

Gate-induced layer sliding induces non-volatile switching of magnetism in tetralayer graphene

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This file contains all reviewer reports in order by version, followed by all author rebuttals in order by version.

Version 0:

Reviewer comments:

Reviewer #1

(Comments for the Author)

The authors report electrically controlled stacking domains in marginally twisted bilayer/bilayer graphene. The two domains are rhombohedral and Bernal stacked. The gate-controlled domain effects are observed in transport measurements. The Hall measurements reveal an anomalous Hall effect coupled with the domains, leading to the switching on and off of the nonvolatile signals. The sign of the Hall signal is switched by the opposite sign of the D field. The switching of stacking arrangements between rhombohedral and Bernal stacked graphene by doping in graphene has been realized before. This work takes a step forward by measuring these effects in transport, which is important towards nonvolatile devices. The true novelty of the work lies in the observation of the anomalous Hall signal, which accompanies the magnetic phase transition due to gate-controlled structural changes. The paper is well-written, and the results are convincing and repeatable. I thus recommend it for publication.

Below are a few minor points the authors may consider to improve the manuscript.

- (1) The authors claim a quantum phase transition. "Here, we extend the concept of slidetronics to realize a first-order quantum phase transition through gate-induced interlayer sliding motion." This is the only place in the paper where the phrase "quantum phase transition" appears. I think it is not necessary to claim a quantum phase transition. The authors can either choose to remove the word "quantum" or prove it is a quantum phase transition.
- (2) Quantum phases appear several times in the paper. I would suggest changing this to electronic phases. There is no need to include the word quantum.
- (3) Figure 1d shows the control of R_{xx} by a short voltage pulse. How about R_{xy} ? Is it switchable in the same fashion?
- (4) Does the gate-induced layer sliding work at higher temperatures? I imagine it would work well at room temperature.
- (5) The equipotential curve is clearer in Extended Data 7 (e.g., panel h). Maybe incorporate it into the main figure?
- (6) Regarding the mechanism of switching the sign of AHE by the electric field: The results suggest that the orbital magnetism (or valleys) is coupled to the layer degrees of freedom. If we name the layers as 1, 2, 3, 4 from top to bottom, is it possible that the effect arises from 123 and 234, depending on the D-field direction?

Reviewer #3

(Comments for the Author)

Compared to the trivial Bernal stacking of graphene, rhombohedral stacking hosts more exotic electronic phases due to reduced kinetic energy and enhanced Coulomb interactions. In this manuscript, D. Brandon et al. claim that gate voltage can induce interlayer sliding between Bernal stacking and a mixed rhombohedral–Bernal stacking configuration. This leads to the central observation of the work: a switching between a no-AHE (paramagnetic) state and an AHE (ferromagnetic) state. Such magnetic switching is further claimed to be nonvolatile. While the transport signatures are clear and intriguing, I have concerns regarding the interpretation of the results and the sufficiency of the supporting evidence. I therefore cannot recommend publication unless the following issues are adequately addressed:

1. It is unclear how the contrast in Kelvin probe measurements (negative vs positive potential) is unambiguously attributed to rhombohedral and Bernal stacking, respectively. A rigorous justification and clear assignment are needed.
2. The authors attribute the observed hysteresis to doping-induced interlayer sliding. However, the hysteresis/bistability could also originate from interaction-driven electronic phase transitions without involving structural changes. Additional

evidence is needed to substantiate the structural interpretation. For instance, Raman spectroscopy or Kelvin probe measurements under varying gate voltage could directly track stacking evolution.

3. The authors attribute the observed anomalous Hall effect (AHE) to the rhombohedral stacking regions within the mixed-phase structure. However, rhombohedral stacking constitutes a smaller area fraction than Bernal stacking in this mixed state (Fig. 1b). Based on this spatial distribution, the AHE signal should be weaker than that observed in purely rhombohedral-stacked graphene. why does the authors' measurement yield a stronger AHE signal instead?

Reviewer #4

(Comments for the Author)

The authors present transport on 4-layer graphene devices made by stacking two Bernal bilayers with almost zero twist angle. Such a structure is expected to have rhombohedral and Bernal domains, as they confirm by Kelvin-probe measurements, and thus to show a mixed transport behavior with characteristics of both phases. They observe such mixed behavior. Moreover, they find that gate voltages can switch with hysteresis between different mixtures (either evenly mixed or Bernal-dominant), implying electrically-induced sliding, a phenomenon the corresponding author is an undisputed expert with. As a result, they can robustly electrically switch on and off an anomalous Hall contribution from the rhombohedral phase that persists up to 8 K, which they advertise as nonvolatile switching of magnetism. I think this is moderately interesting, but perhaps not too surprising or useful.

More interesting and novel, at least from my perspective, is the finding that the switching can be induced purely by doping even at zero displacement field. As far as I know this is new kind of "ferro" effect, I'm not sure it has a name, where the structure changes hysteretically as function of doping - neat! And it connects smoothly to a ferroelectric regime where the same structural change is induced purely by dipole coupling (at zero doping). The theory given in the supplement, calculating the total electronic free energy difference based on single-particle bands and relating it to the barrier for domain motion, appears almost implausibly simple but fits the switching contours so well that it is hard to argue with.

Apart from this choice of emphasis, I can find little to criticize. I recommend publication. It's clearly presented and well argued. Most of the data is from a single device, with another much less good device shown in the extended data - the authors might add something about why it's difficult to get such devices working. Also, they should address the temperature dependence of the sliding transitions - do they know what temperature the hysteresis survives to, and is it relevant to the free energies involved?

Reviewer #5

(Comments for the Author)

The authors have studied the effect of gates on a slightly twisted tetralayer graphene. They find that, changing the carrier density, a sliding of one of the layers of tetralayer graphene is induced and the system goes from a Rhombohedral (actually a Rhombohedral-Bernal mixed) stacking to a pure Bernal stacking. They claim that the switching is reproducible. Then they study the phase diagram of this sliding with the displacement field and the density. Finally, they show the switching between a magnetic to a non-magnetic state using Hall resistance measurements. Although the switching from these states are quite appealing and the system they have studied is of interest to the scientific community, I believe that the results would fit better in a more specialized journal, mainly because I find that some of the results are not being reproduced in other regions of the device and even in other devices. Furthermore, several issues that I enumerate below should be addressed before publication:

1) There have been previous works where the change from a rhombohedral to a Bernal stacking has been studied before. Furthermore, in those works the transformation seems to be more complete than in the present work. Maybe a further characterization of the samples after the shifting of the layers due to the change in the carrier density using KPFM would be useful.

2) The authors claim that in their samples, the surface potential of rhombohedral graphene is 22 mV smaller than Bernal and that this is consistent with previous reports. In my opinion, this is a bit misleading since in extended data Fig. 2c the work function is -30.05 mV while in 2d it is -13.60. The mean is -22mV but not the actual value. Furthermore, it seems that in Ref [37] Atri et al. find a similar value for the work function but they claim that this value is constant and independent of the region where the measurement is taken (although the values for the each of the potentials can vary from region to region). This is not the case for the measurements in this work.

3) The authors claim in the fourth paragraph that hysteresis appears only in several parts of the device, while in the fifth paragraph claim that the switching is highly robust and reproducible. Both sentences seem to be in contradiction. Furthermore, the first one raises the question about reproducibility in different devices.

4) The authors also claim that their results could be useful as a nonvolatile memory device. In my opinion this sentence is also a bit misleading since in previous paragraphs they claim that the switching behaviour depends on the initial domain configuration and domain wall pinning strength. Furthermore, they do not have a full rhombohedral domain and very large voltages would be required to have them.

5) The authors claim there is a good agreement between the contour lines of Fig. 3 agree well with the calculation of ΔU . I do agree that some of the lines seem to match the theoretical calculation, but those in the negative high-carrier density regime do not seem to match.

- 6) Could the authors comment on the measurement of the third row and third column of extended Fig. 9?
- 7) As I said in the beginning of this report, I find that some of the results are not reproduced, this is particularly evident in device B. For example, in all of the measurements shown in extended Fig. 11 show an AHE, hence there is no switching of the magnetic state. Therefore, I wonder how much these results are on having an appropriate initial stacking configuration or how much the results depend on having domain boundaries and if the authors have any other additional results in other devices which they can comment on.
- 8) The tight-binding calculations of figures S1 seems a bit different to what has been reported before. Could the authors comment on this result?

Some other minor comments:

- 9) The authors mainly cite experimental works regarding the superconducting and correlated phases of tetralayer rhombohedral graphene. I believe that theoretical works that have brought some light to the emergence of these phenomena could be of interest for the community and also be given credit to. For example: Nature Comm. 17, 232 (2025) and Phys. Rev. Lett. 135, 136503 (2025) and Phys. Rev. Research 6, L012003 among many others. Of course, this is only a suggestion if the authors do not think that they are relevant for their work, they can disregard my comment.
- 10) Although it is clear from the text and the caption, blue and red arrows in Fig. 1c are a bit confusing since they could be interpret as going up and down in temperature from 1.5 K, separating the arrows or adding a clear label on the arrows would probably make the figure more clear.

Version 1:

Reviewer comments:

Reviewer #1

(Comments for the Author)

The authors have made significant efforts in addressing reviewers' comments. The manuscript is significantly improved. Although the microscopic mechanism is not fully understood yet, the experimental results are sufficiently interesting to warrant a publication.

Reviewer #3

(Comments for the Author)

The authors have addressed all of my concerns, and I therefore recommend the manuscript for publication in Nature Nanotechnology.

Reviewer #4

(Comments for the Author)

The authors have now shown reproducibility between devices and persistence of the switching up to room temperature. They have dealt thoroughly with all the substantive reviewer comments. I would now endorse publication.

Reviewer #5

(Comments for the Author)

I thank the authors for taking the time of answering my comments and for improving the reproducibility of the results. I believe that the quality of the manuscript has improved, but I still stand with my previous recommendation of publishing the work in a more specialized journal for the same reasons as in my previous report. Furthermore, I still have some comments regarding this and the discussion on the physical interpretation of the results.

1) With respect to the reproducibility of the results it is true that the authors have been able to fabricate two new devices and they are able to reproduce the results of device A, but they also claim that fabricating the devices is challenging and that obtaining favorable results depend on having domain walls between the B and the RB regions. My question is, which is the percentage of working devices that show the switching they have with respect to those they fabricate and do not show them or show similar results to those of device B?

2) The authors claim that the quantum oscillations experiments serve only as qualitative measures of the domain ratio. Nevertheless, before that they claim that almost half of the domains are B and the other half RB. This is a bit confusing/misleading.

3) If I understand correctly (please correct me if I am missing something), the authors discuss the fact that the region where they are able to observe the AHE is similar to that in the work by Han et al. (Nature 643, 654) where a quarter metal state is found. They also claim that the difference in the magnitude of the AHE is due to a proximity effect between the domain wall and the quarter metal. From this, I assume that a quarter metal state (or at least a half metal) is needed in order to observe the switching and the AHE. In the work by Han, the doping levels are not so high as in the measurements reported in the present work. It has been shown both experimentally (Nat. Nanotechnol. 19, 188–195 (2024), Nature Physics volume 21, 1765–1772 (2025), arXiv:2606.05356) and theoretically (Phys. Rev. B 107, 104502 (2023), Phys. Rev. B 110, 245118 (2024), Phys. Rev. Lett 135, 136503 (2025), Adv Materials e14008 (2025), Nature Communications 17, 232 (2026)) that

depending on the doping level and displacement field applied, the tetralayer rhombohedral graphene suffers transitions from a quarter metal to a normal metal going through several other phases. In the present work, the authors go to values of doping larger of $1.5 \times 10^{12} \text{ cm}^{-2}$ where a quarter metal is not expected. Moreover, in the revised manuscript there are new measurements of the switching of one of the devices for different temperatures. From what I understand from the mean field calculations, the energy differences between the different states is small, so I would not expect these states to survive such high temperatures (Phys. Rev. B 107, 104502 (2023), Nature Communications 17, 232 (2026)). Could the authors comment on my rationalization or if some of my assumptions are wrong?

Version 2:

Reviewer comments:

Reviewer #5

(Comments for the Author)

I thank again the authors for taking the time of answering my comments and for adding the information on the reproducibility of the results of the different devices. They have answered all my concerns satisfactorily.

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We thank the reviewers for the careful assessment of our manuscript and their insightful comments and suggestions. These comments helped us to significantly improve our manuscript. We would like to respond to the comments point-by-point below.

Reviewer #1 (Comments for the Author):

The authors report electrically controlled stacking domains in marginally twisted bilayer/bilayer graphene. The two domains are rhombohedral and Bernal stacked. The gate-controlled domain effects are observed in transport measurements. The Hall measurements reveal an anomalous Hall effect coupled with the domains, leading to the switching on and off of the nonvolatile signals. The sign of the Hall signal is switched by the opposite sign of the D field. The switching of stacking arrangements between rhombohedral and Bernal stacked graphene by doping in graphene has been realized before. This work takes a step forward by measuring these effects in transport, which is important towards nonvolatile devices. The true novelty of the work lies in the observation of the anomalous Hall signal, which accompanies the magnetic phase transition due to gate-controlled structural changes. The paper is well-written, and the results are convincing and repeatable. I thus recommend it for publication.

We appreciate the reviewer's positive comments on the quality and novelty of our work.

Below are a few minor points the authors may consider to improve the manuscript. (1) The authors claim a quantum phase transition. "Here, we extend the concept of slidetronics to realize a first-order quantum phase transition through gate-induced interlayer sliding motion." This is the only place in the paper where the phrase "quantum phase transition" appears. I think it is not necessary to claim a quantum phase transition. The authors can either choose to remove the word "quantum" or prove it is a quantum phase transition.

Thank you for the suggestion. We removed the word "quantum", and changed the phrase to "first-order electronic phase transition".

(2) Quantum phases appear several times in the paper. I would suggest changing this to electronic phases. There is no need to include the word quantum.

We agree that "electronic phases" is more appropriate than "quantum phases" in our context, and we made the corresponding changes throughout the main text.

(3) Figure 1d shows the control of R_{xx} by a short voltage pulse. How about R_{xy} ? Is it switchable in the same fashion?

The data in Fig. 1d is taken in the paramagnetic region at $B = 0$ T; hence, R_{yx} is zero irrespective of the structure. Running the same measurement within the magnetic region (large- $|D|$, small- n region) should reveal the on-off switching of the anomalous Hall effect. However,

because of the leakage of R_{xx} into the Hall resistance measurement due to the misalignment of the electrical contacts, we require antisymmetrization to obtain an accurate value of R_{yx} . Namely, we have to sweep the magnetic field each time after the switching, which makes it challenging to measure R_{yx} within a similar time scale as in Fig. 1d. Instead, we performed the measurement scheme presented in the previous Extended Data Fig. 6, where we applied the voltage pulse to switch the structure between rhombohedral-Bernal-mixed and Bernal-dominant states and swept the magnetic field back and forth to measure R_{yx} . Measuring R_{yx} in both structural states revealed on-off switching of the anomalous Hall effect and magnetic hysteresis.

(4) Does the gate-induced layer sliding work at higher temperatures? I imagine it would work well at room temperature.

We thank the reviewer for the suggestion. We measured the temperature dependence of the gate-induced switching in a new device, labeled device D, which we present in Figs. R1 and R2. The hysteresis in R_{xx} as a function of n persists all the way to room temperature, as shown in Fig. R1. We further investigated the switching boundary within the space of carrier density and displacement field across multiple temperatures, as shown in Fig. R2. Here, the switching boundary (the contours corresponding to the sudden jump in resistance) follows the constant free-energy-difference lines, as in the case of the low-temperature measurement. We included the temperature dependence of gate-induced switching in Extended Data Figs. 9 and 10.

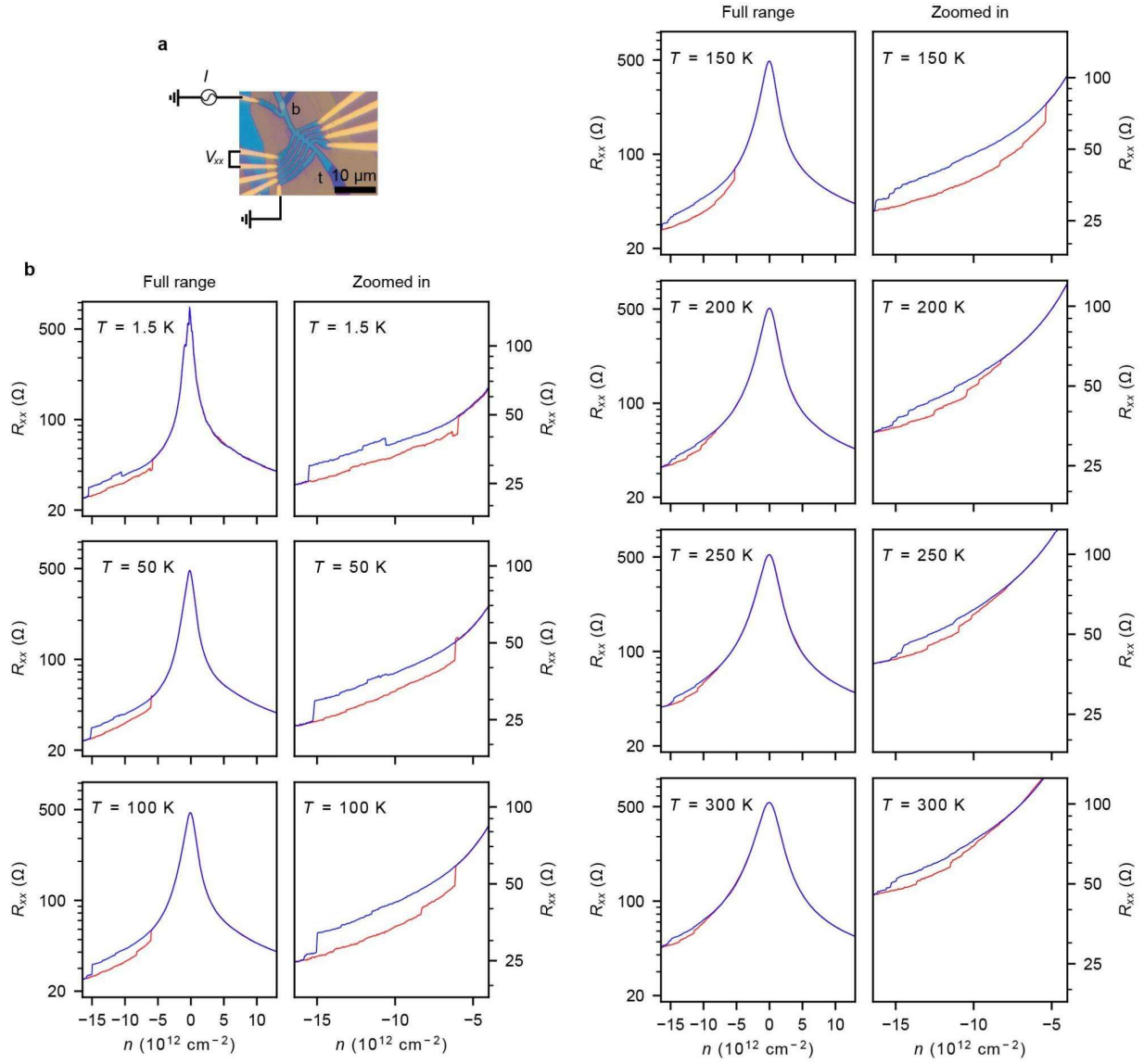


Fig. R1: Temperature dependence of the gate-induced switching in device D. **a**, Optical microscope image of the device with the measurement configuration labeled. **b**, R_{xx} measured as a function of n in the forward (red) and backward (blue) directions at $D/\epsilon_0 = -0.006 \text{ V/nm}$ for temperatures from $T = 1.5 \text{ K}$ to 300 K . The left panels show the full range of n , and the right panels show a zoomed-in view of the hysteresis region, which persists all the way to room temperature. Both are plotted on a log scale.

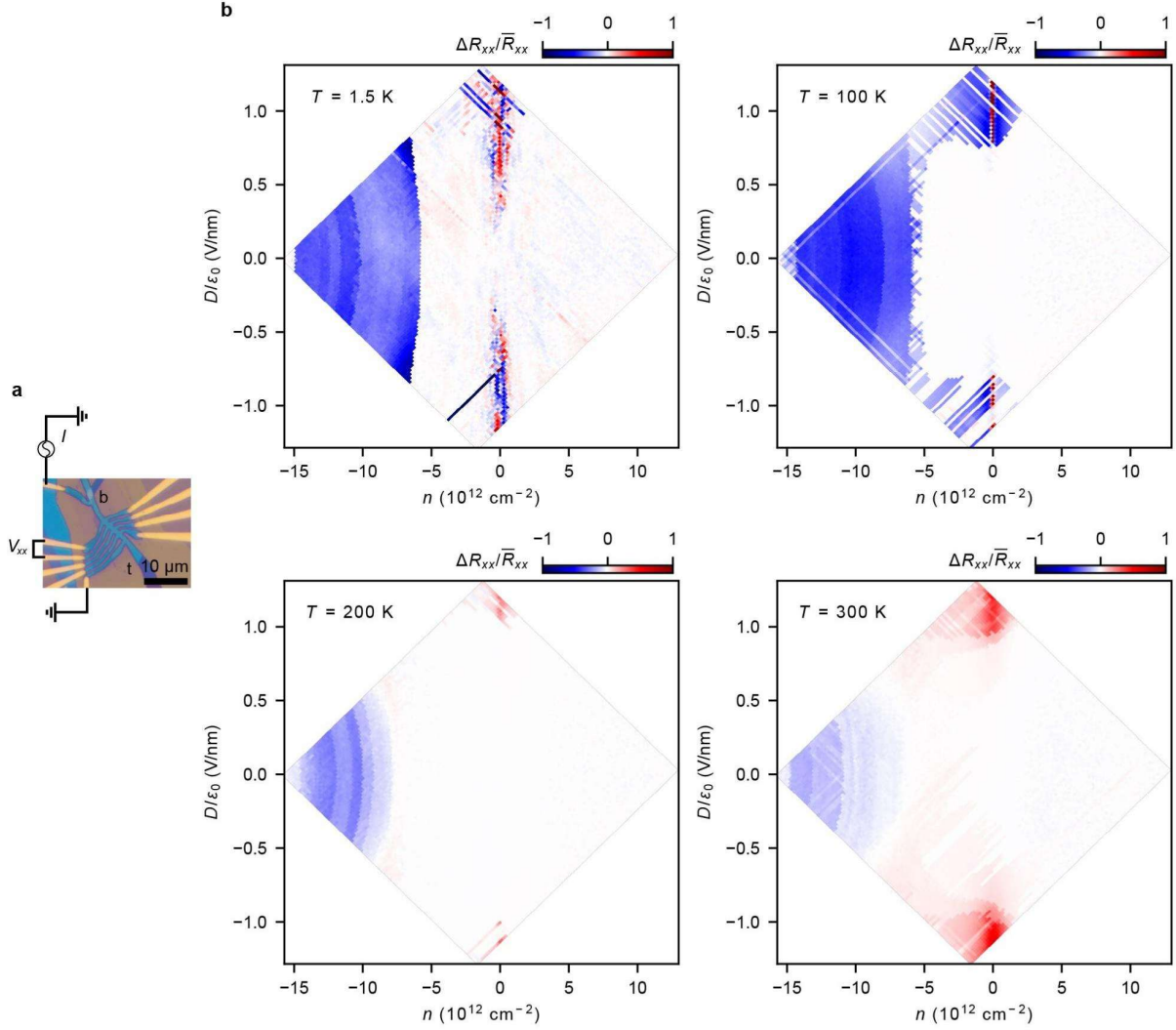


Fig. R2: Temperature dependence of the switching boundary in device D. **a**, Optical microscope image of the device with the measurement configuration labeled. **b**, $\Delta R_{xx}/\bar{R}_{xx}$ measured following the same procedure as in Figs. 2 and 3a for temperatures from $T = 1.5 \text{ K}$ to 300 K . The change in the position of the switching boundary likely originates from a change in the pinning strength of the domain walls as a function of temperature. At $T = 100 \text{ K}$, the switching boundary varies from scan to scan, leading to diagonal features along the top- and bottom-gate sweep directions. This variability arises likely because the domain wall can be pinned at either of two distinct pinning sites that are close in energy at this temperature. On repeated sweeps, the domain wall settles at one site or the other, so the rhombohedral-Bernal mixed state forms with a slightly different domain configuration each time it is prepared, leading to scan-to-scan variation in the transport hysteresis. We also note that the magnitude and sign of the hysteresis in R_{xx} change with temperature. As the resistance value is expected to be highly sensitive to the domain configuration within the device, an accurate understanding of the origin of these resistance changes will require simultaneous real-space imaging and transport measurements, which remain future work.

(5) The equipotential curve is clearer in Extended Data 7 (e.g., panel h). Maybe incorporate it into the main figure?

We thank the reviewer for the suggestion. In Fig. 3a, we showed only the data taken from the primary contact configuration for this device. Meanwhile, we agree that the equipotential curves from the secondary contact configuration are clearer in the previous Extended Data Fig. 7h (now Extended Data Fig. 4h), as the reviewer points out. In fact, we used that figure to draw the blue dotted lines in Fig. 3a. We highlighted this procedure in the caption of Extended Data Fig. 4h as follows: “Given the higher clarity of the minor transitions, the blue equipotential lines in Fig. 3 are extracted from this dataset.” We further highlighted it in the main text as follows: “blue dashed lines are taken from Extended Data Fig. 4h”.

(6) Regarding the mechanism of switching the sign of AHE by the electric field: The results suggest that the orbital magnetism (or valleys) is coupled to the layer degrees of freedom. If we name the layers as 1, 2, 3, 4 from top to bottom, is it possible that the effect arises from 123 and 234, depending on the D-field direction?

We agree that the coupling between the layer polarization and the valley degrees of freedom is likely important in explaining the sign reversal of the AHE we observed. However, let us clarify that this coupling alone cannot account for a sign reversal if you consider pure rhombohedral graphene. Pure rhombohedral tetralayer graphene becomes layer-polarized under a displacement field, to either the top or bottom layer, depending on the direction of the field. Flipping the sign of D reverses two quantities simultaneously: within a given valley, both the sign of the orbital magnetism and the sign of the Berry curvature change [F. Zhang *et al.*, Phys. Rev. Lett. **106**, 156801 (2011)]. This is summarized in Table R1.

The applied magnetic field couples to the orbital magnetism and selects which valley is occupied, while the Berry curvature of that valley sets the sign of the AHE. As we apply a positive magnetic field under $D > 0$, the valley with positive orbital magnetism is selected (K valley), whose Berry curvature gives a negative AHE. Under $D < 0$, the same positive magnetic field again selects the valley with positive orbital magnetism, but this is now the K' valley, and its Berry curvature again gives a negative AHE. Because flipping D reverses both the orbital magnetism and the Berry curvature, their relative sign is fixed. Therefore, the sign of AHE for a given magnetic field remains the same upon reversing D , as long as we consider pure rhombohedral graphene. This microscopic explanation is consistent with our macroscopic symmetry argument in the main text, which states that the sign of the AHE should remain the same upon reversing D in an inversion-symmetric system.

This is the reason we hypothesized that the domain boundary between rhombohedral and Bernal tetralayer graphene is a possible source of AHE. This boundary naturally breaks inversion symmetry and may host an AHE that reverses sign as a function of D . One possibility is that, at the domain boundary, the relation between the orbital magnetism and the Berry curvature changes with the sign of the displacement field due to a mechanism we do not fully understand yet. Here, the displacement field is related to the layer polarization, as the reviewer

pointed out. Although this is an intriguing possibility, it remains speculation without solid experimental and theoretical evidence, and further research is required to test this hypothesis. We included the table and this discussion in Supplementary Information section 6 under “Microscopic discussion on the sign of anomalous Hall effect in pure rhombohedral graphene”.

D-field	Valley	Orbital magnetism	Berry curvature
D > 0 (Bottom layer polarized)	K	+	-
	K'	-	+
D < 0 (Top layer polarized)	K	-	+
	K'	+	-

Table R1: Orbital magnetism and Berry curvature for different displacement fields in pure rhombohedral graphene. Sign of orbital magnetism and Berry curvature for different displacement fields. The external magnetic field couples to the orbital magnetism, which in turn sets the sign of the anomalous Hall effect (AHE) through the Berry curvature. Within this picture, the sign of the AHE should not change upon reversing the displacement field.

Reviewer #3 (Comments for the Author):

Compared to the trivial Bernal stacking of graphene, rhombohedral stacking hosts more exotic electronic phases due to reduced kinetic energy and enhanced Coulomb interactions. In this manuscript, D. Brandon et al. claim that gate voltage can induce interlayer sliding between Bernal stacking and a mixed rhombohedral–Bernal stacking configuration. This leads to the central observation of the work: a switching between a no-AHE (paramagnetic) state and an AHE (ferromagnetic) state. Such magnetic switching is further claimed to be nonvolatile. While the transport signatures are clear and intriguing, I have concerns regarding the interpretation of the results and the sufficiency of the supporting evidence. I therefore cannot recommend publication unless the following issues are adequately addressed:

We appreciate the reviewer's comments on the potential value of our work.

1. It is unclear how the contrast in Kelvin probe measurements (negative vs positive potential) is unambiguously attributed to rhombohedral and Bernal stacking, respectively. A rigorous justification and clear assignment are needed.

We identified the rhombohedral and Bernal domains from the size and shape imbalance between the two domains. Small-angle twisted bilayer graphene forms triangular AB and BA domains, separated by sharp domain walls. These domains are energetically degenerate and therefore occupy equal areas. In small-angle twisted double bilayer graphene, however, the ABAB (Bernal) and ABCA (rhombohedral) domains are not degenerate: Bernal stacking is slightly energetically favorable in the absence of doping or a displacement field. Here, to lower the total energy, the Bernal domains expand while the rhombohedral domains shrink, with the growing Bernal domains bulging outward (convex walls) and the shrinking rhombohedral domains left with concave walls. This produces a characteristic size and shape imbalance, larger/convex Bernal versus smaller/concave rhombohedral, as observed previously in real space (Fig. R3a) [D. Halbertal *et al.*, Nat. Commun. **12**, 242 (2021)]. The same group subsequently measured the local density of states by scanning tunneling spectroscopy and directly confirmed that the smaller (larger) domains correspond to rhombohedral (Bernal) stacking (Fig. R3b) [A. Kerelsky *et al.*, Proc. Natl. Acad. Sci. **118**, e2017366118 (2021)].

Our Kelvin probe force microscopy of small-angle twisted double bilayer graphene (Fig. R3c,d) shows a similar size and shape imbalance, allowing us to assign the smaller, concave domains to rhombohedral stacking and the larger, convex domains to Bernal stacking. The smaller, concave rhombohedral domains exhibit the lower, negative surface potential, while the larger, convex Bernal domains exhibit the higher, positive potential. This observation is consistent with the smaller work function reported for the rhombohedral structure relative to the Bernal structure [S. S. Atri *et al.*, Adv. Phys. Res. **3**, 2300095 (2024)]. We adjusted the main text to make this logic clear:

“A clear area imbalance is observed between the two domains. As Bernal stacking is more energetically favorable at charge neutrality under zero displacement field [30, 39, 40], we can assign the smaller, concave domains to rhombohedral stacking and the larger, convex domains to Bernal stacking. We also find that the surface potential of rhombohedral graphene is smaller than that of Bernal, namely, the work function of rhombohedral graphene is smaller, consistent with the previous report (see Supplementary Information section 15) [41].”

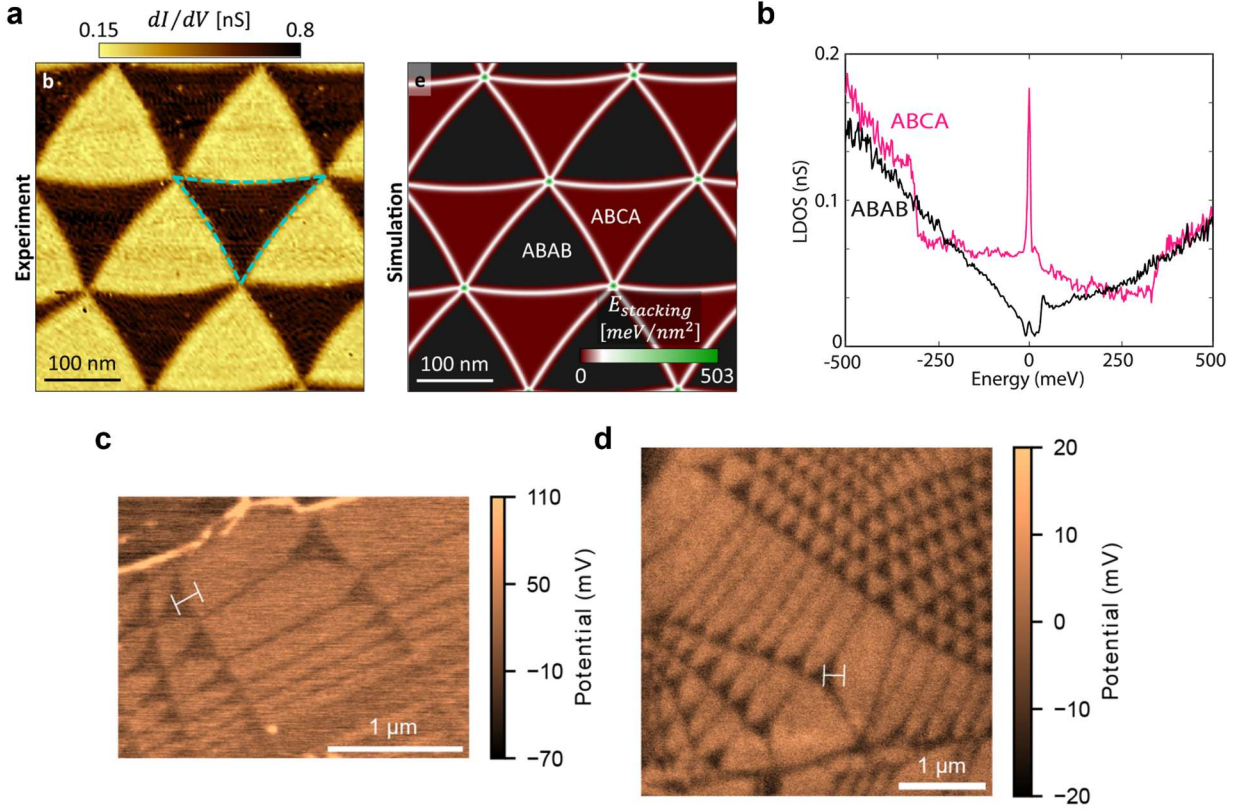


Fig. R3: Identification of rhombohedral and Bernal domains in twisted double bilayer graphene. **a**, Scanning tunneling spectroscopy map of twisted double bilayer graphene. The ABCA phase bends inward (dashed green line), revealing the higher energy of ABCA (rhombohedral) as compared to ABAB (Bernal) stacking. The right panel shows the simulation result, which agrees well with the experiment. Adapted from [D. Halbertal *et al.*, Nat. Commun. **12**, 242 (2021)]. **b**, Scanning tunneling spectroscopy local density of state of ABCA and ABAB graphene domains in small-angle twisted double bilayer graphene taken at the center of each domain. Adapted from [A. Kerelsky *et al.*, Proc. Natl. Acad. Sci. **118**, e2017366118 (2021)]. **c,d**, Our Kelvin probe force microscopy images taken on twisted double bilayer graphene.

2. The authors attribute the observed hysteresis to doping-induced interlayer sliding. However, the hysteresis/bistability could also originate from interaction-driven electronic phase transitions without involving structural changes. Additional evidence is needed to substantiate the structural interpretation. For instance, Raman spectroscopy or Kelvin probe measurements under varying gate voltage could directly track stacking evolution.

As the reviewer pointed out, first-order phase transitions of correlated electronic phases can produce hysteresis, which has been reported before in multilayer rhombohedral graphene [H. Zhou *et al.*, Nature **598**, 429 (2021); T. Han *et al.*, Nature **623**, 41 (2023)]. While such electronic phase transitions can produce hysteresis, we do not believe that this effect is causing the hysteresis in our device for the following reasons.

First, our hysteresis appears in the high-carrier-density regions where correlated phases are not observed. The hysteresis due to electron correlation appears along the phase boundaries of the interaction-driven correlated phases in rhombohedral graphene. These phases exist only at low densities in rhombohedral graphene, typically around or less than 10^{12} cm^{-2} , where the Fermi energy is close to the flat-band regions of the rhombohedral band structure [H. Zhou *et al.*, Nature **598**, 429 (2021); T. Han *et al.*, Nature **623**, 41 (2023)]. Meanwhile, the hysteresis in our device is observable up to a much higher carrier density of $1.55 \times 10^{13} \text{ cm}^{-2}$ (Fig. 1c), where the band dispersion is much larger, and the effect of electron correlations is nearly negligible. This discrepancy indicates that the gate-induced hysteresis we observe is not of electron-correlation origin.

Second, our hysteresis occurs at room temperature, well above the temperature at which correlated phases are observed. We measured the temperature dependence of the gate-induced switching in a new device, labeled device D, which we present in Figs. R4 and R5. The hysteresis in R_{xx} as a function of n persists all the way to room temperature, as shown in Fig. R4. We further investigated the switching boundary within the space of carrier density and displacement field across multiple temperatures, as shown in Fig. R5, which again shows hysteretic switching up to room temperature. The persistence of hysteretic switching well above the transition temperature of correlated phases provides further evidence that the gate-induced hysteresis we observe does not originate from electron correlations.

Finally, the structural switching between Bernal and rhombohedral graphene through electrostatic gating has been imaged in real space previously, with infrared scattering-type scanning near-field optical microscopy (IR-SNOM) [H. Li *et al.*, Nano Lett. **20**, 3106 (2020)] and with scanning tunneling microscopy (STM) [M. Yankowitz *et al.*, Nat. Mater. **13**, 786 (2014)]. We prepared the coexisting Bernal and rhombohedral graphene structure in a manner similar to that of the previous report and obtained a similar free-energy phase diagram, but with a different probe: real-space imaging in their case [H. Li *et al.*, Nano Lett. **20**, 3106 (2020)] and transport measurements in ours. Therefore, it is reasonable to attribute our hysteresis observation to the structural phase transition between Bernal and rhombohedral graphene.

Simultaneous real-space imaging and transport measurement are highly appealing, as they would provide a direct structural foundation for understanding transport behavior. However, Raman spectroscopy averages the signal over a scale of about a micrometer, larger than our expected domain size of several hundred nanometers. KPFM is a surface-potential measurement technique, and the electrostatic potential of the tetralayer is screened by the top gate, so it cannot be applied directly to our dual-gated structure. Therefore, simultaneous transport and real-space imaging of the structure remain future work. We included the

temperature dependence of gate-induced switching in the Extended Data Figs. 9 and 10 and the above discussion in Supplementary Information section 11 under “Structural interpretation of the hysteresis”.

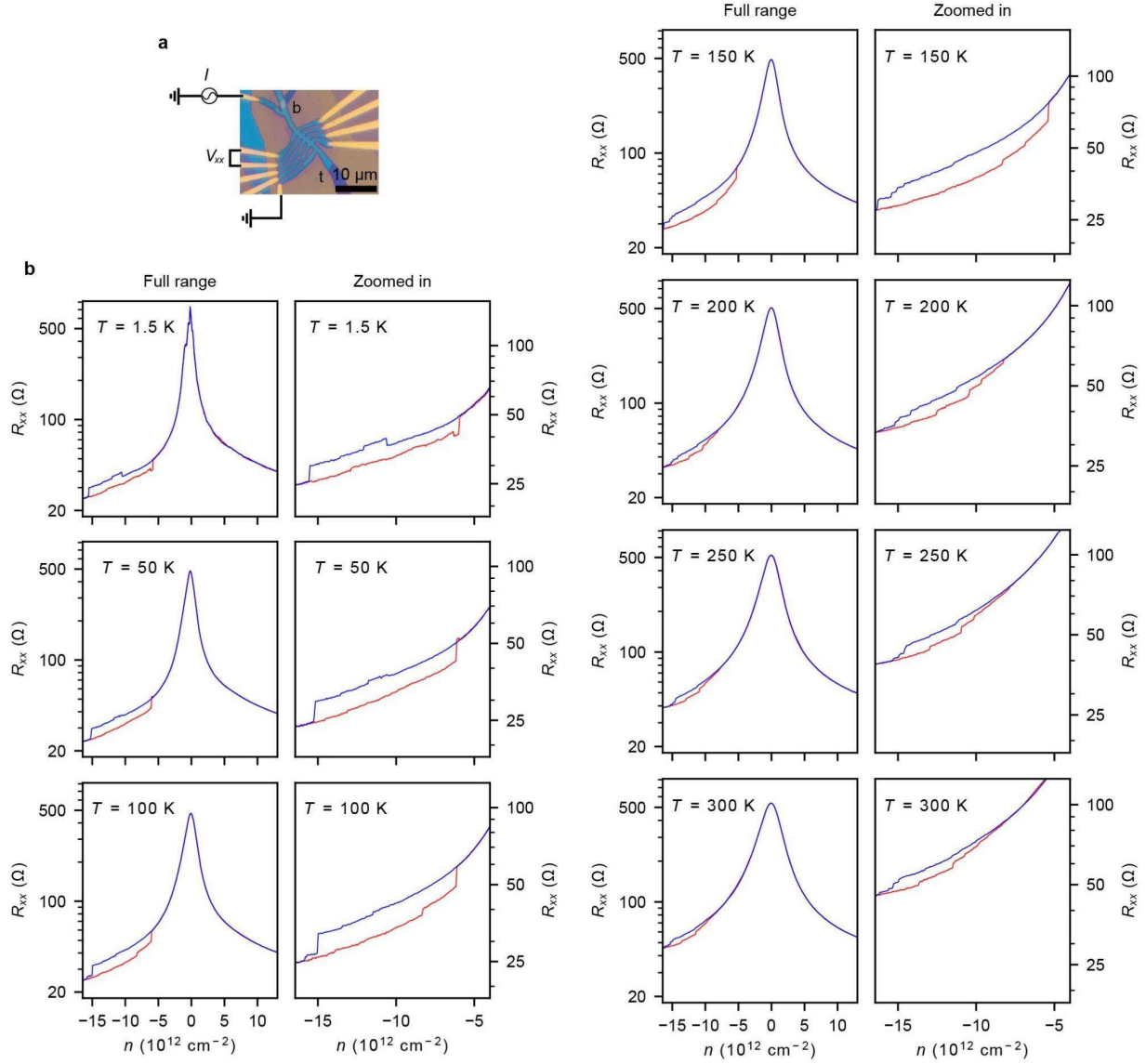


Fig. R4: Temperature dependence of the gate-induced switching in device D. **a**, Optical microscope image of the device with the measurement configuration labeled. **b**, R_{xx} measured as a function of n in the forward (red) and backward (blue) directions at $D/\epsilon_0 = -0.006 \text{ V/nm}$ for temperatures from $T = 1.5 \text{ K}$ to 300 K . The left panels show the full range of n , and the right panels show a zoomed-in view of the hysteresis region, which persists all the way to room temperature. Both are plotted on a log scale.

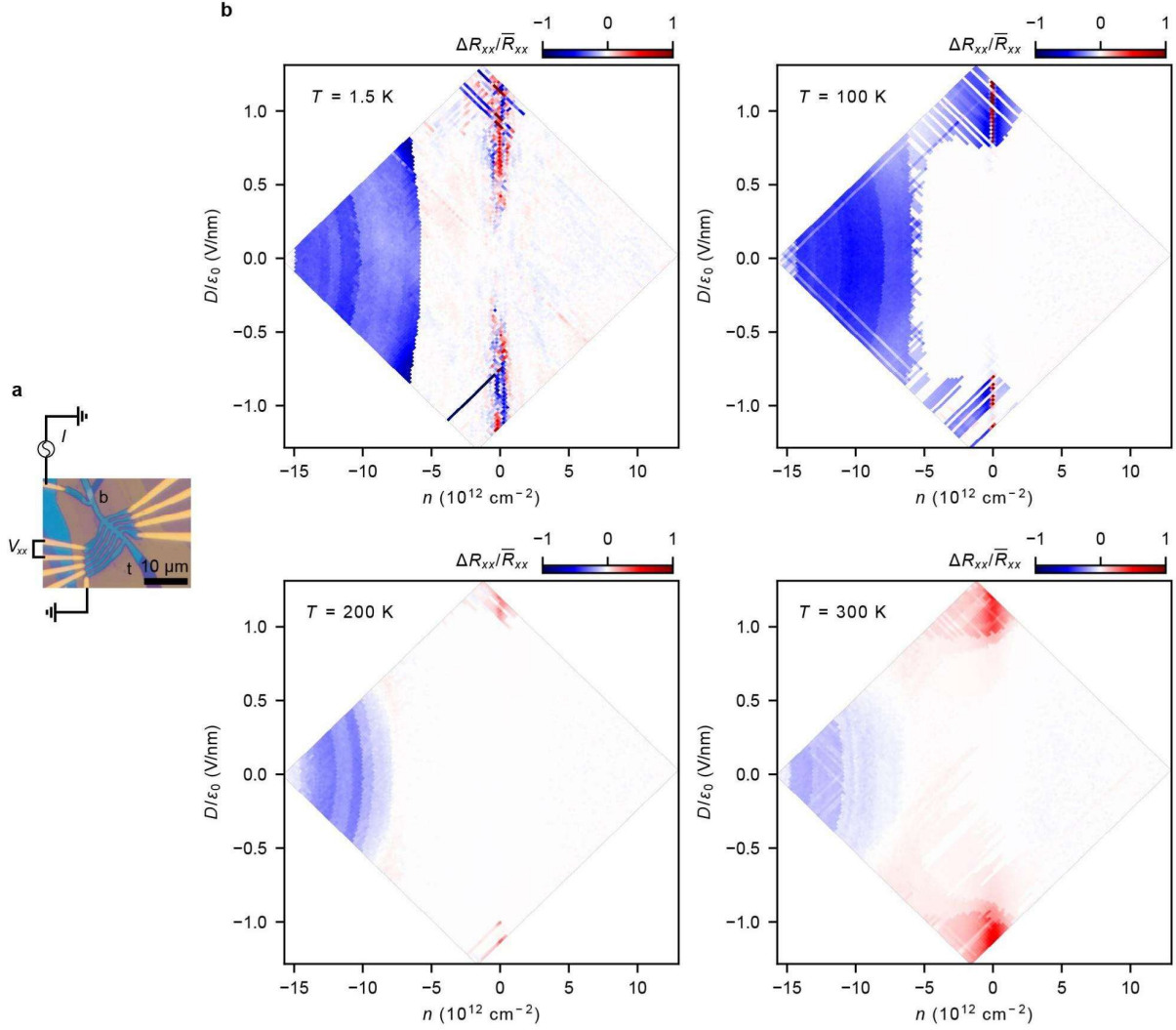


Fig. R5: Temperature dependence of the switching boundary in device D. **a**, Optical microscope image of the device with the measurement configuration labeled. **b**, $\Delta R_{xx}/\bar{R}_{xx}$ measured following the same procedure as in Figs. 2 and 3a for temperatures from $T = 1.5 \text{ K}$ to 300 K . The change in the position of the switching boundary likely originates from a change in the pinning strength of the domain walls as a function of temperature. At $T = 100 \text{ K}$, the switching boundary varies from scan to scan, leading to diagonal features along the top- and bottom-gate sweep directions. This variability arises likely because the domain wall can be pinned at either of two distinct pinning sites that are close in energy at this temperature. On repeated sweeps, the domain wall settles at one site or the other, so the rhombohedral-Bernal mixed state forms with a slightly different domain configuration each time it is prepared, leading to scan-to-scan variation in the transport hysteresis. We also note that the magnitude and sign of the hysteresis in R_{xx} change with temperature. As the resistance value is expected to be highly sensitive to the domain configuration within the device, an accurate understanding of the origin of these resistance changes will require simultaneous real-space imaging and transport measurements, which remain future work.

3. The authors attribute the observed anomalous Hall effect (AHE) to the rhombohedral stacking regions within the mixed-phase structure. However, rhombohedral stacking constitutes a smaller area fraction than Bernal stacking in this mixed state (Fig. 1b). Based on this spatial distribution, the AHE signal should be weaker than that observed in purely rhombohedral-stacked graphene. why does the authors' measurement yield a stronger AHE signal instead?

The reviewer makes an astute observation. While it is difficult to make direct device-to-device comparisons of R_{yx} given the variance in R_{xx} between devices, our anomalous Hall effect (AHE) signal is indeed larger than that reported for pure rhombohedral tetralayer graphene [T. Han *et al.*, Nature **623**, 41 (2023)], especially at large doping above 10^{12} cm^{-2} .

We attribute this discrepancy to a different origin of the AHE. We hypothesize that the major contribution to the AHE in our device originates not from a pure rhombohedral region, but from the domain boundary between rhombohedral and Bernal tetralayer graphene. This hypothesis stems from our observation that the sign of the AHE reverses as we reverse the direction of the displacement field D . Based on the symmetry argument and the microscopic discussion of the Berry curvature (detailed in the Supplementary Information section under “Microscopic discussion on the sign of anomalous Hall effect in a pure rhombohedral graphene”), pure rhombohedral graphene should exhibit the same sign of AHE upon reversing the direction of D . We therefore speculate that the domain boundary provides an additional, larger, D -odd contribution to the AHE, which dominates the signal we observe in our sample. This picture is also consistent with the larger AHE we observe compared to that observed in pure rhombohedral graphene. We note that this remains speculation, and further experimental and theoretical studies are required to confirm it.

We updated our discussion in the main text to give this interpretation: “In addition, comparing with a previous report [23], we find that the region where we observe AHE corresponds to the spin- and valley-polarized quarter-metal phase of pure rhombohedral tetralayer graphene, but with major distinctions where a sign reversal is observed as a function of D , and the magnitude of AHE in our device is larger than that reported in pure rhombohedral tetralayer graphene, especially at large doping above 10^{12} cm^{-2} . These observations suggest that the AHE we observe may originate from a proximity effect from the spin- and valley-polarized quarter-metal in the rhombohedral region to either the domain wall or the adjacent Bernal region.”

Reviewer #4 (Comments for the Author):

The authors present transport on 4-layer graphene devices made by stacking two Bernal bilayers with almost zero twist angle. Such a structure is expected to have rhombohedral and Bernal domains, as they confirm by Kelvin-probe measurements, and thus to show a mixed transport behavior with characteristics of both phases. They observe such mixed behavior. Moreover, they find that gate voltages can switch with hysteresis between different mixtures (either evenly mixed or Bernal-dominant), implying electrically-induced sliding, a phenomenon the corresponding author is an undisputed expert with. As a result, they can robustly electrically switch on and off an anomalous Hall contribution from the rhombohedral phase that persists up to 8 K, which they advertise as nonvolatile switching of magnetism. I think this is moderately interesting, but perhaps not too surprising or useful.

More interesting and novel, at least from my perspective, is the finding that the switching can be induced purely by doping even at zero displacement field. As far as I know this is new kind of "ferro" effect, I'm not sure it has a name, where the structure changes hysteretically as function of doping - neat! And it connects smoothly to a ferroelectric regime where the same structural change is induced purely by dipole coupling (at zero doping). The theory given in the supplement, calculating the total electronic free energy difference based on single-particle bands and relating it to the barrier for domain motion, appears almost implausibly simple but fits the switching contours so well that it is hard to argue with.

Apart from this choice of emphasis, I can find little to criticize. I recommend publication. It's clearly presented and well argued. Most of the data is from a single device, with another much less good device shown in the extended data - the authors might add something about why it's difficult to get such devices working. Also, they should address the temperature dependence of the sliding transitions - do they know what temperature the hysteresis survives to, and is it relevant to the free energies involved?

We appreciate the reviewer's positive comments on the quality and novelty of our work. In light of the reviewer's suggestion, we fabricated and measured two additional samples, which exhibit similar behavior to our previous device A, labeled devices C and D. Both devices are prepared by rotating and stacking the two bilayer graphene layers by -0.02 degrees. These devices address the questions of reproducibility and the temperature dependence of the sliding transition.

Figure R6 shows the measured switching boundary in device C, which closely resembles the boundary measured in device A. We further measured the Hall resistance in the large- $|D|$, low- n regions in both rhombohedral-Bernal mixed and Bernal-dominant states. Upon measuring the Hall resistance in both states, we observe anomalous Hall effect only in the rhombohedral-Bernal mixed state, as shown in Fig. R7, reproducing our original device A.

In device D, we measured the temperature dependence of the gate-induced switching, as shown in Figs. R8 and R9. The hysteresis in R_{xx} as a function of n persists all the way to room temperature, as shown in Fig. R8. We further investigated the switching boundary within the space of carrier density and displacement field across multiple temperatures in Fig. R9. Importantly, the constant-free-energy-difference contours (the contours that correspond to the sudden jump in resistance) are almost the same as in the low-temperature measurement. This means that the n and D dependence of the free energy difference is almost unchanged as a function of temperature. This is consistent with our theoretical calculation, which suggests that the internal energy difference ΔU makes a much larger contribution than the entropy term $T\Delta S$. The change in the position of the switching boundary with temperature likely originates from the temperature dependence of the pinning strength of the domain walls.

After cooling device D down again, we found that the switching boundary was changed, as shown in Fig. R10, implying a change in the rhombohedral and Bernal domain configuration after the thermal cycling. This new boundary enabled us to measure the Hall resistance in the rhombohedral-Bernal mixed and Bernal-dominant states in the large- $|D|$, low- n regions. Upon measuring the Hall resistance in both states, we find anomalous Hall effect only in the rhombohedral-Bernal mixed state, as shown in Fig. R11, again reproducing the result of device A.

We included the reproduced results in devices C and D, along with the temperature dependence, in Extended Data Figs. 7, 8, 9, and 10 and Supplementary Information section 5 under “Additional transport measurement of device D” and Figs. S4, S5, and S6.

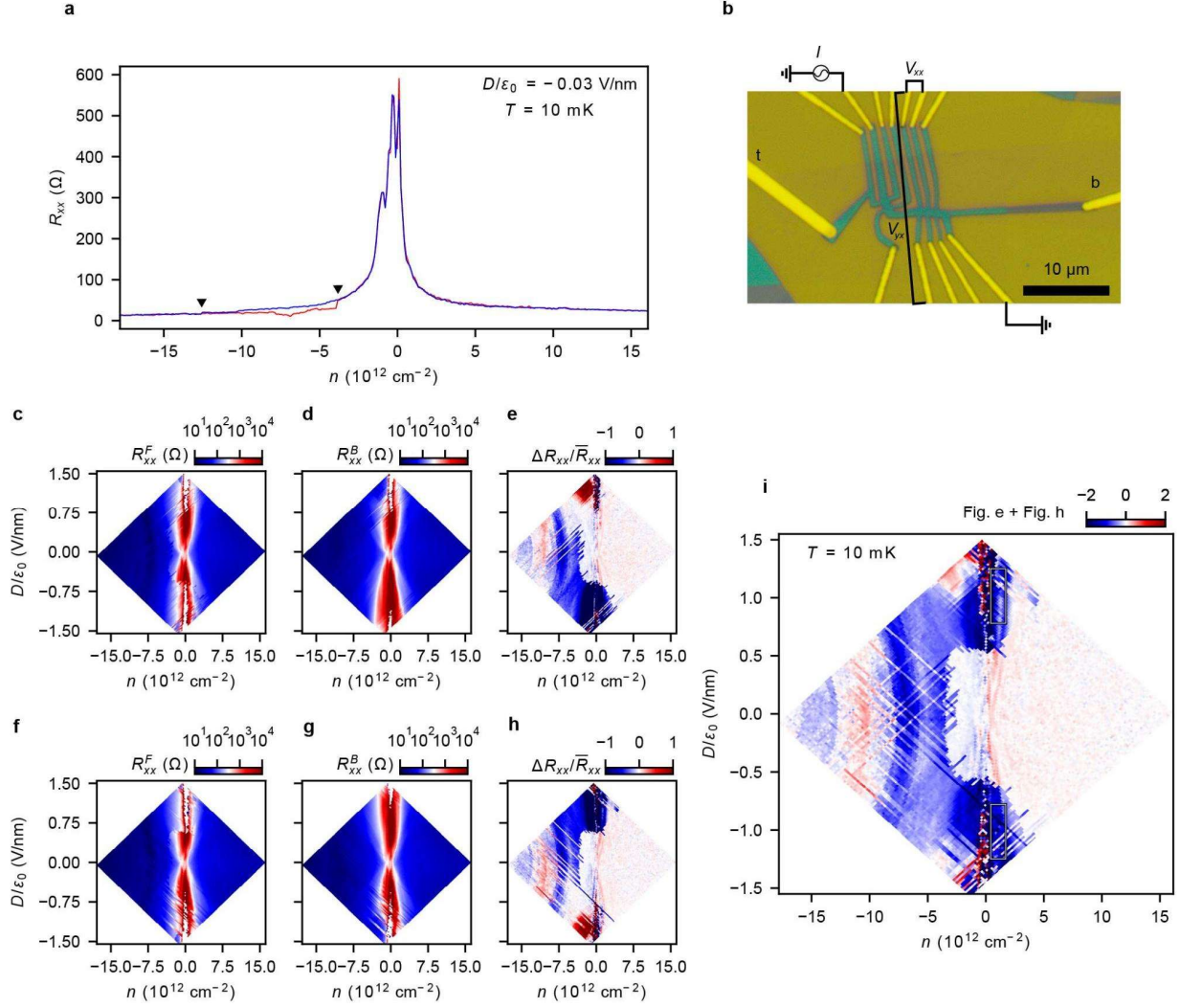


Fig. R6: Gate-induced switching in device C. **a**, Carrier density n dependence of R_{xx} scanned in the forward (red) and backward (blue) directions at $D/\epsilon_0 = -0.03 \text{ V/nm}$. The triangles highlight the points at which the switching happens. **b**, Optical microscope image of the device with the measurement configuration labeled. **c-h**, Measurement of R_{xx} and $\Delta R_{xx}/\bar{R}_{xx}$ following the measurement scheme in Fig. 2. **i**, The sum of **e** and **h**. The white and black boxes indicate the areas in which we measured the Hall resistance in Fig. R7. The switching boundary in this device varies from scan to scan, leading to diagonal features along the top- and bottom-gate sweep directions. This variability arises likely because the domain wall can be pinned at either of two distinct pinning sites that are close in energy. On repeated sweeps, the domain wall settles at one site or the other, so the rhombohedral-Bernal mixed state forms with a slightly different domain configuration each time it is prepared, leading to scan-to-scan variation in the transport hysteresis.

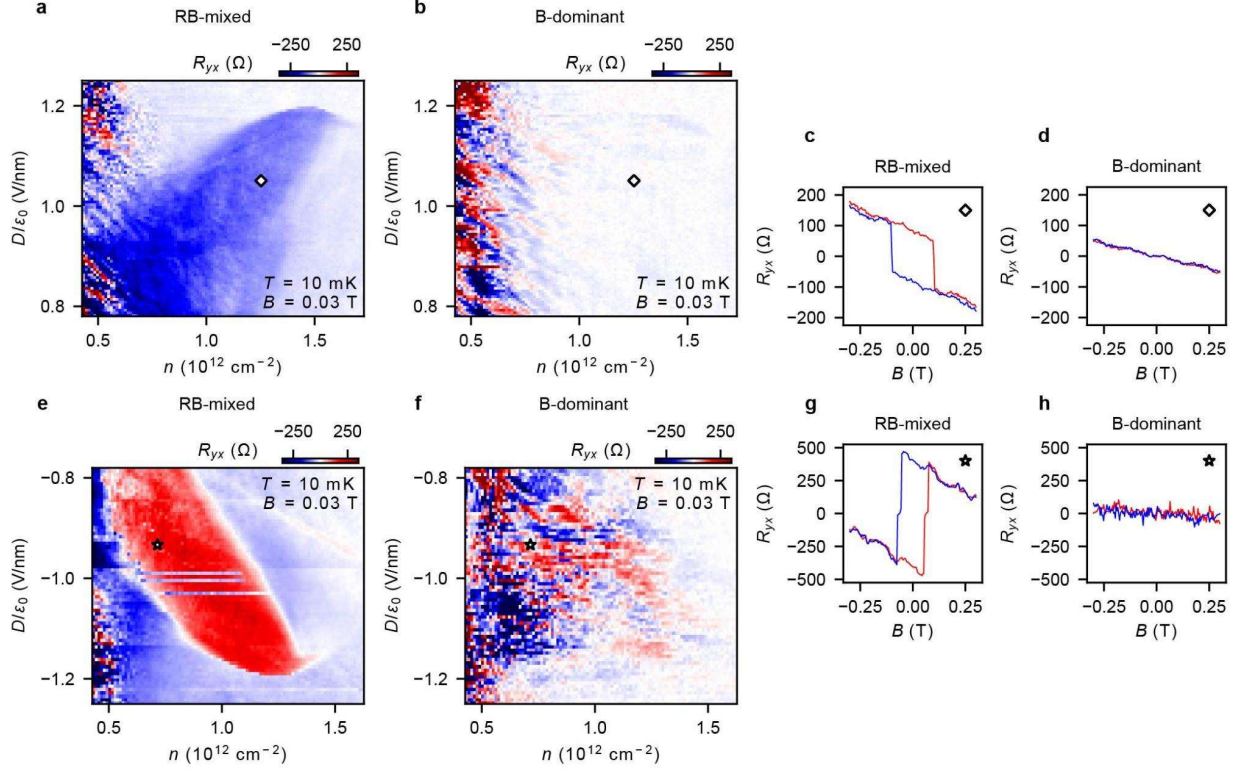


Fig. R7: Hall resistance measurements in device C. **a,b**, R_{yx} measured at $B = 0.03$ T in the positive D and small positive n region, in the RB-mixed (rhombohedral-Bernal-mixed, **a**) and B-dominant state (Bernal-dominant, **b**), respectively. Large negative R_{yx} appears exclusively in the RB-mixed state, indicating an anomalous Hall effect (AHE). **c,d**, R_{yx} measured at $T = 10$ mK as a function of B in both the forward (red) and backward (blue) directions at the diamond position for the RB-mixed (**c**) and B-dominant state (**d**), respectively. A nonzero R_{yx} at $B = 0$ T and the hysteresis appear only in the RB-mixed state. **e,f**, The same as **a** and **b** measured in the negative D region. A large positive AHE appears only in the RB-mixed state. **g,h**, R_{yx} measured at $T = 10$ mK at the star position in the RB-mixed (**g**) and B-dominant state (**h**), respectively.

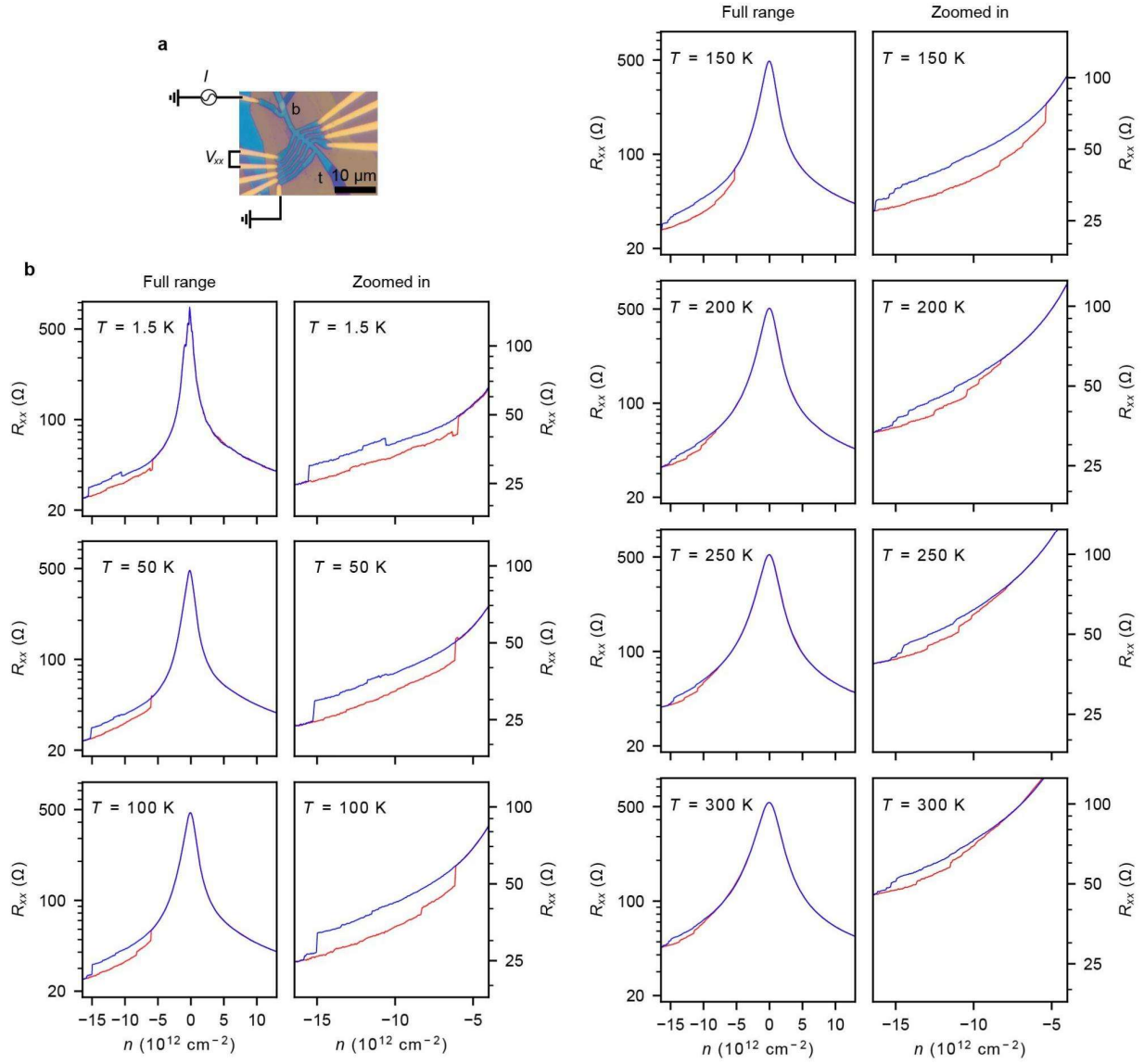


Fig. R8: Temperature dependence of the gate-induced switching in device D. **a**, Optical microscope image of the device with the measurement configuration labeled. **b**, R_{xx} measured as a function of n in the forward (red) and backward (blue) directions at $D/\epsilon_0 = -0.006 \text{ V/nm}$ for temperatures from $T = 1.5 \text{ K}$ to 300 K . The left panels show the full range of n , and the right panels show a zoomed-in view of the hysteresis region, which persists all the way to room temperature. Both are plotted on a log scale.

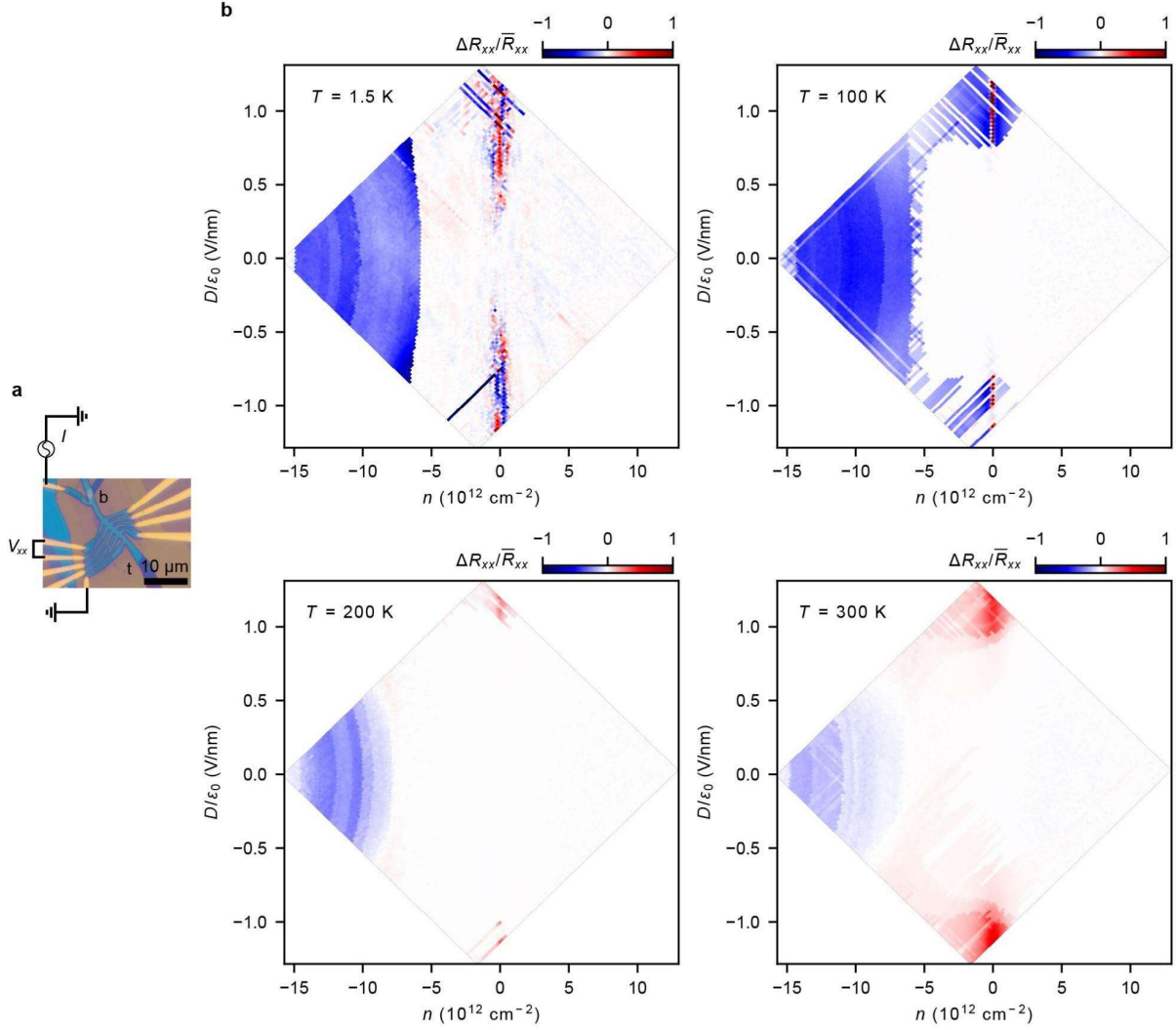


Fig. R9: Temperature dependence of the switching boundary in device D. **a**, Optical microscope image of the device with the measurement configuration labeled. **b**, $\Delta R_{xx}/\bar{R}_{xx}$ measured following the same procedure as in Figs. 2 and 3a for temperatures from $T = 1.5 \text{ K}$ to 300 K . The change in the position of the switching boundary likely originates from a change in the pinning strength of the domain walls as a function of temperature. At $T = 100 \text{ K}$, the switching boundary varies from scan to scan, leading to diagonal features along the top- and bottom-gate sweep directions. This variability arises likely because the domain wall can be pinned at either of two distinct pinning sites that are close in energy at this temperature. On repeated sweeps, the domain wall settles at one site or the other, so the rhombohedral-Bernal mixed state forms with a slightly different domain configuration each time it is prepared, leading to scan-to-scan variation in the transport hysteresis. We also note that the magnitude and sign of the hysteresis in R_{xx} change with temperature. As the resistance value is expected to be highly sensitive to the domain configuration within the device, an accurate understanding of the origin of these resistance changes will require simultaneous real-space imaging and transport measurements, which remain future work.

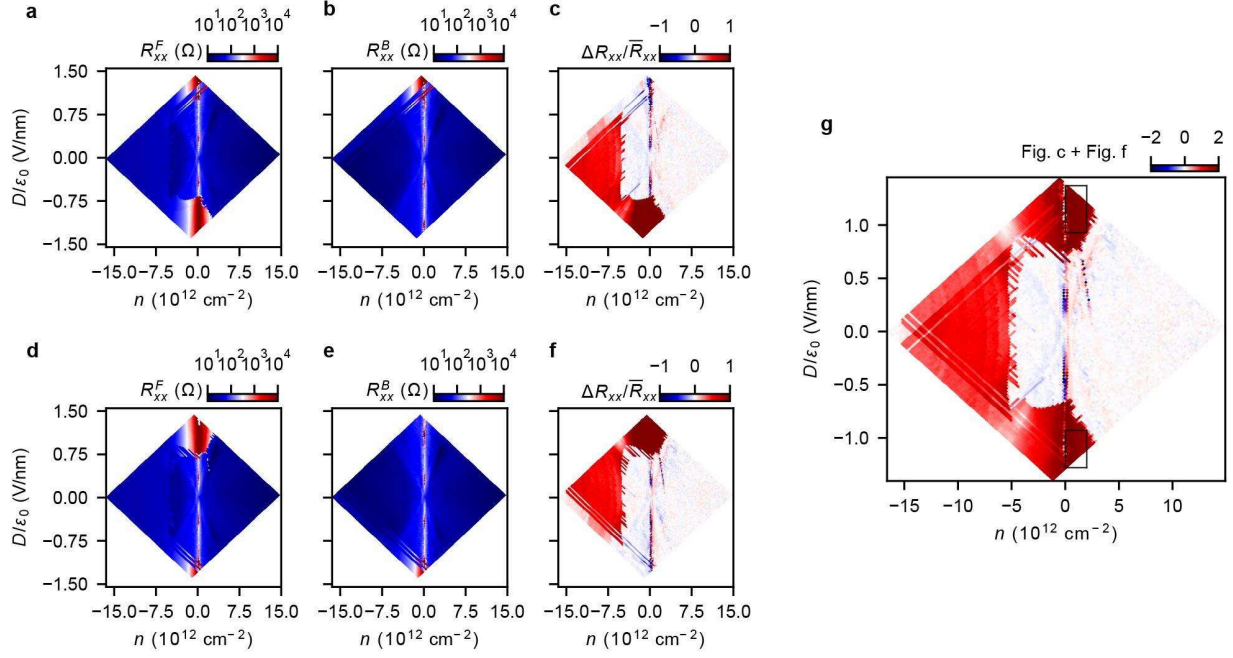


Fig. R10: Switching boundary after thermal cycle in device D. a-f, Measurement of R_{xx} and $\Delta R_{xx}/\bar{R}_{xx}$ following the same measurement scheme of Fig. 2. **g**, The sum of **c** and **f**. The black boxes indicate the areas in which we measured the Hall resistance in Fig. R11.

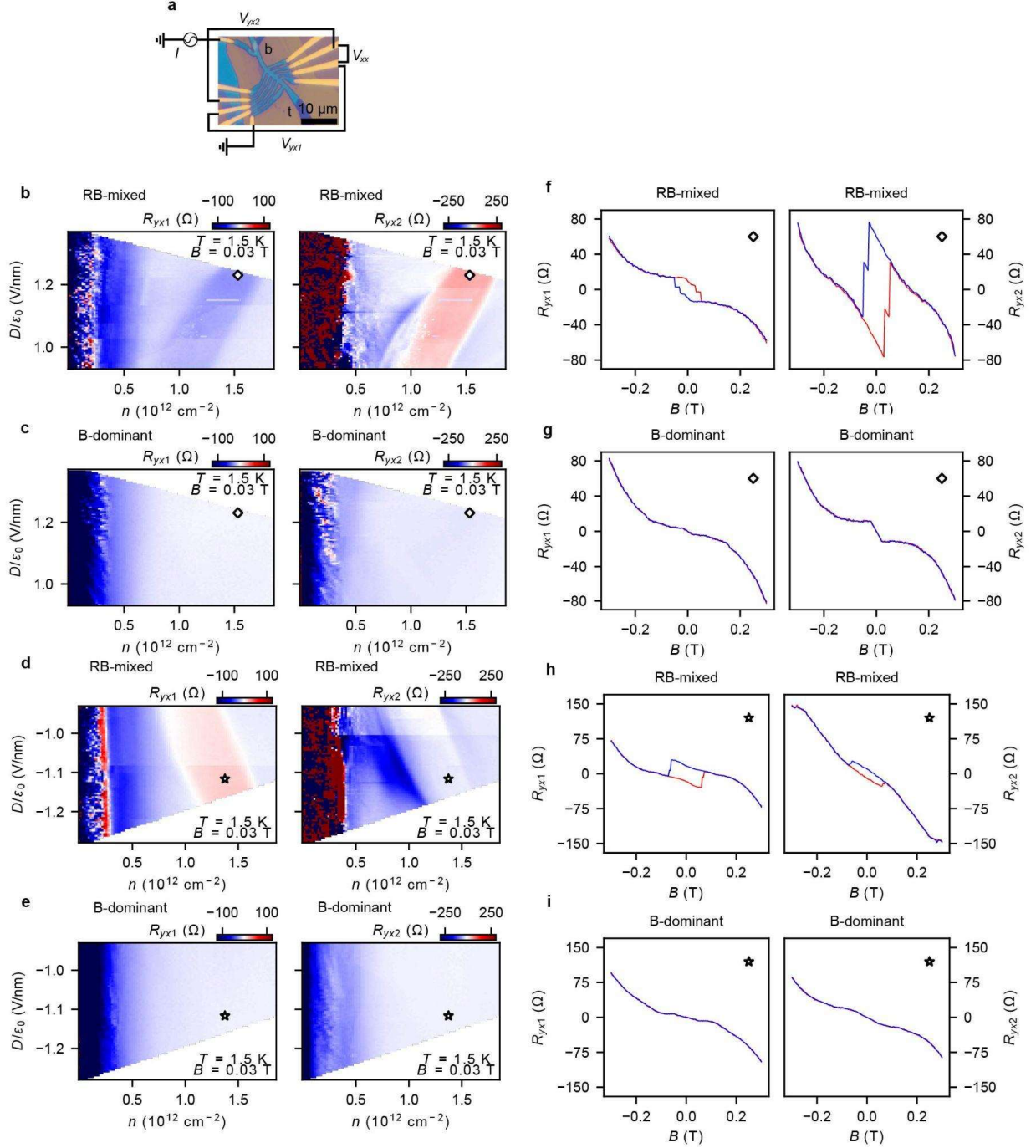


Fig. R11: Hall resistance measurements in device D. **a**, Optical microscope image of the device with the measurement configuration denoted. **b,c**, R_{yx1} and R_{yx2} measured at $B = 0.03 \text{ T}$ in the positive D and small positive n region, in the RB-mixed (**b**) and B-dominant state (**c**), respectively. R_{yx1} and R_{yx2} are measured at the locations denoted in **a** by V_{yx1} and V_{yx2} . **d,e**, R_{yx1} and R_{yx2} measured at $B = 0.03 \text{ T}$ in the negative D and small positive n region, in the RB-mixed (**d**) and B-dominant state (**e**), respectively. The horizontal line features at $D/\epsilon_0 = -1.08 \text{ V/nm}$ and $D/\epsilon_0 = -1.01 \text{ V/nm}$ in **d** originate from a slight change in the structural domain configuration upon reaching one of the domain-wall depinning voltages. **f,g**, R_{yx1} and R_{yx2} measured at $T = 1.5$

K at the diamond position as a function of B in both the forward (red) and backward (blue) directions for the RB-mixed (**f**) and B-dominant state (**g**), respectively. A nonzero R_{yx} at $B = 0$ T and the hysteresis appear only in the RB-mixed state. The nonlinear magnetic field dependence in the B-dominant state may suggest the multicarrier nature of the device. **h,i**, R_{yx1} and R_{yx2} measured at $T = 1.5$ K at the star position in the RB-mixed (**h**) and B-dominant state (**i**), respectively. Again, a nonzero R_{yx} at $B = 0$ T and the hysteresis appear only in the RB-mixed state. We note that the sign of the AHE for R_{yx1} in device D differs from those observed in devices A, B, and C. In those devices, the AHE is negative at positive D and positive at negative D . The same behavior is observed for R_{yx2} in device D, whereas for R_{yx1} in device D, the AHE is positive on both sides of the displacement field. We believe this difference in AHE within the same device is related to differences in domain configuration and to how the rhombohedral region and the domain boundary contribute to the AHE. Simultaneous transport measurement and real-space imaging would be required to better understand this behavior, which remains future work. It is important to note, however, that device D supports our main conclusion that the AHE can be switched on and off in a nonvolatile manner by controlling the crystal structure through gating.

Reviewer #5 (Comments for the Author):

The authors have studied the effect of gates on a slightly twisted tetralayer graphene. They find that, changing the carrier density, a sliding of one of the layers of tetralayer graphene is induced and the system goes from a Rhombohedral (actually a Rhombohedral-Bernal mixed) stacking to a pure Bernal stacking. They claim that the switching is reproducible. Then they study the phase diagram of this sliding with the displacement field and the density. Finally, they show the switching between a magnetic to a non-magnetic state using Hall resistance measurements. Although the switching from these states are quite appealing and the system they have studied is of interest to the scientific community, I believe that the results would fit better in a more specialized journal, mainly because I find that some of the results are not being reproduced in other regions of the device and even in other devices. Furthermore, several issues that I enumerate below should be addressed before publication:

We thank the reviewer for their positive assessment of the work and the suggestions. To address the major concern about reproducibility raised by the reviewer, we fabricated and measured two additional samples, labeled devices C and D. Both devices are prepared by rotating and stacking the two bilayer graphene layers by -0.02 degrees. These devices exhibit similar behavior to our previous device A and address the reproducibility concern.

Figure R12 shows the gate-induced switching measurement in device C, which closely resembles the boundary measured in device A. We further measured the Hall resistance in the large- $|D|$, low- n regions in both rhombohedral-Bernal mixed and Bernal-dominant states. Upon measuring the Hall resistance in both states, we observe anomalous Hall effect only in the rhombohedral-Bernal mixed state, as shown in Fig. R13, similar to our original device A.

Figure R14 illustrates the gate-induced switching measurement in device D, which again closely resembles the boundary measured in devices A and C. We then measured the Hall resistance in the large- $|D|$, low- n regions in both rhombohedral-Bernal mixed and Bernal-dominant states. As with devices A and C, we observe on/off switching of the anomalous Hall effect between the two states (Fig. R15). Together, the observation of gate-induced switching and the on/off behavior of the anomalous Hall effect across devices A, C, and D demonstrate that our findings are reproducible across multiple devices, directly addressing the reviewer's concern.

We included the reproduced results in devices C and D in Extended Data Figs. 7 and 8 and in Supplementary Information section 5 under "Additional transport measurement of device D" and Figs. S4, S5, and S6.

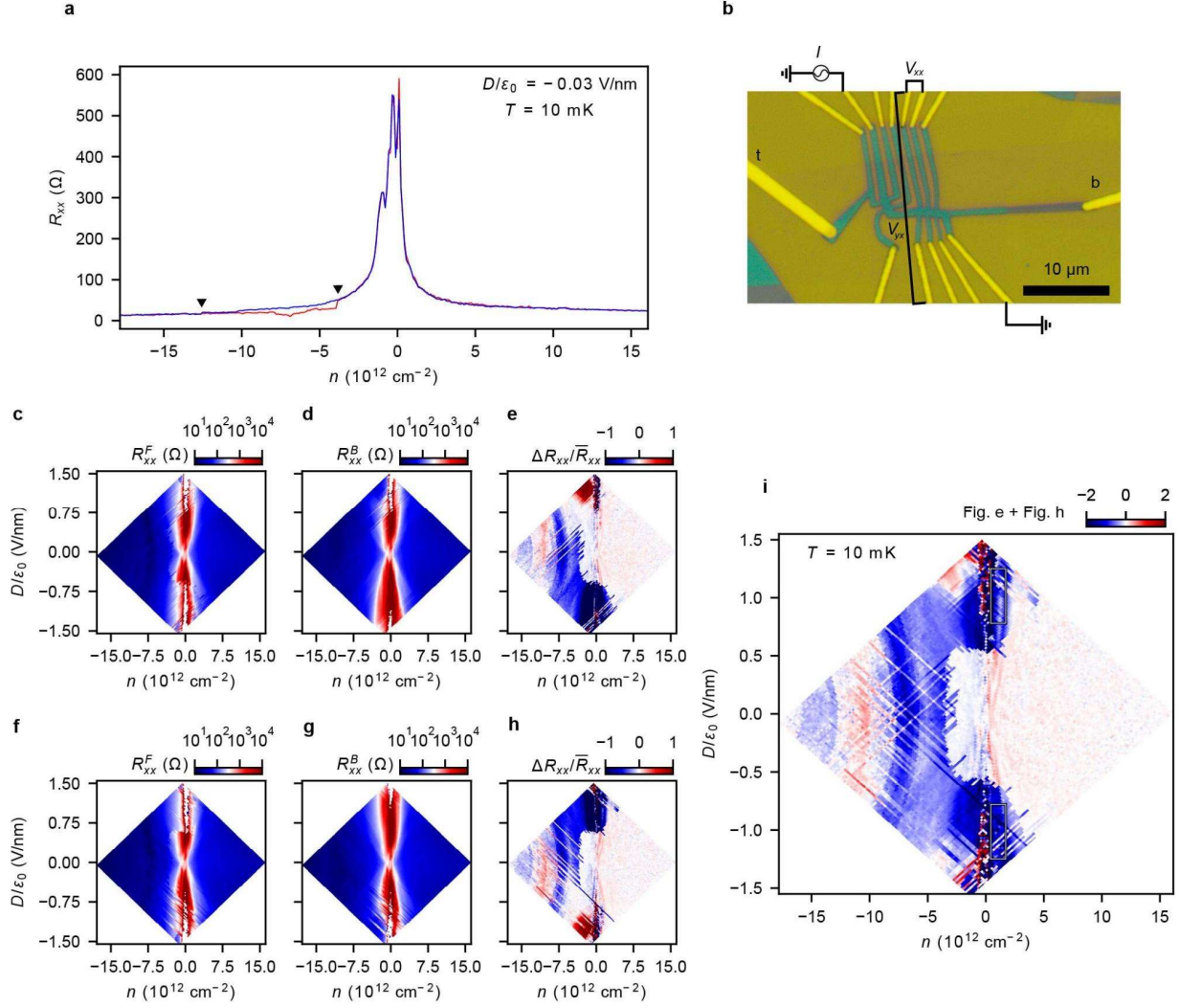


Fig. R12: Gate-induced switching in device C. **a**, Carrier density n dependence of R_{xx} scanned in the forward (red) and backward (blue) directions at $D/\epsilon_0 = -0.03 \text{ V/nm}$. The triangles highlight the points at which the switching happens. **b**, Optical microscope image of the device with the measurement configuration labeled. **c-h**, Measurement of R_{xx} and $\Delta R_{xx}/\bar{R}_{xx}$ following the measurement scheme in Fig. 2. **i**, The sum of **e** and **h**. The white and black boxes indicate the areas in which we measured the Hall resistance in Fig. R13. The switching boundary in this device varies from scan to scan, leading to diagonal features along the top- and bottom-gate sweep directions. This variability arises likely because the domain wall can be pinned at either of two distinct pinning sites that are close in energy. On repeated sweeps, the domain wall settles at one site or the other, so the rhombohedral-Bernal mixed state forms with a slightly different domain configuration each time it is prepared, leading to scan-to-scan variation in the transport hysteresis.

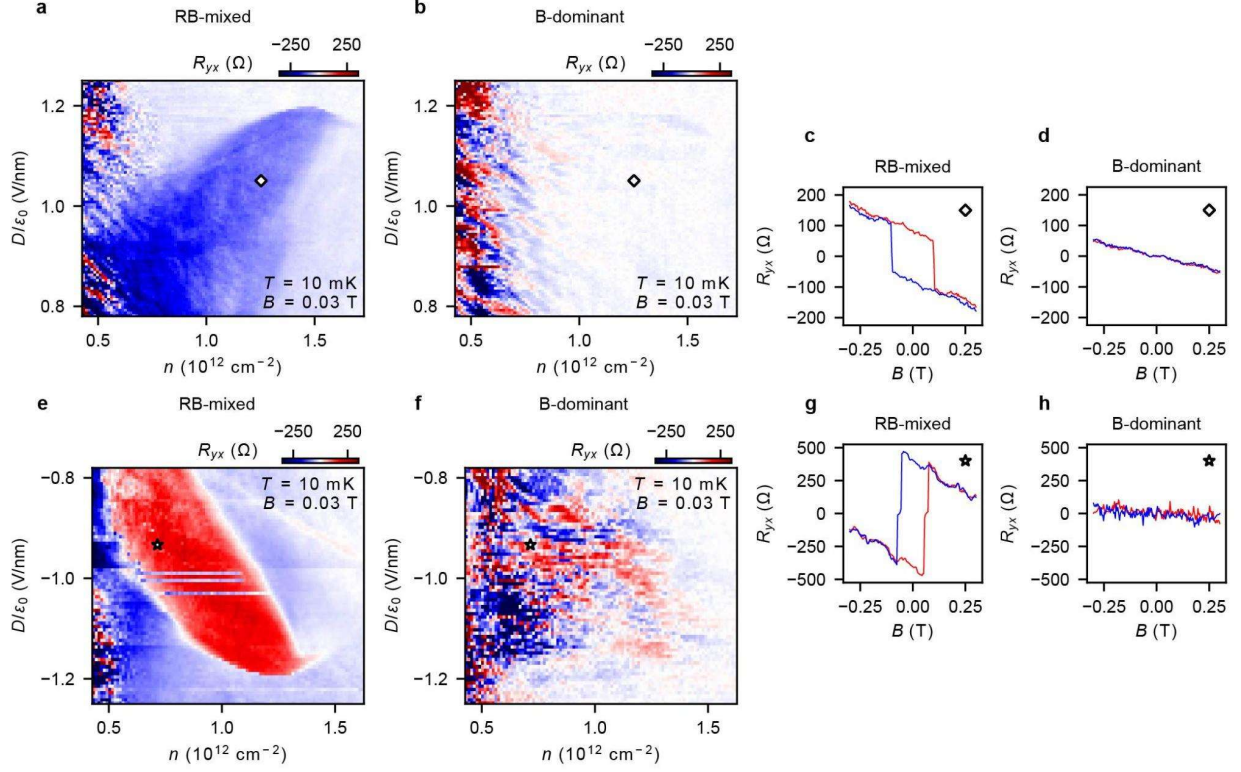


Fig. R13: Hall resistance measurements in device C. **a,b**, R_{yx} measured at $B = 0.03$ T in the positive D and small positive n region, in the RB-mixed (rhombohedral-Bernal-mixed, **a**) and B-dominant state (Bernal-dominant, **b**), respectively. Large negative R_{yx} appears exclusively in the RB-mixed state, indicating an anomalous Hall effect (AHE). **c,d**, R_{yx} measured at $T = 10$ mK as a function of B in both the forward (red) and backward (blue) directions at the diamond position for the RB-mixed (**c**) and B-dominant state (**d**), respectively. A nonzero R_{yx} at $B = 0$ T and the hysteresis appear only in the RB-mixed state. **e,f**, The same as **a** and **b** measured in the negative D region. A large positive AHE appears only in the RB-mixed state. **g,h**, R_{yx} measured at $T = 10$ mK at the star position in the RB-mixed (**g**) and B-dominant state (**h**), respectively.

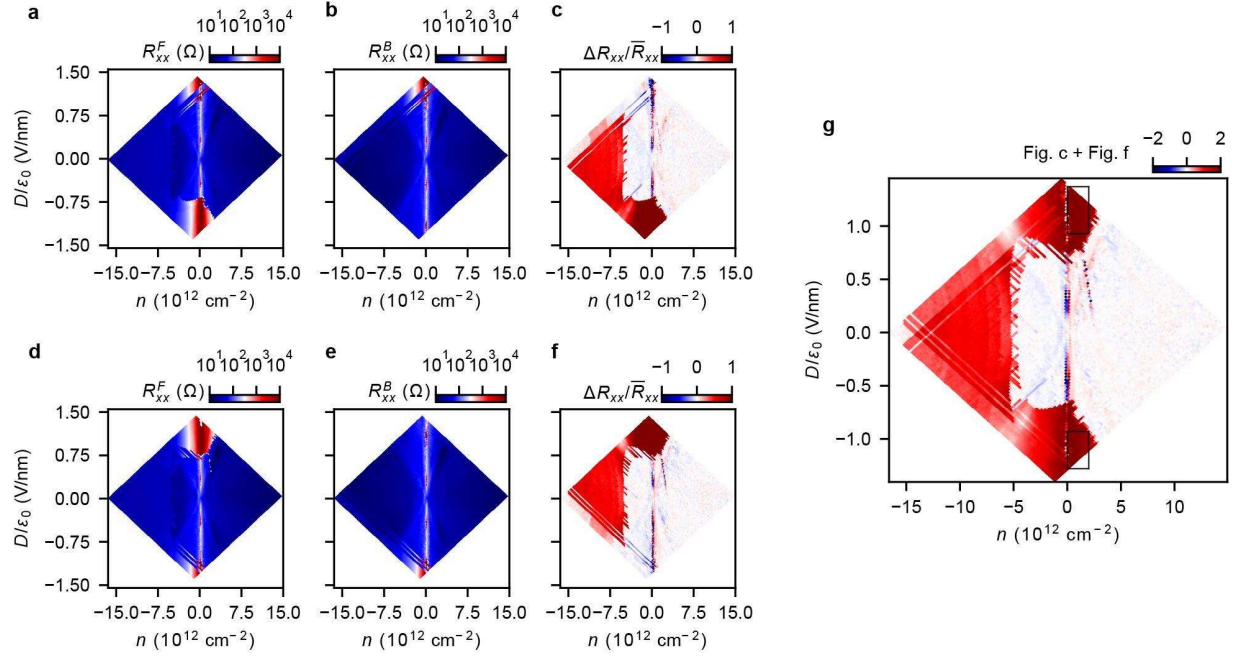


Fig. R14: Gate-induced switching in device D. **a-f**, Measurement of R_{xx} and $\Delta R_{xx}/\bar{R}_{xx}$ following the same measurement scheme of Fig. 2. **g**, The sum of **c** and **f**. The black boxes indicate the areas in which we measured the Hall resistance in Fig. R15.

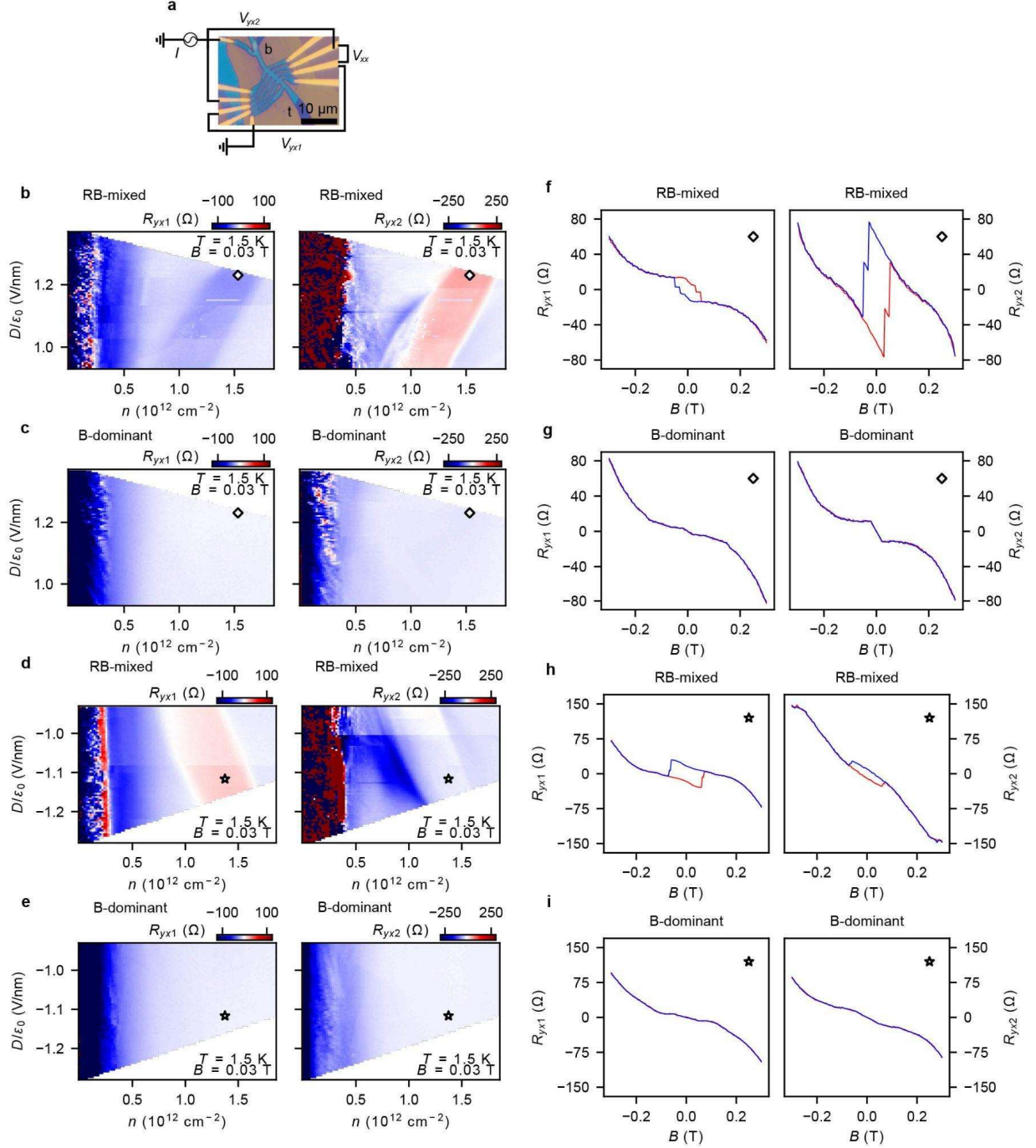


Fig. R15: Hall resistance measurements in device D. **a**, Optical microscope image of the device with the measurement configuration denoted. **b,c**, R_{yx1} and R_{yx2} measured at $B = 0.03$ T in the positive D and small positive n region, in the RB-mixed (**b**) and B-dominant state (**c**), respectively. R_{yx1} and R_{yx2} are measured at the locations denoted in **a** by V_{yx1} and V_{yx2} . **d,e**, R_{yx1} and R_{yx2} measured at $B = 0.03$ T in the negative D and small positive n region, in the RB-mixed (**d**) and B-dominant state (**e**), respectively. The horizontal line features at $D/\epsilon_0 = -1.08$ V/nm and $D/\epsilon_0 = -1.01$ V/nm in **d** originate from a slight change in the structural domain configuration upon reaching one of the domain-wall depinning voltages. **f,g**, R_{yx1} and R_{yx2} measured at $T = 1.5$

K at the diamond position as a function of B in both the forward (red) and backward (blue) directions for the RB-mixed (f) and B-dominant state (g), respectively. A nonzero R_{yx} at $B = 0$ T and the hysteresis appear only in the RB-mixed state. The nonlinear magnetic field dependence in the B-dominant state may suggest the multicarrier nature of the device. h, i, R_{yx1} and R_{yx2} measured at $T = 1.5$ K at the star position in the RB-mixed (h) and B-dominant state (i), respectively. Again, a nonzero R_{yx} at $B = 0$ T and the hysteresis appear only in the RB-mixed state. We note that the sign of the AHE for R_{yx1} in device D differs from those observed in devices A, B, and C. In those devices, the AHE is negative at positive D and positive at negative D . The same behavior is observed for R_{yx2} in device D, whereas for R_{yx1} in device D, the AHE is positive on both sides of the displacement field. We believe this difference in AHE within the same device is related to differences in domain configuration and to how the rhombohedral region and the domain boundary contribute to the AHE. Simultaneous transport measurement and real-space imaging would be required to better understand this behavior, which remains future work. It is important to note, however, that device D supports our main conclusion that the AHE can be switched on and off in a nonvolatile manner by controlling the crystal structure through gating.

1) There have been previous works where the change from a rhombohedral to a Bernal stacking has been studied before. Furthermore, in those works the transformation seems to be more complete than in the present work. Maybe a further characterization of the samples after the shifting of the layers due to the change in the carrier density using KPFM would be useful.

We agree that simultaneous real-space imaging and transport measurements are attractive future directions. Unfortunately, the established real-space techniques are difficult to directly apply to our device. KPFM is a surface-potential measurement technique, and the electrostatic potential of the tetralayer is screened by the top gate, so it cannot be applied directly to our dual-gated structure. Domain imaging in dual-gated devices has been achieved before using infrared scattering-type scanning near-field optical microscopy (IR-SNOM) by using monolayer graphene top gates [H. Li *et al.*, Nano Lett. **20**, 3106 (2020)], but this approach is also not readily available to us, as we used thick graphite for our top gate, which is optically opaque and metallic in the infrared and therefore screens the near-field from the buried layers.

Despite the absence of direct imaging, our quantum oscillation measurements provide strong evidence that a substantial change in the domain proportion occurs in our device. Extended Data Fig. 1 (device A) and Fig. R16 (device D) show the quantum oscillations in both the Bernal-dominant and the rhombohedral-Bernal-mixed states. In the Bernal-dominant state, the device exhibits clear oscillations consistent with Bernal tetralayer graphene [Y. Shi *et al.*, Phys. Rev. Lett. **120**, 096802 (2018)], indicating that nearly the entire area of the device is in the Bernal structure. In the rhombohedral-Bernal-mixed state, by contrast, the oscillations become noticeably blurred. This arises from the addition of individual quantum oscillations of the Bernal and rhombohedral structures. The blurred-out oscillation features indicate that the Bernal and rhombohedral domains exist in almost a one-to-one ratio in the device. This result indicates that

the domain proportion has changed from almost 100% Bernal to roughly half-Bernal-half-rhombohedral through gating, a substantial shift in the domain ratio.

We note, however, that this quantum-oscillation analysis is only a qualitative measure of the domain ratio. A quantitative determination of the proportion and arrangement of Bernal and rhombohedral domains would require simultaneous real-space imaging and transport measurement as a function of carrier density and displacement field. Such a measurement remains an intriguing direction for future work. We included the result of quantum oscillation in device D and the discussion about the domain proportion in Supplementary Information section 4 under “Discussion on domain proportions” and Fig. S4.

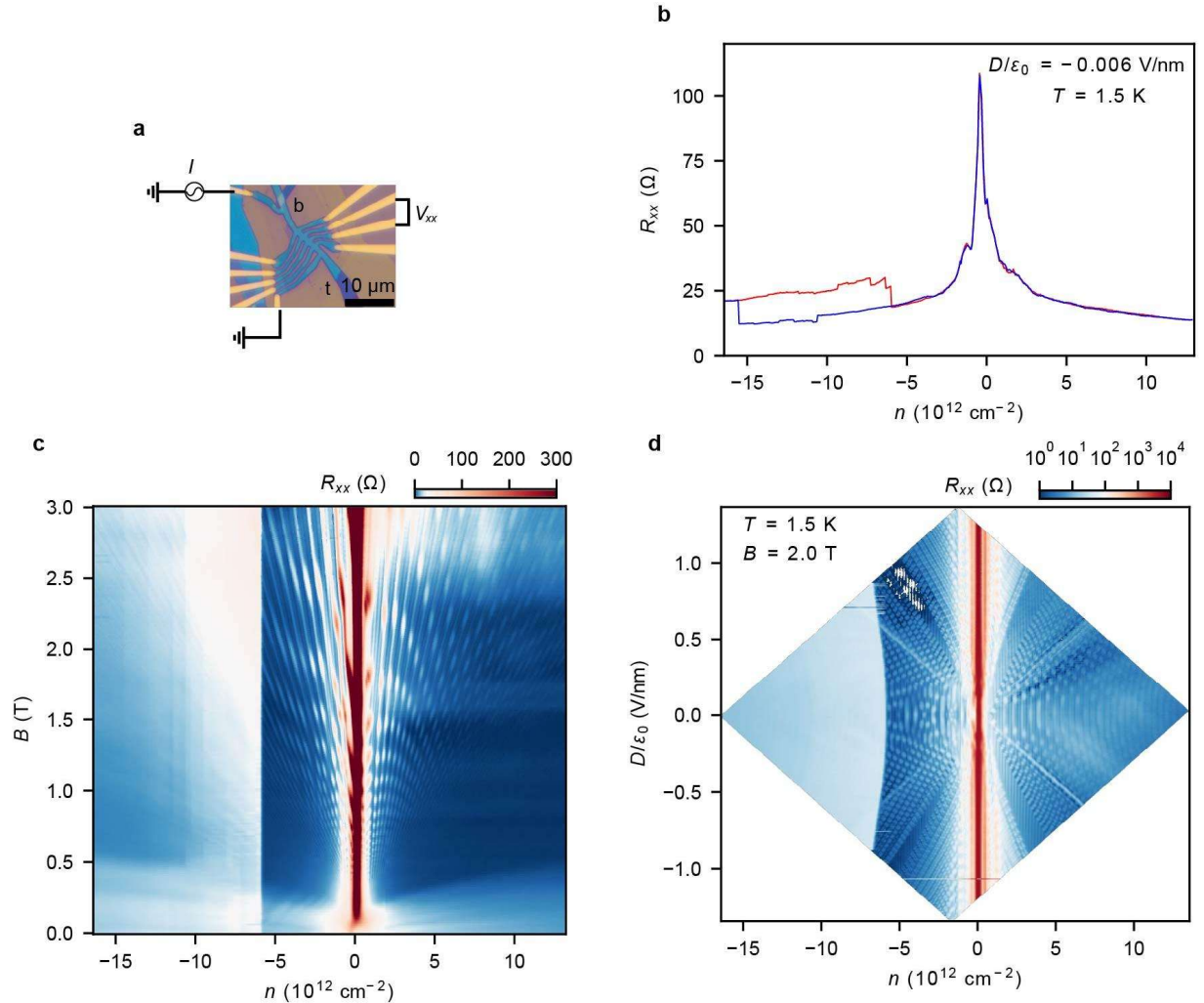


Fig. R16: Hysteresis and quantum oscillations in device D. **a**, Optical microscope image of the device with the measurement configuration labeled. **b**, R_{xx} measured in the forward (red) and backward (blue) scan directions of carrier density n at a constant displacement field of $D/\epsilon_0 = -0.006 \text{ V/nm}$, where ϵ_0 is the vacuum permittivity. **c**, Landau fan diagram of R_{xx} measured in the increasing direction of n at $D/\epsilon_0 = -0.006 \text{ V/nm}$. Clear oscillations consistent with Bernal tetralayer graphene appear after the transition to the Bernal-dominant state at $n = -6 \times 10^{12} \text{ cm}^{-2}$.

². d , R_{xx} measured by first going to the largest-hole-density corner (to realize the rhombohedral-Bernal-mixed structure), then sweeping n in the increasing direction at constant D at $B = 2$ T. A clear transition is again observed, across which the quantum oscillations consistent with Bernal tetralayer graphene appear.

2) The authors claim that in their samples, the surface potential of rhombohedral graphene is 22 mV smaller than Bernal and that this is consistent with previous reports. In my opinion, this is a bit misleading since in extended data Fig. 2c the work function is -30.05 mV while in 2d it is -13.60. The mean is -22mV but not the actual value. Furthermore, it seems that in Ref [37] Atri et al. find a similar value for the work function but they claim that this value is constant and independent of the region where the measurement is taken (although the values for the each of the potentials can vary from region to region). This is not the case for the measurements in this work.

We thank the reviewer for raising this point. The reviewer is correct that -22 mV is the average of two measurements (-30.05 and -13.60 mV) rather than a single observed value. We agree that Atri *et al.*'s measurement is likely closer to the intrinsic value of the work function difference [S. S. Atri *et al.*, Adv. Phys. Res. **3**, 2300095 (2024)]. Their result is established using two-pass sideband KPFM in an N₂ atmosphere at 100 mbar. Our measurements, by contrast, were performed in ambient conditions using single-pass frequency-modulation KPFM. These differences in the measurement scheme and the measurement environment affect the apparent surface potential contrast between rhombohedral and Bernal regions.

First, in single-pass frequency-modulation KPFM, the topographic and electrostatic responses are acquired simultaneously; hence, the measured potential is convolved with topographic crosstalk. Two-pass sideband KPFM, by contrast, measures topography and surface potential in separate passes, suppressing the topographic crosstalk. The two-pass scan yields a more faithful measure of the surface potential contrast, but we could not implement this method due to the limited capability of our instrument.

The second factor is the measurement environment. Because our measurements were performed under ambient conditions, adsorbed water and other airborne contaminants form a thin layer on the sample surface, producing surface dipoles that contribute directly to the measured surface potential. The N₂ atmosphere backfilled after high-vacuum pumping, as used by Atri *et al.*, eliminates this contribution and yields an intrinsic surface potential.

For these reasons, we believe the value of Atri *et al.* (-19 mV) is more reliable, and we used it in our comparison with theory. To reflect this change, we updated the main text to avoid the quantitative discussion of the work function difference: "We also find that the surface potential of rhombohedral graphene is smaller than that of Bernal, namely, the work function of rhombohedral graphene is smaller, consistent with the previous report (see Supplementary Information section 15) [41]." We further added the discussion about comparison of different KPFM methods as "Comparison of KPFM methods" in Supplementary Information section 15.

3) The authors claim in the fourth paragraph that hysteresis appears only in several parts of the device, while in the fifth paragraph claim that the switching is highly robust and reproducible. Both sentences seem to be in contradiction. Furthermore, the first one raises the question about reproducibility in different devices.

We thank the reviewer for this feedback. Our message here is that the hysteretic switching is robust and reproducible within the same region of a single device. Namely, we consistently observe switching of the resistance when we apply a voltage above the critical value, as shown in Fig. 1d. To make this point clear, we modified the sentence as follows: “Figure 1d shows the repeated switching behavior when the sample is subjected to short pulses of gate voltage. The resistance switches between the two values throughout the pulse sequence, demonstrating that the hysteretic switching within the same region of the same device is reproducible.”

We agree that this should be clearly distinguished from reproducibility across different devices. It is true that we do not observe gate-induced switching in all regions of our devices. This is mainly because switching requires preexisting domain walls separating Bernal and rhombohedral tetralayer graphene, which are device-location dependent, and a large hole doping induced by an electric field close to the breakdown field of hBN. Despite these challenges, we successfully fabricated two additional devices (devices C and D) that exhibit almost the same gate-induced switching behavior as our original device (device A), as discussed at the beginning of the response to reviewer #5 in Figs. R12-15. We included the reproduced results in devices C and D in Extended Data Figs. 7 and 8 and in Supplementary Information section 5 under “Additional transport measurement of device D” and Figs. S4, S5, and S6.

4) The authors also claim that their results could be useful as a nonvolatile memory device. In my opinion this sentence is also a bit misleading since in previous paragraphs they claim that the switching behaviour depends on the initial domain configuration and domain wall pinning strength. Furthermore, they do not have a full rhombohedral domain and very large voltages would be required to have them.

We agree that it is an overclaim to mention that it could be useful as a nonvolatile memory device at this stage. As the reviewer points out, we need a particular domain configuration, domain wall pinning strength, and a large voltage to induce switching. There are emerging approaches to overcome these limitations, for example, using interfacial structural superlubricity [N. Roy *et al.*, Nat. Nanotechnol. **21**, 530 (2026)]. Integrating such techniques with our gate-induced sliding is a promising direction for future work. We, however, agree that currently it is too early to claim the application as a memory device. Hence, we modified the sentence as follows: “This result indicates that the sliding phase transition between Bernal and rhombohedral graphene could be of interest for future memory-related functionalities”.

5) The authors claim there is a good agreement between the contour lines of Fig. 3 agree well with the calculation of ΔU . I do agree that some of the lines seem to match the

theoretical calculation, but those in the negative high-carrier density regime do not seem to match.

We thank the reviewer for this careful observation. We agree that while some of the experimental contour lines track the calculated ΔU reasonably well, the agreement is not quantitatively perfect over the full phase diagram, particularly in the negative high-carrier-density regime. Our intention was not to claim a parameter-free quantitative fit to the contour lines, but rather to show that the calculated free-energy difference ΔU captures the qualitative trend observed experimentally. Below, we discuss both why the quantitative agreement may degrade in this regime and how our qualitative conclusion remains robust.

The discrepancy likely originates from our approximation of treating the effective dielectric constant of tetralayer graphene ϵ_r as a constant value, which is used to convert the displacement field D to the interlayer energy difference u_D in tetralayer graphene. This quantity ϵ_r is not a constant in reality but depends on both the displacement field D and the carrier density n , since the out-of-plane polarizability of the multilayer is itself a function of band filling and band structure. A fully rigorous treatment would require solving the layer-resolved charge distribution and the internal electric field in tetralayer graphene self-consistently at each (n, D) point via a Hartree calculation [E. McCann *et al.*, Rep. Prog. Phys. **76**, 056503 (2013)]. Such a treatment is computationally demanding across the full phase diagram. We therefore adopted the standard approach in the multilayer graphene literature of using a single effective ϵ_r to convert D to u_D . The value used in the main calculation, $\epsilon_r = 4.1$, was taken from a related calculation [H. Li *et al.*, Nano Lett. **20**, 3106 (2020)].

This approximation is expected to be most reliable in the moderate-carrier-density regime and less accurate at high carrier density, where screening effects become stronger. We believe this density-dependent screening is one likely reason why the quantitative agreement degrades in the negative high-carrier-density regime. Importantly, this limitation cannot be fully resolved simply by choosing a different constant ϵ_r ; a quantitatively accurate treatment would require a density- and field-dependent, self-consistent calculation, which lies beyond the scope of the present work.

To draw out a meaningful conclusion within this approximation, we focus on the robustness of the qualitative conclusion rather than on optimizing a quantitative fit. To this end, we recomputed the energy spectrum under several reasonable variations of the model parameters, as shown in Fig. R17. Specifically, we varied $\Delta\Phi$ around our measured average value of -22 mV; tested a larger $\epsilon_r = 5.5$ from [R. Xiao *et al.*, Phys. Rev. B **84**, 165404 (2011)]; and used alternative tight-binding parameters from [E. McCann *et al.*, Rep. Prog. Phys. **76**, 056503 (2013); M. S. Dresselhaus and G. Dresselhaus, Adv. Phys. **51**, 1 (2002)].

Across these variations, the same qualitative behavior persists: rhombohedral stacking becomes energetically favorable in the large-hole-doping region, and in the large- $|D|$ close to the charge-neutral region, consistent with the experimental observations. Some parameter choices, for example, those shown in Figs. R17f and R17j, give particularly good apparent

agreement with the experimental contours. However, we do not claim that these are the uniquely correct physical parameters. Given the size of the parameter space, it would likely be possible to find parameter combinations that improve the quantitative agreement, but such agreement alone would not establish the physical correctness of those parameters. The purpose of the parameter study is instead to demonstrate that the qualitative result is robust against reasonable parameter variations.

We modified the phrasing in the main text to emphasize the qualitative agreement as follows: “These contour lines agree qualitatively with the theoretical calculation in Fig. 3b, which plots the energy difference between the two structures.” We also added the calculations of ΔU against different parameters to Supplementary Information section 9 as Fig. S9, together with the accompanying discussion under “Effect of free-parameter variation on the relative energy spectrum”.

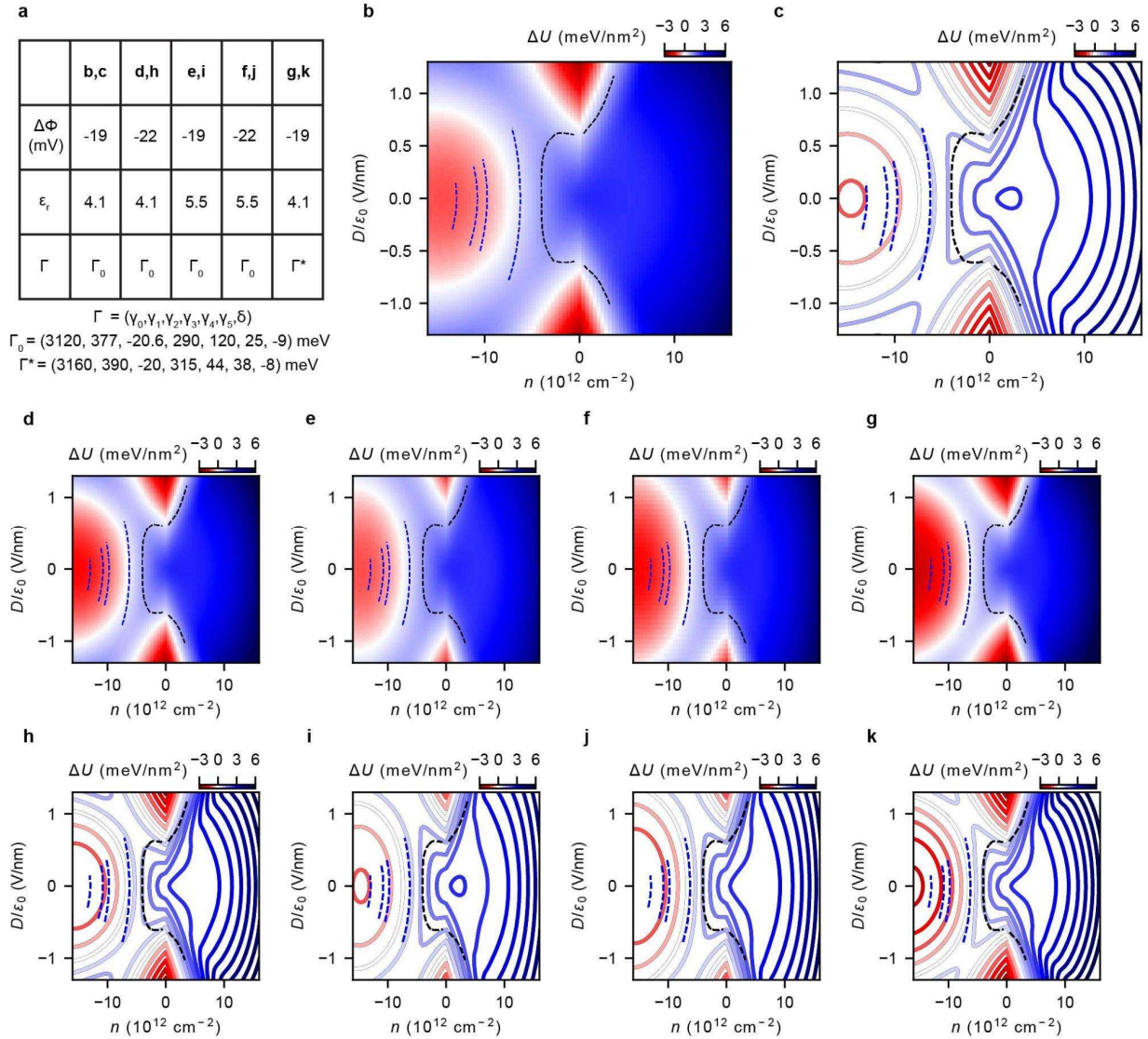


Fig. R17: Comparison of different parameters on ΔU . **a**, Table of the different parameters used to calculate ΔU . We test different values of the work function difference $\Delta\Phi$, dielectric constant ϵ_r , and tight-binding parameters. **b**, Calculated ΔU using the parameters outlined in **a**. This is the same as Fig 3b. **c**, Contour map of **b**. **d-k**, Calculated ΔU and contour map using the parameters outlined in **a**.

6) Could the authors comment on the measurement of the third row and third column of extended Fig. 9?

We noticed that the coercive field of the magnetic switching varies from sweep to sweep. Figure R18 shows the data extracted from Extended Data Fig. 9, which the reviewer asked about. The bottom row is our raw R_{yx} data, while the top row is the data antisymmetrized as a function of the magnetic field to remove the effect of R_{xx} leakage due to contact misalignment. As can be seen from the raw data for the rhombohedral-Bernal-mixed (RB-mixed) state, the coercive field is not the same in each magnetic field sweep. In particular, in the third column the anomalous Hall effect switches sign even before B crosses zero. This produces the “intermediate”-looking state after antisymmetrization. We note that this “intermediate”-looking state is not real; there are only magnetization-up and magnetization-down states, as evidenced by the raw data.

This sweep-to-sweep variability of the coercive field likely reflects the small magnetic energy scale of the ferromagnetism in our sample. As indicated by the relatively low magnetic transition temperature of around 8 K, the switching barrier between the up and down magnetization states is comparable to $k_B T$ at our measurement temperature ($T = 1.5$ K), so the magnetization switching can be thermally activated. We believe this thermal fluctuation leads to the sweep-to-sweep variability in the coercive field, causing switching to occasionally occur before $B = 0$ T. We added the above discussion in the caption of Extended Data Fig. 6 (previous Extended Data Fig. 9).

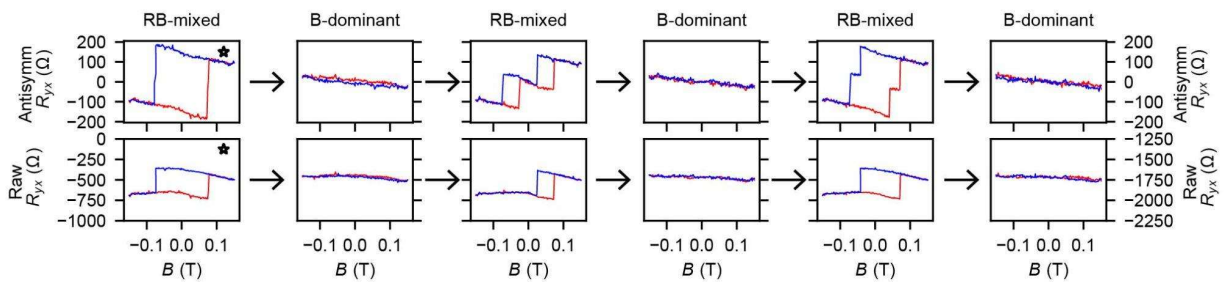


Fig. R18: Repeated switching between magnet and non-magnet. Antisymmetrized and raw R_{yx} as a function of B in the forward (red) and backward (blue) sweeps, measured sequentially from left to right by repeatedly switching between the RB-mixed and B-dominant states. We note that the coercive field for the magnetization switching varies from sweep to sweep. This sometimes makes the switching appear to pass through an “intermediate”-looking state after antisymmetrization. We note that this “intermediate”-looking state is not real; there are only magnetization-up and magnetization-down states, as evidenced by the raw data.

7) As I said in the beginning of this report, I find that some of the results are not reproduced, this is particularly evident in device B. For example, in all of the measurements shown in extended Fig. 11 show an AHE, hence there is no switching of the magnetic state. Therefore, I wonder how much these results are on having an appropriate initial stacking configuration or how much the results depend on having domain boundaries and if the authors have any other additional results in other devices which they can comment on.

We reproduced the full switching of the AHE in two additional devices, labeled devices C and D, which show similar behavior to our original device A: the AHE appears in the rhombohedral-Bernal mixed state, but completely disappears in the Bernal-dominant state. This is discussed in detail at the beginning of our response to Reviewer #5 and shown in Figs. R12-15.

As the reviewer points out, the gate-induced sliding transition depends sensitively on the initial domain configuration and the pinning of the domain walls. The sliding transition proceeds through the motion of preexisting domain walls, so a preexisting domain wall is a prerequisite for switching, as established by previous real-space imaging [H. Li *et al.*, Nano Lett. **20**, 3106 (2020); K. Ko *et al.*, Nat. Mater. **22**, 992 (2023)]. For the sliding transition to occur, this domain wall must then be depinned from its pinning sites by the applied gate voltage. The pinning sites include the sample edge, the AA-stacking regions arising from the marginal twist angle between the layers, and bubbles or interfacial contamination [K. Ko *et al.*, Nat. Mater. **22**, 992 (2023)]. Because the distribution of domain walls, the locations of the pinning sites, and the pinning energies all vary from device to device, the gate-induced switching behavior is device- and location-dependent. These factors determine not only whether gate-induced switching occurs, but also whether the AHE can be fully switched on and off.

Device B is a case where the AHE cannot be fully switched on and off, and this is consistent with the weak gate-induced switching we observed in this device. The original domain configuration is already largely mixed. This is evidenced by the weak quantum oscillations across the entire region of the gate-voltage phase diagram, including the electron-doped region (Fig. S2b in Supplementary Information section 3). The weak quantum oscillations originate from the addition of the individual quantum oscillations of the Bernal and rhombohedral structures, meaning that both the Bernal and rhombohedral domains are of substantial size (see the response to question 1 and Fig. R16). We attribute this coexistence of Bernal and rhombohedral structures across the entire phase diagram to a slightly larger twist angle as compared to device A, which produces a domain network of many small triangular domains. Here, the large number of pinning sites impedes domain-wall motion, and the domains can no longer switch strongly [K. Ko *et al.*, Nat. Mater. **22**, 992 (2023)]. This makes it impossible to fully switch on and off the AHE in device B. We emphasize that this originates from a device-specific domain configuration: in devices C and D, which likely have larger domains, we were able to fully switch the AHE on and off, reproducing the behavior of our original device A.

We added the discussion about the expected domain configuration in Supplementary Information section 3 under “Transport measurement and domain configuration of device B”.

8) The tight-binding calculations of figures S1 seems a bit different to what has been reported before. Could the authors comment on this result?

The band structures shown in the original manuscript are calculated using the tight-binding parameters from [A. A. Avetisyan *et al.*, Phys. Rev. B **80**, 195401 (2009)]. We additionally calculated the band structure using the tight-binding parameters from [E. McCann *et al.*, Rep. Prog. Phys. **76**, 056503 (2013); M. S. Dresselhaus and G. Dresselhaus, Adv. Phys. **51**, 1 (2002)], shown in Fig. R19. We find that most features of the band structure are consistent between the calculations using the two different sets of tight-binding parameters. We added the figures of the band structure calculation for different parameters in Supplementary Information section 10 under “Comparison of band structures for different tight-binding parameters”.

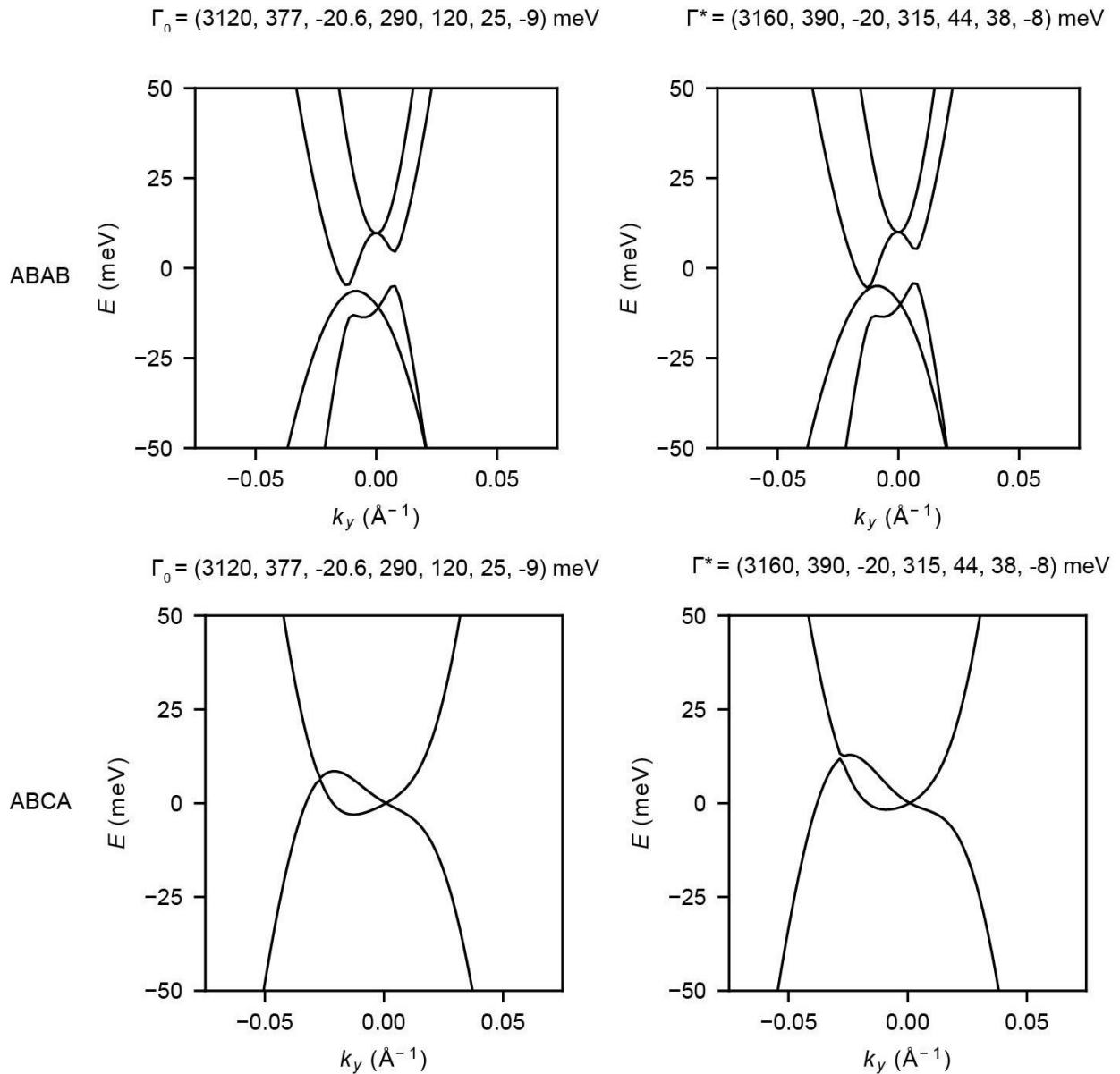


Fig. R19: Band structures calculated for different tight-binding parameters. The tight-binding band structure of Bernal (ABAB, top) and rhombohedral (ABCA, bottom) at $D = 0$, for tight-binding parameters taken from [A. A. Avetisyan *et al.*, Phys. Rev. B **80**, 195401 (2009)] and from [E. McCann *et al.*, Rep. Prog. Phys. **76**, 056503 (2013); M. S. Dresselhaus and G. Dresselhaus, Adv. Phys. **51**, 1 (2002)].

Some other minor comments:

9) The authors mainly cite experimental works regarding the superconducting and correlated phases of tetralayer rhombohedral graphene. I believe that theoretical works that have brought some light to the emergence of these phenomena could be of interest for the community and also be given credit to. For example: Nature Comm. 17, 232 (2025) and Phys. Rev. Lett. 135, 136503 (2025) and Phys. Rev. Research 6, L012003 among many others. Of course, this is only a suggestion if the authors do not think that they are relevant for their work, they can disregard my comment.

We thank the reviewer for their suggestion. We added the theoretical works on the superconducting and correlated phases of tetralayer rhombohedral graphene in the citations.

10) Although it is clear from the text and the caption, blue and red arrows in Fig. 1c are a bit confusing since they could be interpret as going up and down in temperature from 1.5 K, separating the arrows or adding a clear label on the arrows would probably make the figure more clear.

We thank the reviewer for their suggestion. In order to make the figure clearer, we moved the arrows down and added a clear label within the figure.

List of changes:

Changes made in the main text and Supplementary Information are highlighted in yellow.

Main text:

- We adjusted the language around quantum phases and phase transitions. (Comments 1 and 2 from Reviewer 1)
- We updated the main text to discuss the reproducibility of the switching and the temperature dependence measurements. (Comment 4 from Reviewer 1 and Comments from Reviewers 4 and 5)
- We updated the main text with the identification of Bernal and rhombohedral domains in our KPFM image. (Comment 1 from Reviewer 3)
- We updated the main text to highlight our interpretation of the magnitude of our anomalous Hall effect. (Comment 3 from Reviewer 3)
- We changed the value of the work function difference used in our calculation in Fig. 3b. (Comment 2 from Reviewer 5)
- We updated the main text to clarify our points on the robustness of the switching and the potential use of the switching for memory-related applications. (Comments 3 and 4 from Reviewer 5)
- We updated the main text to discuss the qualitative match between experiment and theory. (Comment 5 from Reviewer 5)
- We included citations for the theoretical works on the correlated phases in rhombohedral graphene suggested by Reviewer 5. (Comment 9 from Reviewer 5)
- We updated Fig. 1 to make the arrow direction labeling clearer. (Comment 10 from Reviewer 5)

Extended Data:

- We moved the previous Extended Data Figs. 1, 2, 5, 10, and 11 to Supplementary Information to make room for new figures.
- We included two additional figures, Extended Data Figs. 9 and 10 on the temperature dependence of the hysteresis. (Comment 4 from Reviewer 1 and Comments from Reviewer 4).
- We updated the caption for Extended Data Fig. 4. (Comment 5 from Reviewer 1)

- We included two additional figures, Extended Data Figs. 7 and 8 on sliding phase transition and on/off switching of anomalous Hall effect on a new device, device C. (Reproducibility comments from Reviewers 4 and 5)
- We updated the caption of Extended Data Fig. 6 to explain the “intermediate” looking state. (Comment 6 from Reviewer 5)

Supplementary Information:

- We included a new table and section 1 named “Summary of devices” which gives an overview of all the transport devices measured in this work.
- We included a new table and section 6 named “Microscopic discussion on the sign of anomalous Hall effect in a pure rhombohedral graphene” to discuss the sign of anomalous Hall effect. (Comment 6 from Reviewer 1)
- We included a new section 11 named “Structural interpretation of the hysteresis” to discuss our structural interpretation of the hysteresis. (Comment 2 from Reviewer 3)
- We included a new section 5 named “Additional transport measurement of device D” and three additional Figures, Figures S4, S5, and S6, on measurements from a new device, device D, to address the reproducibility concerns. (Reproducibility comments from Reviewers 4 and 5)
- We included a new section 4 named “Discussion on domain proportions” to discuss our estimation of the domain proportions. (Comment 1 from Reviewer 5)
- We included a new section 15 named “Comparison of KPFM methods” to compare our KPFM measurement with the literature. (Comment 2 from Reviewer 5)
- We included a new section 9 named “Effect of free-parameter variation on the relative energy spectrum” to examine and discuss the effects of the free-parameters on our theoretical calculation. (Comment 5 from Reviewer 5)
- We included a new section 3 named “Transport measurement and domain configuration of device B” to show and interpret our measurements on device B. (Comment 7 from Reviewer 5)
- We included a new section 10 named “Comparison of band structures for different tight-binding parameters” to compare the band structures for the two different sets of tight-binding parameters. (Comment 8 from Reviewer 5)

We thank the reviewers for the careful assessment of our manuscript and their insightful comments and suggestions. These comments helped us to improve our manuscript significantly. We respond to the comments point by point below.

Reviewer #1 (Comments for the Author):

The authors have made significant efforts in addressing reviewers' comments. The manuscript is significantly improved. Although the microscopic mechanism is not fully understood yet, the experimental results are sufficiently interesting to warrant a publication.

We thank the reviewer for their positive assessment and for recognizing the improvements made in the revised manuscript. We appreciate their support for publication.

Reviewer #3 (Comments for the Author):

The authors have addressed all of my concerns, and I therefore recommend the manuscript for publication in Nature Nanotechnology.

We thank the reviewer for carefully evaluating our revised manuscript. We are pleased that our revisions have addressed all of their concerns, and we appreciate their recommendation for publication.

Reviewer #4 (Comments for the Author):

The authors have now shown reproducibility between devices and persistence of the switching up to room temperature. They have dealt thoroughly with all the substantive reviewer comments. I would now endorse publication.

We thank the reviewer for their careful assessment and constructive comments throughout the review process. We appreciate their support for publication.

Reviewer #5 (Comments for the Author):

I thank the authors for taking the time of answering my comments and for improving the reproducibility of the results. I believe that the quality of the manuscript has improved, but I still stand with my previous recommendation of publishing the work in a more specialized journal for the same reasons as in my previous report. Furthermore, I still have some comments regarding this and the discussion on the physical interpretation of the results.

We thank the reviewer for carefully reassessing our revised manuscript and for noting the improvement in its quality and the reproducibility of our results. Below, we address the remaining scientific points in detail.

1) With respect to the reproducibility of the results it is true that the authors have been able to fabricate two new devices and they are able to reproduce the results of device A, but they also claim that fabricating the devices is challenging and that obtaining favorable results depend on having domain walls between the B and the RB regions. My question is, which is the percentage of working devices that show the switching they have with respect to those they fabricate and do not show them or show similar results to those of device B?

We included a list of all the fabricated devices in Table R1. In total, we fabricated 15 dual-gated, twisted double bilayer graphene devices. Seven of these devices (devices X1 to X7) had major problems, including a small gate range, a gate that did not work properly, or a twist angle between the layers that was too large. The angle between the layers is sometimes off from the targeted twist angle, due to unintentional strain. For example, devices X3 and X4 had a final twist-angle misalignment between bilayers greater than 1 degree, creating a nanometer-scale moiré pattern instead of the micrometer-scale moiré pattern we require for the sliding transition.

Among the 8 devices without major problems, we observed gate-induced structural switching in 7 of them (devices A to G). We observed the anomalous Hall effect (AHE) in 4 of them (devices A to D), for which we show detailed measurements in the main text, Extended Data, and Supplementary Information. Devices E, F, and G show gate-induced structural switching, as shown in Fig. R1. In devices E and F, owing to the limited gate range, we could not measure the region of phase space where the AHE may appear (slightly electron-doped, large $|D|$ regions). In device G, while we observed gate-induced structural switching, we could only realize the Bernal-dominant state in the region of phase space where the AHE may appear. Here, we did not observe any AHE, consistent with the Bernal-dominant state. Device B is the only device in which we observed the AHE in both gate-history-dependent states. This is consistent with the weak structural switching in this device: the weak quantum oscillations across the entire gate-voltage range indicate that substantial rhombohedral and Bernal domains coexist even in the Bernal-favored state, and consequently the AHE is not completely switched off, as discussed in “Transport measurement and domain configuration of device B” section of Supplementary Information.

Among the 8 devices without major problems, we did not observe gate-induced structural switching in 1 of them (device H). This device had a moderate gate range, around $-1.6 \times 10^{13} \text{ cm}^{-2}$ at $|D/\varepsilon_0| > 0.5 \text{ V/nm}$, reaching similar levels to device F, but did not exhibit gate-induced structural switching. Although it is nontrivial to identify the reason why we do not observe structural switching, we speculate that it is related to the initial structural domain configuration of the device. Even in device A, where we observed substantial structural switching in two contact pairs, we did not observe any structural switching in the remaining two contact pairs, as illustrated in Extended Data Fig. 2. This observation suggests that the initial structural domain configuration of the device is critical for observing the structural switching. For example, we cannot achieve any switching if we had a pure Bernal tetralayer graphene device without a domain wall, which is possible through relaxation even if we made marginally-twisted double bilayer graphene. Therefore, it is not surprising that we do not observe the structural switching in one device out of eight.

To summarize:

Fabrication yield: 8/15 devices sufficiently functional for evaluating the gate-induced switching: They had no misalignment of twist angle and could reach a carrier density of at least $-1.3 \times 10^{13} \text{ cm}^{-2}$ (devices A to H).

Gate-induced structural-switching yield: 7/8 devices showed gate-induced structural (sliding) switching (devices A to G).

AHE switching: Devices A, C, and D show complete on/off switching; Device B shows incomplete switching. Devices E and F could not access the AHE-relevant phase space, and device G could access only the B-dominant state there.

We included Fig. R1 as Fig. S15, Table R1 as Table 3, and the above discussion under “Switching across all devices” in Supplementary Information.

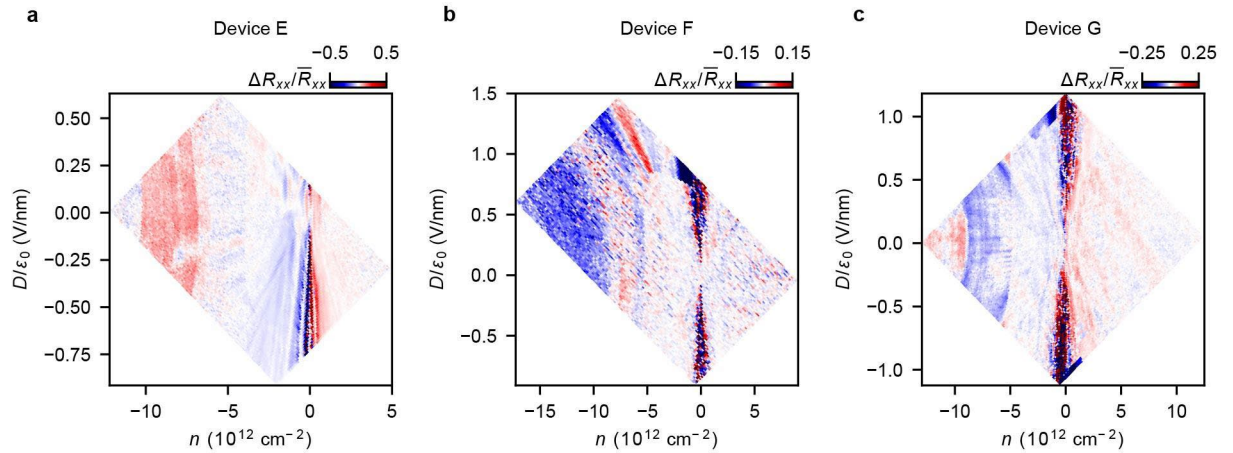


Fig. R1: Gate-induced structural switching in three other devices. a-c, Measurement of $\Delta R_{xx}/\bar{R}_{xx}$ on devices E-G following the same measurement scheme as in Fig. 2

Characterized devices	Lowest carrier density	Structural switching	AHE region accessible?	AHE observed?	Other comments
A	$-1.6 \times 10^{13} \text{ cm}^{-2}$	Yes	Yes	Yes	
B	$-1.4 \times 10^{13} \text{ cm}^{-2}$	Yes	Yes	Yes	Only device with AHE in both states, likely due to the mixed structure in both states.
C	$-1.7 \times 10^{13} \text{ cm}^{-2}$	Yes	Yes	Yes	
D	$-1.6 \times 10^{13} \text{ cm}^{-2}$	Yes	Yes	Yes	
E	$-1.3 \times 10^{13} \text{ cm}^{-2}$	Yes	Not accessible	N/A	Could not measure the region where the AHE exists.
F	$-1.6 \times 10^{13} \text{ cm}^{-2}$ only at $ D/\epsilon_0 > 0.5 \text{ V/nm}$	Yes	Not accessible	N/A	Could not measure the region where the AHE exists.
G	$-1.3 \times 10^{13} \text{ cm}^{-2}$	Yes	Yes, only in B-dominant state.	No	As we can only access the AHE region in the B-dominant state in this device, we observed no AHE.
H	$-1.6 \times 10^{13} \text{ cm}^{-2}$ only at $ D/\epsilon_0 > 0.5 \text{ V/nm}$	No	Yes, only in B-dominant state.	No	
Devices with major problems	Primary issue with device				
X1	Lowest carrier density is only $-0.6 \times 10^{13} \text{ cm}^{-2}$	N/A	N/A	N/A	
X2	Lowest carrier density is only $-0.5 \times 10^{13} \text{ cm}^{-2}$	N/A	N/A	N/A	
X3	Angle between bilayers > 1 degree	N/A	N/A	N/A	
X4	Angle between bilayers > 1 degree	N/A	N/A	N/A	
X5	Gates did not work properly, likely due to defective dielectric	N/A	N/A	N/A	
X6	Top gate does not function	N/A	N/A	N/A	
X7	Top gate shorted to device	N/A	N/A	N/A	

Table R1: Summary of all the devices we fabricated.

2) The authors claim that the quantum oscillations experiments serve only as qualitative measures of the domain ratio. Nevertheless, before that they claim that almost half of the domains are B and the other half RB. This is a bit confusing/misleading.

We agree with the reviewer's assessment. Our previous wording of "roughly half-Bernal-half-rhombohedral" was unnecessarily quantitative given the nature of the quantum-oscillation analysis. We have modified this statement. Our conclusion from the quantum oscillations is only that both stacking configurations exist in the RB-mixed state, whereas the B-dominant state is predominantly Bernal. A quantitative domain area fraction would require real-space imaging.

We have replaced the phrase "The blurred-out oscillation features indicate that the Bernal and rhombohedral domains exist in almost a one-to-one ratio in the device. This result indicates that the domain proportion has changed from almost 100% Bernal to roughly half-Bernal-half-rhombohedral through gating, a substantial shift in the domain ratio." with "This indicates an enhancement of rhombohedral domain proportion relative to the Bernal-dominant state." in the Supplementary Information.

3) If I understand correctly (please correct me if I am missing something), the authors discuss the fact that the region where they are able to observe the AHE is similar to that in the work by Han et al. (Nature 643, 654) where a quarter metal state is found. They also claim that the difference in the magnitude of the AHE is due to a proximity effect between the domain wall and the quarter metal. From this, I assume that a quarter metal state (or at least a half metal) is needed in order to observe the switching and the AHE. In the work by Han, the doping levels are not so high as in the measurements reported in the present work. It has been shown both experimentally (Nat. Nanotechnol. 19, 188–195 (2024), Nature Physics volume 21, 1765–1772 (2025), arXiv:2606.05356) and theoretically (Phys. Rev. B 107, 104502 (2023), Phys. Rev. B 110, 245118 (2024), Phys. Rev. Lett 135, 136503 (2025), Adv Materials e14008 (2025), Nature Communications 17, 232 (2026)) that depending on the doping level and displacement field applied, the tetralayer rhombohedral graphene suffers transitions from a quarter metal to a normal metal going through several other phases. In the present work, the authors go to values of doping larger of $1.5 \times 10^{12} \text{ cm}^{-2}$ where a quarter metal is not expected. Moreover, in the revised manuscript there are new measurements of the switching of one of the devices for different temperatures. From what I understand from the mean field calculations, the energy differences between the different states is small, so I would not expect these states to survive such high temperatures (Phys. Rev. B 107, 104502 (2023), Nature Communications 17, 232 (2026)). Could the authors comment on my rationalization or if some of my assumptions are wrong?

We thank the reviewer for their comments on our interpretation of the anomalous Hall effect (AHE) we observe. Below, we show that the region where we observe AHE is within the spin- and valley-polarized quarter-metal region of rhombohedral tetralayer graphene. Figure R2 compares our observation of AHE with other groups' measurements on rhombohedral tetralayer graphene [T. Han et al., Nature **643**, 654 (2025); S. Kalantre et al., arXiv:2606.05356; O.

Sheekey *et al.*, arXiv:2605.30316]. Three independent groups identified the spin-valley polarized quarter-metal region through quantum oscillation and magnetometry measurements. Here, we compare with experimental reports rather than calculated phase diagrams, since it is nontrivial to convert the interlayer energy difference to the displacement field D , as discussed in detail in “Effect of free-parameter variation on the relative energy spectrum” in Supplementary Information. We overlaid our AHE region as a red dashed line on top of their measurement. We can see that the regions where we observe AHE are within the quarter-metal regions.

This observation supports our discussion that the AHE we observe is related to the quarter-metal phase of rhombohedral tetralayer graphene. Note that although the AHE appears within the quarter-metal phase of rhombohedral tetralayer graphene, its D -odd sign and its larger magnitude indicate the AHE signal cannot be explained from a pure rhombohedral quarter metal, as discussed in “Microscopic discussion on the sign of anomalous Hall effect in pure rhombohedral graphene” in Supplementary Information. Hence, we propose that the AHE we observe may originate from a proximity effect from the quarter-metal in the rhombohedral region to either the domain wall or the adjacent Bernal region.

Regarding the temperature dependence, the reviewer is correct that the correlated states are not expected to survive to room temperature, and our data are consistent with this expectation. The correlation-driven magnetism in our device is indeed fragile: the AHE disappears above ~ 8 K, as shown in Extended Data Fig. 5. This temperature scale is comparable to the ordering temperature expected from mean-field calculations [A. Ghazaryan *et al.*, Phys. Rev. B **107**, 104502 (2023)].

We would like to clarify that the room-temperature measurements we added in Extended Data Figs. 9 and 10 concern the gate-induced structural (sliding) transition, not the magnetic transition. These are two distinct phenomena with very different energy scales. The sliding transition is structural in origin and is known to persist to room temperature owing to the high energy barrier associated with interlayer sliding [H. Li *et al.*, Nano Lett. **20**, 3106 (2020)], consistent with our observation. The magnetic switching, by contrast, is limited to below ~ 8 K by the correlation energy scale, exactly as the reviewer anticipates. In other words, the structure can be set nonvolatily at any temperature up to 300 K, whereas realizing on/off switching of AHE requires low temperature due to the relatively small correlation energy scale.

We have included citations to measurements of the quarter-metal phase in pure tetralayer rhombohedral graphene from the literature and made the distinction between the temperature dependence of both the structural (sliding) switching and the magnetic transition clear in the main text.

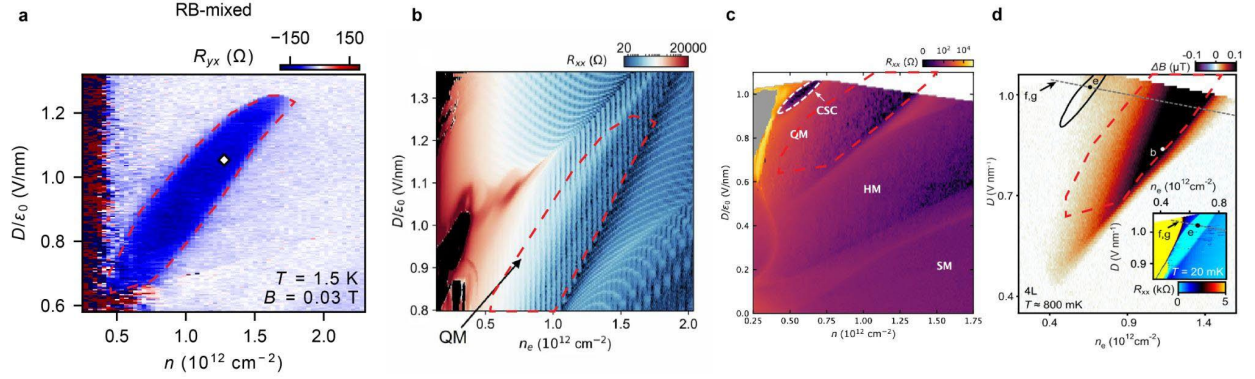


Fig. R2: Comparison between our measurement of the anomalous Hall effect (AHE) and the quarter metal state in the literature. **a**, Our measurement of the AHE in device A. The red dashed line outlines the region where we observe the AHE and is overlaid on the measurements from the literature. **b**, Magnetotransport measurement of the quarter metal phase from [T. Han *et al.*, Nature **643**, 654 (2025)]. The quarter metal phase (QM) is identified by the degeneracy of the quantum oscillations. **c**, Transport measurement of the quarter metal phase from [S. Kalantre *et al.*, arXiv:2606.05356]. The phase is determined from the degeneracy of quantum oscillations. **d**, nanoSQUID-on-tip magnetometry measurement of the quarter metal phase from [O. Sheekey *et al.*, arXiv:2605.30316]. The fringe fields measured with this technique identify the quarter-metal phase owing to the nonzero net orbital magnetic moment in the quarter-metal phase.

List of changes:

Changes made in the main text and Supplementary Information are highlighted in yellow.

Main text:

- We have included reference to the additional devices which exhibited structural switching.
- We have added additional citations which reference new measurements of the quarter metal phase.
- We have clarified our statements on the two different temperature-dependent measurements, the structural switching and the AHE.

Extended Data:

- N/A

Supplementary Information:

- We have modified the text in “Discussion on domain proportions” to increase clarity.
- We have included a new section “Switching across all devices” as well as Table 3, and Fig. S15 in order to highlight switching in three additional devices and our overall success rates in the fabrication of these devices.