The origins of noise in the Zeeman splitting of spin qubits in natural-silicon devices

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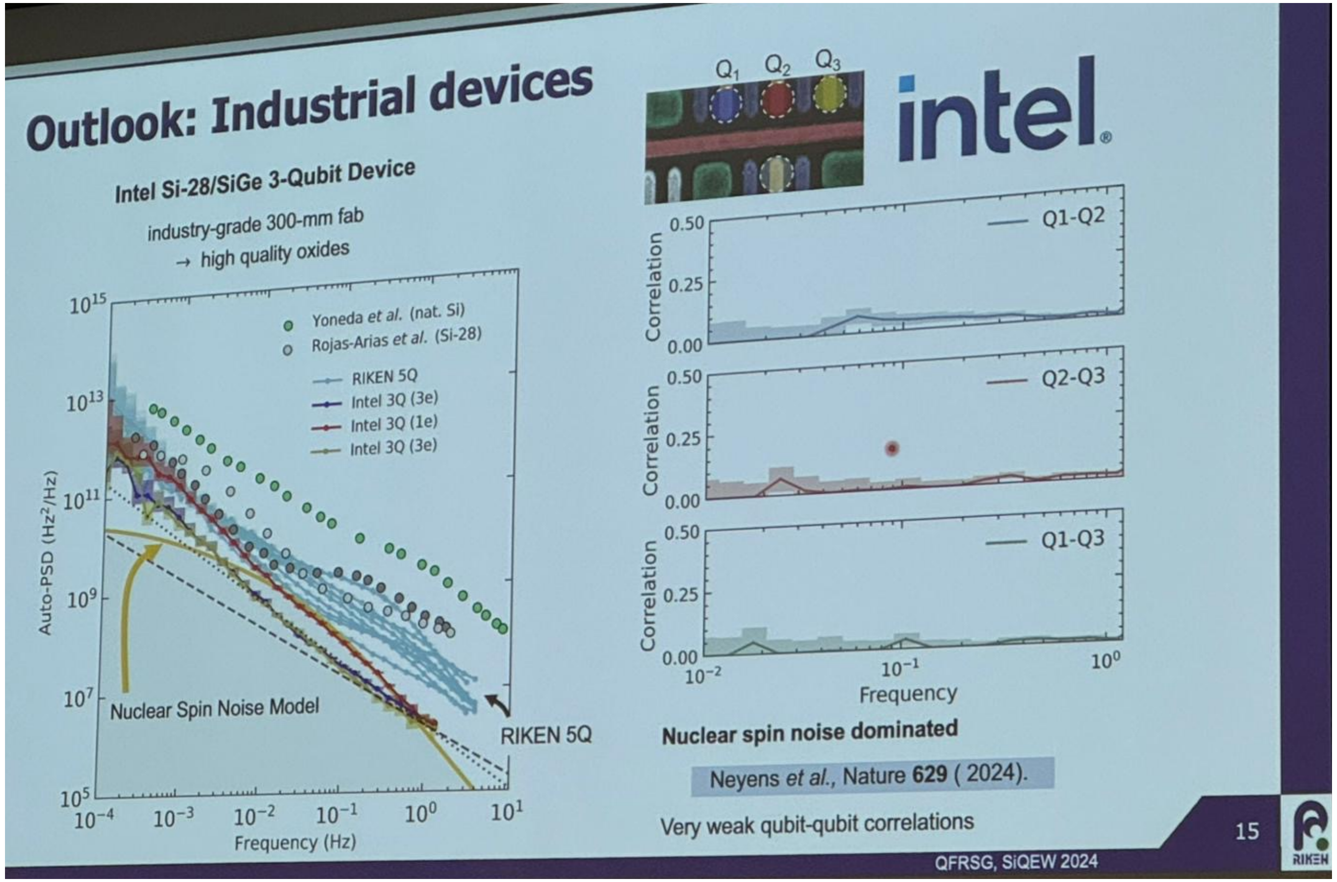
We measure and analyze noise-induced energy-fluctuations of spin qubits defined in quantum dots made of isotopically natural silicon. Combining Ramsey, time-correlation of single-shot measurements, and CPMG experiments, we cover the qubit noise power spectrum over a frequency range of nine orders of magnitude without any gaps. We find that the low-frequency noise spectrum is similar across three different devices suggesting that it is dominated by the hyperfine coupling to nuclei. The effects of charge noise are smaller, but not negligible, and are device dependent as confirmed from the noise cross-correlations. We also observe differences to spectra reported in GaAs [Phys. Rev. Lett. 118, 177702 (2017), Phys. Rev. Lett. 101, 236803 (2008)], which we attribute to the presence of the valley degree of freedom in silicon. Finally, we observe T_2^* to increase upon increasing the external magnetic field, which we speculate is due to the increasing field-gradient of the micromagnet suppressing nuclear spin diffusion.

Generated by AI

Motivation for us



Leon Camenzind, Silicon Quantum Electronics Workshop 2024

Statement : Nuclear spin noise domination already at “slow” regime

Support

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Bayesian estimation of correlation functions

Ángel Gutiérrez-Rubio[1], Juan S. Rojas-Arias[1], Jun Yoneda[2], Seigo Tarucha[1,3], Daniel Loss[1,3,4], and Peter Stano[3,5,*]

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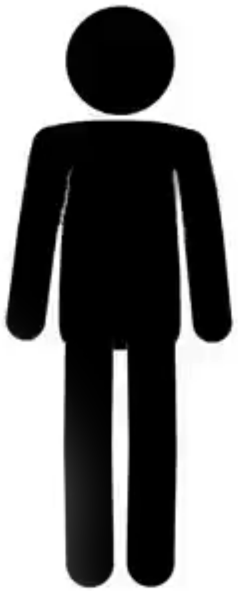
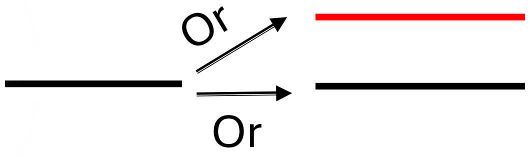
Abstract

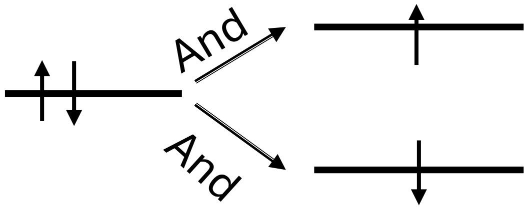
We apply Bayesian statistics to the estimation of correlation functions. We give the probability distributions of auto- and cross-correlations as functions of the data. Our procedure uses the measured data optimally and informs about the certainty level of the estimation. Our results apply to general stationary processes and their essence is a nonparametric estimation of spectra. It allows one to better understand the statistical noise fluctuations, assess the correlations between two variables, and postulate parametric models of spectra that can be further tested. We also propose a method to numerically generate correlated noise with a given spectrum.

Charge noise



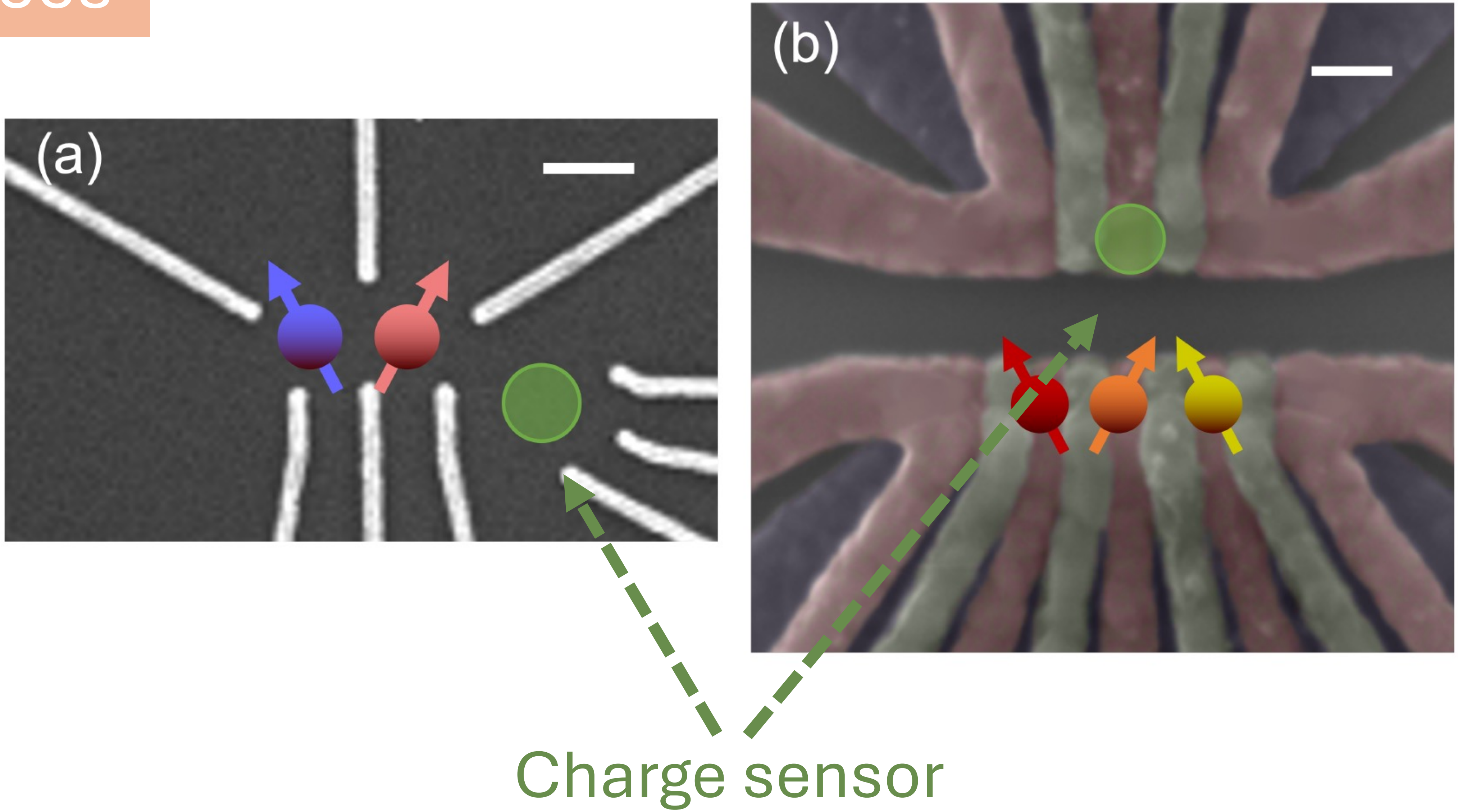


Spin noise



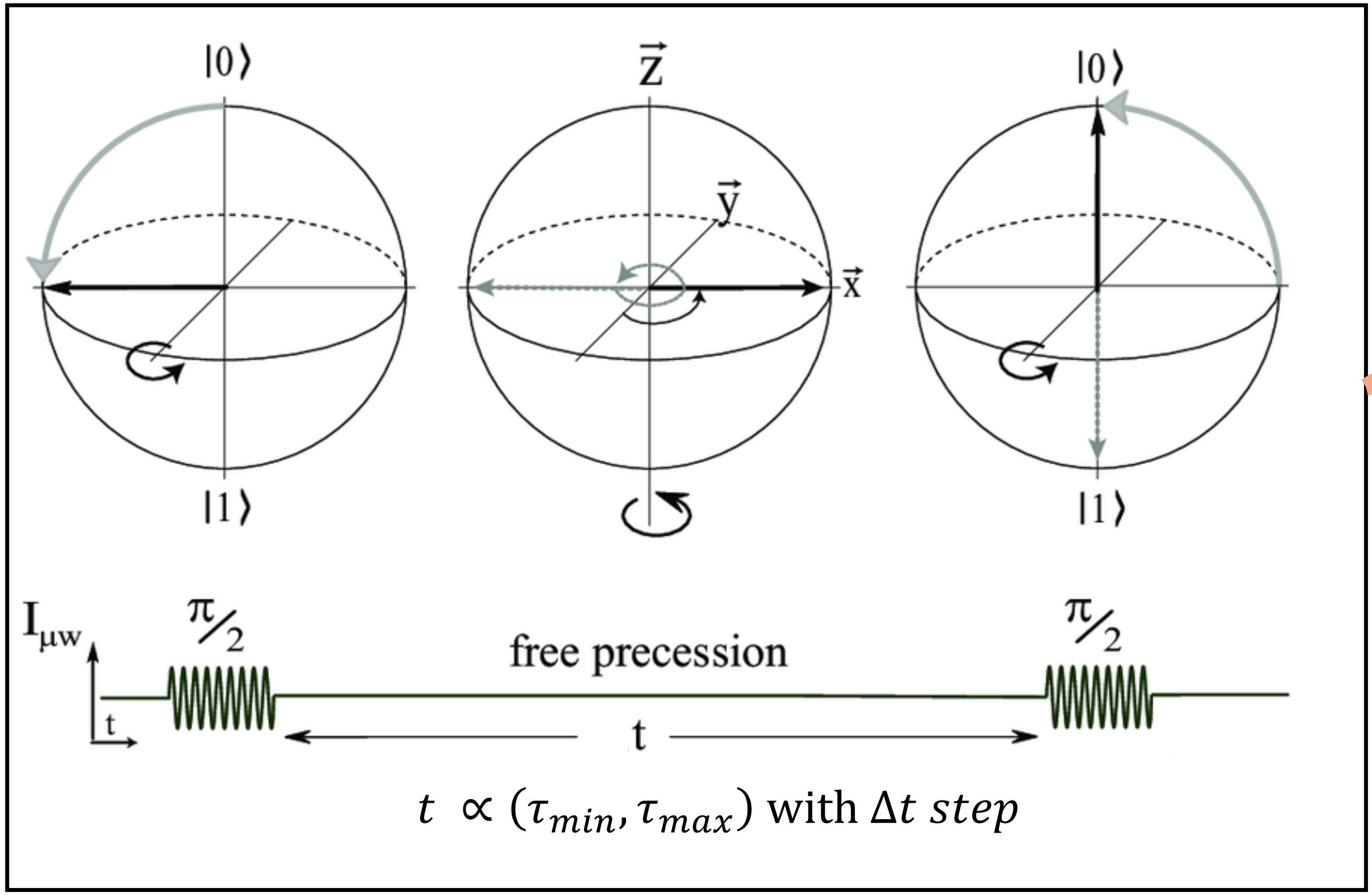
Devices

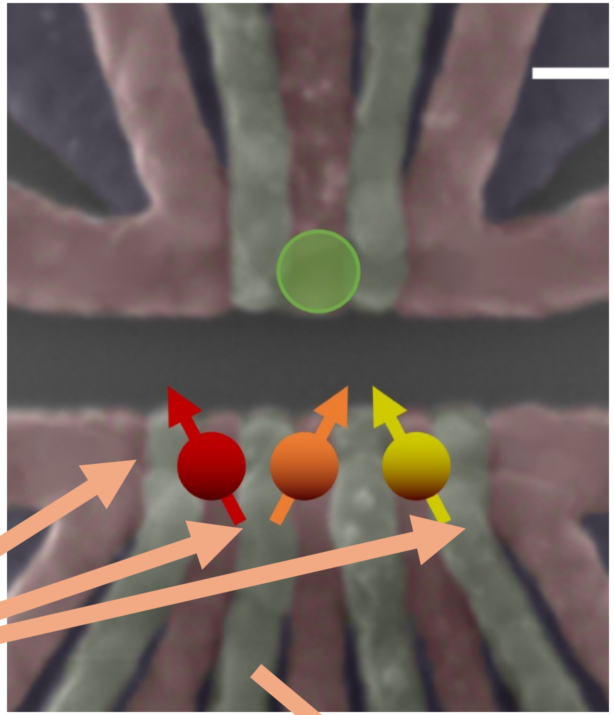
Natural Silicon Si-29



”Universal” Auto PSD

A single-qubit Ramsey Sequence

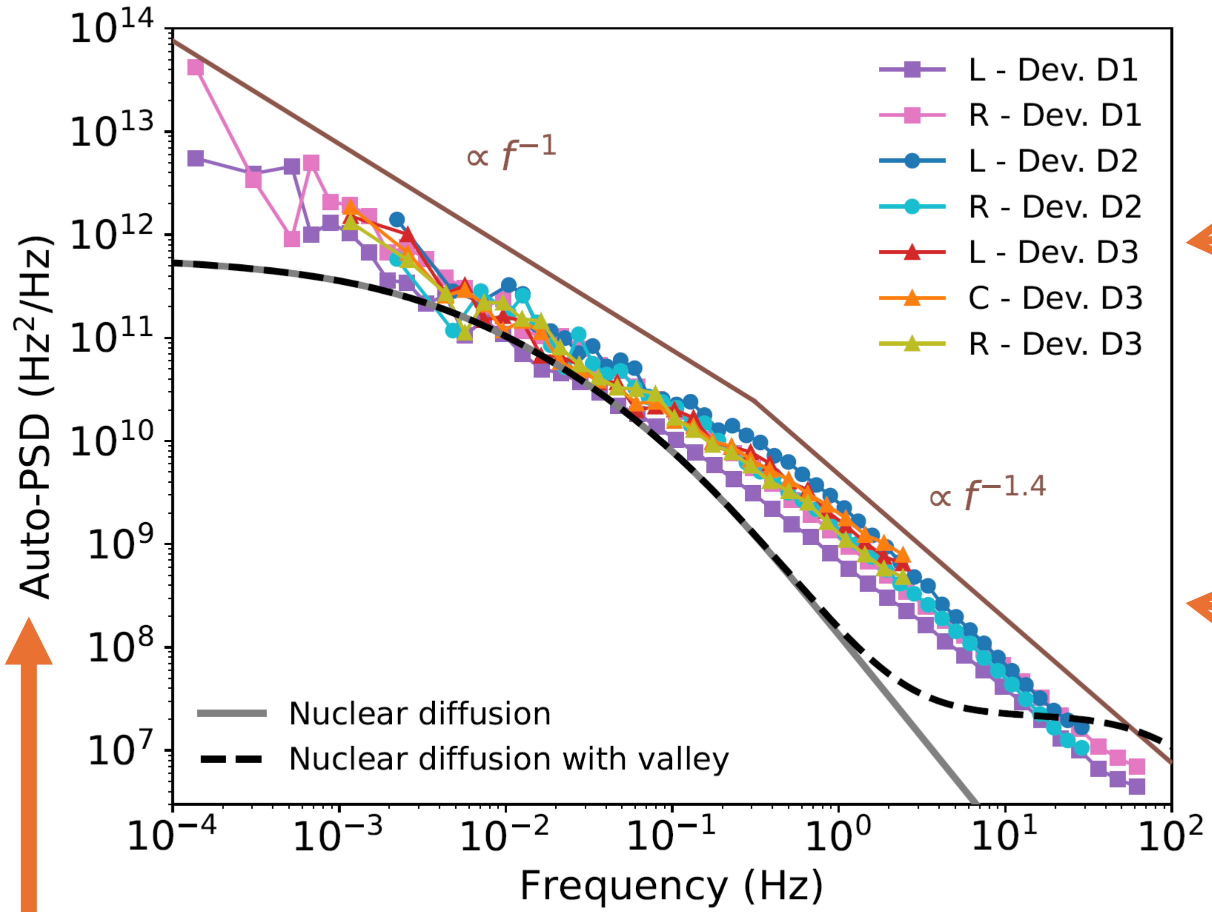


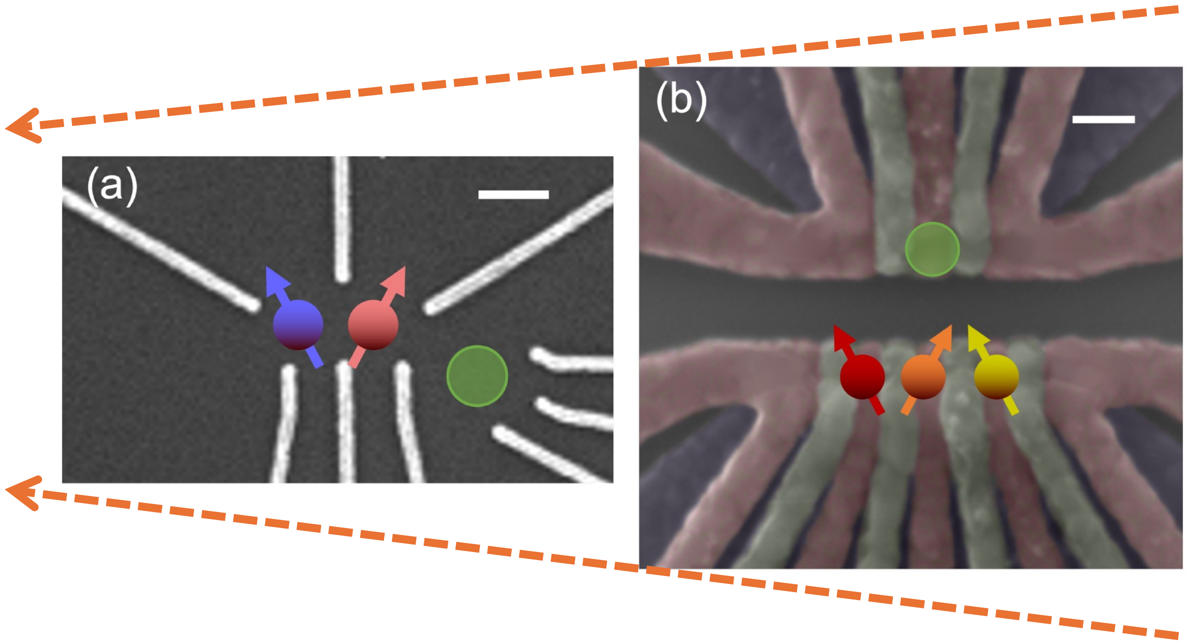


Bayesian estimation

Energies vs **time** (record acquisition)

"Universal" Auto PSD

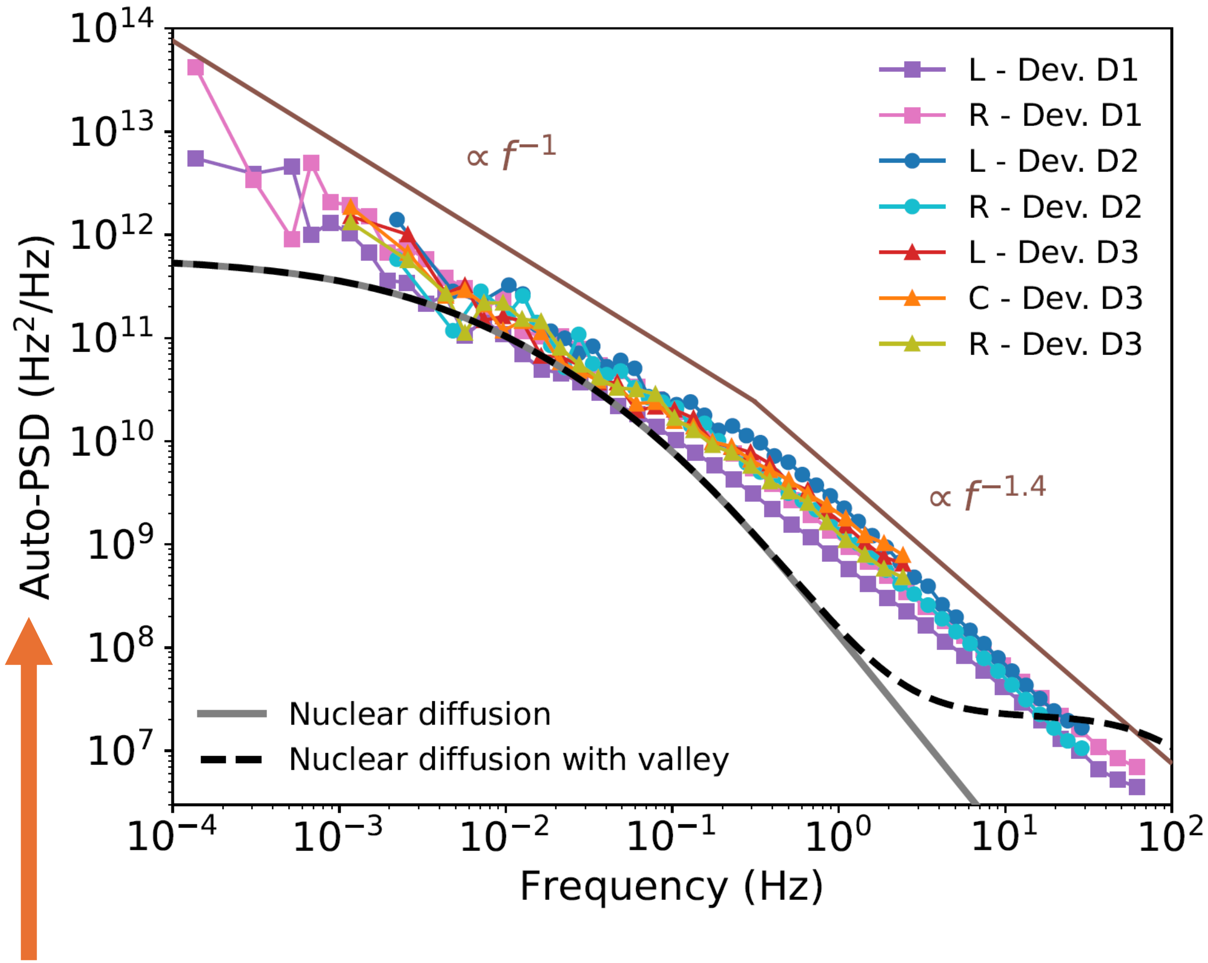




2x2Q + 1x3Q

Autocorrelation of qubit energies!

”Universal” Auto PSD

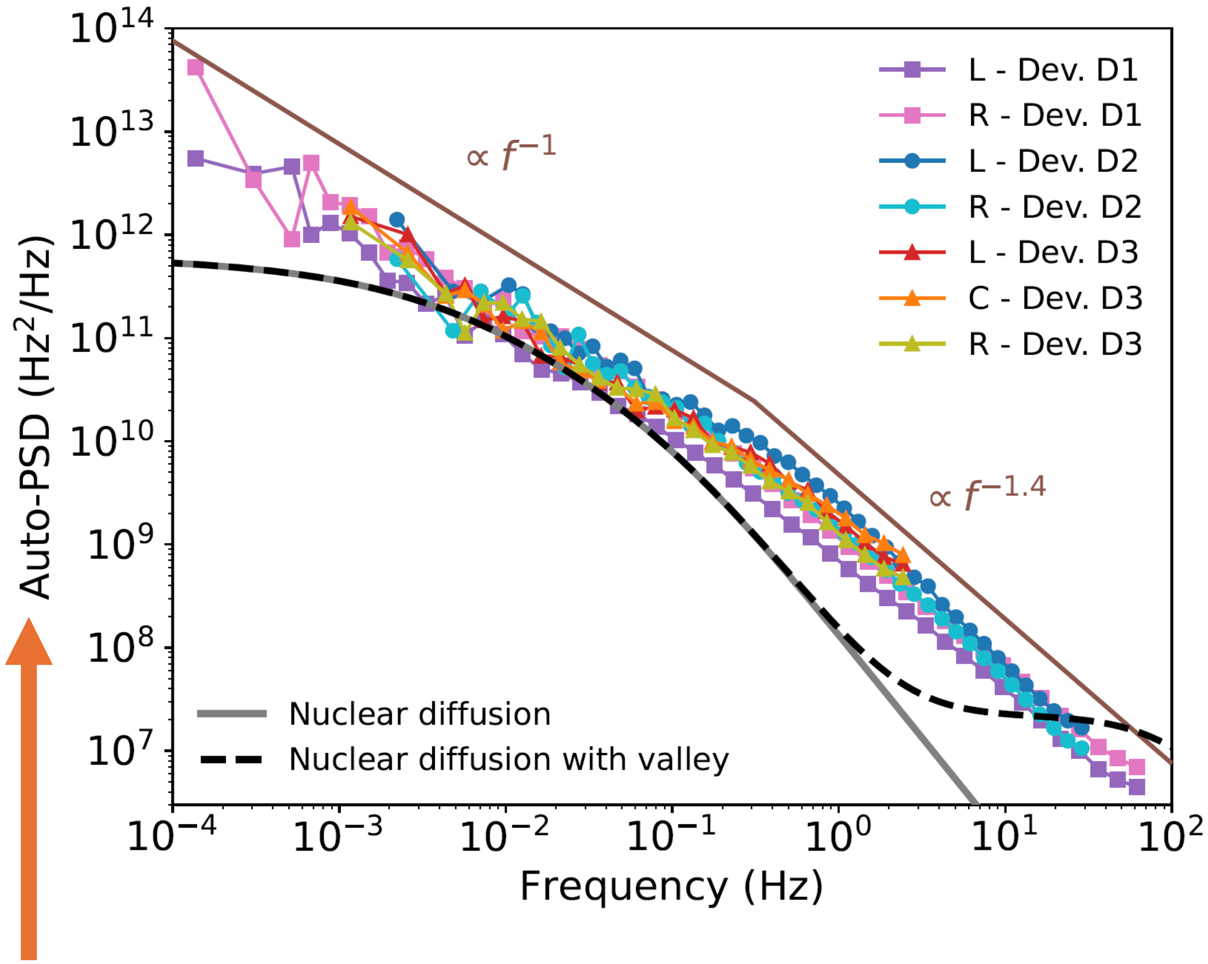


Autocorrelation of qubit energies!

Experiment: similar behavior of different devices

Statement: **Material-based noise**

"Universal" Auto PSD



Autocorrelation of qubit energies!

Experiment: similar behavior of different devices

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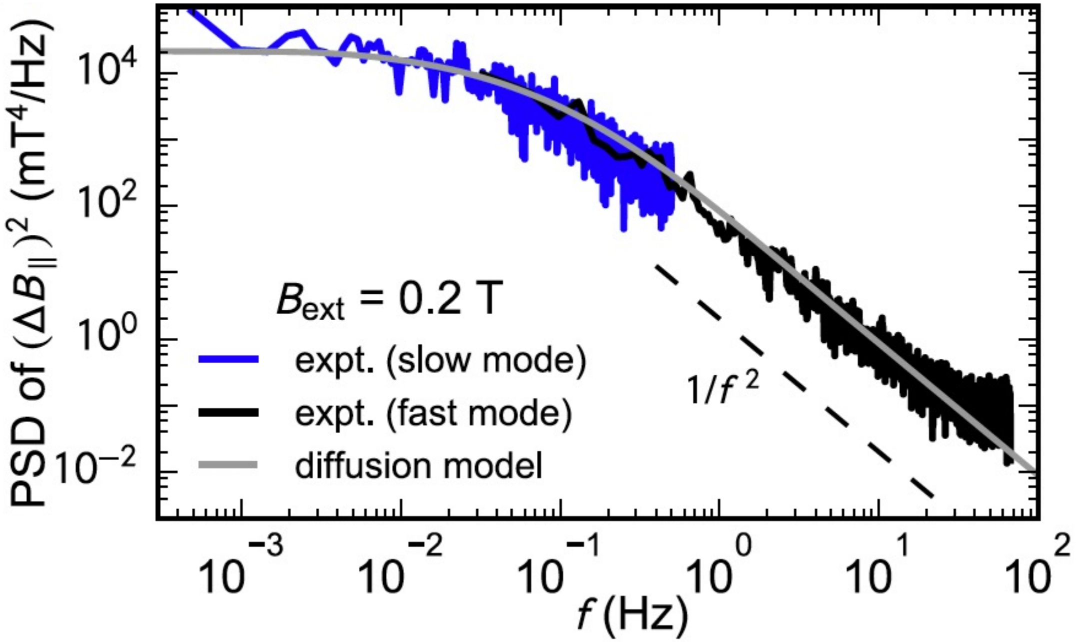
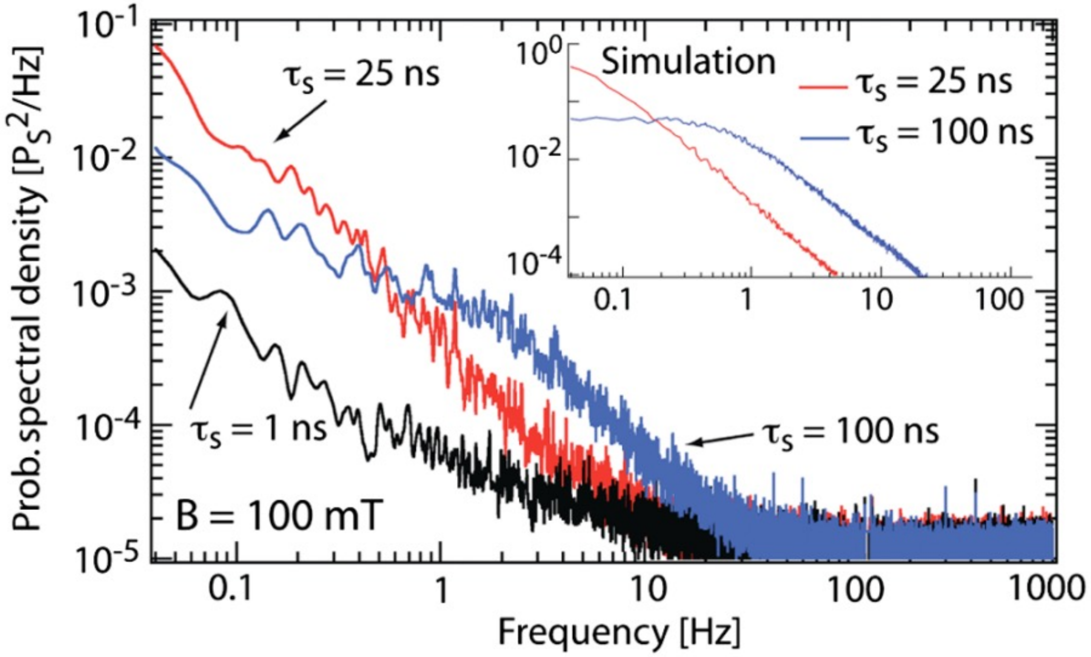
Charge noise?

Spin noise?

1/f2 for GaAs





PRL **118,** 177702 (2017) PHYSICAL REVIEW LETTERS week ending 28 APRIL 2017

Spectrum of the Nuclear Environment for GaAs Spin Qubits

Filip K. Malinowski,[1] Frederico Martins,[1] Łukasz Cywiński,[2] Mark S. Rudner,[1,3] Peter D. Nissen,[1] Saeed Fallahi,[4] Geoffrey C. Gardner,[4,5] Michael J. Manfra,[6,7] Charles M. Marcus,[8] and Ferdinand Kuemmeth[1]

PRL **101,** 236803 (2008) PHYSICAL REVIEW LETTERS week ending 5 DECEMBER 2008

Measurement of Temporal Correlations of the Overhauser Field in a Double Quantum Dot

D. J. Reilly,[1,*] J. M. Taylor,[2] E. A. Laird,[1] J. R. Petta,[3] C. M. Marcus,[1] M. P. Hanson,[4] and A. C. Gossard[4]

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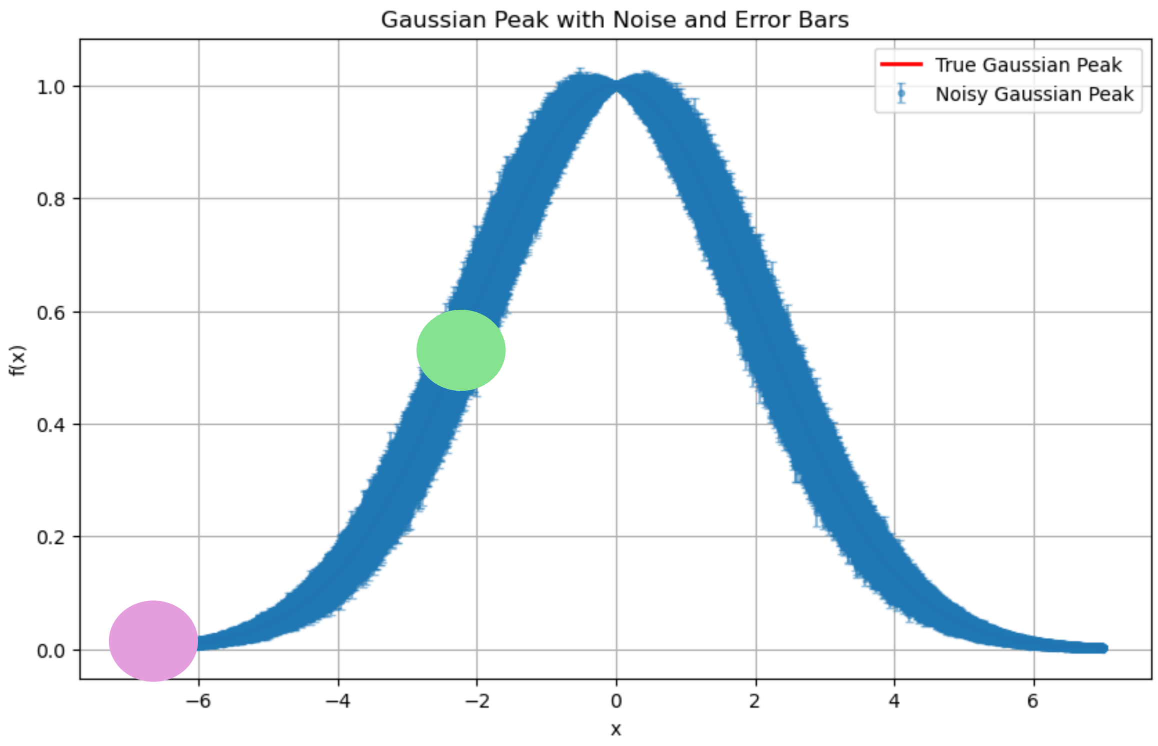
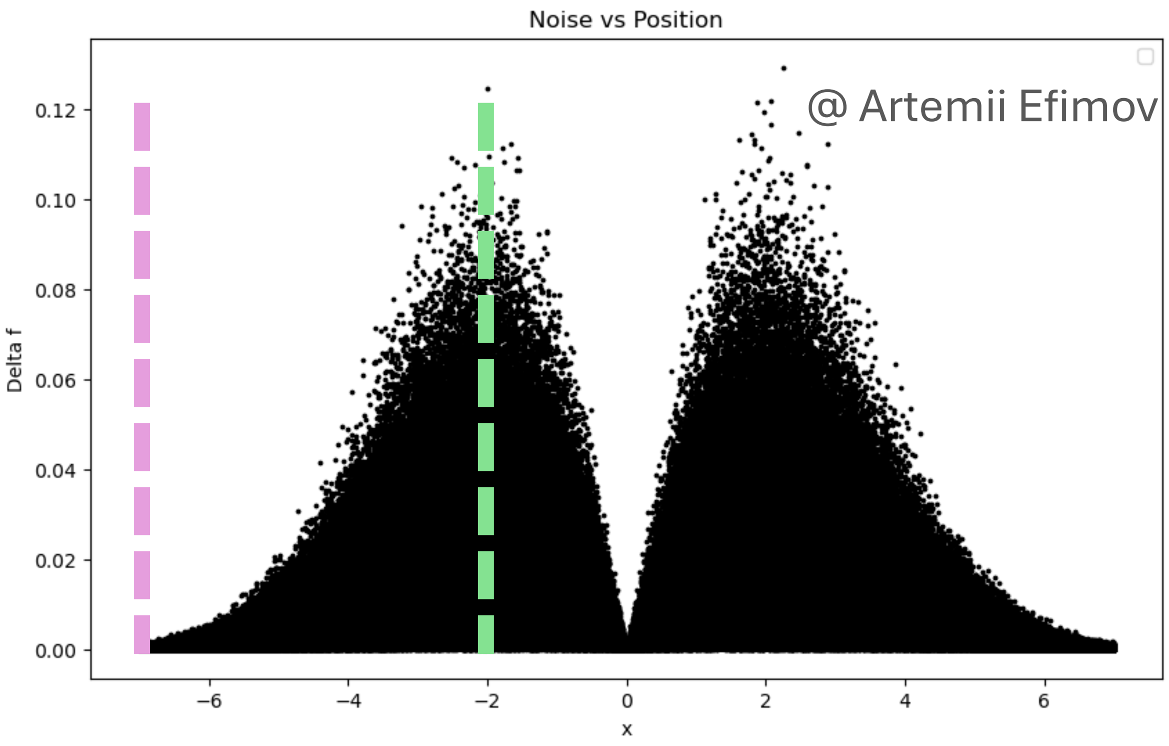
(Received 24 December 2007; published 4 December 2008)

Charge noise: general





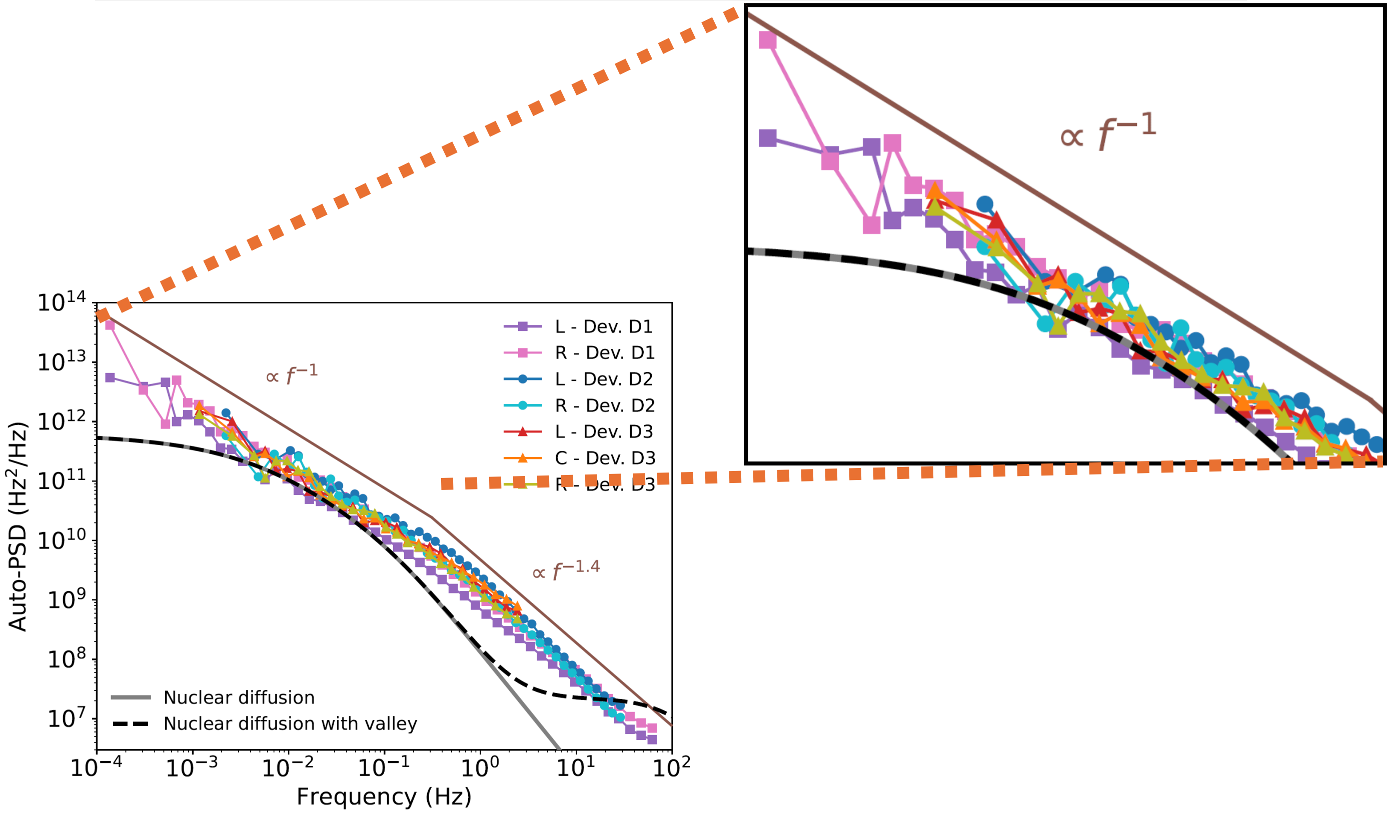
Sensitive point

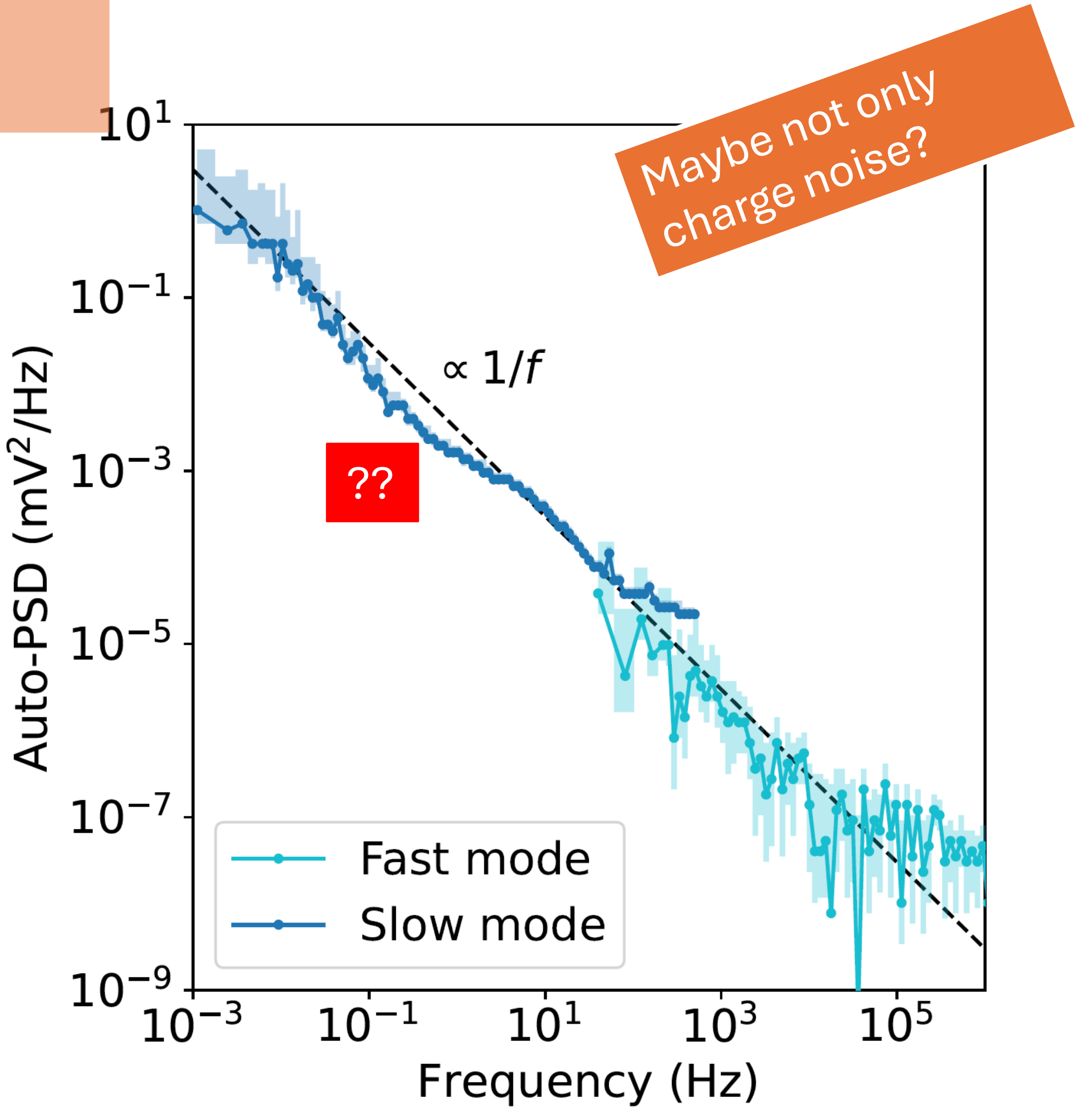
Non-sensitive point

"Charge noise" - > Auto-PSD( ) - Auto-PSD( )

Charge noise for charge sensor

order to determine the noise spectrum over a broad fre-
quency range, we use two measurement modes. First, a fast mode, where we acquire reflectometry voltages with a rate of 1 MHz for a time span of 0.1 s. Second, a slow mode, with an acquisition rate of 1 kHz for 1 hour. The
charge noise auto PSD is obtained through the differ-

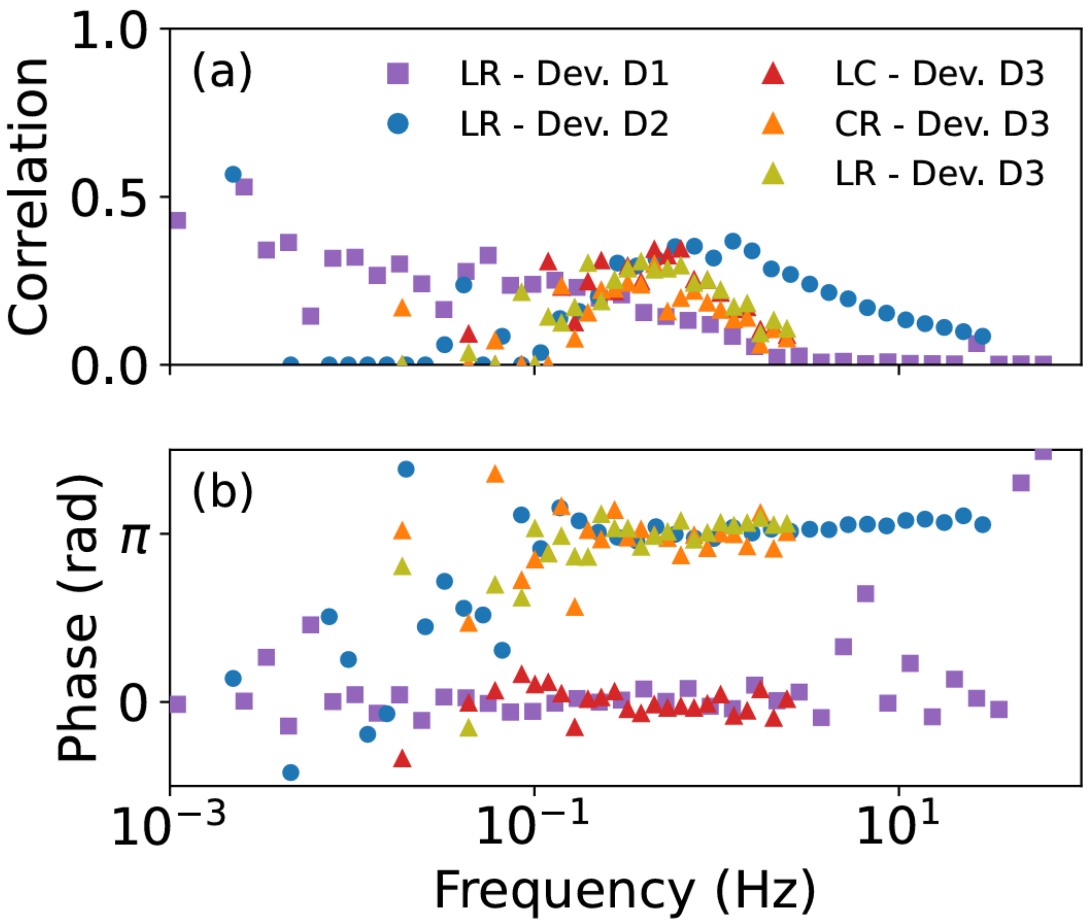




Charge noise contribution

Statement:

hyperfine interaction: **local**
charge noise: **long range**



Collection of cross-PSDs for all qubit pairs in each device.
Normalized magnitude (a) and phase (b) of the correlations.

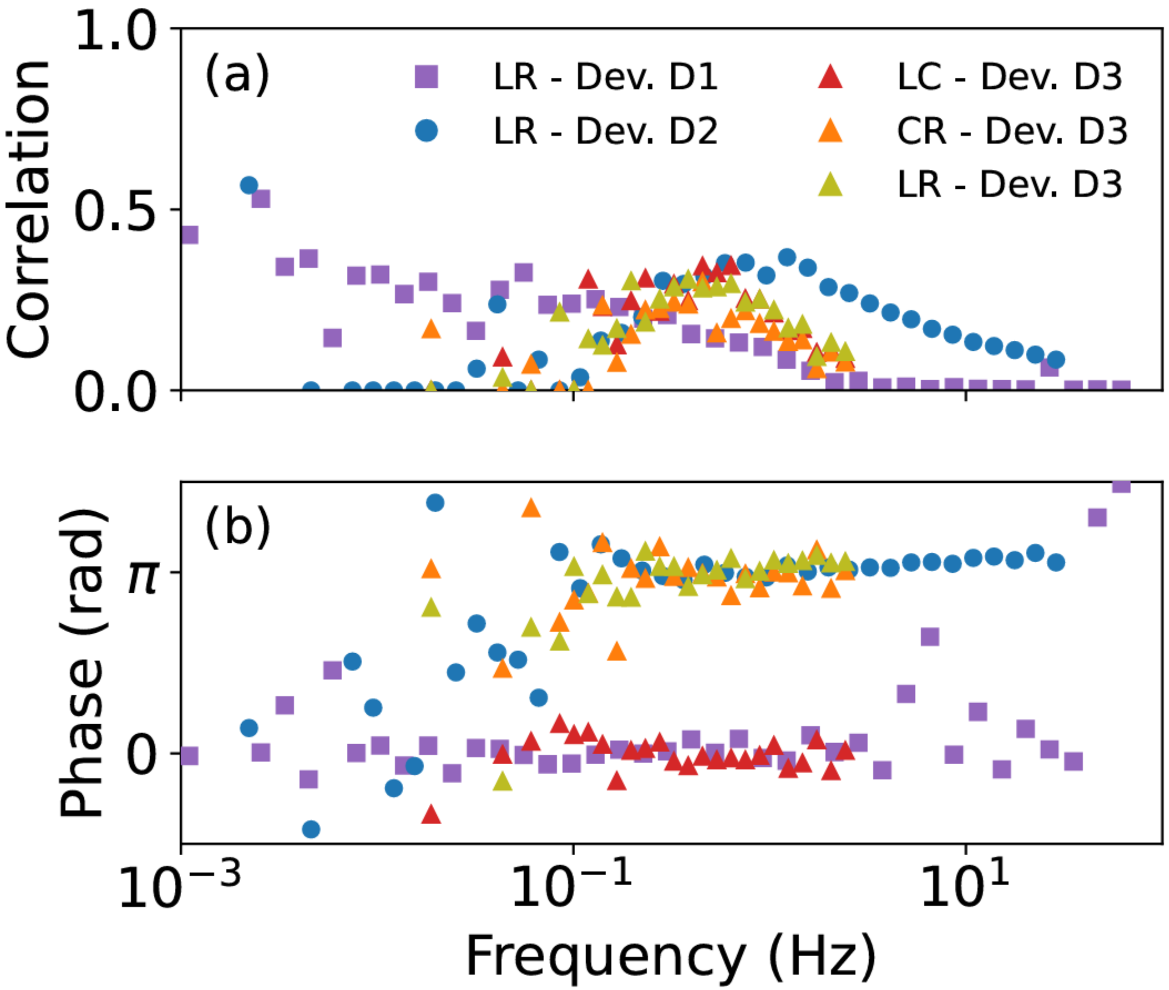
Charge noise contribution

a) Non-zero amplitude -> contribution of charge noise?

b) Device dependence -> different mechanism?

the auto and cross-PSDs are dominated by different phenomena, and the charge-noise sources are near the qubits.

Phase is either 0, or pi, otherwise randomised due to zero amplitude -> no delay in transmitting noise to different qubits



But how?

Correlation of qubit energies via Bayesian estimation

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Bayesian estimation of correlation functions

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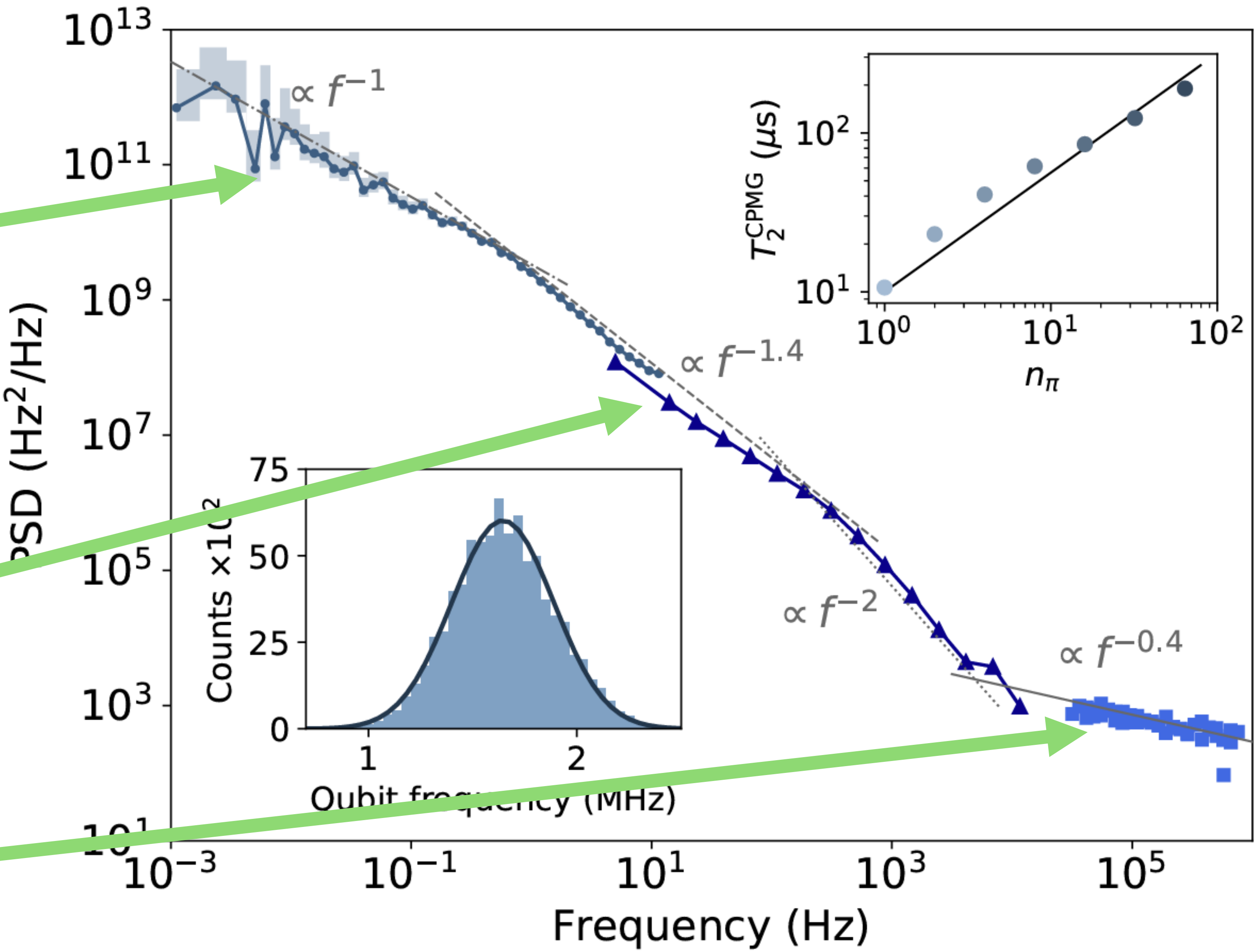
Time correlation of single-shot measurements

CPMG dynamical decoupling



What if we apply a B-field?

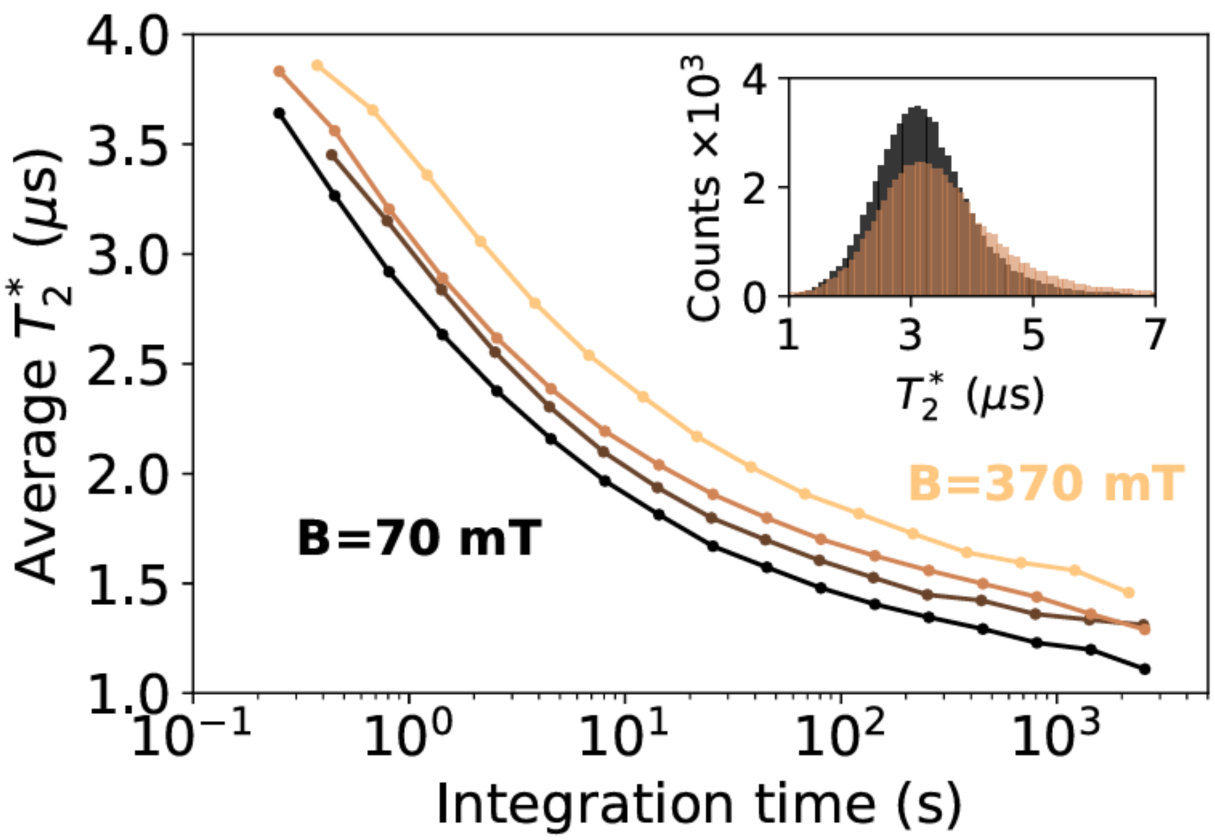
~~Magnetic-field induced nuclear spin polarisation~~

$$\gamma_n = -8.465 \frac{MHz}{T}$$

$$(B = 370mT)$$

Larmor -> $\frac{\gamma}{2\pi} B \ll kbT$

Changes in micromagnet field
=> mIsmatch in Zeeman energy of a nuclear spin pair -> Suppressing nuclear diffusion



B ↗ T2 ↗

Int time ↗ T2 ↘

$$A + Bcos(2\pi\nu_0\tau)\exp\left(-\frac{\tau}{T_2^*}\right)^2$$

Conclusions

Similar low freq noise across seven devices,

Qualitive agreement with diffusion model

Charge noise deviation on the sensor

Crosscorrelation between the qubits within a chip

} Hyperfine coupling is dominated

$f^{-1} \rightarrow f^{-1.4}$ *instead of* f^{-2} in GaAs } Valleys?

Novelty in the measurement of intermidiate regime: look details the paper

$\mathbf{B}_{\text{ext}}$ **(mT)**	ν_L (MHz)	ν_R (MHz)	B_L^{MM} (mT)	B_R^{MM} (mT)	ΔB (mT)
70	4980	5121	107.8	112.8	5.0
230	10521	10739	145.6	153.4	7.8
300	12693	12921	153.1	161.3	8.2
370	14808	15046	158.6	167.1	8.5