In van der Waals heterostructures, proximity between layers of different materials can be exploited to generate new states of matter\(^1\), or to use one layer to probe the properties of the other\(^2\). Indeed, correlated insulating, superconducting, nematic and time-reversal-symmetry-broken states emerge when uncorrelated electronic systems are stacked together\(^3\). Heterostructures involving strongly correlated systems as their constituents therefore hold promise to realize previously unknown phases or find coupling mechanisms between the layers. A particularly interesting set of ground states to pair is a superconductor and a Mott insulator. Unconventional superconductivity often emerges when a Mott insulator is destroyed by doping\(^4\),\(^5\), but how these two phases interact when stacked as individual building blocks remains to be explored.

This combination is naturally realized in 4Hb-TaS\(_2\), in which two two-dimensional (2D) structures of tantalum disulfide (TaS\(_2\)), octahedral (1T) and trigonal prismatic (2H), are alternatingly stacked\(^6\) (Fig. 1a, b). In bulk form, 2H-TaS\(_2\) is a superconductor with a critical temperature \(T_c = 0.7\) K (ref. \(^7\)), whereas 1T-TaS\(_2\) is a correlated insulator\(^8\) with electrons localized on a triangular lattice, predicted to host a quantum-spin-liquid ground state\(^8,9\). This suggestion is supported by muon spin relaxation (\(\mu\)SR)\(^10-12\) and nuclear magnetic resonance measurements\(^13,14\), which did not find long-range magnetic order. Furthermore, although the resistivity clearly shows insulating behaviour, residual specific heat\(^15,16\), thermal conductivity\(^17\) and scanning tunneling microscopy\(^18,19\) measurements indicate gapless neutral excitations.

Combined, these results point towards a gapless spin-liquid ground state in bulk 1T-TaS\(_2\).

Recent scanning tunneling microscopy studies on 1T/1H heterostructures of TaS\(_2\) and tantalum diselenide (TaSe\(_2\)) revealed Kondo coupling between the localized and the itinerant electrons in the 1T and 1H layers\(^20,21\). Such interactions can melt the 1H insulator into a metal through a mean-field hybridization with the 1H layers, akin to doping the spin liquid, enabling various ground states. Indeed, the superconducting phase of 4Hb-TaS\(_2\) is anomalous, compared with the bulk 2H polymorph: its critical temperature is increased to about 2.7 K and it breaks time-reversal symmetry below \(T_c\) (ref. \(^4\)). The fate of the 1T layers is particularly interesting. They may order magnetically\(^22,23\), or become metallic owing to charge transfer to the 1H layers, rendering the Mott physics irrelevant. Alternatively, they may remain in a gapless spin-liquid state or assume a different spin-liquid order at intermediate coupling.

Recent numerical studies have suggested that the ground state at intermediate coupling is likely a chiral spin liquid (CSL)\(^24,25\). A lightly doped CSL may give way to chiral superconductivity and chiral metallicity\(^26\).

Here we investigate this system using scanning superconducting quantum interference device (SQUID) microscopy. We study the magnetic landscape of the sample in both the superconducting and normal phases, and in small external magnetic fields. In the superconducting phase, time-reversal symmetry breaking (TRSB) is manifested in a spontaneous vortex phase. The magnetic and thermal history of the spontaneous vortex phase reveal that TRSB persists up to 3.6 K, above...
In the superconducting phase, we infer the 2D vortex density, critical temperature. By imaging the distribution of individual vortices, we studied the spontaneous vortex density, following thermal cycles and through global transport and magnetometry. We confirmed that the external field was less than 5 mOe (Methods). Field cooling (FC) the sample in an external field of 1.3 Oe generated 287 vortices in the same region. Surprisingly, a subsequent ZFC resulted in 32 vortices, suggesting an intrinsic magnetic memory in the sample. The intrinsic magnetic field required to generate this vortex density corresponds to about 100 mG. We verified that the magnetic state does not originate from an inhomogeneous superconducting transition and that it does not originate from magnetic or superconducting objects in our set-up (Methods and Extended Data Figs. 1–4). The magnetic state is therefore intrinsic to the sample.

To find the onset temperature of this intrinsic magnetism, we repeatedly imaged the spontaneous vortex density, following thermal cycles to increasing temperatures (Fig. 1c–e). The external field remained off during this process. The remnant field gradually decayed with increasing cycle temperature, until a thermal cycle reaching 3.63 K resulted in a single vortex within our field of view (Fig. 1e), similar to the original state of the sample. The magnetic state therefore onsets at a temperature \( T^* = 3.6 \) K, with a clear separation (about 1 K) between the superconducting transition and the onset of magnetization.

To investigate how the remnant magnetization depends on the external field, we performed field cools, cycling the temperature to 3.5 K, slightly below \( T^* \). To track the spontaneous field, we record vortex configurations formed after cooling through \( T_c \) with no external magnetic field. Therefore, we followed each FC with a ZFC (cycle temperature with varying maximum cycle temperature). The remnant field recorded in the sample after each zero-field cooling (ZFC), as a function of the cycle temperature. The field was inferred from the spontaneous vortex density measured following each thermal cycle, at \( T = 1.7 \) K, in a 75 µm by 95 µm scan area. Error bars represent the number of vortices partially included in the scanned area.

**Spontaneous vortex phase and magnetic memory**

We studied two 4Hb-TaS\(_2\) single crystals. The low selenium (Se) concentration significantly improves the quality of single crystals (Methods). We used scanning SQUID magnetometry and susceptibility to study the superconducting state (Methods). We confirmed that superconductivity onsets sharply at \( T_c = 2.7 \) K, both through the local characterization and through global transport and magnetometry (Methods and Extended Data Figs. 1–4).

In type II superconductors, the vortex density is determined by the magnetic field present when the superconductor is cooled through its critical temperature. By imaging the distribution of individual vortices in the superconducting phase, we infer the 2D vortex density, \( n_v \), and the corresponding average magnetic field, \( B = n_v \Phi_0 \), where \( \Phi_0 = \hbar / 2e \) is the flux quantum, \( \hbar \) is Planck’s constant and \( e \) is the electronic charge. Figure 1 summarizes the main evidence for magnetic memory in 4Hb-TaS\(_2\), with varying maximum cycle temperature.

First, when zero-field cooling (ZFC) the sample from 4 K to 1.7 K, we observed a single vortex in a 95 µm by 75 µm region (Fig. 1c), indicating that the external field was less than 5 mOe (Methods). Field cooling (FC) the sample in an external field of 1.3 Oe generated 287 vortices in the same region. Surprisingly, a subsequent ZFC resulted in 32 vortices (Fig. 1d,e). The spontaneous appearance of vortices following ZFC suggests an intrinsic magnetic memory in the sample. The intrinsic magnetic field required to generate this vortex density corresponds to about 100 mG. We verified that the magnetic state does not originate from an inhomogeneous superconducting transition and that it does not originate from magnetic or superconducting objects in our set-up (Methods and Extended Data Figs. 1–4). The magnetic state is therefore intrinsic to the sample.

![Figure 1: Spontaneous vortex phase in 4Hb-TaS\(_2\). a, Schematic of a 1T/1H layer comprising half of the 4Hb unit cell. The superconducting 1H layer interacts with the localized moments on the 1T layer through Kondo coupling. The localized spins are arranged on a triangular lattice of stars of David. A chiral spin liquid residing on the 1T layers is a candidate for the TRSB state. b, In this phase, localized spins fluctuate but keep the chirality (P), shown as the solid angle between three spins (S\(_1\), S\(_2\), S\(_3\)), fixed. c, Sample temperature (T; top) and external magnetic field (H; bottom) as a function of time, showing field cooling and through global transport and magnetometry.

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**Spontaneous vortex phase in 4Hb-TaS\(_2\).**

- **a**, Schematic of a 1T/1H layer comprising half of the 4Hb unit cell. The superconducting 1H layer interacts with the localized moments on the 1T layer through Kondo coupling. The localized spins are arranged on a triangular lattice of stars of David. A chiral spin liquid residing on the 1T layers is a candidate for the TRSB state.
- **b**, In this phase, localized spins fluctuate but keep the chirality (P), shown as the solid angle between three spins (S\(_1\), S\(_2\), S\(_3\)), fixed.
- **c**, Sample temperature (T; top) and external magnetic field (H; bottom) as a function of time, showing field cooling and through global transport and magnetometry.

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**Spontaneous vortex phase and magnetic memory**

We studied two 4Hb-TaS\(_{1.99} \)Se\(_{0.01} \) single crystals. The low selenium (Se) concentration significantly improves the quality of single crystals (Methods). We used scanning SQUID magnetometry and susceptibility to study the superconducting state (Methods). We confirmed that superconductivity onsets sharply at \( T_c = 2.7 \) K, both through the local characterization and through global transport and magnetometry (Methods and Extended Data Figs. 1–4).

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2.8 K), and then imaged the vortex distribution and computed the remnant field (Fig. 2a). By repeating this process with various external fields, we obtained a magnetization curve for the sample, representative of its response at 3.5 K (Fig. 2b). The magnetization curve shows hysteretic behaviour, reminiscent of a ferromagnet. It is noted that above the polarization field of the loop, the internal magnetization continues to rise linearly with external magnetic field, unlike a standard hysteresis loop. To verify that the magnetic memory is generated in the normal state, we cooled the sample from 4.2 K to 3 K with an external field of 0.3 Oe, then turned the field off, and further cooled the sample to 1.7 K (Fig. 2c). In this procedure, the magnetic field was never turned on when the sample was superconducting. This procedure generated the same spontaneous vortex density as the FC–ZFC procedure (Fig. 2d,e), demonstrating that the magnetic memory is generated independently of superconductivity.

Absence of magnetic signals above \(T_c\)

The spontaneous vortex phase, magnetic memory and hysteresis above \(T_c\) imply that TRS is broken at about 3.6 K. To determine the magnetic order, we directly imaged the magnetic landscape of the sample both below \(T_c\) (without vortices) and above \(T_c\) (2.7 K < \(T\) < 3.6 K). We did not observe a signal within our magnetic noise (Fig. 3). In particular, a net magnetization would generate magnetic fields at the edge of the sample. To test this, we directly imaged the magnetic landscape near the edge (Fig. 3d–h). In the superconducting state, we observed a step of 1 m\(\Phi_0\) across the edge (Fig. 3e), due to demagnetization fields or due to interaction between the sensor and the sample. In the normal state, we observed a small step, 0.1 m\(\Phi_0\), across the edge (Fig. 3f), corresponding to a magnetic field step of about 0.2 mG. This corresponds to a maximum moment density of about 10^{16} \(\mu_B\) cm\(^{-3}\), where \(\mu_B\) is the Bohr magneton, or an inter-moment distance of 40 nm, assuming a uniform distribution of spin-1/2 moments. We also performed global magnetization measurements, which were not hysteretic in fields up to 7 T (Extended Data Fig. 5). These results agree with previous \(\mu\)SR measurements.

Discussion

The magnetic field detected in the normal state is 250-times smaller than the field corresponding to the spontaneous vortex density. Although the microscopic origin of the TRSB phase cannot be determined directly from our measurements, several mechanisms can be ruled out based on the normal state signals. It is hard to reconcile the experimental observations with conventional ferromagnetic ordering. The large inter-moment distance suggests that the interactions are dominated by Ruderman–Kittel–Kasuya–Yosida interactions. However,
the moments are dilute compared with the electron gas, suggesting that the Ruderman–Kittel–Kasuya–Yosida interactions are random in sign. This type of interactions leads to glass-like behaviour, rather than ferromagnetism. In addition, for such a dilute moment concentration, the Ruderman–Kittel–Kasuya–Yosida interactions are random in space, and finite chirality could lead to a spontaneous magnetic field.

Another example, yet to have been resolved, is the pseudogap phase of the cuprates, where TRSB was revealed by μSR and Kerr effect measurements. A loop current order, where the average magnetization over a unit cell is zero, has been proposed as a microscopic origin for these results. Indeed, such an order is not detectable through SQUID measurements. However, the TRSB phase in the pseudogap region differs from the one in 4Hb-TaS$_2$, as the former generates a μSR signature, while the latter is gapless. It is also noted that the order proposed for the cuprates does not generate a net magnetic flux, and therefore cannot cause vortices in the superconductor.

One TRSB order consistent with our observations is a CSL residing on the 1T layers. In this phase, although TRS is broken by a non-zero average magnetic flux, and therefore cannot cause vortices in the superconductor. Another example, yet to have been resolved, is the pseudogap phase of the cuprates, where TRSB was revealed by μSR and Kerr effect measurements. A loop current order, where the average magnetization over a unit cell is zero, has been proposed as a microscopic origin for these results. Indeed, such an order is not detectable through SQUID measurements. However, the TRSB phase in the pseudogap region differs from the one in 4Hb-TaS$_2$, as the former generates a μSR signature, while the latter is gapless. It is also noted that the order proposed for the cuprates does not generate a net magnetic flux, and therefore cannot cause vortices in the superconductor.

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the chirality onsets about 3.6 K. These differences could be driven by the interactions between the 1T and 1H layers. For example, it is possible that 4Hb hosts a gapless spin liquid at high temperatures that undergoes a gapping transition at a lower temperature. The resulting gapped CSL accounts for our observations in the normal state.

Although a CSL state is consistent with our results, there is no direct evidence for this scenario in our data. Furthermore, the mechanism through which a CSL induces spontaneous vorticity is unclear. In Supplementary Note 1, we discuss a possible scenario where the superconducting phase is itself chiral. A chiral superconductor generates an internal magnetization that may generate spontaneous vortices. In this scenario, the chirality of the CSL acts as an ordering field that aligns the domains of the CSC. Supplementary Notes 2 and 3 explain why the data provided here cannot decisively prove whether the superconducting state is chiral and suggest alternative coupling mechanisms that do not require a CSC.

Resolving the order parameters of both the normal and superconducting states requires additional experimental work. For example, Sagnac interferometry could provide additional information on the TRSB in both the normal and superconducting states. The superconducting order parameter could be probed by Josephson interferometry.

In conclusion, we have shown that the alternating stacking compound 4Hb-TaS2 supports an unusual TRSB phase in its normal state. This magnetic memory gives rise to a spontaneous vortex phase in the superconducting state, without generating a magnetic signal in the normal state. This TRSB order is consistent with all classes of magnetic states previously reported to exist near superconductors—ferromagnetism, loop current orders and vestigial chiral orders. The spontaneous vortices generated by this magnetic phase provide an easily accessible way to probe the coupling between unconventional magnetism and superconductivity, a puzzle shared by systems such as high-Tc superconductors, twisted bilayer graphene, spin-liquid-metal heterostructures and Kagome superconductors. Future experiments on 4Hb-TaS2 should determine whether the superconducting state is indeed unconventional, and study the connection between the bulk magnetic state and the topological superconductivity recently reported on the surface. In other systems, our results show that Mott insulators and other frustrated magnetic states can be efficiently probed by coupling them to superconductors.

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Methods

Sample preparation
High-quality single crystals of 4Hb-TaS2 were grown using the chemical vapour transport method. A stoichiometric mix of tantalum (Ta) and sulfur (S) was sealed in a quartz ampoule under vacuum. Addition of 1% Se significantly improves the sample quality. The mixture underwent a sintering process, forming a boule of 4Hb-TaS2−xSe0.01. The boule was crushed and placed in a 200–220-mm-long quartz ampoule with 16-mm diameter. Iodine was added as a transport agent, and the ampoule was sealed under vacuum. The ampoule was then placed in a three-zone furnace, where the hot ends were heated to 800 °C and the middle part was kept at 750 °C. After about 30 days, the ampoule was quenched in cold water.

The crystal structure and chemical composition were verified using X-ray diffraction and electron energy dispersive spectroscopy in a scanning electron microscope.

The data shown in Figs. 1, 2b and 3 and Extended Data Figs. 1 and 4 were taken from sample 1, and the data shown in Fig. 2d and Extended Data Fig. 2 were taken from sample 2. Sample 1 was cut from the same single crystal used for previous μSR and scanning tunnelling microscopy studies.

Scanning SQUID microscopy
Simultaneous local magnetometry and susceptometry measurements were performed by scanning a planar SQUID with a 0.75-µm pick-up loop over a cleaved surface of the sample. The cleaved sample was glued onto an aluminium-clad printed circuit board sample holder using GE Varnish (Lakeshore Cryotronics). Susceptometry measurements were performed by a mutual inductance measurement using a second coil (diameter 3 µm) concentric to the SQUID’s pick-up loop. An alternating current (1 mA RMS, at about 1 kHz) applied to this coil generates a local magnetic field of about 1.5 G RMS. The superconductor screens this field, generating a change in the flux penetrating the SQUID’s pick-up loop. This change was recorded simultaneously to the d.c. measurement using a lock-in amplifier. Scans were performed at a constant sensor–sample distance.

An external magnetic field was applied using a copper coil wrapped around the microscope setup. Earth’s magnetic field was reduced by including two concentric low-temperature μ-metal (A4K, Amunetec) cylindrical shields with diameters of 96 mm and 100 mm around the microscope and coil, achieving fields as small as 5–10 mG near the sample. Further cancellation was achieved by applying a small current through the copper coil, reaching fields of about 3 mG. ‘Zero field’ measurements were performed under these conditions (about 3 mG).

Temperature was monitored with a silicon diode and thermal cycles were performed at a rate of about 0.5 K min−1 with an open-loop control. The peak temperature at each cycle was held for 3 min before the sample was cooled. Before thermal cycles, the SQUID was retracted over 100 µm from the sample to avoid field distortions owing to the superconducting material on the sensor.

Global magnetometry and resistivity measurements
Global magnetization measurements were performed using a SQUID magnetometer (MPMS, Quantum Design). An approximately 10 mg sample was glued to a quartz sample holder using GE varnish. For determining $T_c$, the sample was cooled at zero field to 1.8 K. The magnetization was then measured as a function of temperature between 1.8 K and 5 K, with an external field of 100 mG. To measure the magnetization at the normal state, the sample was cooled at zero field to 2.8 K. The magnetization was measured while the field was ramped to 7 T, then swept to −7 T and back to zero field.

Resistivity measurements as a function of the temperature were performed in a commercial system (DynaCool PPMS, Quantum Design). Electrical contacts in a van der Pauw configuration were made using silver paste. The current–voltage curves were verified to be linear in the current range used for the measurements.

Elimination of extrinsic origins for the spontaneous vortices
The spontaneous vortices could be caused by several effects that are not related to the normal state of the sample. These effects could be divided into two categories. (1) Temperature-related effects such as temperature gradients across the sample and a wide superconducting transition. In these scenarios, portions of the sample remain superconducting at temperatures $2.7 \, K < T < 3.6 \, K$. These superconducting spots could distort the magnetic fields or host vortices above the average $T_c$. (2) System-related effects such as magnetic or superconducting materials in the microscope, which cause external fields.

One way to rule out these artefacts is by performing a control experiment in which the 4Hb-TaS2 sample is replaced with a different superconductor with a similar $T_c$, and the training and vortex counting experiment is repeated. An appropriate control sample must have a sharp superconducting transition (width <0.1 K, similar to 4Hb-TaS2) and a homogeneous superfluid density with penetration depth <100 nm at 1.7 K, to enable vortex counting. It must also be free of magnetic contaminations and have dimensions similar to 4Hb-TaS2. Samples that conform to all these requirements are scarce. We have therefore chosen an alternative path, in which we ruled out each possible artefact individually by carefully characterizing the superconductivity in 4Hb-TaS2, and the magnetic fields in our system.

Absence of superconductivity above $T_c$
Extended Data Fig. 1a shows a series of susceptibility images taken at various temperatures below and above the critical temperature $T_c = 2.7 \, K$. We define $T_c$ as the temperature at which the local diamagnetic response disappears. The images show that the superfluid density is homogeneous both at our base temperature and closer to $T_c$, at 2.6 K. Slightly above $T_c$, at 2.8 K, the diamagnetic response disappeared, and we did not detect other traces of superconductivity. Furthermore, vortices that appeared in the d.c. magnetometry images below $T_c$ disappeared at 2.8 K (Extended Data Fig. 1b). Combined, these data show that the entire field of view was normal at 2.8 K. The same behaviour was observed in both samples studied.

To complement the local view of the superconducting transition, we performed global transport and magnetometry measurements (Extended Data Fig. 1d,e). Both measurements showed a sharp transition at 2.7 K. Previous scanning tunnelling microscopy25, transport and specific heat studies on pieces of sample 1 also showed a sharp transition at 2.7 K. The agreement on $T_c$ between measurements by various probes over different length scales on the same sample suggests that there are no traces of superconductivity in the sample above $T_c$.

Finally, to verify that the temperature cycles have been conducted slowly enough to allow the sample to completely thermalize, we trained the sample and then kept it at 3 K without an external field for various amounts of time, between 3 min and 12 min (Extended Data Fig. 2). The spontaneous vortex density obtained after a subsequent ZFC to 1.7 K did not decay over time, for up to 12 min. These timescales are much larger than the electronic timescales of the system, further excluding superconducting fluctuations in the normal state as a mechanism to preserve magnetic memory.

Absence of external field sources in the set-up. Vortices can be generated by a ferromagnetic or superconducting material near the sample, which creates or distorts magnetic fields in its vicinity. Although the gradiometric design of our SQUID does not enable us to detect the absolute field present at the sample, it imposes a strict limit on the homogeneity of the field. On the one hand, such material must generate 100 mG at the sample, to account for the observed spontaneous vortex densities. On the other hand, variations over distances as large as 100 µm are smaller than 0.3 mG (Fig. 3). There are two geometries that may satisfy these constraints: a large, uniform, weakly magnetic
material that is positioned close to the sample or a point-like object that resides far away. The only large object that is close enough to the SQUID to generate such homogeneous fields is the sample-holder printed board. We measured its magnetic moment using a global magnetometer and did not detect magnetism below 3.5 K, up to external fields of 7 T (Extended Data Fig. 3). Experiments on sample 2 were performed with a different holder and yielded similar results. A point dipole that satisfies these constraints must be positioned about 10 cm away from the sample and have magnetization of about 0.1 Am². Although such an object could generate the required field, it cannot account for the observed temperature dependence, as the sample is heated locally, with extremely small temperature variations far away from the sample.

To complement this analysis, we directly measured the fields near the sample. A homogeneous field is not detectable by our gradiometric SQUID. However, we can detect it by inserting materials that locally distort the field lines. For example, the repulsion of magnetic fields from a superconductor generates a magnetic-field pattern near the edges of a superconductor. Thus, by imaging this Meissner response from a (non-magnetic) superconductor, we can directly detect the homogeneous fields present near the sample. It is noted that although vortices can be induced at low fields only close to $T_c$, Meissner currents are generated in response to external field at any temperature below $T_c$. Both the FC vortex density and the Meissner currents are proportional to the applied field, but measuring Meissner currents eliminates the need to cross $T_c$ for the training process. Thus, an appropriate superconducting sample for this experiment would have $T_c > 3.6$ K, so that the Meissner currents could be detected before and after the training procedure. The size of the sample is also important. For a circular sample of radius $R$, the Meissner current $I_M$ required to completely screen an external field $B_{ext}$ satisfies

$$B_{ext} = \frac{\mu_0 I_M}{2R},$$

where $\mu_0$ is the vacuum permeability. A large sample ($R = 1$ mm) would generate a large response, exceeding the dynamic range of the sensor’s feedback electronics. Small changes over this signal, owing to a possible magnetic memory, would be difficult to detect. We therefore used a multilayer niobium diselenide (NbSe₂$_2$; $T_c = 7.2$ K) flake with dimensions of $R = 30$ μm. Such a flake fits into our field of view, which enables us to estimate the Meissner response before and after the training process. Specifically, we can control the expected signal-to-noise ratio from the trained sample using the training field.

We exfoliated the NbSe₂ flake onto a silicon chip and glued it onto a sample holder instead of the 4Hb-TaS₂ sample. We have not changed other parts of the set-up. Extended Data Fig. 4a,b shows how the NbSe₂ flake probes a homogeneous external field, applied using our copper coil, at 4.2 K. The signal detected by the SQUID is linear in the applied field and the response at 'zero field' is below our detection threshold, consistent with the low field (<5 mG) inferred from counting vortices in the untrained 4Hb-TaS₂ sample. On the basis of the data in Figs. 1 and 2, we expect the magnetic fields generated following a training process to be about 10% of the applied training fields. To test whether these fields are present at the sample, we trained the NbSe₂ flake in a field of 0.25 Oe (Extended Data Fig. 4c). Keeping the field turned on, we measured the Meissner response at 1.7 K and then turned the field off and measured the Meissner response again (Extended Data Fig. 4d). The expected remnant field should have generated a signal of 2 mΦ₀ at the flake (10% of the signal when the field was turned on; Extended Data Fig. 4e), with an expected signal-to-noise ratio of 10. The observed 'trained' signal was below our noise threshold. Thus, if parts of the system can be trained at low temperatures, the magnetic field they generate is at least ten times too small to account for the spontaneous vortices.

**Data availability**

The data that support the findings of this study are available from the corresponding authors upon reasonable request.

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**Author contributions**

E.P. and B.K. designed the experiments. E.P., A.V.B. and B.K. performed the scanning SQUID measurements. I.F., A.A. and A.K. prepared the samples. A.A. performed the global characterization measurements. E.P., B.K., E.A., E.B., I.K., J.R. and A.K. discussed the data and interpreted the results. E.P. and B.K. wrote the manuscript with contributions from all co-authors.

**Competing interests**

The authors declare no competing interests.

**Additional information**

**Supplementary information**

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Author contributions E.P. and B.K. designed the experiments. E.P., A.V.B. and B.K. performed the scanning SQUID measurements. I.F., A.A. and A.K. prepared the samples. A.A. performed the global characterization measurements. E.P., B.K., E.A., E.B., I.K., J.R. and A.K. discussed the data and interpreted the results. E.P. and B.K. wrote the manuscript with contributions from all co-authors.

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Additional information

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Extended Data Fig. 1 | Determination of $T_c$. (a) Local susceptibility maps taken at different temperatures below and above $T_c$. Below $T_c$, the diamagnetic response is homogeneous to within $\pm 2\%$ of the space-averaged signal, even at $T = 2.6\, \text{K}$, close to $T_c$. At $T = 2.8\, \text{K}$ ($> T_c$) we detect no signal within our noise level, demonstrating that the system is completely normal within our field of view. (b) Local magnetometry images of the sample following a field cool at various temperatures. The images clearly show vortices below $T_c$, which are completely absent above $T_c$ (note the change to the colour span at $T = 2.8\, \text{K}$). Scale bars, 20 µm. (c) Local temperature dependence of the susceptibility taken at a representative single point on the sample. (d) Resistance measurements as a function of temperature. (e) Global magnetization measured after field cooling the sample with an external field of 100 Oe. All measurements show a sharp superconducting transition at ~2.7 K.
Extended Data Fig. 2 | Absence of magnetic memory decay with time. 
(a) The sample was first trained by field-cooling it through 3.6 K. It was then kept at 3 K for various amounts of time, before ZFC to 1.7 K and measuring the resulting vortex density. (b–d) SQUID images of the spontaneous vortices in the superconducting phase after waiting for (b) 3 min, (c) 6 min, and (d) 12 min at 3 K. The vortex density did not change as a function of time waited at the normal state. Scale bars, 30 μm.
Extended Data Fig. 3 | Global magnetization of the sample-holder printed circuit board. The magnetization was measured at 2 K, showing no hysteresis when the field was swept from −7 T to 7 T.
Extended Data Fig. 4 | Absence of magnetic memory in a NbSe₂ flake. (a) To demonstrate how the Meissner response of a NbSe₂ flake can be used to probe external magnetic fields, we measured its magnetic signal at 4.2 K, at various magnetic fields. (b) The corresponding magnetic flux images at 4.2 K, showing signals due to the Meissner response. Note that both the presence of an external field and its polarity can be detected through the Meissner effect. When the field is turned off (scan #2) the signal disappears. (c) A “field cooling” protocol from 4.2 K to 1.7 K, like that used in Fig. 1. (d) The corresponding magnetic flux images. After the field is turned off at 1.7 K (scan #6), the Meissner response disappears, demonstrating that there is no remnant field in the system. (e) Line cuts showing the Meissner response from scans #4 – 6. The data from scan #5 (field on) is multiplied by 0.1.
Extended Data Fig. 5 | Absence of global magnetic signal above \( T_c \). The global magnetization of the sample as a function of the external field, taken at 3.2 K. The magnetic response was not hysteretic for fields up to 7 T.