Low frequency resistance noise in near magic angle twisted bilayer graphene

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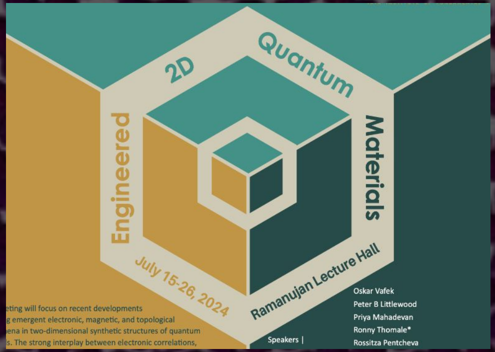
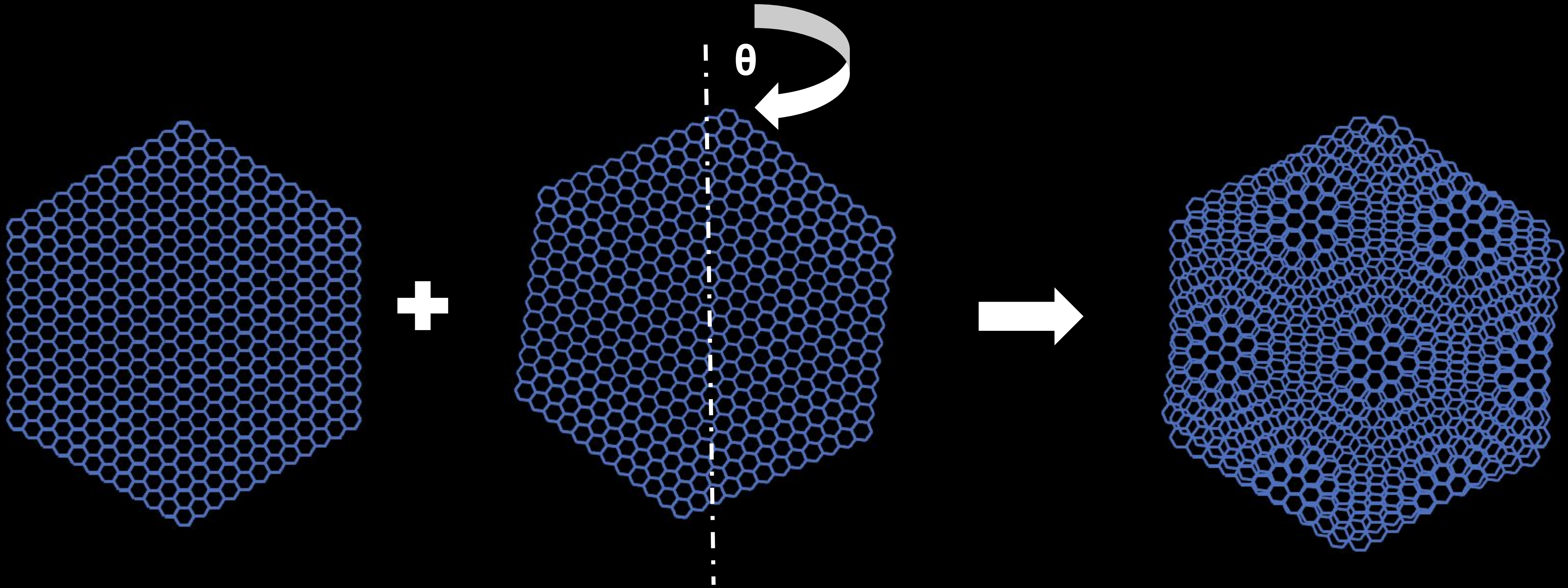


ICTS

Outline

- Brief introduction on twisted bilayer graphene
- Low frequency 1/f noise measurement techniques
- Results and discussions

Moiré superlattice of graphene



Monolayer graphene 1 Monolayer graphene 2 Twisted bilayer graphene

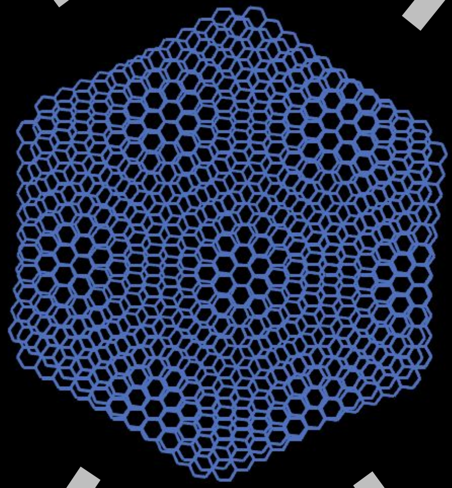
Novel electronic states of Moiré graphene

Superconductivity

Cao *et al., Nature* 556, 80–84 (2018)
Lu et al., *Nature* 574, 653–657 (2019)

Correlated insulator

Cao *et al*., *Nature* 556, 80–84 (2018)
Yankowitz *et al*., Science 363, 1059–1064 (2019)



Orbital ferromagnetism

Sharpe *et al., Science* 365, 605–608 (2019)
Serlin *et al., Science* 367, 900-903 (2019)

Topological phases

Nuckolls *et al*., *Nature 588,610-615* (2020)
Wu *et al*., *Nat.* materials 20, 488-494 (2021)

Non Fermi-liquid behaviour

Ghawri *et al., Nat. Commun*. 13, 1522 (2022)

Broken symmetry states

Bhowmik *et al., Nat. Phys.* 18, 639 (2022)

ARTICLE

Microscopic Mechanism of 1/*f* Noise in Graphene: Role of Energy Band Dispersion

Atindra Nath Pal,[†,*] Subhamoy Ghatak,[†] Vidya Kochat,[†] E. S. Sneha,[†] Arjun Sampathkumar,[‡] Srinivasan Raghavan,[‡] and Arindam Ghosh[†]

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NANO LETTERS

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Low-Frequency Electronic Noise in Single-Layer MoS_2 Transistors

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nature COMMUNICATIONS

ARTICLE

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Current crowding mediated large contact noise in graphene field-effect transistors

Paritosh Karnatak[1,*], T. Phanindra Sai[1,*], Srijit Goswami[1,*,†], Subhamoy Ghatak[1], Sanjeev Kaushal[2] & Arindam Ghosh[1,3]

PRL **113,** 026601 (2014) PHYSICAL REVIEW LETTERS week ending 11 JULY 2014

Fermi-Edge Transmission Resonance in Graphene Driven by a Single Coulomb Impurity

Paritosh Karnatak,[*] Srijit Goswami,[†] Vidya Kochat, Atindra Nath Pal,[‡] and Arindam Ghosh

Department of Physics, Indian Institute of Science, Bangalore 560 012, India

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2D Materials

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PAPER

Electrical noise inside the band gap of bilayer graphene

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PAPER

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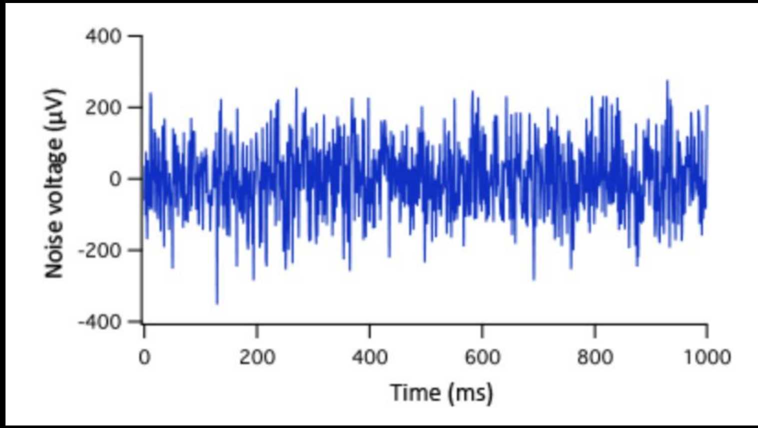
Optimal architecture for ultralow noise graphene transistors at room temperature†

Saloni Kakkar, *[a] Paritosh Karnatak,[a] Md. Ali Aamir,[a] Kenji Watanabe, [b] Takashi Taniguchi[b] and Arindam Ghosh[a,c]

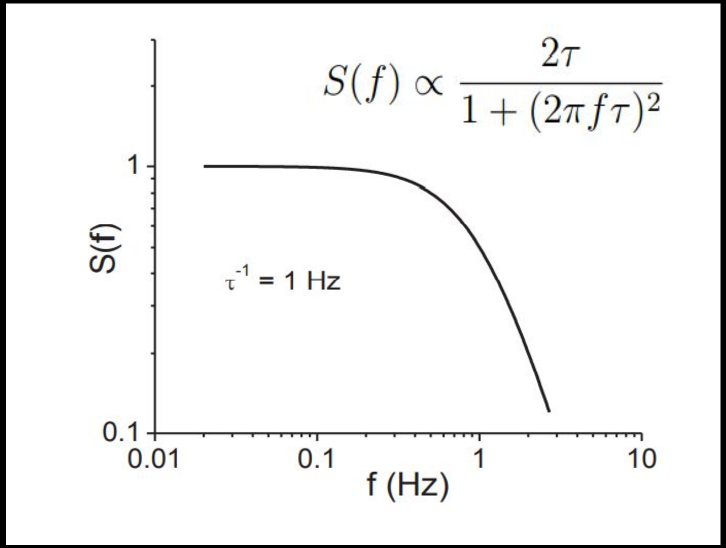
Noise and its power spectral density, $S_v(f)$

Voltage fluctuation in real time

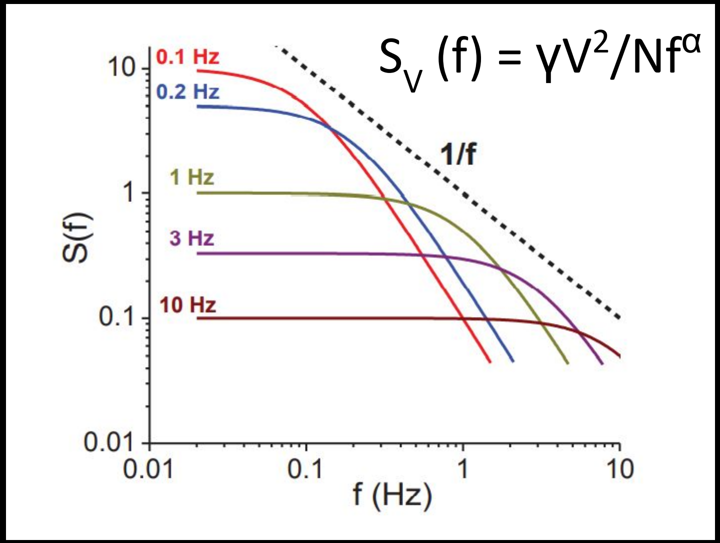


F.T

Lorentzian power spectrum

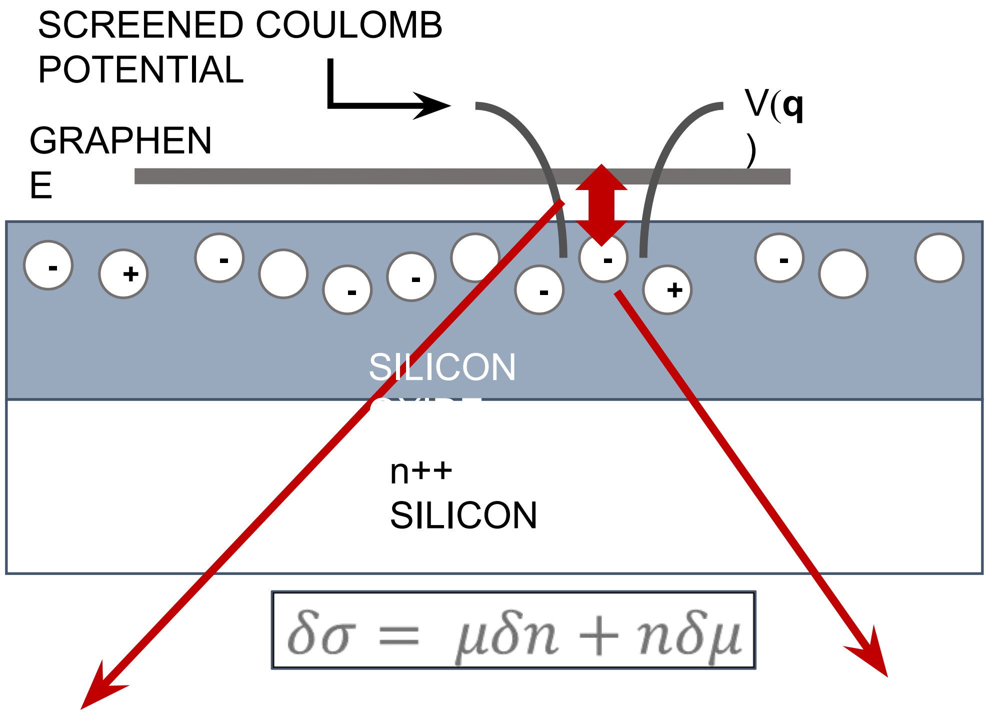


1/f type power spectrum



γ_H : phenomenological Hooge parameter.

McWhorter model of correlated number-mobility fluctuation noise



$$\delta\sigma = \mu\delta n + n\delta\mu$$

Fluctuating Coulomb potential:

- ❑ mobility fluctuations ∝ 1/n
- ❑ Noise magnitude ∝ screening

Trapping-Detrapping process:

- ❑ Carrier number fluctuation
- ❑ Noise magnitude ∝ $1/n^2$

Trans-conductance:

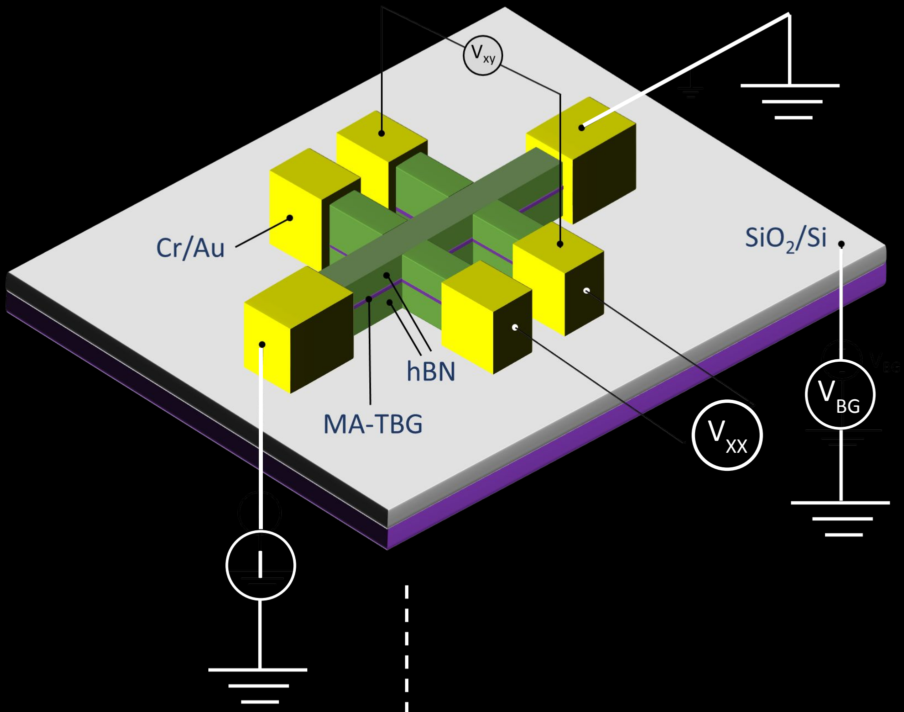
$$g_m = \frac{\partial I_{sd}}{\partial V_g}$$

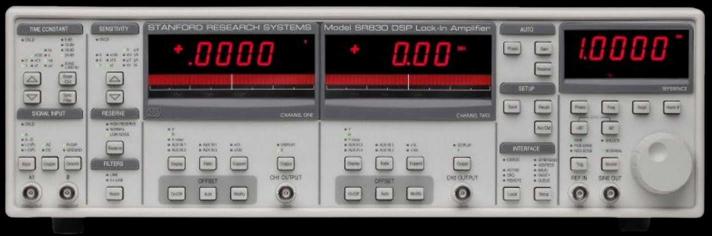
MACWHORTER MODEL

$$\frac{S_R}{R^2} = \frac{6.2e^2 k_B T}{A C_{ox}^2 \kappa f} D_t \left(\frac{g_m}{I_{sd}}\right)^2$$

Trap DOS for SiO2
~ $10^{17} eV^{-1} cm^{-3}$

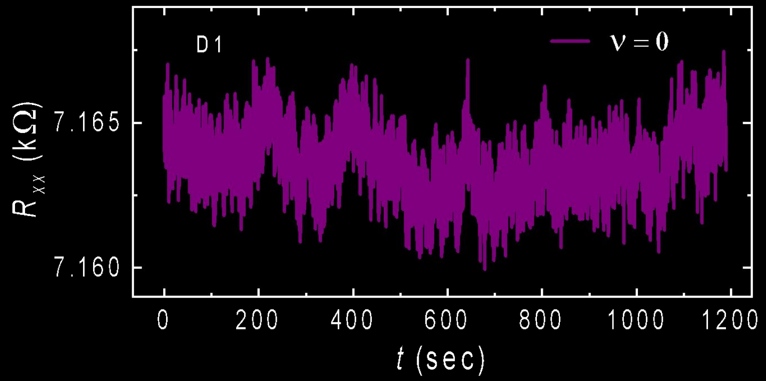
Noise measurement techniques





Lock-in amplifier

Data acquisition using DAQ Card : Digitization



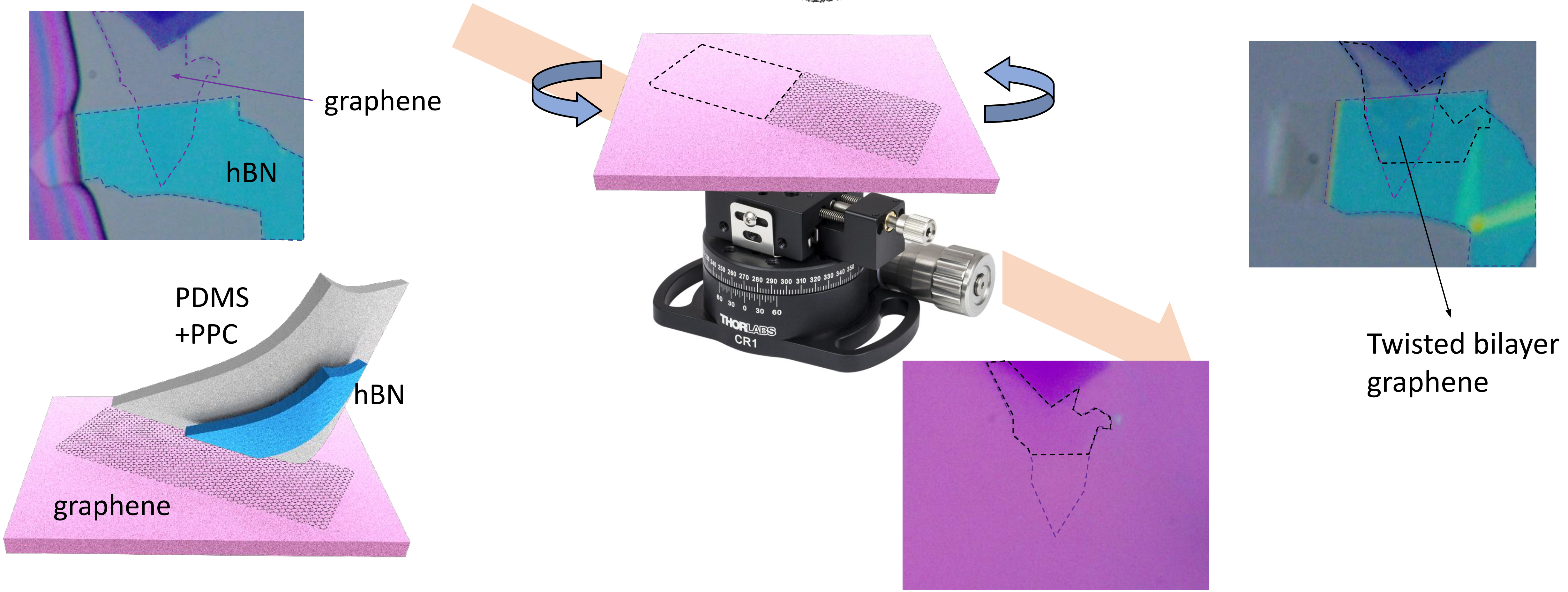
Digital signal processing

Fast- Fourier transform (FFT)

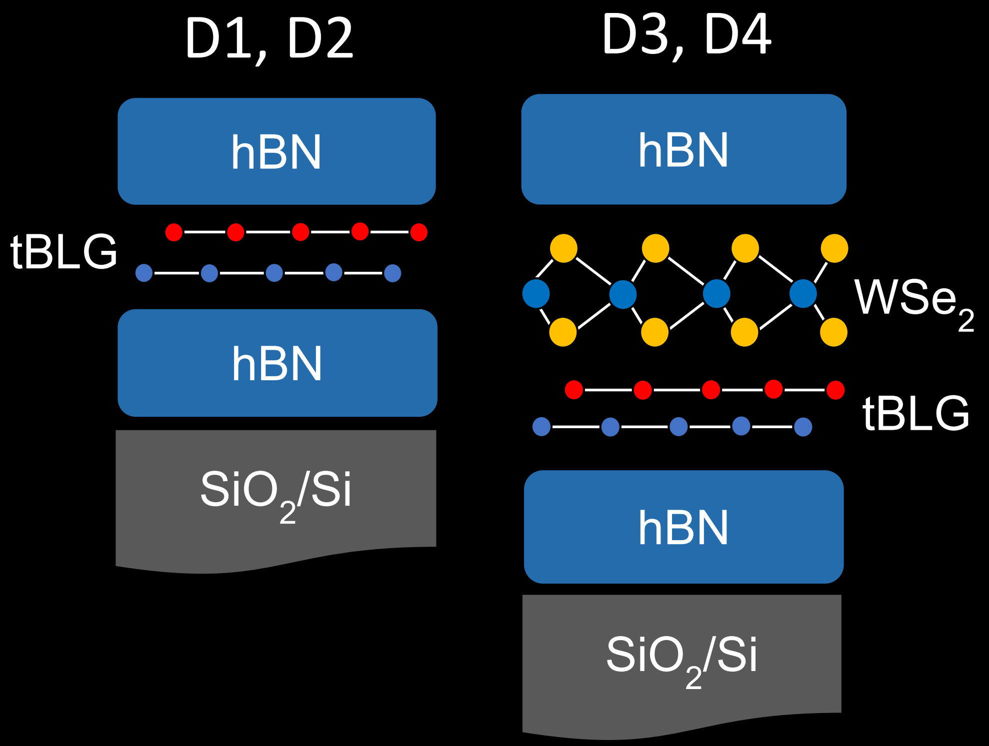
Power spectral density (S_V)

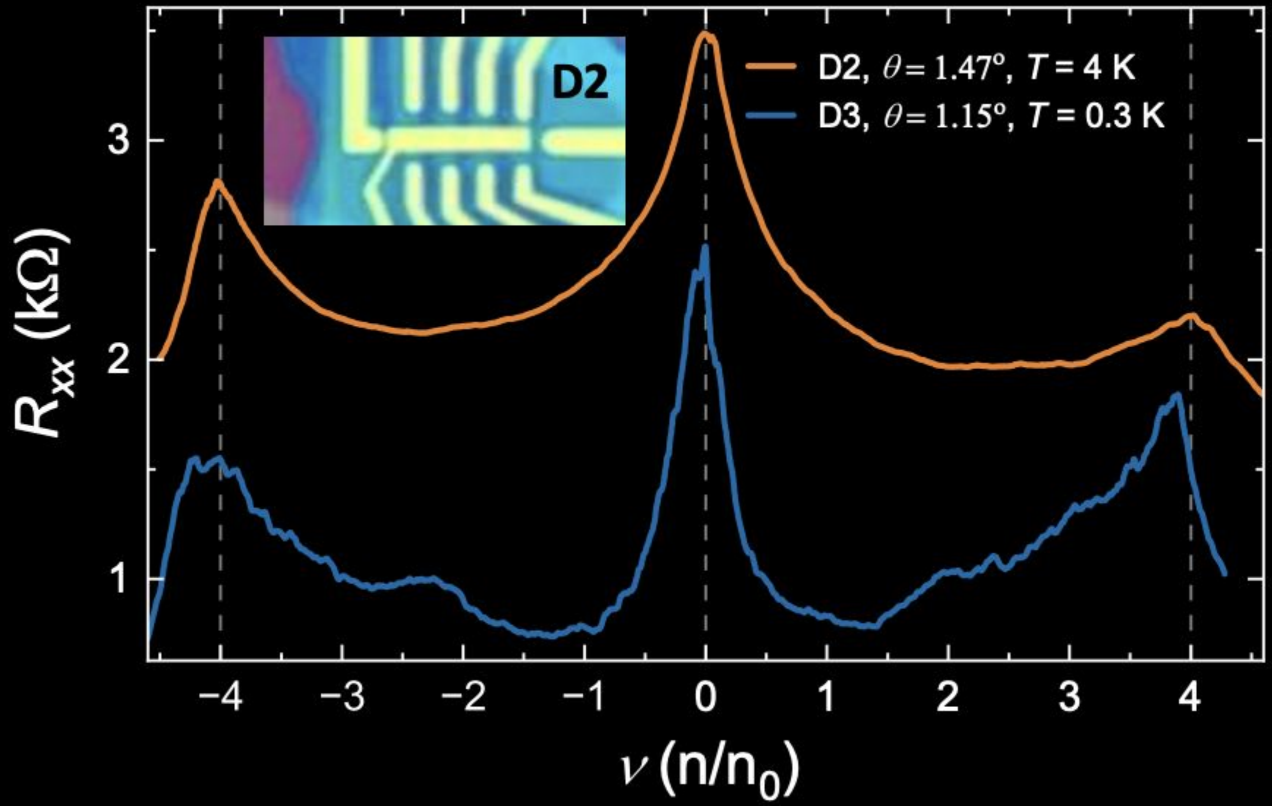
Twisted bilayer graphene – Devices

Tear-and-stack method



Device architecture & electrical transport in twisted bilayer graphene.

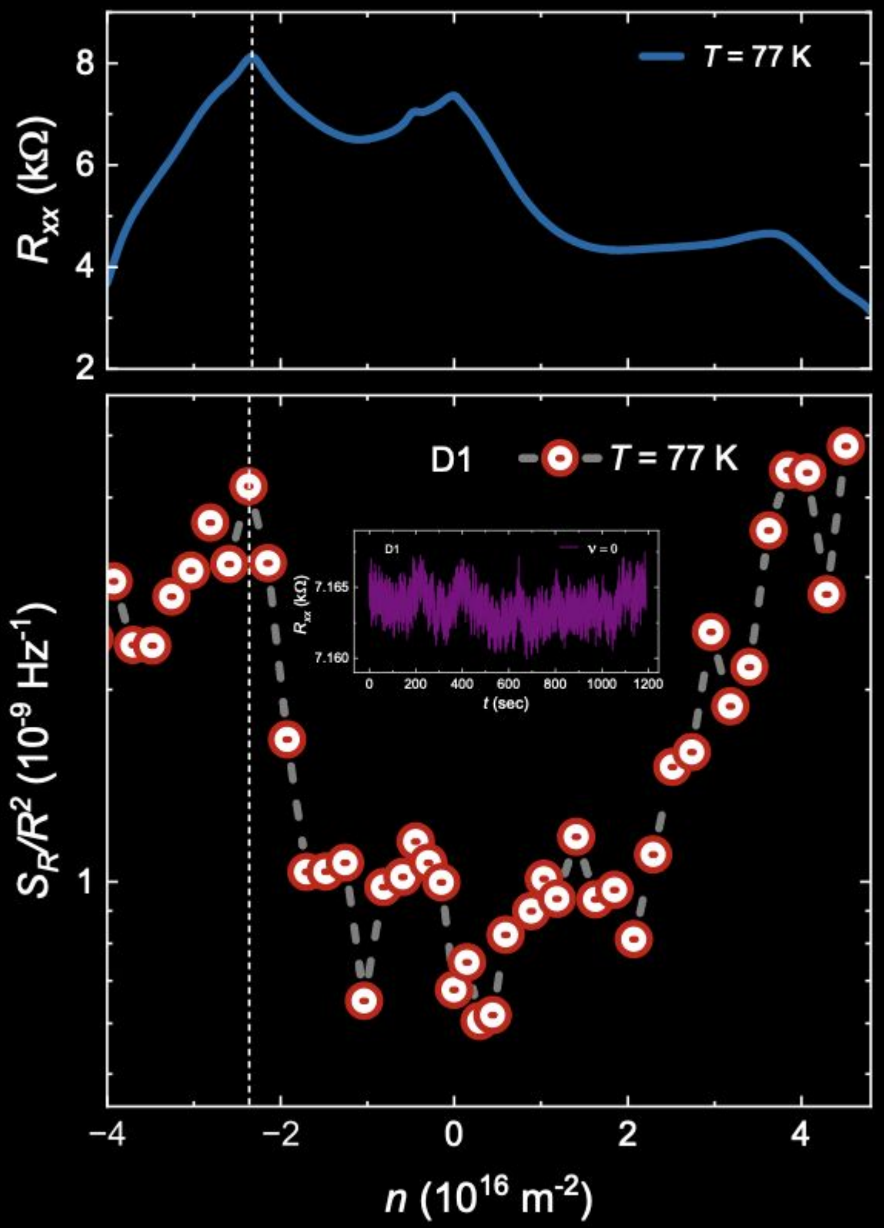


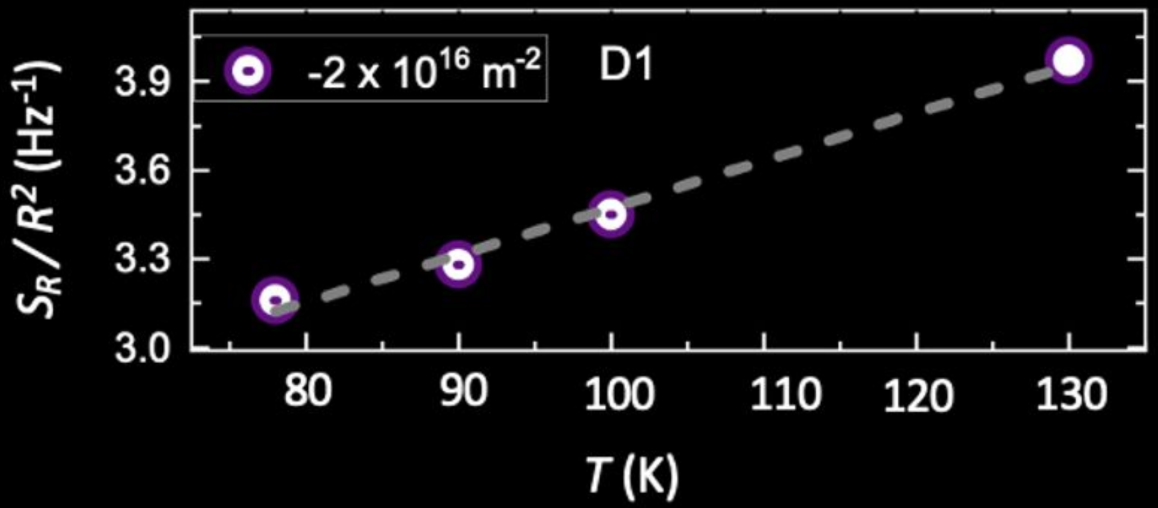


D1 (tBLG), D3 (tBLG/WSe_2) : $\theta \approx 1.1^0$

D2 (tBLG), D4 (tBLG/WSe_2) : $\theta \approx 1.4^0$

Noise behavior at high T limit (77 K-300 K)

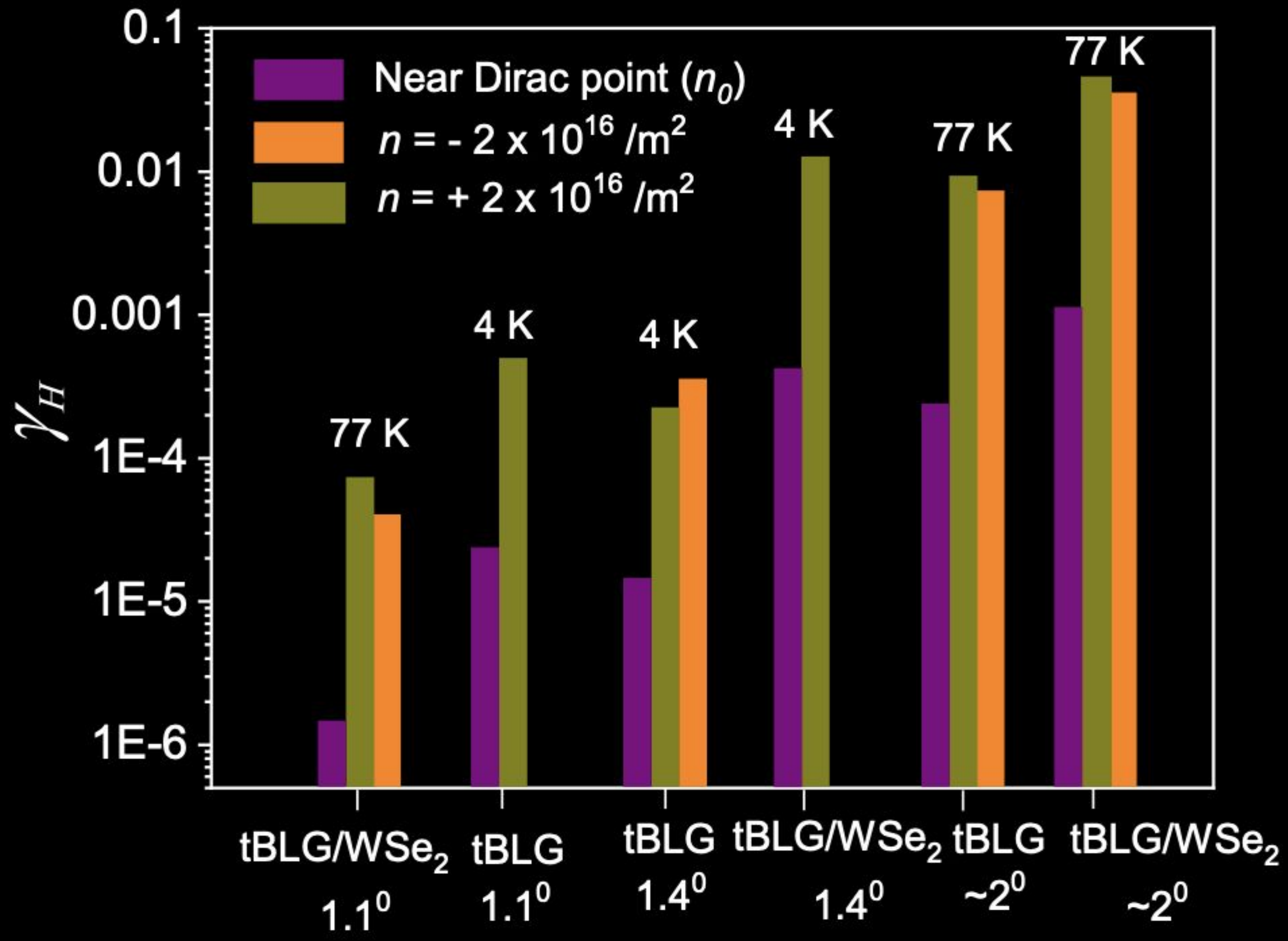




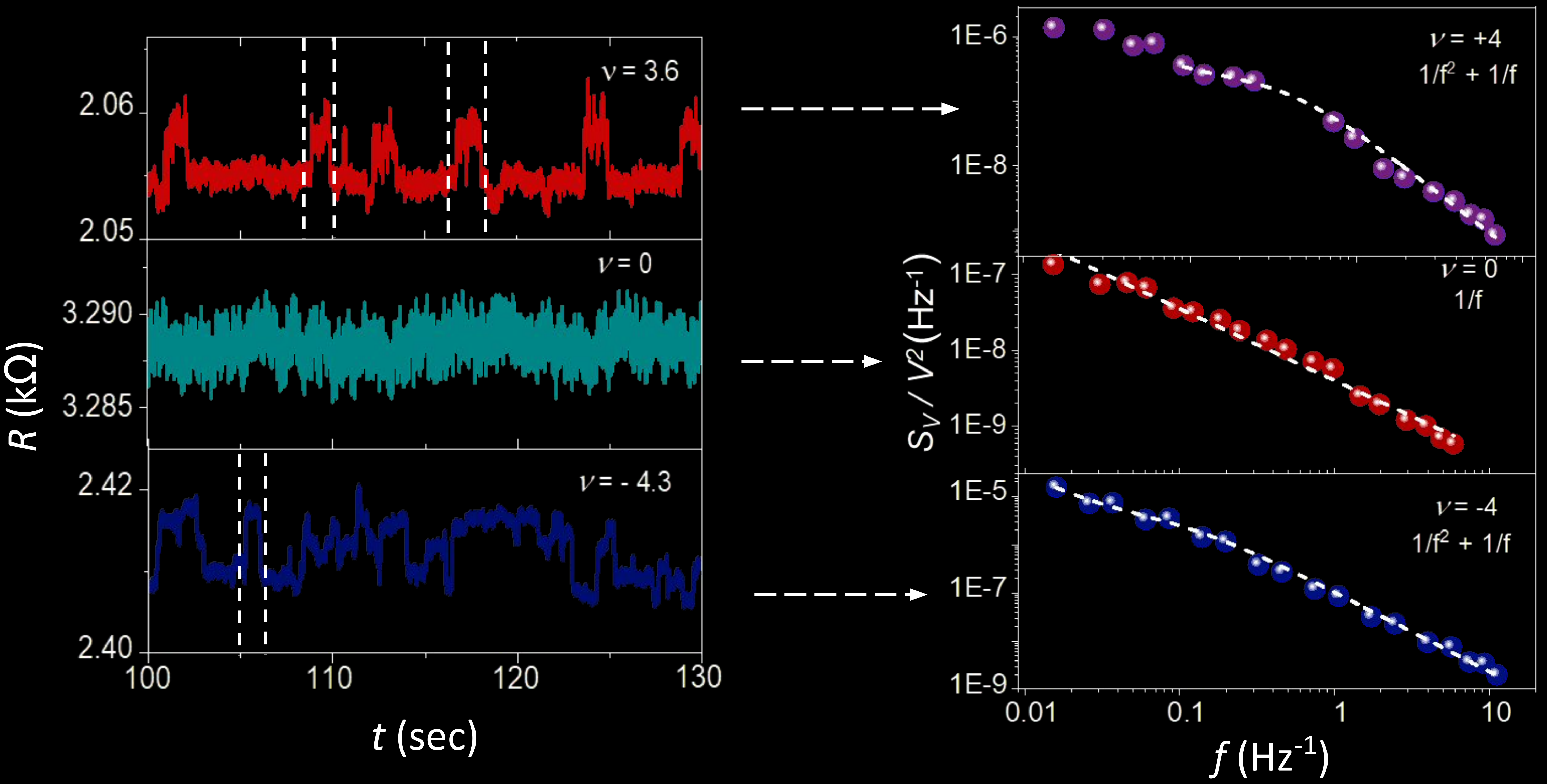
$$\frac{S_R}{R^2} = \frac{D_{it} k_B T}{dWL} \left(\frac{d\sigma}{dn}\right)^2 \left(\frac{J_1}{\sigma^2}\right)$$

- Origin of noise : carrier number fluctuation (McWhorter model)
- Trap density of the hBN traps, $D_{it} \approx 10^8$ eV^{-1} cm^{-2}

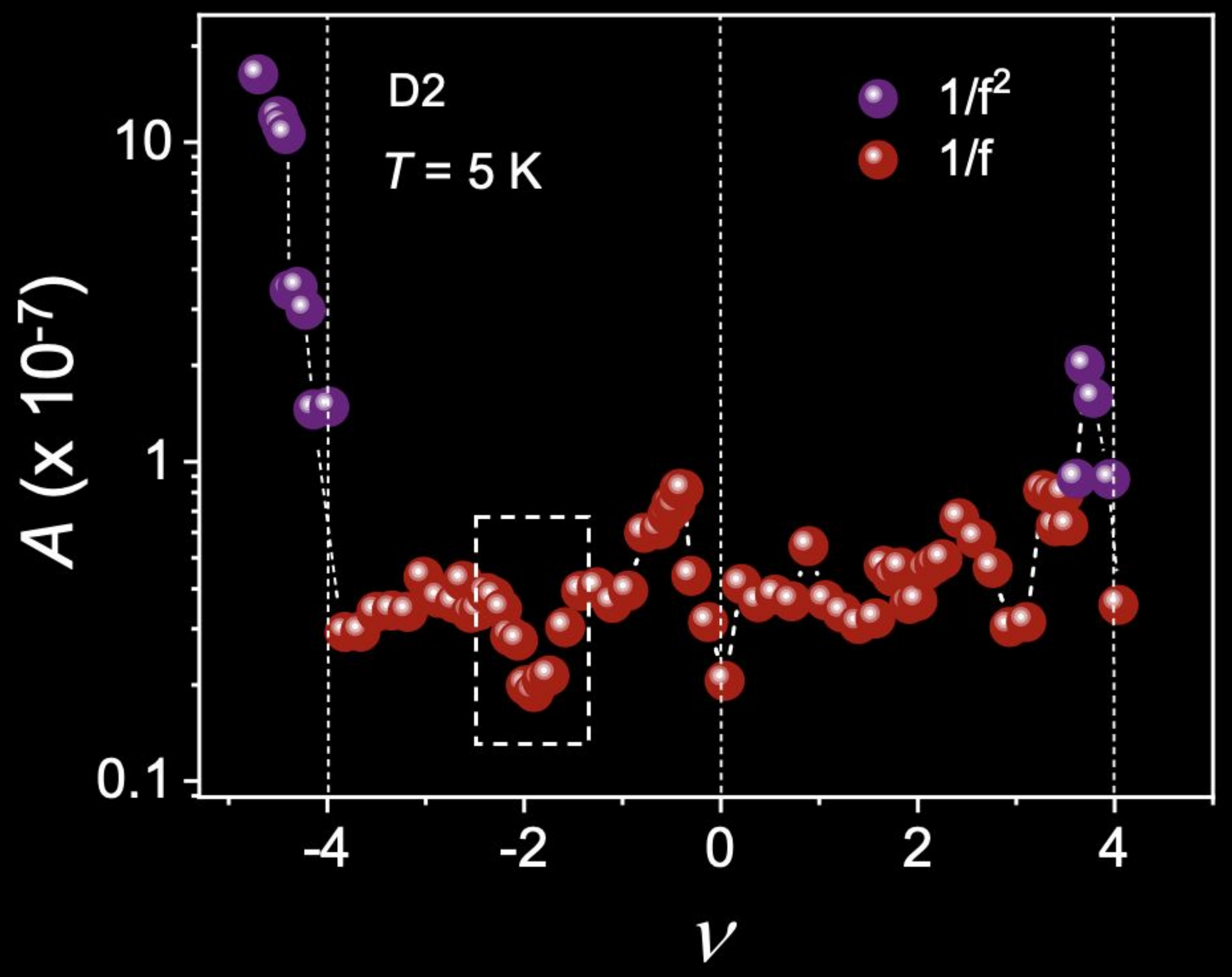
Calculation of Hooge parameter for different θ_{twist}



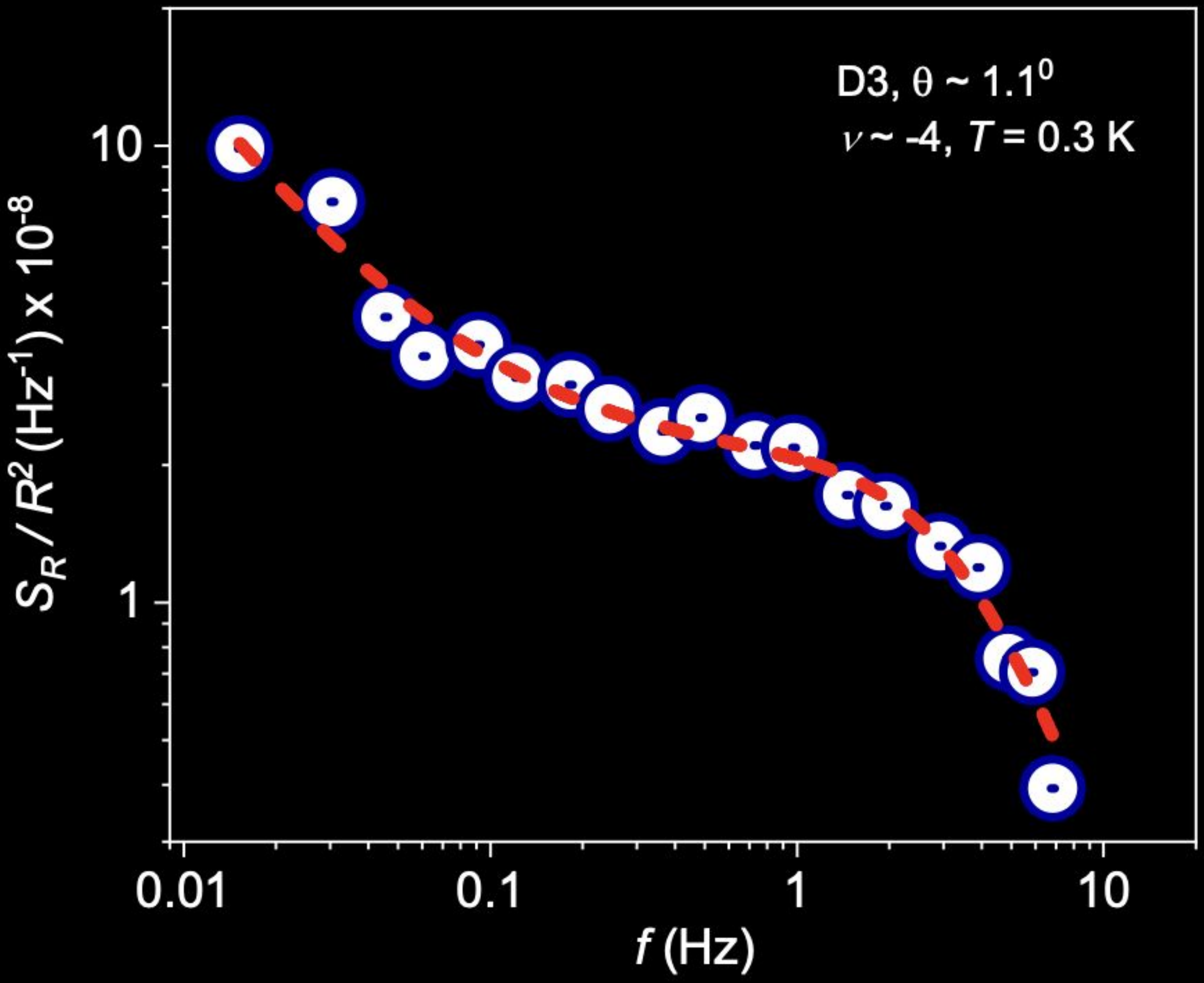
Observation of RTS signal at low temperature (≈ 5 K)



Noise behavior at low temperatures (≈ 5 K) for $\theta \approx 1.4^0$



Lorentzian component in power spectral density

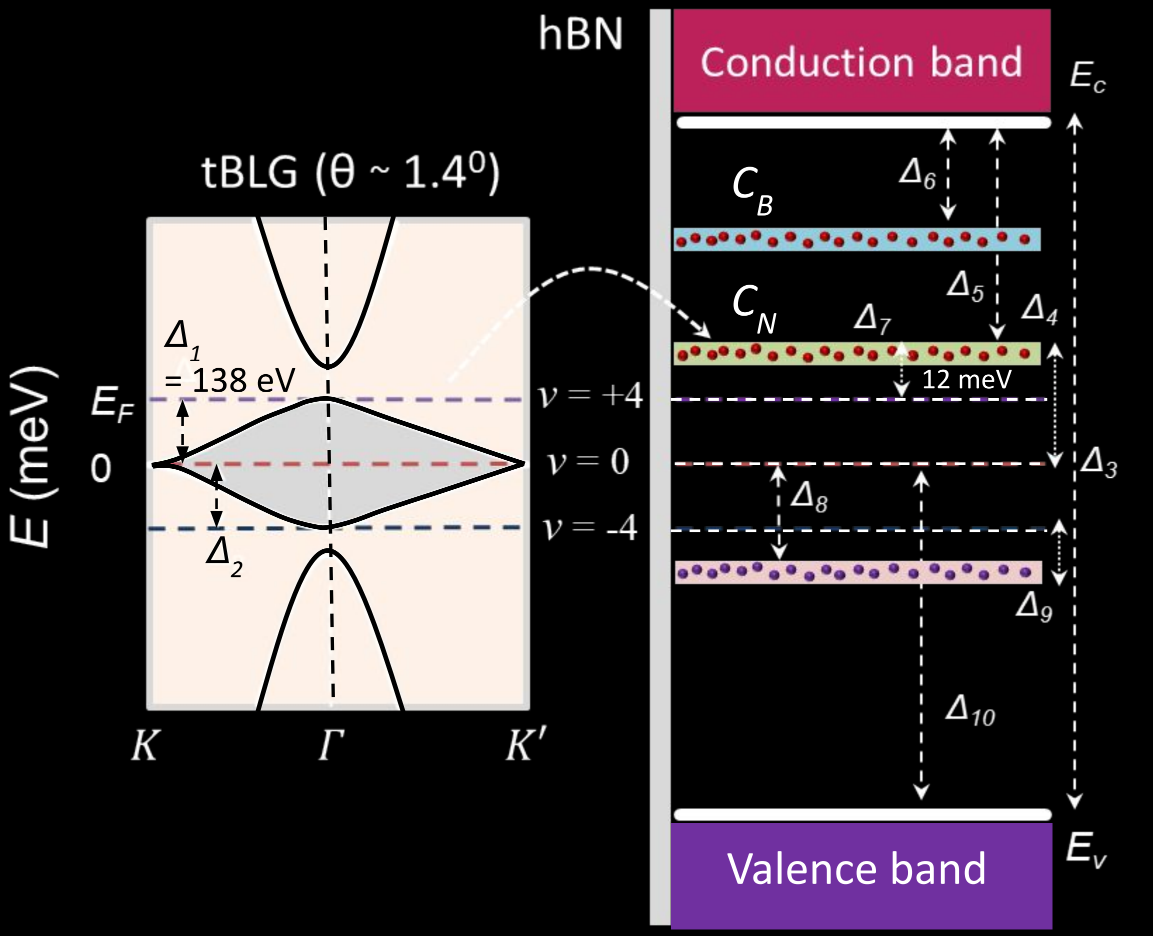


$$\frac{S_R}{R^2} = \frac{a}{f^\alpha} + \frac{b f_c}{f^2 + f_c^2}$$

1/f *$1/f^2$*

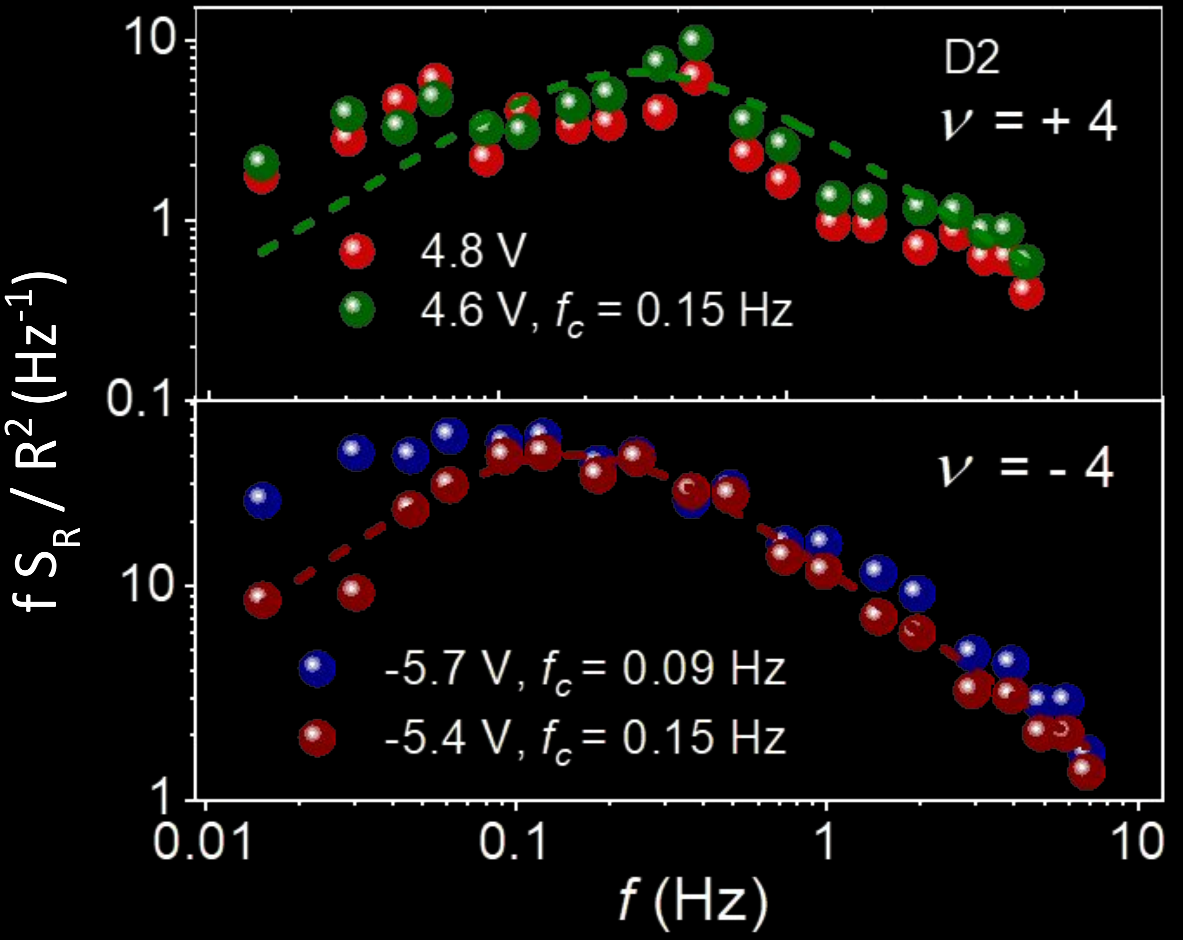
- b/a ≈ 200
- Dominance of $1/f^2$ component near *ν* = -4
- Generation-recombination noise

Model for occurrence of RTS and impurity level in hBN



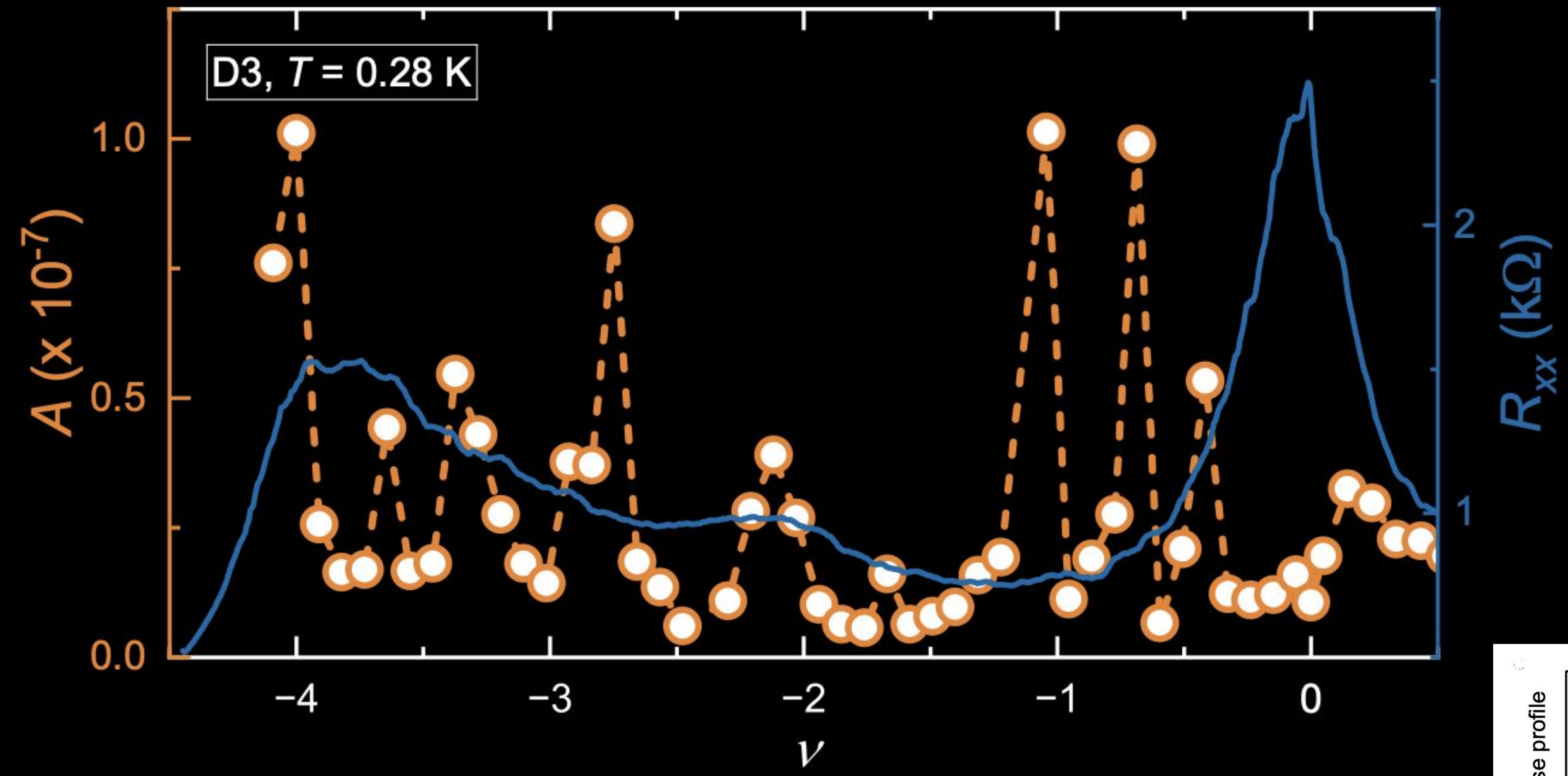
Δ_5 = 2.85 eV : C_N

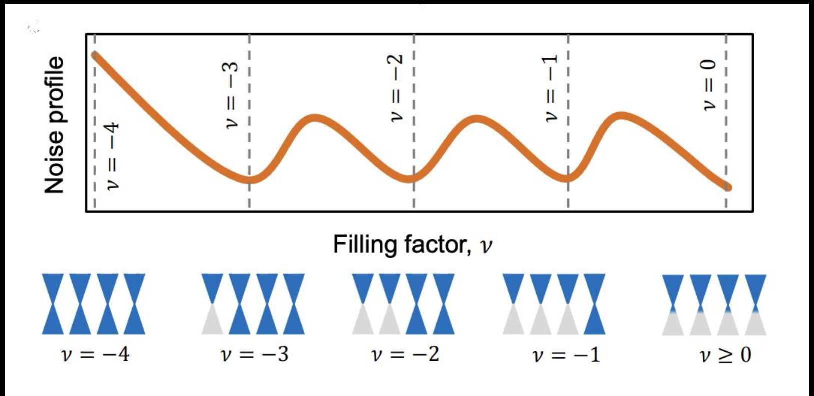
Δ_6 = 1.65 eV : C_B



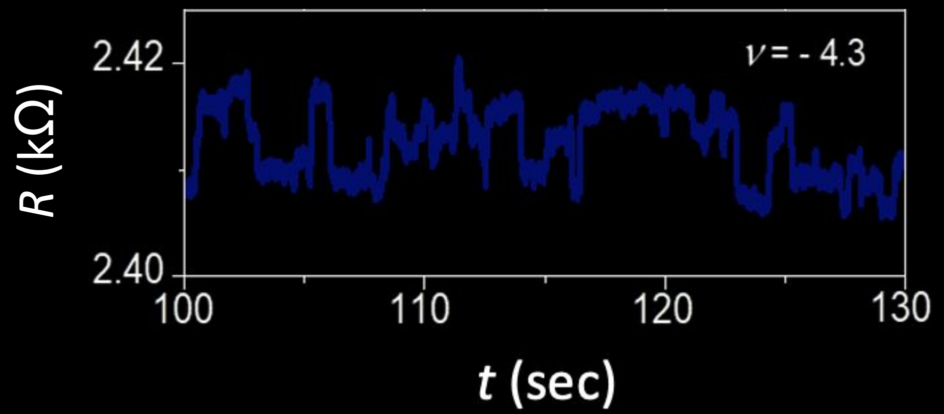
$$f_c \sim \tau_0^{-1} \exp(-\Delta/k_B T)$$

Filling factor dependence of noise near magic angle

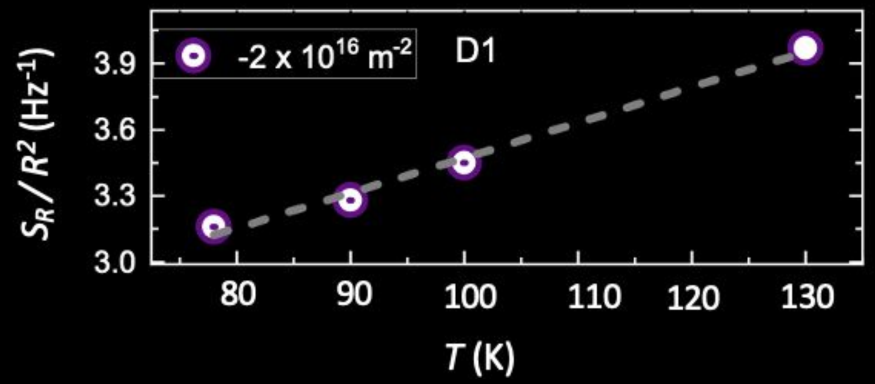




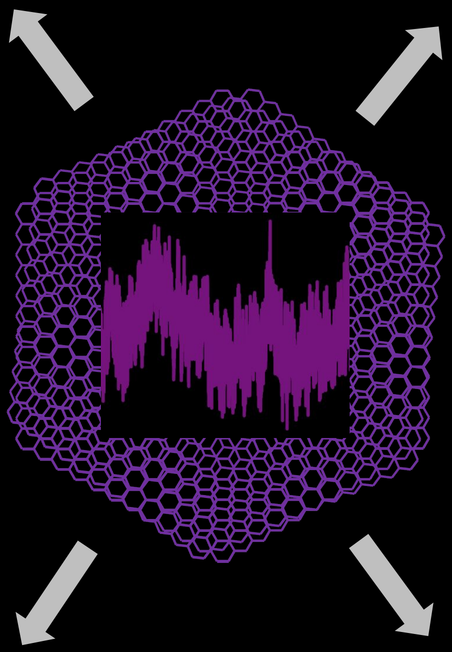
Summary

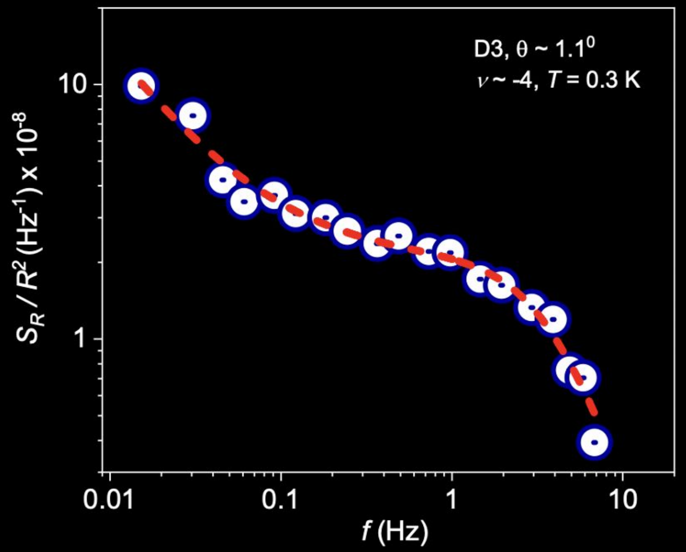


RTS signal near $\nu = \pm 4$ at T < 10 K.



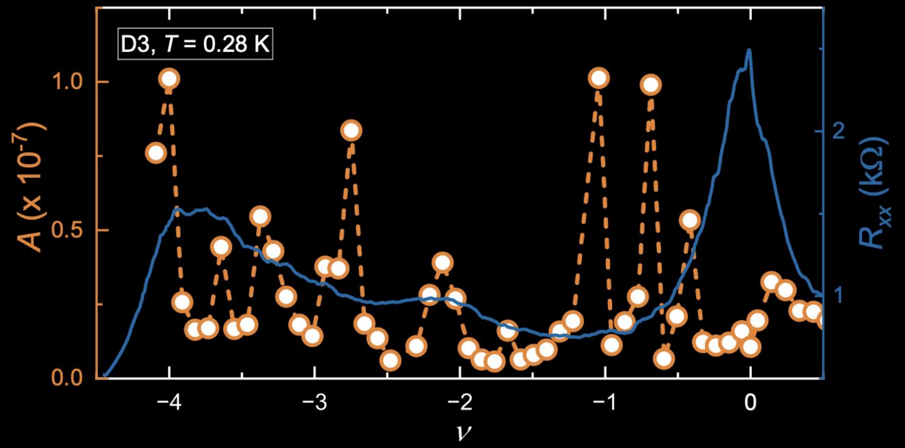
Origin of noise : carrier number fluctuations (McWhorter model) at T > 70 K .





Dominance of $1/f^2$ component near $\nu = -4$

Better probe ?



Near integer filling, series of noise minima in near magic angle sample.

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Aparna P

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Thank you for your attention!