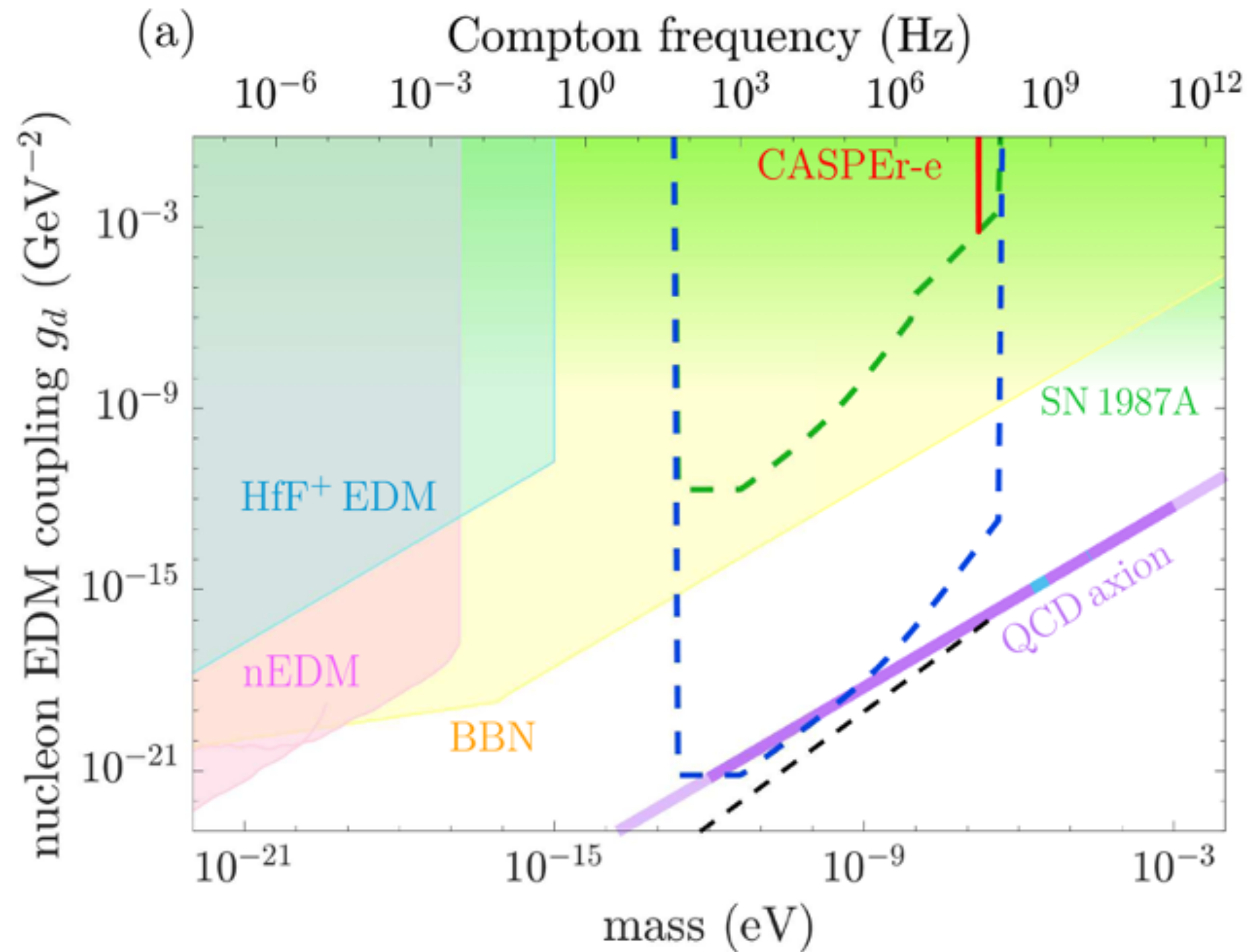
5 σ detection limits at 21 B_0 values



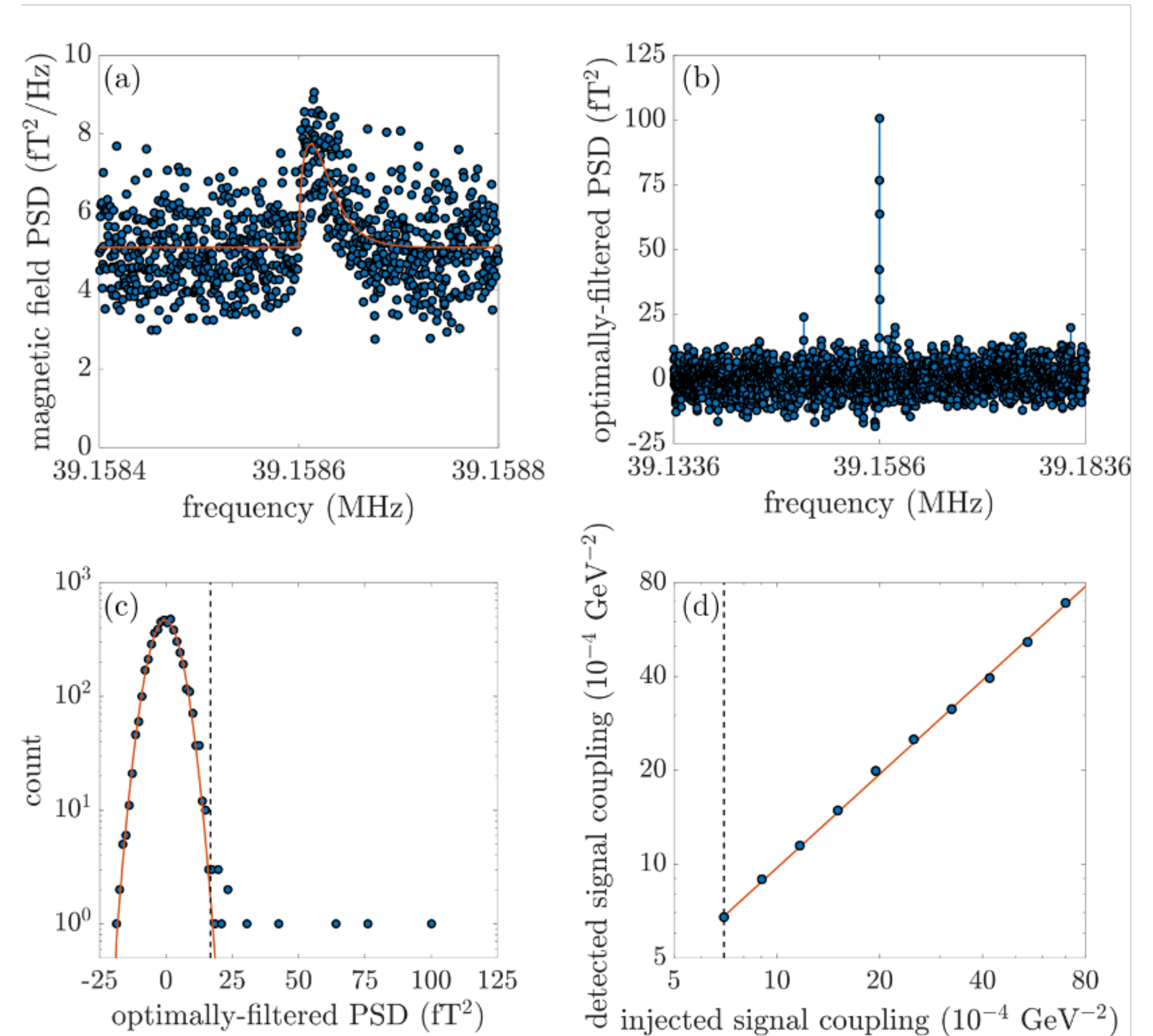
[Aybas et al., PRL 126, 141802 (2021)]

Magnetic Sensors

Data analysis with CASPEr-Electric



$$S_{total} = S_{measurement} + S_{simulated\ axion}$$

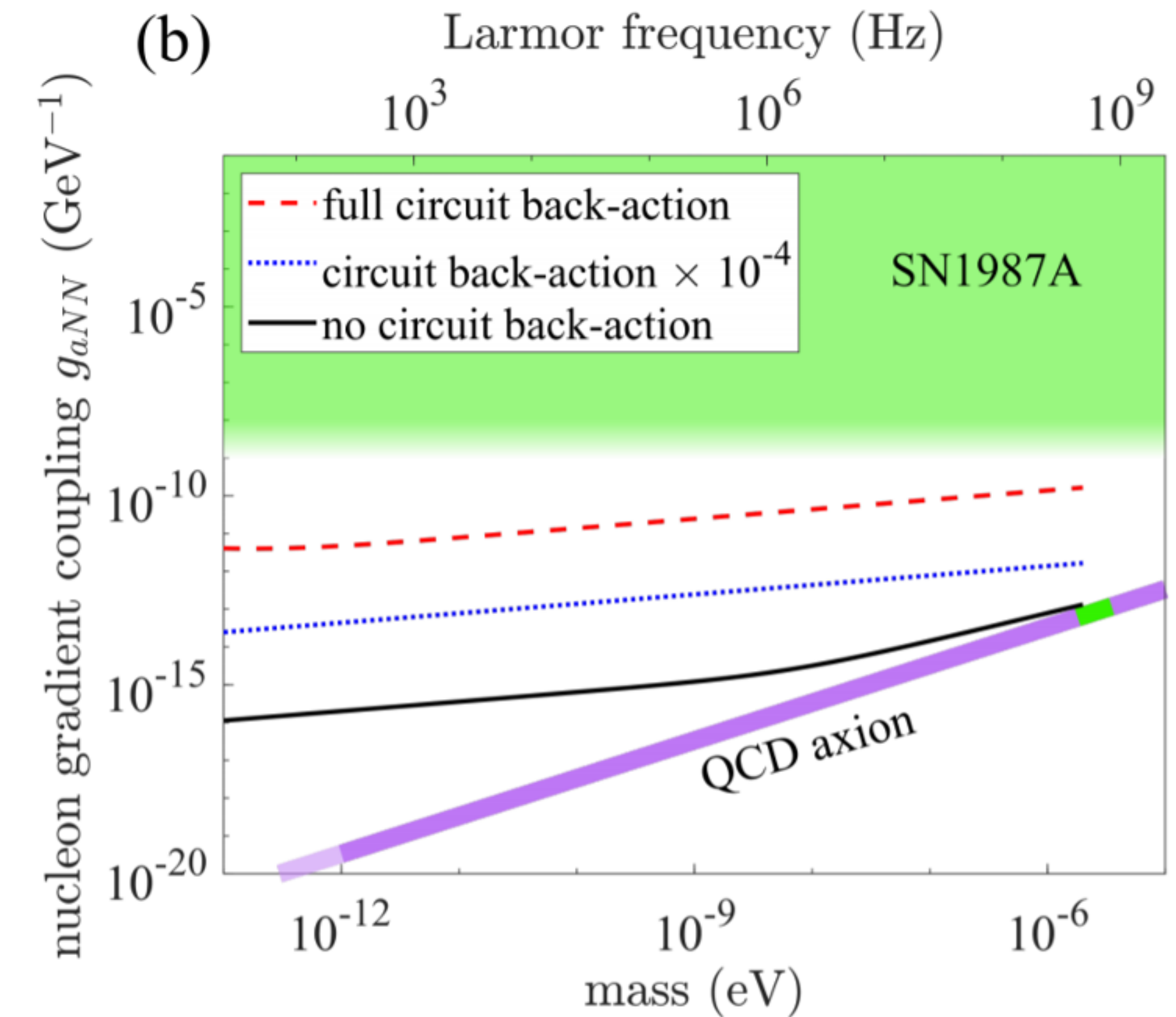
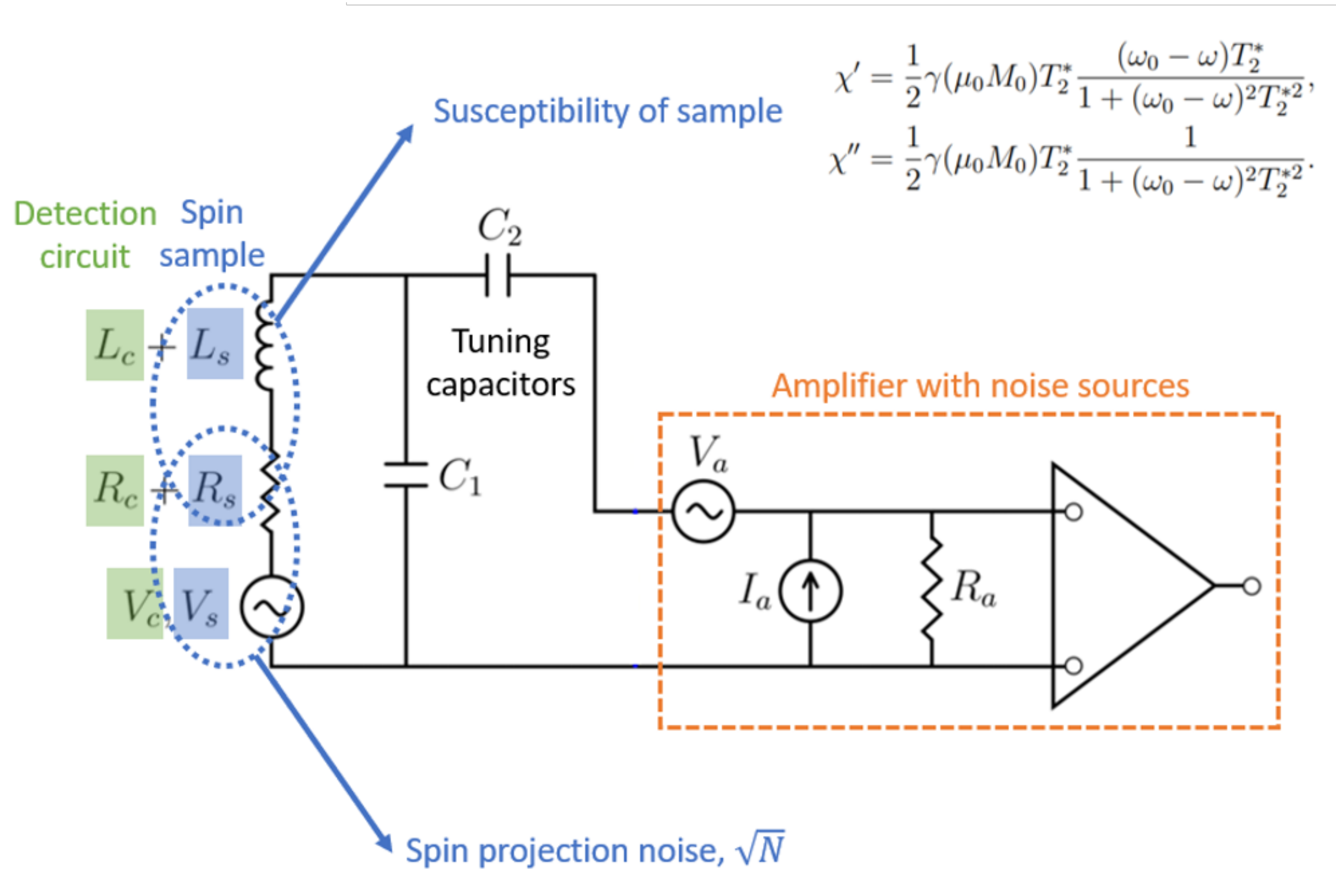


Magnetic Sensors

Fundamental sensitivity limit

Two noise sources:

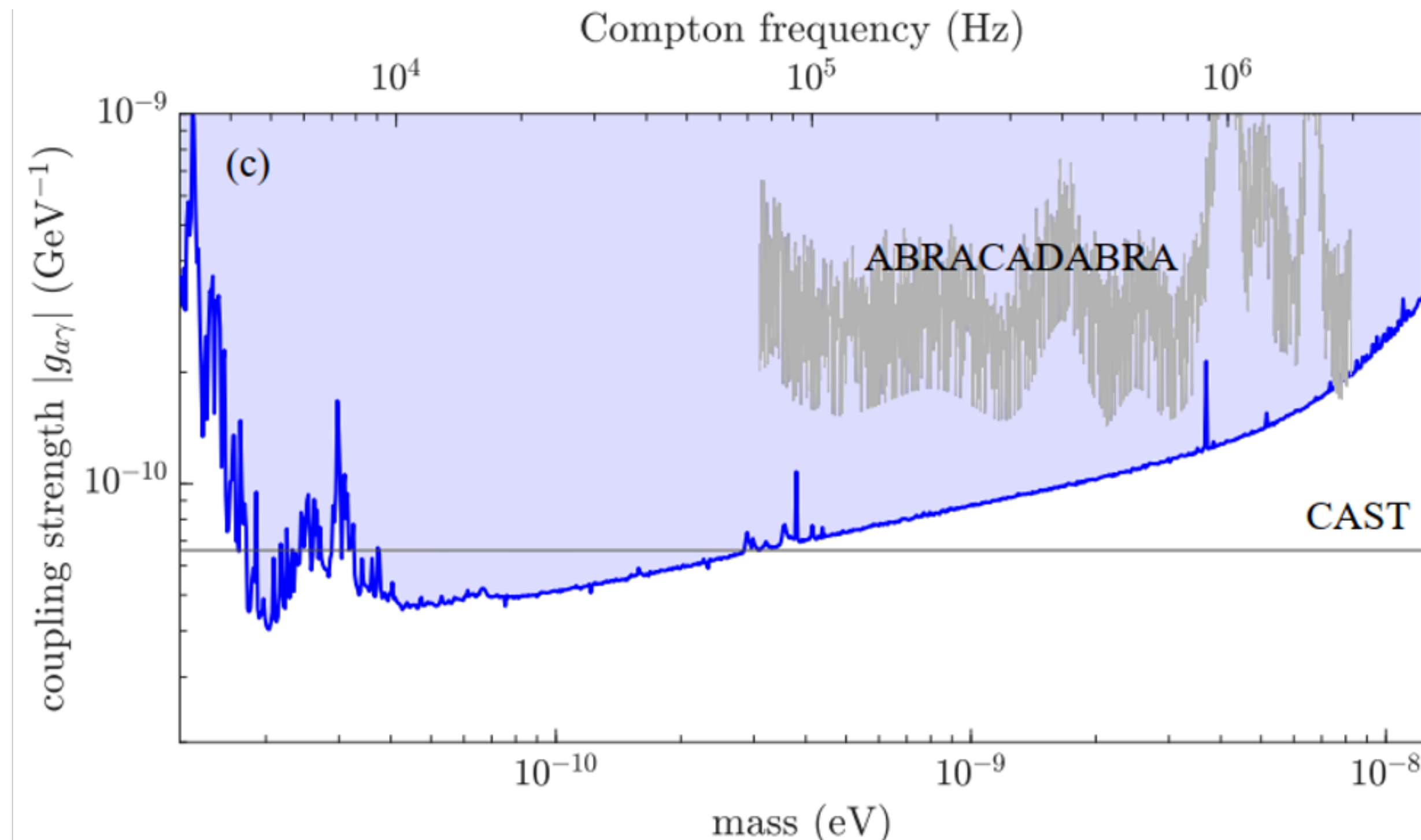
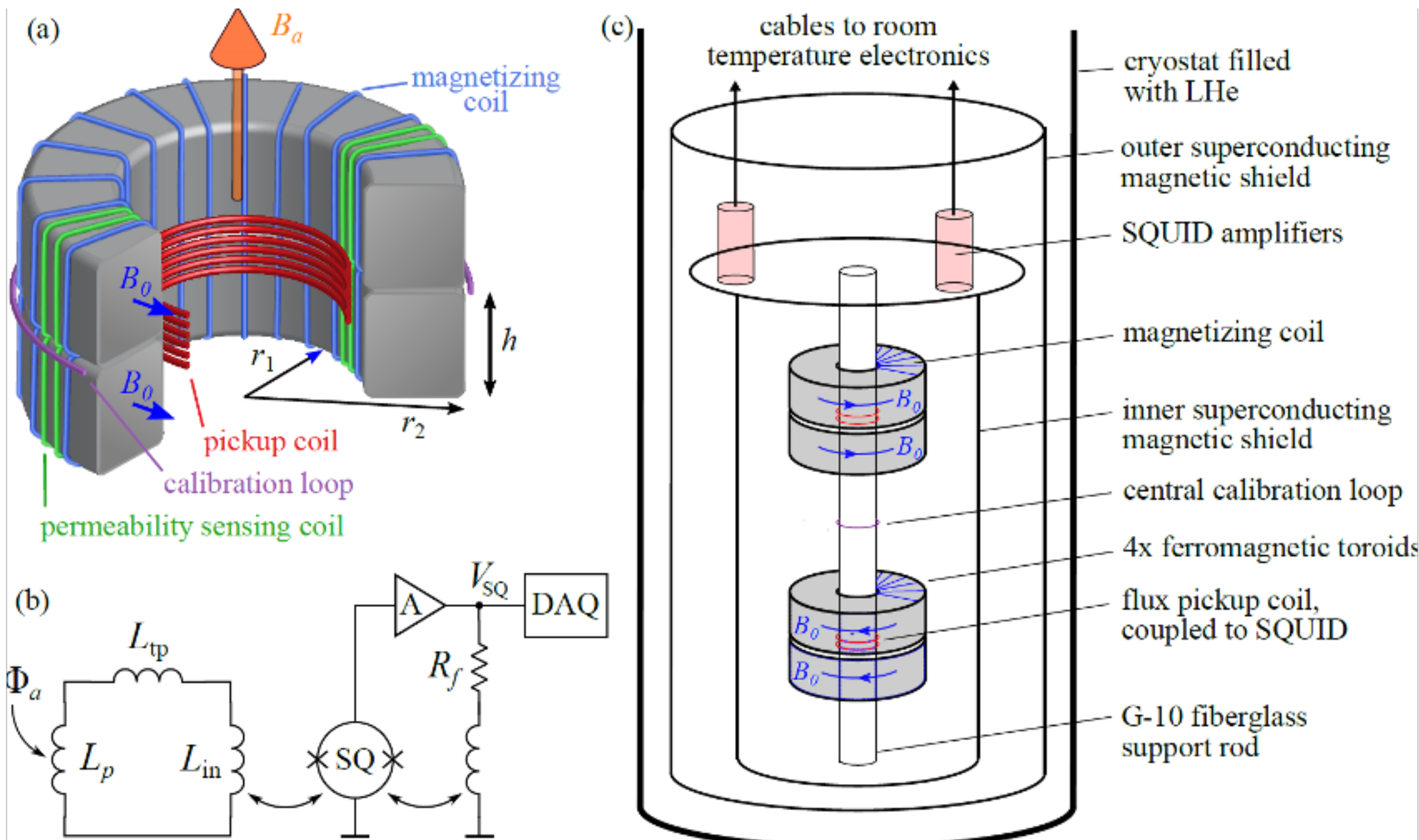
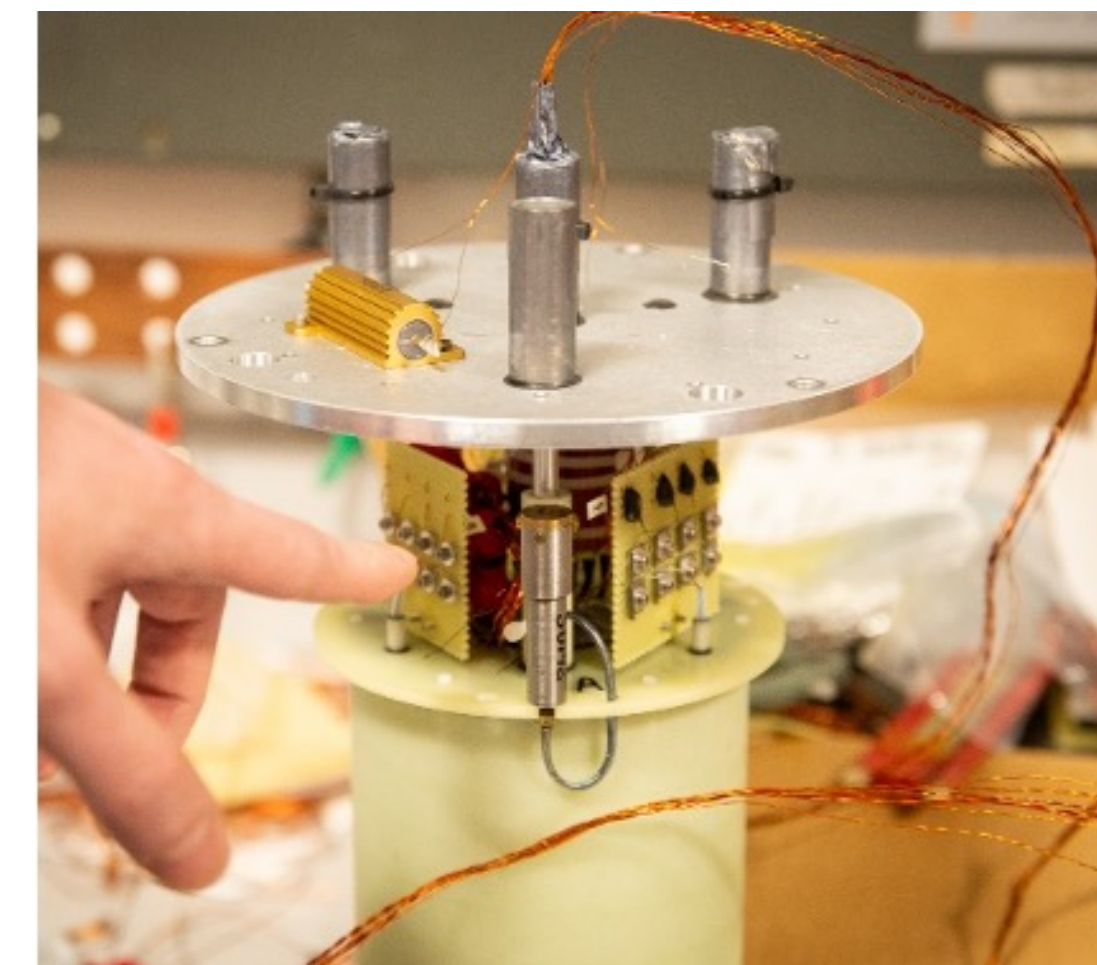
circuit back-action (radiation damping) -> can be suppressed
 quantum spin projection noise



Magnetic Sensors

Inductive detection with SQUIDS

$$\vec{\nabla} \times \vec{H} = \vec{J}_f + \frac{g_{a\gamma}}{\mu_0 c} \frac{\partial a}{\partial t} \vec{B}$$

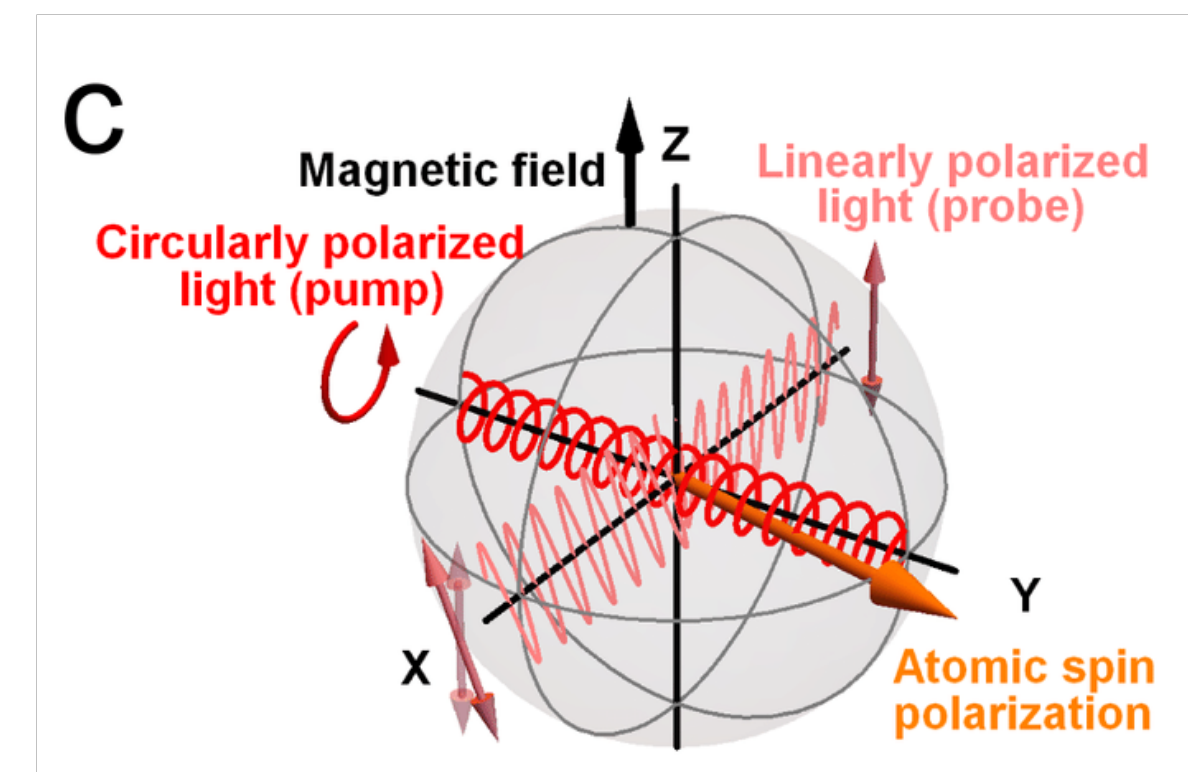
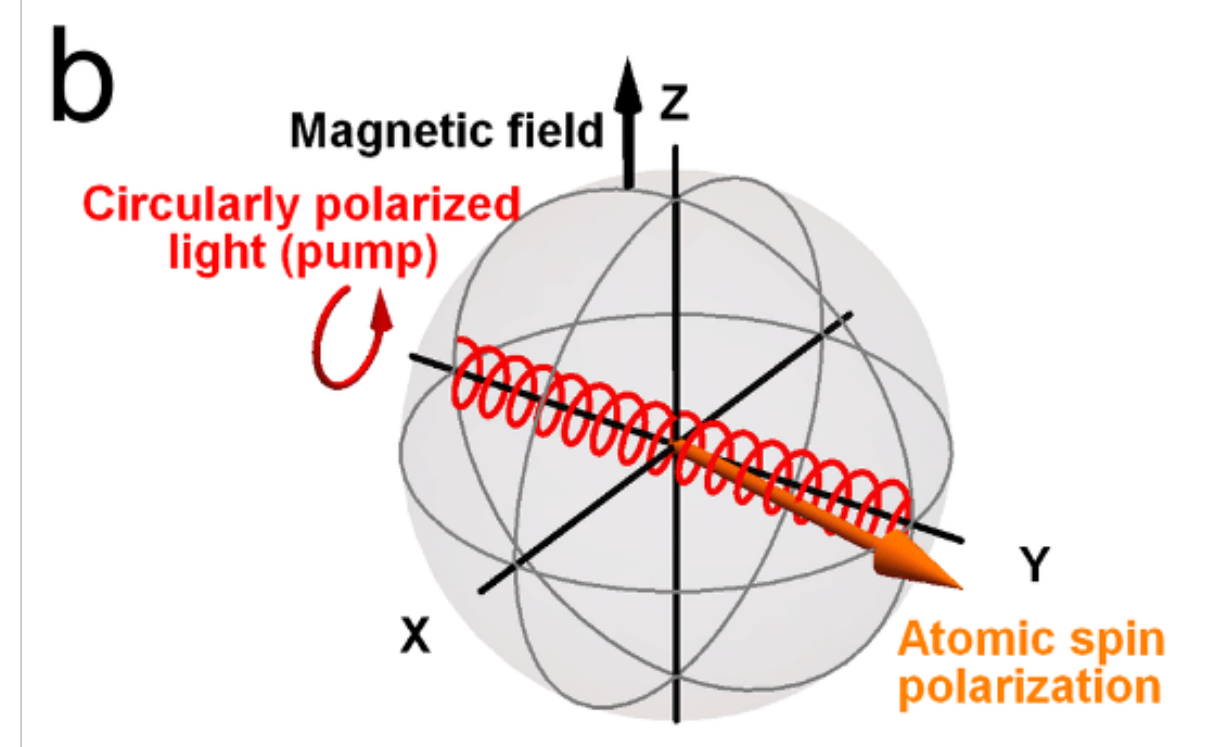
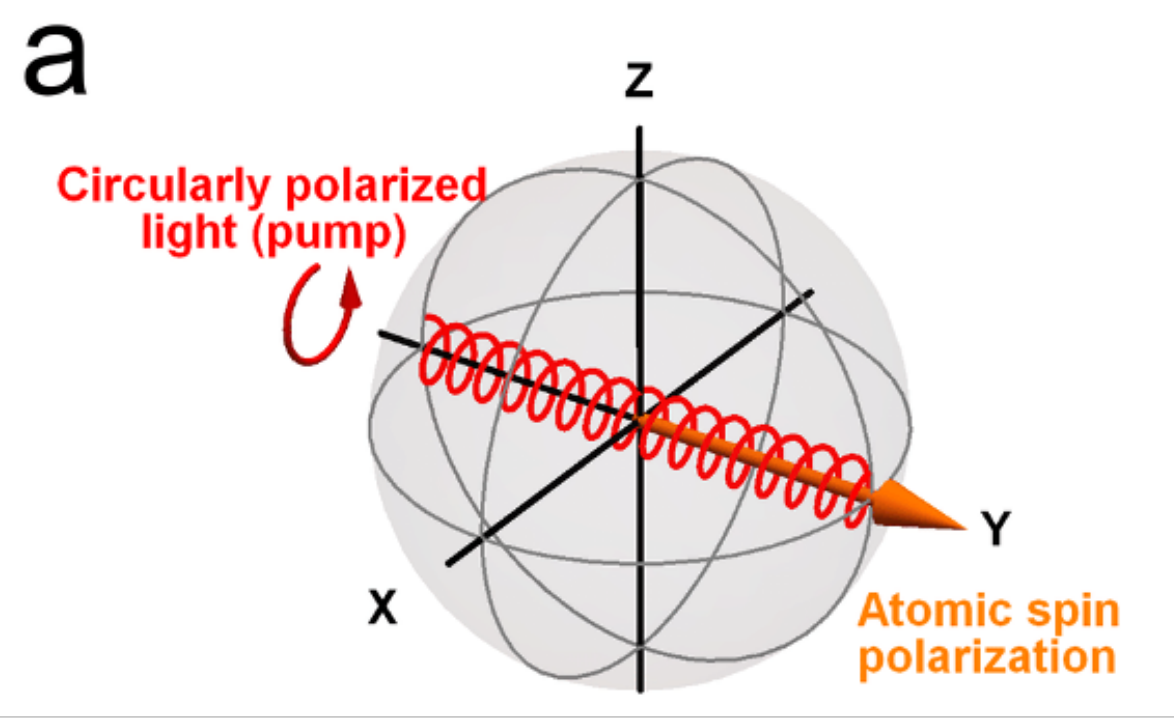
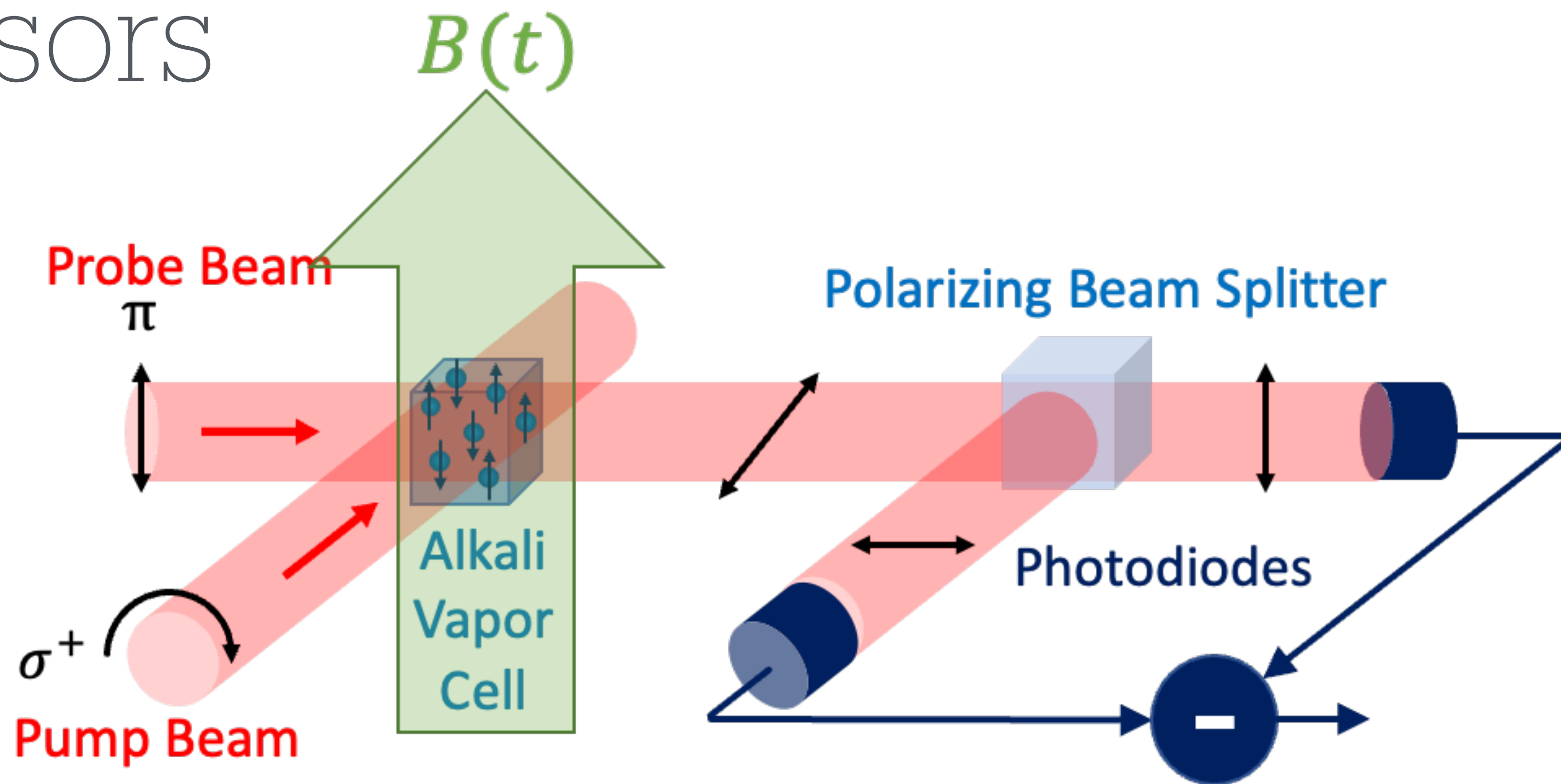


[Gramolin et al., Nature Physics 17, 79 (2021)]

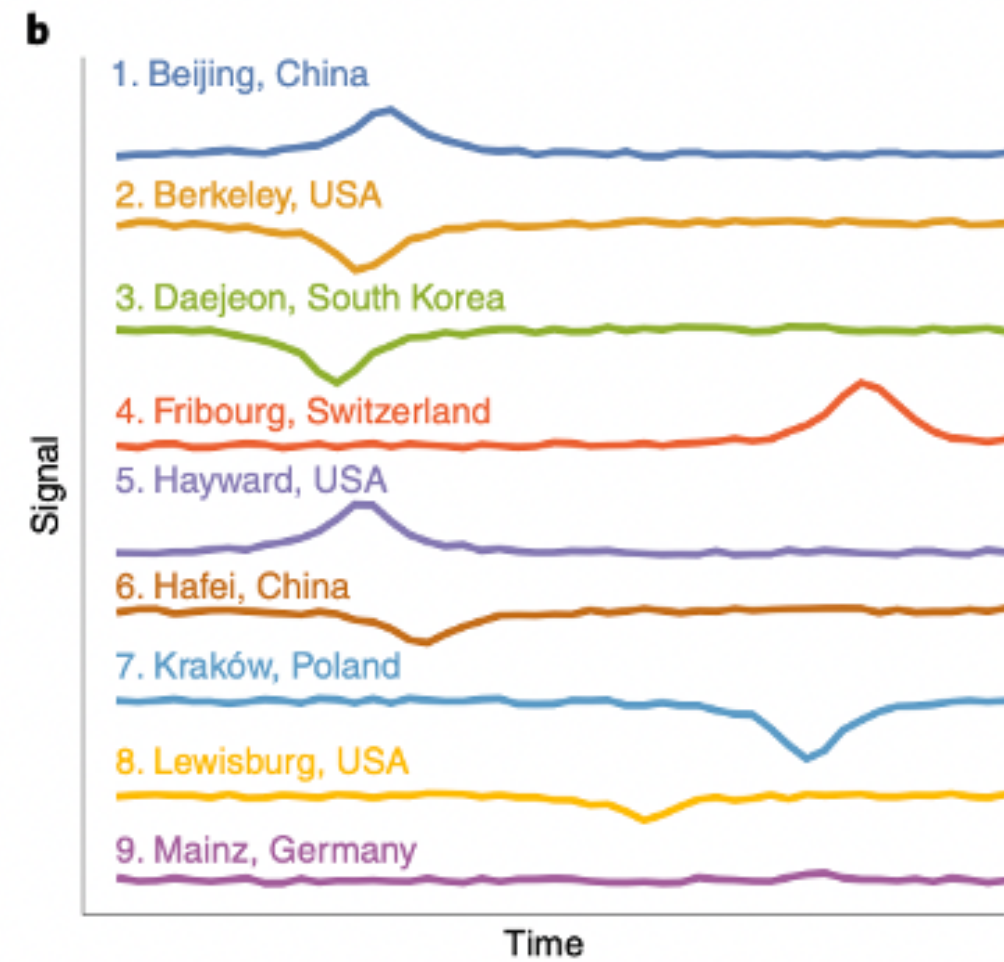
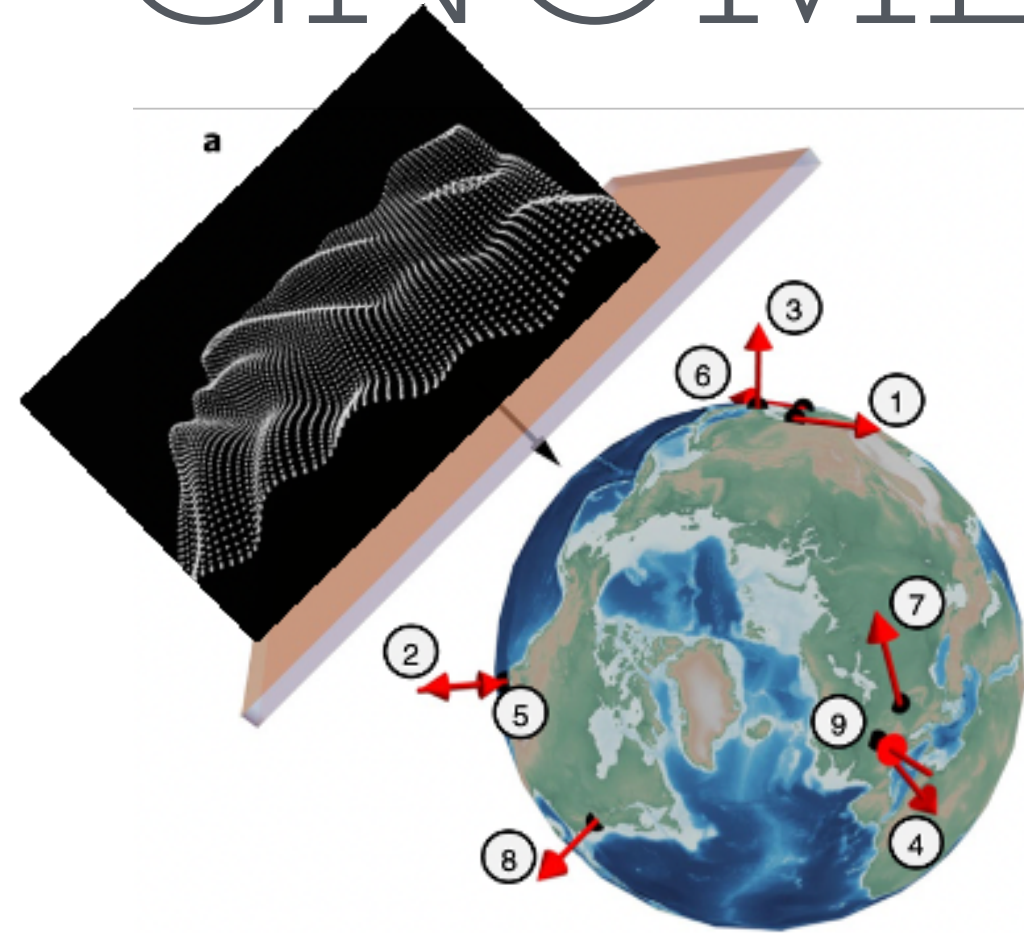
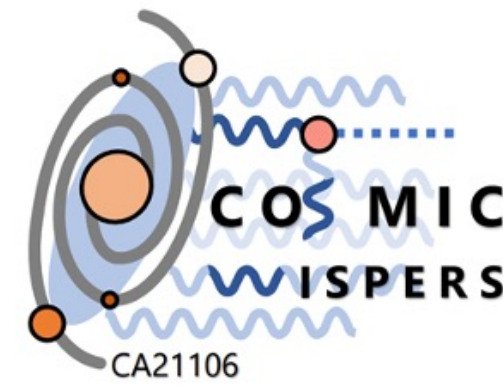
Magnetic Sensors

Optical detection

$$\phi \propto \langle S_x \rangle = S_0 \frac{g\mu_B}{\hbar} B_z$$



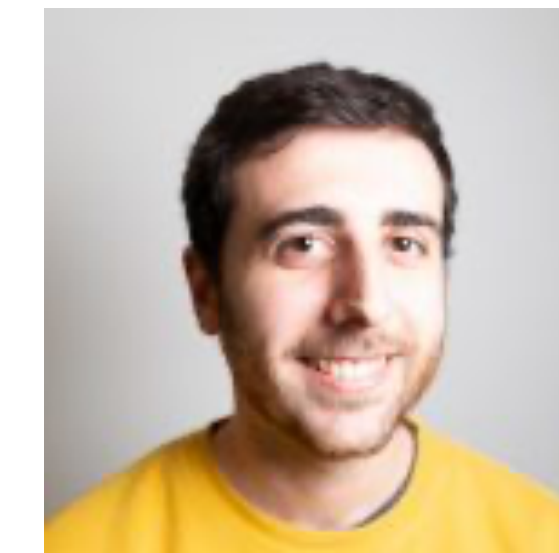
GNOME Collaboration



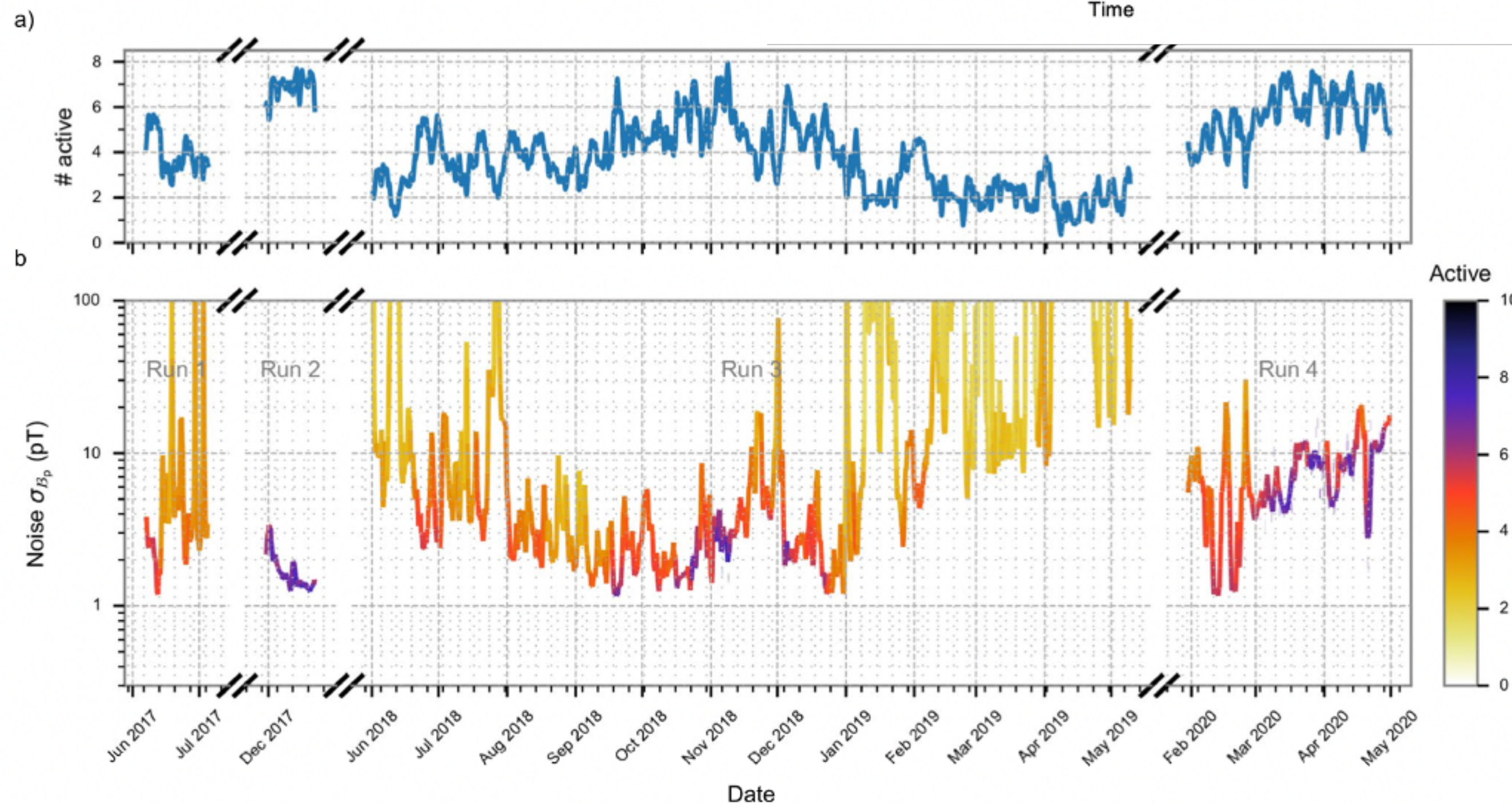
[budker.uni-mainz.de/gnome/]



Dima Budker



Dani Gavilán's talk!



- Broadband or tunable magnetometers
- Sensitivity to tiny signals with model-dependent line-shapes
- Data analysis with coincidence statistics

[Nature Physics 17, 1396–1401 (2021)]

GNOME @Bilkent



MSc Students:
Silvana Abi Mershed
Ahmed Alzaidi
Sara Dinçoğlu

BSc Students:
İdil Gözel
Gökalp Elaçmaz

Optical Magnetometry for:

ZULF NMR (Increase signal to noise ratio & coherence time, improve shield & cell designs, shieldless operation at Earth's magnetic field)

Magnetic signatures from elusive particles
(GNOME axion dark matter search, *and more!*)



Funded by TÜBİTAK 2232-B



MAGNETIC DISCUSSION

Bruno Tuschek

Cartoon by **Bruno Tuschek**
(3 February 1921–25 May 1978)

Thank you!