Stripe-Nematic Phase of Composite Fermions

Chengyu Wang, S. K. Singh, C. T. Tai, A. Gupta, L. N. Pfeiffer, K. W. Baldwin, and M. Shayegan
Department of Electrical and Computer Engineering, Princeton University, Princeton, New Jersey 08544, USA

(Received 13 June 2025; revised 27 October 2025; accepted 4 December 2025; published 2 January 2026)

Electronic stripe-nematic phases are fascinating, strongly correlated states characterized by spontaneous rotational symmetry breaking. In the quantum Hall regime, such phases typically emerge at half-filled, high-orbital-index ($N \geq 2$) Landau levels (LLs) where the short-range Coulomb interaction is softened by the nodes of electron wave functions. In the lowest ($N = 0$) LLs, these phases are not expected. Instead, composite fermion (CF) liquids and fractional quantum Hall states, which are well explained in the picture of weakly interacting CF quasiparticles, are favored. Here, we report the observation of an unexpected stripe-nematic phase in the *lowest* LL at filling factor $\nu = 5/8$ in ultra-high-quality GaAs two-dimensional *hole* systems, evinced by a pronounced in-plane transport anisotropy. Remarkably, $\nu = 5/8$ can be mapped to a half-filled, high-index CF LL ($N_{CF} = 2$), analogous to the $N = 2$ hole LL. Our finding signals a novel stripe-nematic phase of CFs driven by the residual long-range interaction among these emergent quasiparticles. This phase is surprisingly robust, surviving up to ~100 mK. Its absence in electron-type systems suggests that severe LL mixing stemming from the large hole effective mass and nonlinear LL fan diagram plays a crucial role in modifying the CF-CF interaction.

DOI: 10.1103/79lt-2p4n

The concept of quasiparticles is pivotal for understanding the complex electronic properties in condensed matter physics. In solids, the behavior of electrons in a periodic potential created by the atomic lattice can be effectively described using Bloch electrons—quasiparticles that resemble free electrons but with a renormalized effective mass. In the extreme quantum limit of a two-dimensional electron system (2DES), where electrons partially occupy the lowest ($N = 0$), highly degenerate Landau level (LL), strong electron-electron Coulomb interaction leads to the emergence of exotic correlated phases such as fractional quantum Hall states (FQHSs) [1–3]. These many-body electronic phases can be phenomenologically understood through an effective single-particle framework by introducing a new type of quasiparticles known as composite fermions (CFs), which are formed by attaching an even number of magnetic flux quanta to each electron [4–6]. The flux attachment reduces the external magnetic field and, in an effective mean-field theory, also screens the Coulomb interaction. As a result, two-flux CFs (^{2}CFs) experience zero effective magnetic field B^* at LL filling factor $\nu = 1/2$ and form a compressible Fermi sea. This has been confirmed experimentally [7–9]. As the system moves away from $\nu = 1/2$, the ^{2}CFs experience a finite $B^* = B - B_{1/2}$ and form their own LLs, known as lambda levels (ΛLs) [6]. Similar to electrons, ^{2}CFs exhibit integer QHSs when ΛLs are fully occupied, which manifest as Jain-sequence FQHSs at $\nu = n/(2n \pm 1)$, $n = 1, 2, 3\ldots$

Electron-electron interaction in excited ($N \geq 1$) LLs, however, is rather different, because the nodes of electron wave functions soften the short-range part of the Coulomb interaction, giving rise to exotic correlated states, which are not favored in the $N = 0$ LLs. One peculiar example is the candidate non-Abelian FQHS observed in half-filled $N = 1$ LL at $\nu = 5/2$ [10], which is believed to originate from BCS-like CF pairing [11–13]. In higher $N \geq 2$ LLs, stripe or electronic versions of liquid-crystal-like phases characterized by significant in-plane transport anisotropy emerge at half fillings, e.g., at $\nu = 9/2$ [14–23]. Early Hartree-Fock theories predicted that these phases stem from unidirectional charge-density waves consisting of stripes with alternating integer ν (e.g., $\nu = 4$ and 5) [16–18,24]. At finite temperatures, and in the presence of quantum fluctuations and disorder, the stripe order can be disrupted, leading to nematic phases [19,20,22]. In the remainder of the Letter, we refer to such phases as stripe-nematic (SN) phases. In a more general picture, nematic orders can also arise from Pomeranchuk instability of Fermi seas [21,23].

We report here the observation of an unusual, *anisotropic* phase at $\nu = 5/8$ in the lowest LL of ultra-high-quality GaAs 2D hole systems (2DHSs). The LL filling $\nu = 5/8$ can be mapped to a *hole-flux* CF ΛL filling $\nu_{CF} = 5/2$, representing a half-occupied $N_{CF} = 2$ ΛL on top of two fully occupied lower ΛLs ($N_{CF} = 0$ and 1). The exotic phase we observe at $\nu = 5/8$ is, therefore, very likely a manifestation of an SN phase of *interacting CFs*; see Fig. 1(c). This phase is novel and intricate because both the SN phase and the CF quasiparticles forming this phase have collective origins.

We studied ultra-high-quality 2DHSs confined to GaAs quantum wells grown on GaAs (001) substrates by

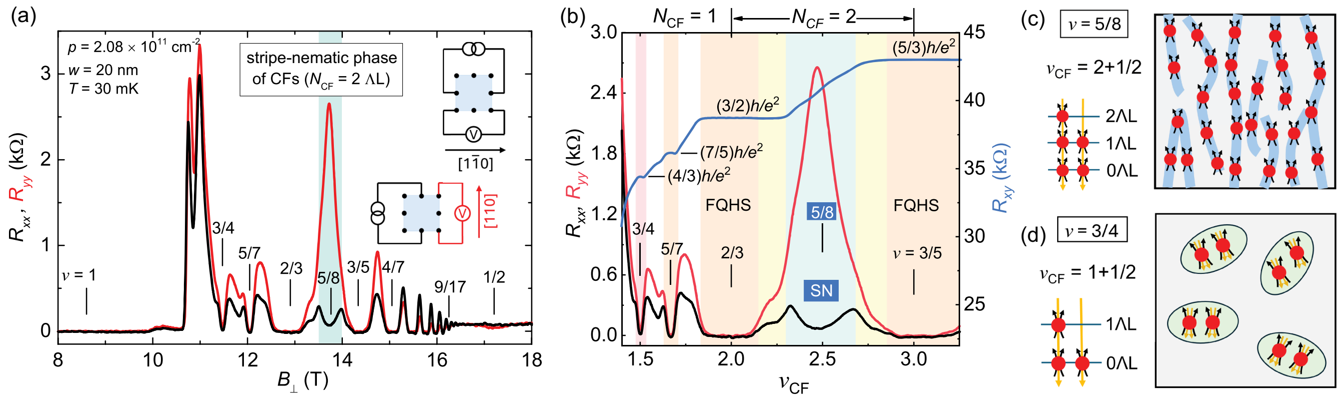

FIG. 1. An SN phase of CFs in the lowest LL. (a) Longitudinal resistances R_{xx} and R_{yy} vs perpendicular magnetic field $B_\perp$ measured along two mutually perpendicular crystal directions at $T \simeq 30$ mK. The circuit configurations used for the measurements are shown in the right insets. Our 2DHS exhibits a highly anisotropic behavior between two Jain-sequence FQHSs $\nu = 2/3$ and $3/5$, showing a peak anisotropy ($R_{yy}/R_{xx} \simeq 40$) near $\nu = 5/8$. This signals the emergence of an SN phase in the FQHS regime. (b) R_{xx}, R_{yy}, and Hall resistance R_{xy} are plotted as a function of CF filling factor, ν_{CF}. FQHSs identified by vanishing R_{xx} and R_{yy}, and accompanied by quantized Hall plateaus, are observed at $\nu = 3/5$, $2/3$, $5/7$, and $3/4$, corresponding to $\nu_{CF} = 3$, 2, $5/3$, and $3/2$, respectively. No R_{xy} plateau is seen near $\nu = 5/8$ ($\nu_{CF} = 5/2$). (c) Origin of the SN phase at $\nu = 5/8$: first, we map hole LL filling $\nu = 5/8$ to CF ΛL filling $\nu_{CF} = 5/2$, where CFs fully occupy the $N_{CF} = 0$ and $N_{CF} = 1$ ΛLs and half occupy the topmost, $N_{CF} = 2$ ΛL. An SN phase of CFs forms in the half-filled $N_{CF} = 2$ ΛL, analogous to electronic SN phases in high LLs, e.g., at $\nu = 9/2$. (d) Origin of the exotic $\nu = 3/4$ FQHS: paired FQHS of CFs in the half-filled $N_{CF} = 1$ ΛL. We assume CFs are fully spin polarized; this is reasonable, given the very large $B_\perp$ where our observations are made.

molecular beam epitaxy. They were grown following the optimization of the growth chamber vacuum integrity and the purity of the source materials [25] as well as an optimized, stepped-barrier design [26,27]. We performed our experiments on 4×4 mm^2 van der Pauw geometry samples cleaved from a 2-inch GaAs wafer with alloyed In:Zn contacts at the four corners and side midpoints. The samples were cooled in a dilution refrigerator with a base temperature of $\simeq$30 mK. We measured the longitudinal resistances along [1$\bar{1}$0] (R_{xx}) and [110] (R_{yy}) crystal directions [28] and the Hall resistance R_{xy} using the conventional, low-frequency ($\sim$17 Hz), lock-in amplifier technique.

We focus on transport measurements on a GaAs 2DHS in the lowest LL ($\nu < 1$). Figure 1(a) presents R_{xx} and R_{yy} vs perpendicular magnetic field $B_\perp$. We observe a dramatic anisotropic behavior at $\nu = 5/8$: R_{xx} exhibits a deep minimum while R_{yy} shows a maximum (with $R_{yy}/R_{xx} \simeq 40$), reminiscent of the SN phases that typically emerge in high ($N \geq 2$) LLs [14,15,22]. Such anisotropic behavior at $\nu = 5/8$ is also seen in two other samples with similar 2D hole densities, but different quantum well widths; see Supplemental Material (SM) Fig. S5 [29]. As we elaborate later, this anisotropic behavior signals the emergence of an SN phase of interacting ^{2}CFs in a half-filled, high ($N_{CF} = 2$) ΛL. The SN phase at $\nu = 5/8$ is in stark contrast to the nearly isotropic behavior we observe elsewhere in the lowest LL ($\nu < 1$). Near $\nu = 1/2$, R_{xx} and R_{yy} are featureless and have similar values, consistent with an isotropic Fermi sea of ^{2}CFs. On the lower-$B_\perp$ side of $\nu = 1/2$, a sequence of minima, which signal the Jain-sequence FQHSs, are observed at $\nu = 2/3, 3/5, 4/7, \ldots$, up to $9/17$. It is worth noting that, between $\nu = 1$ and $2/3$, an *even-denominator* FQHS emerges at $\nu = 3/4$, consistent with what was recently reported in ultra-high-quality GaAs 2DHSs [40,41]. These observations collectively demonstrate the exceptionally high quality of the GaAs 2DHS in our Letter.

To shed light on the origin of the exotic SN phase at $\nu = 5/8$, we present our data in the ^{2}CF picture by plotting R_{xx}, R_{yy}, and R_{xy} in Fig. 1(b) as a function of ν_{CF}, where ν_{CF} is the CF ΛL filling factor obtained from the relation $\nu = \nu_{CF}/(2\nu_{CF} + 1)$. The Jain-sequence FQHSs at $\nu = 2/3$ and $3/5$, evinced by wide, quantized R_{xy} plateaus accompanied with vanishing R_{xx} and R_{yy}, can be interpreted as integer QHSs of ^{2}CFs with $\nu_{CF} = 2$ and 3. An SN phase is observed between $\nu = 2/3$ and $3/5$ (between $\nu_{CF} = 2$ and 3). Here, CFs fully occupy the $N_{CF} = 0$ and $N_{CF} = 1$ ΛLs, and partially occupy the $N_{CF} = 2$ ΛL, assuming CFs are fully spin polarized. The peak anisotropy is seen near $\nu = 5/8$, corresponding to $\nu_{CF} = 2 + 1/2$, where the topmost $N_{CF} = 2$ ΛL is half occupied [Fig. 1(c)]. No R_{xy} plateau is seen near $\nu = 5/8$. These observations highly resemble the conventional SN phases reported in high LLs of GaAs 2DESs [14,15,22], suggesting that what we observe at $\nu = 5/8$ is an SN phase. Remarkably, this SN phase is observed in the lowest LL, emerging from interacting ^{2}CFs rather than interacting holes.

Several other observations support our claim that CFs are interacting in a partially filled ΛL in our 2DHS. The filling

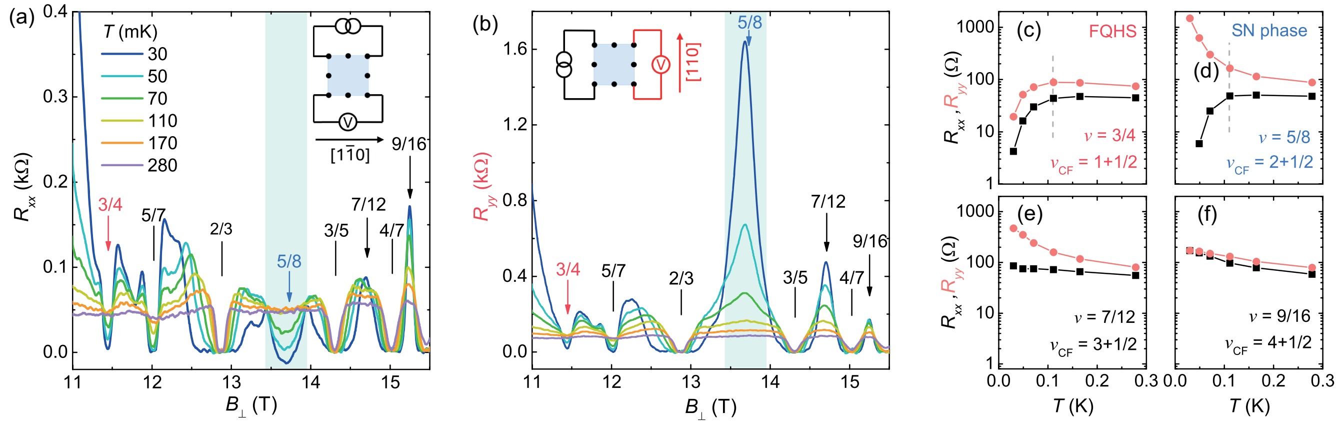

FIG. 2. Temperature dependence. (a),(b) R_{xx} and R_{yy} vs $B_\perp$ traces measured at different T. Vertical black lines mark the $B_\perp$ positions of odd-denominator FQHSs. Filling factors $\nu = 3/4$, $5/8$, $7/12$, and $9/16$, which correspond to half-integer $\nu_{CF} = 3/2$, $5/2$, $7/2$, and $9/2$, are marked with arrows. Insets show the circuit configurations used for the measurements. (c)–(f) R_{xx} and R_{yy} vs T at $\nu = 3/4$, $5/8$, $7/12$, and $9/16$. At $\nu = 3/4$, as we lower T, both R_{xx} and R_{yy} first slightly increase, and then decrease at $T \lesssim 0.1$ K when an FQHS is developing. At $\nu = 7/12$ and $9/16$, both R_{xx} and R_{yy} monotonically increase with decreasing T. In contrast to these fillings where R_{xx} and R_{yy} exhibit the same trend with T, at $\nu = 5/8$, R_{xx} and R_{yy} deviate from each other and become highly anisotropic at $T \lesssim 0.1$ K, signaling the emergence of an SN phase.

factor $\nu = 3/4$, at which an exotic, even-denominator FQHS is observed [see Fig. 1(b)], can be mapped to $\nu_{CF} = 1 + 1/2$ [Fig. 1(d)]. A likely origin of this FQHS is the CF-CF interaction and pairing in the half-filled $N_{CF} = 1$ ΛL [40,41]. Such CF-CF interaction resembles the electron-electron interaction in the $N = 1$ LLs, which is believed to be the key to stabilizing paired, non-Abelian FQHSs at even-denominator fillings, e.g., at $\nu = 5/2$ [10]. We also note that there are two inflection points in both R_{xx} and R_{yy} between $\nu = 2/3$ and $3/5$, where R_{xy} shows quantization merging into the $\nu = 2/3$ and $3/5$ plateaus [see the yellow-shaded regions in Fig. 1(b)]. Similar features are also seen near $\nu = 2/3$ in two other samples; see SM, Figs. S5 and S6 for details [29]. These features are possibly indications of developing *reentrant* FQHSs, which are believed to be bubble phases of interacting CFs [42–44]. The ν_{CF} positions of these features, $\simeq 2 + 0.25$ and $2 + 0.75$, are close to the ν positions of bubble phases observed in the $N = 2$ LL [45], suggesting that CF-CF interaction in the $N_{CF} = 2$ ΛL is analogous to the electron-electron interaction in the $N = 2$ LL.

Figure 2 displays the temperature dependence data, providing further evidence for the emergence of an SN phase at $\nu = 5/8$; see SM, Fig. S6 for the temperature dependence of two other samples [29]. In Figs. 2(a) and 2(b), we present R_{xx} and R_{yy} vs $B_\perp$ traces [46,47] measured at different T; see SM Fig. S1 for R_{xy} data [29]. As we increase T from 30 mK, the R_{xx} minimum and R_{yy} maximum at $\nu = 5/8$ weaken sharply. Both features disappear at $T \simeq 110$ mK, and they exhibit little temperature dependence as we further increase T to 280 mK. These trends are more clearly revealed in Fig. 2(d). Our observations signal the thermal melting of the SN phase at $\nu = 5/8$, strikingly resembling what was reported for SN phases in high LLs of GaAs 2DESs [14,15,22,48].

In Figs. 2(c), 2(e), and 2(f), we show the temperature dependence of R_{xx} and R_{yy} at other fillings, $\nu = 3/4$, $7/12$, and $9/16$. Similar to $\nu = 5/8$, which corresponds to $\nu_{CF} = 2 + 1/2$, these ν can also be mapped to half-integer ν_{CF}. In contrast to the anisotropic behavior at $\nu = 5/8$, R_{xx} and R_{yy} qualitatively follow the same trend. At $\nu = 3/4$ ($\nu_{CF} = 1 + 1/2$), where the ground state is an FQHS, both R_{xx} and R_{yy} approach zero at low T [Fig. 2(c)] [40]. At $\nu = 7/12$ and $9/16$ ($\nu_{CF} = 3 + 1/2$ and $4 + 1/2$), both R_{xx} and R_{yy} increase slightly at lower T [Figs. 2(e) and 2(f)] [49], consistent with what was reported at FQH plateau-to-plateau transitions [50].

Next, we study the evolution of the CF SN phase in tilted B. The sample is mounted on a rotating stage to support *in situ* tilt; θ is the angle between B and $B_\perp$; see Fig. 3(h). The in-plane magnetic field $B_\parallel = B\sin(\theta)$ is applied along the $[1\bar{1}0]$ (R_{xx}) direction; see SM for data with $B_\parallel$ applied along the [110] (R_{yy}) direction [29]. Figures 3(a)–3(c) display data measured at three different θ. At $\theta = 0$, we observe an SN phase at $\nu = 5/8$ with $R_{yy} \gg R_{xx}$. At $\theta = 27.2°$, R_{xx} and R_{yy} values at $\nu = 5/8$ become very close. At the largest $\theta = 33.4°$, an SN phase emerges again, but now $R_{xx} \gg R_{yy}$. This evolution with θ is summarized in Fig. 3(d), where we present color-scale plots of R_{xx} and R_{yy} as a function of $B_\perp$ and $\sin(\theta)$. With increasing $\sin(\theta)$, the SN phase at $\nu = 5/8$ gradually weakens, then disappears at intermediate θ, and it eventually reappears at large θ with the hard axis switched to the R_{xx} direction. Qualitatively similar behavior was also reported in high LLs of GaAs 2DESs [48,51], where SN

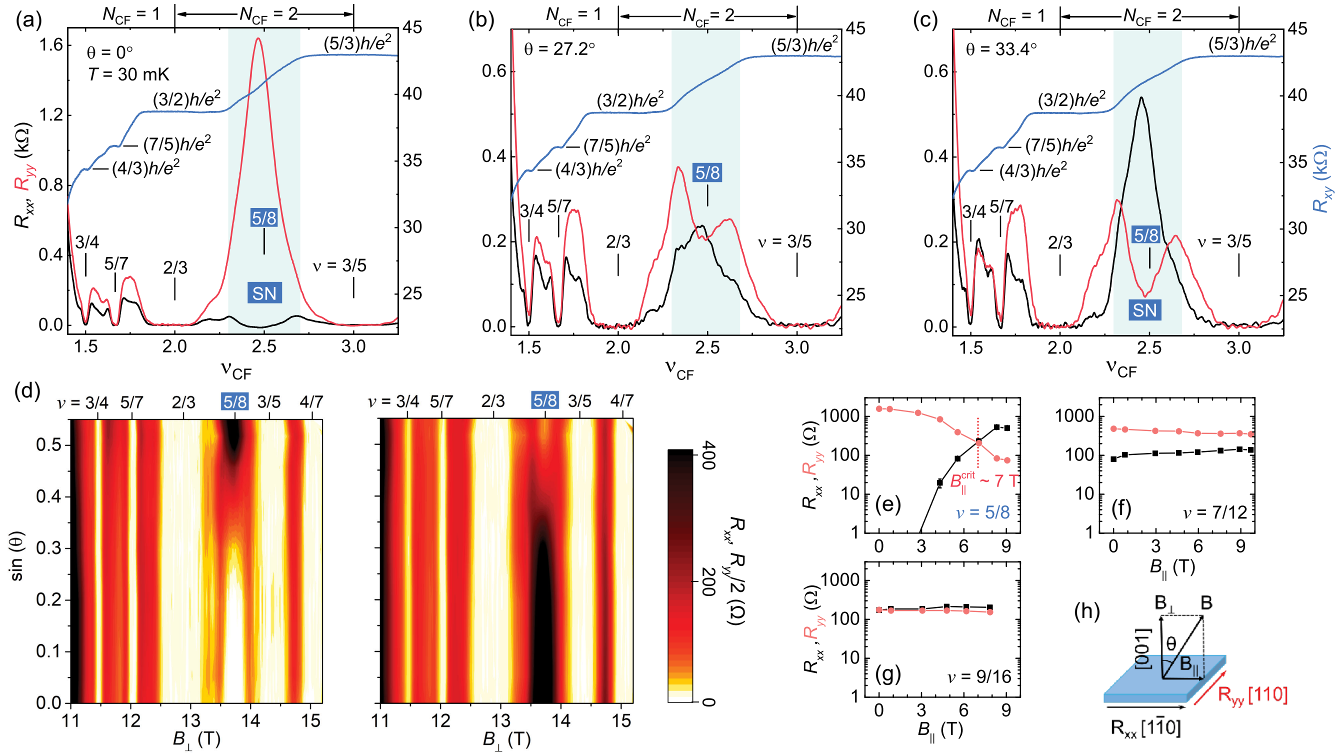

FIG. 3. Role of in-plane magnetic field. (a)–(c) R_{xx}, R_{yy}, and R_{xy} vs ν_{CF} traces measured at (a) $\theta = 0°$, (b) $\theta = 27.2°$, and (c) $\theta = 33.4°$. (d) Color-scale plot of R_{xx} (left) and $R_{yy}/2$ (right) as a function of $B_\perp$ and sin(θ). (e)–(g) R_{xx} and R_{yy} vs $B_\parallel$ at $\nu = 5/8$, 7/12, and 9/16. The circuit configurations for R_{xx} and R_{yy} measurements are the same as shown in Fig. 2. (h) A schematic of the experimental setup.

phases generally align their hard axis to the direction of $B_\parallel$ when $B_\parallel > B_\parallel^{crit}$. However, there are two surprises: (i) we observe a $B_\parallel^{crit} \simeq 7$ T [Fig. 3(e)], significantly larger than the typical values ($B_\parallel^{crit} \lesssim 1$ T) reported for high LL SN phases in GaAs 2DESs [48,51]; (ii) at high θ, the $\nu = 5/8$ state is more fragile than what we observe at $\theta = 0$: the anisotropic behavior disappears at a lower $T \simeq 70$ mK (SM Fig. S2 [29]). This is in contrast to the SN phases in high LLs, which survive up to higher temperatures in the presence of a large $B_\parallel$ [48].

Unlike the SN phase at $\nu = 5/8$, other states in the lowest LL are rather insensitive to θ. The FQHSs observed at $\nu = 3/4$, 5/7, 2/3, 3/5, and 4/7 remain robust with increasing θ [Figs. 3(a)–3(d)], suggesting that these FQHSs are fully spin polarized. This corroborates our assumption that CFs are fully polarized. At $\nu = 7/12$ and 9/16 (corresponding to $\nu_{CF} = 7/2$ and 9/2, respectively), R_{xx} and R_{yy} largely remain constant as a function of $B_\parallel$ [Figs. 3(f) and 3(g)], indicating the absence of SN instability at these fillings.

Our observation of a CF SN phase highlights the important role of residual CF-CF interaction in the FQH regime. Similar to electrons in a high-orbital-index LL, CFs in a high-index ΛL also have nodes in their wave function [4,6]. Intuitively, the nodes in the CF wave function can soften the short-range residual Coulomb repulsion, which is already very weak after forming CFs via flux attachment. Calculations of pseudopotentials for CF-CF interaction indeed suggest that residual CF-CF interaction in excited ($N_{CF} \geq 1$) ΛLs is often attractive [42,52,53]. These calculations also predict that such residual CF-CF interaction can lead to numerous exotic correlated states, including FQHSs at unconventional fillings and stripe and bubble phases of CFs [42,52,53]. FQHSs beyond the Jain sequence emerging from CF-CF interaction were reported in the lowest LL at both odd- and even-denominator fillings [40,41,54–57], e.g., at $\nu = 4/11$ in GaAs 2DESs [55] and at $\nu = 3/4$ in GaAs 2DHSs [40,41]. An exotic bubble phase of CFs was also observed recently near $\nu = 5/3$ in a GaAs 2DES [44]. Note that these states emerge in the $N_{CF} = 1$ CF ΛL, qualitatively similar to the many-body states observed in the $N = 1$ electron LL. The SN phase we observe at $\nu = 5/8$, on the other hand, signals yet another exotic collective state emerging from CF-CF interaction in a higher ($N_{CF} = 2$) CF ΛL.

While the potential for stripe formation in the FQH regime, as discussed in Refs. [42,52], offers a plausible explanation for our data, the robustness of the CF SN phase we observe is intriguing. Collective states of CFs are generally considered exceedingly fragile because the CF-CF interaction is about an order of magnitude weaker than the electron-electron interaction (when LL mixing is ignored) [42,52]. Now, the SN phases in high LLs of GaAs

2DESs and 2DHSs are generally reported only at very low temperatures ($T \leq 50$ mK) [14,15,58], suggesting even more stringent conditions for CF stripe formation. In contrast, the SN phase we observe at $\nu = 5/8$ persists up to $T \simeq 100$ mK, indicating its surprising robustness. Such robustness, together with the $\nu = 3/4$ FQHS we observe in the same sample, demonstrate that CFs in our 2DHS are highly interacting.

We attribute this surprisingly strong CF-CF interaction to the severe LL mixing (LLM) in our 2DHS samples. This seems counterintuitive at first sight, since LLM softens the short-range component of the hole-hole Coulomb repulsion. However, the flux attachment required to form CFs is quantized and can lead to an *overscreening*, rendering CFs in the $N_{\mathrm{CF}} \geq 1$ LLs mutually attractive [42,52,53]. Therefore, the softening of hole-hole Coulomb repulsion by LLM actually results in an enhancement of residual CF-CF *attractive* interaction, and it can lead to a pairing of CFs and the formation of even-denominator FQHSs, e.g., at $\nu = 3/4$ [40,41,59,60]. Our calculated LL fan diagram (SM Fig. S4 [29]) shows that at $\nu = 5/8$, the Coulomb energy is significantly larger than the LL separations, underscoring the importance of LLM. It is also worth noting that the SN phase of CFs we observe at $\nu = 5/8$, as well as the $\nu = 3/4$ FQHS, are absent in ultra-high-quality GaAs 2DESs, even though the mobility of GaAs 2DESs is an order of magnitude higher [25]. Compared to 2DHSs, GaAs 2DESs have a much smaller effective mass, and therefore, experience negligible LLM at high $B_{\perp}$. This is consistent with our conjecture that LLM plays a crucial role in modifying the residual CF-CF interaction that stabilizes the exotic SN phase of CFs.

Acknowledgments—We thank A. Bangura, G. Jones, R. Nowell, and T. Murphy at the National High Magnetic Field Laboratory (NHMFL) for technical assistance. We also thank Roland Winkler for the Landau level calculations and Jainendra K. Jain for illuminating discussions. We acknowledge support by the National Science Foundation (NSF), Grant No. DMR 2104771, for measurements and the Gordon and Betty Moore Foundation's EPiQS Initiative (Grant No. GBMF9615 to L. N. P.) for sample fabrication. Our measurements were partly performed at NHMFL, which is supported by the NSF Cooperative Agreement No. DMR 2128556, by the State of Florida, and by the DOE. This research was funded in part by a QuantEmX grant from the Institute for Complex Adaptive Matter and the Gordon and Betty Moore Foundation through Grant No. GBMF9616 to C. W., S. K. S., and C. T. T.

Data availability—The data that support the findings of this article are openly available [61].

[1] D. C. Tsui, H. L. Stormer, and A. C. Gossard, Two-dimensional magnetotransport in the extreme quantum limit, Phys. Rev. Lett. **48**, 1559 (1982).

[2] R. B. Laughlin, Anomalous quantum Hall effect: An incompressible quantum fluid with fractionally charged excitations, Phys. Rev. Lett. **50**, 1395 (1983).

[3] *Fractional Quantum Hall Effects: New Developments*, edited by B. I. Halperin and J. K. Jain (World Scientific, Singapore, 2020).

[4] J. K. Jain, Composite-fermion approach for the fractional quantum Hall effect, Phys. Rev. Lett. **63**, 199 (1989).

[5] B. I. Halperin, P. A. Lee, and N. Read, Theory of the half-filled Landau level, Phys. Rev. B **47**, 7312 (1993).

[6] J. K. Jain, *Composite Fermions*, (Cambridge University Press, Cambridge, England, 2007).

[7] R. L. Willett, R. R. Ruel, K. W. West, and L. N. Pfeiffer, Experimental demonstration of a Fermi surface at one-half filling of the lowest Landau level, Phys. Rev. Lett. **71**, 3846 (1993).

[8] W. Kang, H. L. Stormer, L. N. Pfeiffer, K. W. Baldwin, and K. W. West, How real are composite fermions?, Phys. Rev. Lett. **71**, 3850 (1993).

[9] D. Kamburov, Y. Liu, M. A. Mueed, M. Shayegan, L. N. Pfeiffer, K. W. West, and K. W. Baldwin, What determines the Fermi wave vector of composite fermions?, Phys. Rev. Lett. **113**, 196801 (2014).

[10] R. Willett, J. P. Eisenstein, H. L. Störmer, D. C. Tsui, A. C. Gossard, and J. H. English, Observation of an even-denominator quantum number in the fractional quantum Hall effect, Phys. Rev. Lett. **59**, 1776 (1987).

[11] G. Moore and N. Read, Nonabelions in the fractional quantum Hall effect, Nucl. Phys. **B360**, 362 (1991).

[12] N. Read and Dmitry Green, Paired states of fermions in two dimensions with breaking of parity and time-reversal symmetries and the fractional quantum Hall effect, Phys. Rev. B **61**, 10267 (2000).

[13] Anirban Sharma, Songyang Pu, and J. K. Jain, Bardeen-Cooper-Schrieffer pairing of composite fermions, Phys. Rev. B **104**, 205303 (2021).

[14] M. P. Lilly, K. B. Cooper, J. P. Eisenstein, L. N. Pfeiffer, and K. W. West, Evidence for an anisotropic state of two-dimensional electrons in high Landau levels, Phys. Rev. Lett. **82**, 394 (1999).

[15] R. R. Du, D. C. Tsui, H. L. Stormer, L. N. Pfeiffer, K. W. Baldwin, and K. W. West, Strongly anisotropic transport in higher two-dimensional Landau levels, Solid State Commun. **109**, 389 (1999).

[16] A. A. Koulakov, M. M. Fogler, and B. I. Shklovskii, Charge density wave in two-dimensional electron liquid in weak magnetic field, Phys. Rev. Lett. **76**, 499 (1996).

[17] M. M. Fogler, A. A. Koulakov, and B. I. Shklovskii, Ground state of a two-dimensional electron liquid in a weak magnetic field, Phys. Rev. B **54**, 1853 (1996).

[18] R. Moessner and J. T. Chalker, Exact results for interacting electrons in high Landau levels, Phys. Rev. B **54**, 5006 (1996).

[19] Eduardo Fradkin and Steven A. Kivelson, Liquid-crystal phases of quantum Hall systems, Phys. Rev. B **59**, 8065 (1999).

[20] Eduardo Fradkin, Steven A. Kivelson, Efstratios Manousakis, and Kwangsik Nho, Nematic phase of the two-dimensional electron gas in a magnetic field, Phys. Rev. Lett. **84**, 1982 (2000).

[21] Vadim Oganesyan, Steven A. Kivelson, and Eduardo Fradkin, Quantum theory of a nematic Fermi fluid, Phys. Rev. B **64**, 195109 (2001).

[22] Eduardo Fradkin, Steven A. Kivelson, Michael J. Lawler, James P. Eisenstein, and Andrew P. Mackenzie, Nematic Fermi fluids in condensed matter physics, Annu. Rev. Condens. Matter Phys. **1**, 153 (2010).

[23] Kyungmin Lee, Junping Shao, Eun-Ah Kim, F. D. M. Haldane, and Edward H. Rezayi, Pomeranchuk instability of composite Fermi liquids, Phys. Rev. Lett. **121**, 147601 (2018).

[24] See also M. Sammon, X. Fu, Yi Huang, M. A. Zudov, B. I. Shklovskii, G. C. Gardner, J. D. Watson, M. J. Manfra, K. W. Baldwin, L. N. Pfeiffer, and K. W. West, Resistivity anisotropy of quantum Hall stripe phases, Phys. Rev. B **100**, 241303(R) (2019).

[25] Yoon Jang Chung, K. A. Villegas Rosales, K. W. Baldwin, P. T. Madathil, K. W. West, M. Shayegan, and L. N. Pfeiffer, Ultra-high-quality two-dimensional electron systems, Nat. Mater. **20**, 632–637 (2021).

[26] Yoon Jang Chung, C. Wang, S. K. Singh, A. Gupta, K. W. Baldwin, K. W. West, R. Winkler, M. Shayegan, and L. N. Pfeiffer, Record-quality GaAs two-dimensional hole systems, Phys. Rev. Mater. **6**, 034005 (2022).

[27] Adbhut Gupta, C. Wang, S. K. Singh, K. W. Baldwin, R. Winkler, M. Shayegan, and L. N. Pfeiffer, Ultraclean two-dimensional hole systems with mobilities exceeding 10^7 cm^2/Vs, Phys. Rev. Mater. **8**, 014004 (2024).

[28] Here, $[1\bar{1}0]$ is defined as the crystal direction perpendicular to the major flat of the GaAs wafer.

[29] See Supplemental Material at http://link.aps.org/supplemental/10.1103/79lt-2p4n, which includes Refs. [30–39], for additional magnetotransport data and the calculated Landau level fan diagram for our GaAs 2DHS.

[30] J. Zhu, W. Pan, H. L. Stormer, L. N. Pfeiffer, and K. W. West, Density-induced interchange of anisotropy axes at half-filled high Landau levels, Phys. Rev. Lett. **88**, 116803 (2002).

[31] J. Pollanen, K. B. Cooper, S. Brandsen, J. P. Eisenstein, L. N. Pfeiffer, and K. W. West, Heterostructure symmetry and the orientation of the quantum Hall nematic phases, Phys. Rev. B **92**, 115410 (2015).

[32] T. Jungwirth, A. H. MacDonald, L. Smrčka, and S. M. Girvin, Field-tilt anisotropy energy in quantum Hall stripe states, Phys. Rev. B **60**, 15574 (1999).

[33] Chengyu Wang, A. Gupta, S. K. Singh, L. N. Pfeiffer, K. W. Baldwin, R. Winkler, and M. Shayegan, Competing many-body phases at small fillings in ultrahigh-quality GaAs two-dimensional hole systems: Role of Landau level mixing, Phys. Rev. B **111**, 085429 (2025).

[34] R. Winkler, *Spin-Orbit Coupling Effects in Two-Dimensional Electron and Hole Systems* (Springer, Berlin, 2003).

[35] Yang Liu, S. Hasdemir, D. Kamburov, A. L. Graninger, M. Shayegan, L. N. Pfeiffer, K. W. West, K. W. Baldwin, and R. Winkler, Even-denominator fractional quantum Hall effect at a Landau level crossing, Phys. Rev. B **89**, 165313 (2014).

[36] M. Lupatini, P. Knüppel, S. Faelt, R. Winkler, M. Shayegan, A. Imamoglu, and W. Wegscheider, Spin reversal of a quantum Hall ferromagnet at a Landau level crossing, Phys. Rev. Lett. **125**, 067404 (2020).

[37] Meng K. Ma, Chengyu Wang, Y. J. Chung, L. N. Pfeiffer, K. W. West, K. W. Baldwin, R. Winkler, and M. Shayegan, Robust quantum Hall ferromagnetism near a gate-tuned $\nu = 1$ Landau level crossing, Phys. Rev. Lett. **129**, 196801 (2022).

[38] Chengyu Wang, A. Gupta, S. K. Singh, C. T. Tai, L. N. Pfeiffer, K. W. Baldwin, R. Winkler, and M. Shayegan, Even-denominator fractional quantum Hall states with spontaneously broken rotational symmetry, Rep. Prog. Phys. **88**, 100501 (2025).

[39] Ke Huang, P. Wang, L. N. Pfeiffer, K. W. West, K. W. Baldwin, Y. Liu, and X. Lin, Resymmetrizing broken symmetry with hydraulic pressure, Phys. Rev. Lett. **123**, 206602 (2019).

[40] Chengyu Wang, A. Gupta, S. K. Singh, Y. J. Chung, L. N. Pfeiffer, K. W. West, K. W. Baldwin, R. Winkler, and M. Shayegan, Even-denominator fractional quantum Hall state at filling factor $\nu = 3/4$, Phys. Rev. Lett. **129**, 156801 (2022).

[41] Chengyu Wang, Adbhut Gupta, Pranav T. Madathil, Siddharth K. Singh, Yoon Jang Chung, Loren N. Pfeiffer loren, Kirk W. Baldwin, and Mansour Shayegan, Next-generation even-denominator fractional quantum Hall states of interacting composite fermions, Proc. Natl. Acad. Sci. U.S.A. **120**, e2314212120 (2023).

[42] Seung-Yeop Lee, Vito W. Scarola, and J. K. Jain, Structures for interacting composite fermions: Stripes, bubbles, and fractional quantum Hall effect, Phys. Rev. B **66**, 085336 (2002).

[43] M. O. Goerbig, P. Lederer, and C. M. Smith, Possible reentrance of the fractional quantum Hall effect in the lowest Landau level, Phys. Rev. Lett. **93**, 216802 (2004).

[44] Vidhi Shingla, Haoyun Huang, Ashwani Kumar, Loren N. Pfeiffer, Kenneth W. West, Kirk W. Baldwin, and Gábor A. Csáthy, A highly correlated topological bubble phase of composite fermions, Nat. Phys. **19**, 689 (2023).

[45] Dohyung Ro, S. A. Myers, N. Deng, J. D. Watson, M. J. Manfra, L. N. Pfeiffer, K. W. West, and G. A. Csáthy, Stability of multielectron bubbles in high Landau levels, Phys. Rev. B **102**, 115303 (2020).

[46] Note that the circuit configurations we use here [insets in Figs. 2(a) and 2(b)] are different from those in Fig. 1, but the traces are qualitatively similar. Because of the geometric effects, in Figs. 2(a) and 2(b), the R_{xx} and R_{yy} values are overall smaller, and the anisotropy at $\nu = 5/8$ is larger, compared to data in Fig. 1 [47].

[47] Steven H. Simon, Comment on "Evidence for an anisotropic state of two-dimensional electrons in high Landau levels", Phys. Rev. Lett. **83**, 4223 (1999).

[48] K. B. Cooper, M. P. Lilly, J. P. Eisenstein, L. N. Pfeiffer, and K. W. West, Onset of anisotropic transport of two-dimensional electrons in high Landau levels: Possible isotropic-to-nematic liquid-crystal phase transition, Phys. Rev. B **65**, 241313(R) (2002).

[49] While the anisotropy at $\nu = 7/12$ increases with decreasing T, no qualitative difference is seen at this filling in R_{xx} and R_{yy} traces—both show a peak in the whole range of T [Figs. 2(a) and 2(b)].

[50] P. T. Madathil, K. A. Villegas Rosales, C. T. Tai, Y. J. Chung, L. N. Pfeiffer, K. W. West, K. W. Baldwin, and M. Shayegan, Delocalization and universality of the fractional quantum Hall plateau-to-plateau transitions, Phys. Rev. Lett. **130**, 226503 (2023).

[51] M. P. Lilly, K. B. Cooper, J. P. Eisenstein, L. N. Pfeiffer, and K. W. West, Anisotropic states of two-dimensional electron systems in high Landau levels: Effect of an in-plane magnetic field, Phys. Rev. Lett. **83**, 824 (1999).

[52] Seung-Yeop Lee, Vito W. Scarola, and J. K. Jain, Stripe formation in the fractional quantum Hall regime, Phys. Rev. Lett. **87**, 256803 (2001).

[53] V. W. Scarola, J. K. Jain, and E. H. Rezayi, Possible pairing-induced even-denominator fractional quantum Hall effect in the lowest Landau level, Phys. Rev. Lett. **88**, 216804 (2002).

[54] V. J. Goldman and M. Shayegan, Fractional quantum Hall states at $\nu = 7/11$ and $9/13$, Surf. Sci. **229**, 10 (1990).

[55] W. Pan, H. L. Stormer, D. C. Tsui, L. N. Pfeiffer, K. W. Baldwin, and K. W. West, Fractional quantum Hall effect of composite fermions, Phys. Rev. Lett. **90**, 016801 (2003).

[56] Yang Liu, D. Kamburov, S. Hasdemir, M. Shayegan, L. N. Pfeiffer, K. W. West, and K. W. Baldwin, Fractional quantum Hall effect and Wigner crystal of interacting composite fermions, Phys. Rev. Lett. **113**, 246803 (2014).

[57] Manohar Kumar, Antti Laitinen, and Pertti Hakonen, Unconventional fractional quantum Hall states and Wigner crystallization in suspended Corbino graphene, Nat. Commun. **9**, 2776 (2018).

[58] M. J. Manfra, R. de Picciotto, Z. Jiang, S. H. Simon, L. N. Pfeiffer, K. W. West, and A. M. Sergent, Impact of spin-orbit coupling on quantum Hall nematic phases, Phys. Rev. Lett. **98**, 206804 (2007).

[59] Chengyu Wang, A. Gupta, S. K. Singh, P. T. Madathil, Y. J. Chung, L. N. Pfeiffer, K. W. Baldwin, R. Winkler, and M. Shayegan, Fractional quantum Hall state at filling factor $\nu = 1/4$ in ultra-high-quality GaAs two-dimensional hole systems, Phys. Rev. Lett. **131**, 266502 (2023).

[60] Tongzhou Zhao, Ajit C. Balram, and J. K. Jain, Composite fermion pairing induced by Landau level mixing, Phys. Rev. Lett. **130**, 186302 (2023).

[61] C. Wang, S. K. Singh, C. T. Tai, A. Gupta, L. N. Pfeiffer, K. W. Baldwin, and M. Shayegan, Supporting data for: "Stripe-nematic phase of composite fermions", 2025, 10.5281/zenodo.17868425.