Dynamic magnetic crossover at the origin of the hidden-order in van der Waals antiferromagnet CrSBr

Two-dimensional (2D) van der Waals materials have been identified to be excellent platforms to host new collective quantum states. They are widely considered as promising materials for future quantum technologies by enabling the next generation of electronic nanodevices. In particular, intrinsic two-dimensional magnets are intensively studied as key components for the realization of spintronics. The stabilization of 2D magnetic materials with a high critical temperature down to the monolayer limit remain a standing challenge. In addition, for a wider application of magnetic monolayers in spin-based electronic devices, semiconducting materials with suitable band gap values and high carrier mobility are highly desirable.

CrX₃ trihalides a priori present suitable bandgap values of 1.2–1.8 eV. However, the exploitation of their electrical properties is limited by their flat bands, and the resulting low carrier mobility. This contrasts with the highly dispersive bands observed in semiconducting transition metal dichalcogenides, with exceptional hole mobility values. The combination of chalcogen and halogen anions thus is a promising route for the realization of large bandwidth semiconducting materials. Furthermore, in such mixed-anion compounds, the relative arrangement of the heavy halides allows for a specific modification of the magnetic interactions by a targeted control of the magnetic anisotropy. In this line, the antiferromagnetic (AFM), mixed-anion, van der Waals material CrSBr stands out by combining a sizeable direct band gap of ΔE = 1.8 eV with an exceptionally large bandwidth, and thus an expected high carrier mobility. Furthermore, CrSBr exhibits a substantial air-stability and a high magnetic critical temperature of T_N ≈ 133 K in bulk, predicted to be even higher in the monolayer. A substantial magnetoresistance has been indeed demonstrated below the ordering temperature. The potential application of CrSBr for spin-based electronic devices is further reinforced by its air-stability and the possibility to tune the anisotropy by external fields.

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The van-der-Waals material CrSBr stands out as a promising two-dimensional magnet. Here, we report on its detailed magnetic and structural characteristics. We evidence that it undergoes a transition to an A-type antiferromagnetic state below T_N ≈ 140 K with a pronounced two-dimensional character, preceded by ferromagnetic correlations within the monolayers. Furthermore, we unravel the low-temperature hidden-order within the long-range magnetically-ordered state. We find that it is associated to a slowing down of the magnetic fluctuations, accompanied by a continuous reorientation of the internal field. These take place upon cooling below T_s ≈ 100 K, until a spin freezing process occurs at T* ≈ 40 K. We argue this complex behavior to reflect a crossover driven by the in-plane uniaxial anisotropy, which is ultimately caused by its mixed-anion character. Our findings reinforce CrSBr as an important candidate for devices in the emergent field of two-dimensional magnetic materials.
by the possibility of exerting magnetic control over the interlayer electronic coupling. On the other hand, the exotic quasi one-dimensional transport properties and the anisotropic optical properties of CrSBr emphasize the potential of mixed-anion chemistry to enlarge the functionalities of 2D van der Waals materials.

Concerning the magnetic properties, the magnetization measurements evidence that CrSBr undergoes an AFM transition below $T_N = 133$ K, together with a soft ferromagnetic behavior under high magnetic fields. Hence, previously an A-type AFM structure, comprising ferromagnetic Cr-bilayers (here we refer to this as a "monolayer") that couple antiferromagnetically across the van der Waals gap, has been proposed. Beyond that the temperature-dependent magnetic properties of CrSBr remain so far unresolved. In particular, recent magneto-electric transport measurements show a change on the sign of the magnetoresistance by lowering the temperature below 40 K, which goes along with the occurrence of an additional, subtle increase of the magnetization in CrSBr below that temperature. This unusual change in the magnetoresistance, in the absence of a well-pronounced phase transition, suggests that a subtle change on the spin structure might occur at low temperatures as the origin for this hidden order. The possibility of further complexity in the magneto-electric properties of CrSBr at low temperatures thus deserves further consideration.

Here, we address these open questions by a detailed characterization of the temperature-dependent magnetic and structural properties of CrSBr by combining neutron scattering, muon spin relaxation spectroscopy, synchrotron X-ray diffraction, and magnetization measurements. We show that the material adopts a long-range A-type magnetic structure below $T_N = 140$ K that persists for the whole temperature range in the magnetically ordered phase. On top of this, we identify a complex magnetic structure, with a slowing down of the magnetic fluctuations by lowering temperature below $T_T = 100$ K, leading eventually to a spin-freezing process at $T^* = 40$ K, which we identify as the origin for a hidden order. We furthermore show that the spin-freezing is accompanied by an uncommon negative thermal expansion of the $a$-axis. The origin of this low temperature crossover is discussed, with special consideration of the role of the uniaxial magnetic anisotropy in the exotic dynamic behavior. These magnetic and structural properties, together with the sizeable band-gap and the large anisotropy within the layers are widening the potential application of CrSBr for spin-based electronic devices.

**Results**

**Determination of the magnetic ground state of CrSBr**

In Fig. 1 the crystal structure of CrSBr is depicted. The material crystallizes in the FeOCl structure-type in the space group $Pmnm$. The structure consists of monolayers of CrSBr, which are bonded through van der Waals interactions along the $c$-axis (Fig. 1a). The monolayers are built up of edge-sharing $[\text{CrS}_2\text{Br}_2]$ octahedral units, with an underlying squared lattice arrangement of Cr(III) cations (Fig. 1b). The chemical bonding along the basal directions involves Cr-(S,Br)-Cr paths along the $a$-axis with a cation-anion-cation angle of $\alpha(\beta) = 95$ (90)° (Fig. 1c), whereas $\delta = 160°$ Cr-S-Cr paths along the $b$-axis (Fig. 1e). Within the CrSBr bilayers, Cr-S-Cr paths connect the two Cr layers with $\gamma = 96°$, as depicted in Fig. 1d.

To identify the structure of the magnetically ordered phase, we have performed temperature-dependent neutron powder diffraction (NPD) measurements. In Fig. 2, the obtained NPD patterns at $T = 160$ K and $1.8$ K are depicted along with the respective Rietveld refinements (see Supplementary Tables 1 and 2). The refined structure for the normal state at $T = 160$ K is in excellent agreement with the previously reported orthorhombic structure with cell dimensions $a = 3.5066(1)$ Å, $b = 4.7485(1)$ Å, and $c = 7.9341(2)$ Å with the space group $Pmnm$. Upon lowering of the temperature, strong magnetic reflections are observed, in accordance with the establishing of a long-range magnetic structure...
Magnetic anisotropy and ferromagnetic correlations in CrSBr

The isothermal magnetization $M(H)$ curves for CrSBr at different temperatures are shown in Fig. 3a–c, for different relative orientations. A soft magnetic behavior is observed, with a complete field-induced polarization without hysteresis. At base temperature, the isothermal magnetization curves along the three different crystal axes (Fig. 3a) show a clear magnetic anisotropy. When the magnetic field is applied along the magnetic easy-axis (i.e., along the crystallographic $b$-axis) a sharp spin-flip transition is observed above $\mu_B H_{\text{flip}} \approx 0.3$ T. On the other hand, when the magnetic field is applied along the other two main crystallographic directions a progressive decoupling is observed, with a linear increase on the magnetization. The substantial difference for the saturation field $\mu_B H_{\text{sat}}$ along the different crystal orientations further reflect the magnetic anisotropy within the in-plane directions, with anisotropy fields of $0.5 \, \text{T}$, $1 \, \text{T}$ and $2 \, \text{T}$ for the three crystallographic $b$, $a$, and $c$-axis respectively. By increasing the temperature, the critical field for the meta-magnetic transition decreases (see Fig. 3b), as well as the saturation fields and the magnetization saturation values. The relative anisotropy fields along the three crystal-axes are on the other hand retained, with values of $0.3 \, \text{T}$, $0.5 \, \text{T}$ and $1 \, \text{T}$ at $T = 100 \, \text{K}$ along the $b$, $a$, and $c$-axis respectively. Finally, the magnetic anisotropy is lost by increasing the temperature above $T_N$ with an isotropic behavior for the three crystal-axes at $150 \, \text{K}$ as shown in Fig. 3c.

Considering the origin of the magnetic anisotropy, one first notices that the magnetic exchange paths along the $a$ and $b$ directions are clearly nonequivalent in CrSBr. In particular, a predominant contribution of the bromine atoms in the magnetic anisotropy through spin-orbit coupling (SOC) is expected. For the related CrX$_3$ halides, an increase in the uniaxial anisotropy is indeed found when increasing the SOC effect, i.e., when going from the in-plane magnet CrCl$_3$ ($0.02–0.03 \, \text{meV}$; $T_c = 17 \, \text{K}$), to the out-of-plane CrBr$_3$ ($0.11–0.19 \, \text{meV}$; $T_c = 32 \, \text{K}$) and CrI$_3$ ($0.68–0.80 \, \text{meV}$; $T_c = 60 \, \text{K}$) counterparts. A careful calculation of the magnetic anisotropy energy values for CrSBr show that the bromine contribution via SOC results in a clear uniaxial anisotropy, favoring the orientation of the spins along the $b$-axis, which is in agreement with the here determined magnetic structure from neutron data. On the other hand, the in-plane orientation – with an intermediate $a$-axis but a hard $c$-axis – results from a considerable shape anisotropy due to the layered character of CrSBr. The presence of uniaxial anisotropy in CrSBr differs from the model 2DXY behavior of the in-plane magnet CrCl$_3$, reinforcing the interest of CrSBr as potential host for exotic magnetic states.

Moreover, the high magnetization values and the S-shape observed in the $M(H)$ curves at $T > T_N$ (Fig. 3c) indicate that
ferromagnetic correlations survive above the \( T_N \). Hence, it is of substantial interest to analyze the soft ferromagnetic behavior under the applied magnetic field, as it allows considering the strength of the FM correlations within the layers. In fact, a higher magnetic critical temperature of \( T_M > 150 \text{ K} \) is derived from the Arrott plots\(^{39,40} \) shown in Fig. 3d. The lack of hysteresis, together with the loss of magnetic anisotropy inferred from the \( \chi(H) \) curves above \( T_N \), indicate this precursory magnetic state to reflect the inherent FM fluctuations within the CrSBr layers, without long-range coherence. The magnetization saturation values, \( M(3T) \), can be fitted to a power law using a fixed exponent of \( \beta = 0.18 \) as obtained for the zero-field data (see Supplementary Fig. 3). An associated onset temperature \( T_{\text{fit}} = 153(6) \text{ K} \) is obtained from this fitting. This onset temperature for the FM correlations agrees with the Arrott plots and is indeed in close agreement with the measured \( T_c \) for isolated monolayers of CrSBr via second harmonic generation measurements\(^{41} \).

Furthermore, we find an enhanced magnetic susceptibility above \( T_M \). Free fitting of the magnetization saturation values to a power law (see Supplementary Fig. 4) gives indeed a higher critical temperature of \( T_M = 175 \text{ K} \), with critical exponent of \( \beta = 0.29(8) \), now in between the 2DXY and the 3D Heisenberg model. Such a high critical temperature has been theoretically predicted for isolated CrSBr monolayers\(^{24} \). Our results clearly show that these high temperature magnetic correlations are already present in bulk CrSBr.

**Low-temperature uniaxial negative thermal expansion in CrSBr**

We turn now the attention to the low-temperature region, where the occurrence of a second subtle increase of the magnetization – below the main AFM transition – is inferred from the magnetic susceptibility measurements. In Fig. 4, we show the magnetic susceptibility for a CrSBr single crystal at different relative orientations, under a low external magnetic field of 0.4 mT. A progressive increase in the susceptibility is observed along the three crystal axis by lowering temperature below \( T = 40 \text{ K} \). This magnetic transition occurs in the absence of a change in the average magnetic structure, i.e., there is no notable change in the intensity and position of the magnetic reflections in the NPD data.

Furthermore, this clearly distinct feature in the magnetization is not associated with any pronounced structural change, as there are no obvious changes to the structural reflections in the NPD data. For a high-precision evaluation of any subtle structural changes, we have furthermore performed temperature-dependent synchrotron X-ray diffraction (XRD) experiments. In Fig. 5a, the synchrotron XRD data at \( T = 250 \text{ K} \) and 10 K as representative members are shown with the respective Rietveld refinements. All synchrotron XRD patterns (see Supplementary Fig. 5) are found to be in excellent agreement with the structure in the same \( Pmnm \) space group. The temperature dependence of the obtained unit cell parameters (see Supplementary Table 3) is shown in Fig. 5b. The parameters are found to change gradually without any discontinuous change in the unit cell metrics, providing evidence for the absence of any distinct structural transition in the material. Interestingly, we observe an uncommon negative thermal expansion of the \( a \)-axis with a characteristic linear thermal expansion coefficient of \( a_a = -6.4 \cdot 10^{-5} \text{ K}^{-1} \). The increase in the \( a \)-axis by lowering temperature is followed by a comparable decrease in the \( b \)-axis with \( a_b = +10.9 \cdot 10^{-5} \text{ K}^{-1} \), until the in-plane cell parameters collapse at low temperature. The \( c \)-axis experiences a more pronounced shrinkage through the whole temperature range with \( a_c = +18.7 \cdot 10^{-5} \text{ K}^{-1} \), meaning a substantial reduction of the interlayer space as expected from the weak van der Waals interactions between monolayers.

It should be noted that a volume negative thermal expansion is observed in some prototypical 2D materials, i.e., graphene and...
Hidden order and spin-freezing in CrSBr

Using muon spin relaxation spectroscopy measurements, we have obtained a microscopic picture of the magnetic interactions in CrSBr. By following the time evolution of the muon spin polarization after implanting muons into the bulk of the crystal, the intrinsic magnetic response is obtained (see Supplementary Note 4). The ZF-μSR spectra shown in Fig. 6a–c display a spontaneous muon spin precession with a single frequency at low temperature, which is indicative for a long-range magnetically ordered state. The loss of initial asymmetry below the ordering temperature, as derived from the weak transverse field measurements, indicates a magnetic volume fraction of ≈90% below the \(T_N(\mu SR) = 132\) K (see Supplementary Fig. 6). This observation is providing evidence of slow spin dynamics in CrSBr that reflect fluctuations of the \(Cr\) magnetic moments. The critical temperature obtained from the μSR data is lower than the \(T_N(NPD) = 140\) K estimated from neutron diffraction. The strongly damped zero field (ZF) μSR spectra above 132 K (Fig. 6c) is however indicative of correlated magnetic moments. This relaxation without oscillations might reflect fast dynamics which enter the μSR time-window (i.e., the MHz range) at a lower \(T_\mu(\mu SR) = 132\) K. The exponential relaxation rate in the paramagnetic state, \(\lambda_{\mu\nu}\), indeed shows a broad increase before it peaks at the \(T_N\), as shown in Fig. 6d. The onset temperature for this precursor dynamic state is located at 160 K < \(T < 180\) K, in qualitative agreement with the magnetization measurements, where we have estimated a \(T_M = 153–175\) K.

The internal field \(B_\mu\), as derived from the muon precession frequency \(B_\mu = \omega/\gamma_\mu\), can be considered as an order parameter in close relation with the internal magnetization. The temperature dependence of \(B_\mu\), as derived from fitting of the ZF-μSR data, is shown in Fig. 6e. Below the \(T_N\), the temperature dependence of the internal field can be approximated to a power law with a fixed model critical exponent of \(\beta = 0.231\) (see Supplementary Fig. 7). By further lowering the temperature, an anomalous decrease in the internal field is clearly evidenced below \(T^* = 40\) K. It is worth stressing that the magnetic volume fraction remains unchanged below \(T^* = 40\) K, and the ZF-μSR spectra are still well-fitted with the one oscillating component.

Further information about the temperature evolution of the internal magnetic field is obtained from the analysis of the temperature dependence of the oscillating fraction, shown in Fig. 6f. In particular, a continuous decrease in the oscillating fraction is observed below \(T_1 = 100\) K, with a weaker decrease below \(T^* = 40\) K. This indicates that a continuous reorientation of the internal magnetic field occurs by lowering temperature below \(T_1 = 100\) K, until it gets fixed below \(T^* = 40\) K. Complementary, the missing fraction as a function of temperature is plotted in Fig. 6g, reflecting the additional loss of asymmetry at low temperature. The missing fraction is shown to experience a prominent increase below \(T_1 = 100\) K, before it saturates below \(T^* = 40\) K reaching a = 10% fraction. A phase separation between a = 90% long-range ordered magnetic phase, and a = 10% “disordered” magnetic state is then followed, the latter being responsible for the additional asymmetry loss.

The muon spin relaxation rates, \(\lambda_1\) and \(\lambda_2\), also show a complex temperature dependence within the ordered state, as shown in Fig. 6d. \(\lambda_1\), which is the depolarization of the oscillating part of the spectrum, contains information mostly about the width of the static internal field distribution. On the other hand, \(\lambda_2\) is associated to the...
observed at a smooth increase in the width of the static internal concomitant, the reorientation of the internal dynamics persist down to the lowest temperatures, i.e., in the quasi-spin-freezing process occurs below 40 K. In this scenario, slow and ZFC measurements (see Fig. 4b).

Discussion

The combination of the techniques applied here reveals that CrSBr displays a rich magnetic phase diagram as a function of temperature, which is comprehensively derived from the presented measurements and summarized in Fig. 7. The temperature-dependent NPD data reveals an average A-type AFM structure for CrSBr in the whole temperature range below $T \approx 140$ K (blue region in Fig. 7). Nonetheless, the dynamic character of the magnetic interactions is first reflected in the lower critical temperature derived from the $\mu$SR data, the phase separation deduced from the $\mu$SR data indicates that a change in the local magnetic structure might occur at low temperature. We therefore consider a combination of both scenarios to explain this low temperature hidden order in CrSBr, as discussed below.

non-oscillating relaxation, being therefore more affected by dynamic effects on the spin fluctuations. In the case of CrSBr, a progressive increase in $\lambda_1$ is observed below $T_{c} = 100$ K, indicating that the reorientation of the internal field is accompanied by a smooth increase in the width of the static internal field distribution. Concomitantly, $\lambda_2$ experiences a slight increase below $T_{c} = 100$ K, then followed by a steep rise below $T^* = 40$ K until a clear peak is observed at $T^* = 40$ K. From the complex temperature dependence of $\lambda_3$ within the magnetically ordered state, a further slowing down of the magnetic fluctuations below $T_{c} = 100$ K can be derived, until a spin-freezing process occurs below 40 K. In this scenario, slow dynamics persist down to the lowest temperatures, i.e., in the quasi-static state below $T^* = 40$ K. The observation of magnetic fluctuations in the MHz-GHz range is thus deduced in the range $T^* \approx 132$ K. The concomitant decrease in the internal field down to base temperature, together with an increase in the ZF-$\mu$SR relaxation rates. We thus understand the spin reorientation to go along with a further slowing down of the fluctuations until a spin-freezing process takes place below $T^* = 40$ K. The concomitant decrease in the internal field, with a clear departure from the 2DXY model, might reflect a more defined uniaxial anisotropy, i.e., Ising like behavior in CrSBr at low temperatures with $d = 1$. The occurrence of this additional spin dimensionality crossover, giving a quasi-static directional spin structure at low temperature as depicted in Fig. 7, could explain the reduction of the internal field considering the time-averaged moment to be different from the true static moment at low temperatures. The continuous change in the direction of the internal magnetic field until it gets fixed in the quasi-static state below $T^* = 40$ K further supports the proposed spin dimensionality crossover.

But, complementary, the possibility of a more complex magnetic state in the static region is also hinted by the observed phase separation to give an $\sim 10\%$ of "disordered" magnetic phase embedded in the long-range ordered predominant phase. In this line, it has been proposed that this low temperature hidden order in CrSBr, and the associated change in the magneto-electric properties, are associated to the magnetic ordering of electronic point defects at low temperature. Nonetheless, the freezing into a frustrated magnetic state, as an alternative explanation for the low temperature magnetic state of CrSBr, might be also considered.
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given the involved Cr-S-Cr (Cr-Br-Cr) super-exchange paths with CrSBr monolayer. The ferromagnetic character of the Cr-Cr interactions from negative to positive magnetoresistance below multilayers and monolayers of CrSBr28,29. The experimental characterization of the short range interactions will unravel the low temperature magnetic complexity. Complementary, magnetic pair distribution technique would be of great interest to magnetic probes such as nuclear magnetic resonance and neutron characterization of the spin dimensionality at low temperature. Understanding the ground state of CrSBr by means of Monte Carlo simulations accounting for the dynamic character of the magnetic interactions may provide further insights on the low temperature magnetic ground-state of CrSBr are required. In particular, a further characterization of the spin dimensionality at low temperature by local magnetic probes such as nuclear magnetic resonance and neutron magnetic pair distribution technique would be of great interest to unravel the low temperature magnetic complexity. Complementary, understanding the ground state of CrSBr by means of Monte Carlo simulations accounting for the dynamic character of the magnetic interactions may provide further insights on the low temperature magnetic structure. This fundamental understanding, combined with the experimental characterization of the short range interactions will shed light into the driving force for the spin reorientation and eventual magnetic frustration of the A-type magnetic structure. Ultimately, understanding the role of the mixed-anion chemistry of CrSBr, with the resulting nonequivalent magnetic exchange paths, in the complex spin dynamics might allow exploration of further functionalities in low dimensional magnets.

In conclusion, we have characterized the temperature-dependent magnetic and structural properties of CrSBr by means of neutron scattering, muon spin relaxation spectroscopy, synchrotron X-ray diffraction, and magnetization measurements. CrSBr is shown to present a complex dynamic magnetic behavior, with a progressive slowing down of the spin fluctuations by lowering temperature. The main antiferromagnetic transition corresponds to the establishing of an A-type magnetic structure below Tc(NPD) = 140 K, with a pronounced two-dimensional character as reflected by the low critical exponent of β = 0.18. Complementary, our μSR study clearly points out the occurrence of an additional low-temperature magnetic transition in CrSBr, with a critical slowing down of magnetic fluctuations below Tc = 100 K until a spin-freezing process takes place at T* = 40 K. This hidden order is shown to happen within the average long-range A-type magnetic structure, suggesting a crossover towards a more uniaxial magnetic character at low temperature.

Overall, our findings reinforce that CrSBr is a promising van der Waals magnet with a strong uniaxial character in the magnetic, structural, as well as in the transport properties. This material may therefore open the door for exploring new applications, such as ultra-compact spintronics. On a broader scope, the inclusion of mixed-anion chemistry stands as a promising route for the design of new van der Waals materials with low dimensional magnetic character.

Methods
CrSBr bulk crystal growth. CrSBr single crystals were grown by chemical vapor transport using elemental chromium (Alfa Aesar 99.99 %)
Due to layered characteristic instrumental resolution parameters characteristic of the diffractometer divergence asymmetry (as implemented in Fullprof; Npr = 7), using $\approx$ to SQUID magnetometry neutron diffraction patterns, that was reacter of the material, a preferential orientation was observed in the S2Br2 was prepared by reacting elemental sulfur (ACROS ORGANICS freshly prepared S2Br2 in a 7:13 molar ratio, as reported elsewhere49. S2Br2 was prepared by reacting elemental sulfur (ACROS ORGANICS 99.999%) and bromine (ACROS ORGANICS 99+ %) under reflux in nitrogen atmosphere using a Schlenck line. The product was purified by vacuum distillation to remove unreacted bromine. The reactants were sealed under vacuum in a 20 cm long quartz ampoule. After thermal treatment in a three-zone furnace with a temperature gradient of 950–880 °C for 140 h, CrSBr crystals were isolated at the middle-cold end of the tube. The needle-shaped black crystals were subsequently washed using warm pyridine, water and acetone. **Neutron diffraction experiments.** Neutron powder diffraction measurements were carried out using the high-resolution diffractometer HRPT at the Swiss Spallation Neutron Source (SINQ), Paul Scherrer Institute. The neutron wavelength of $\lambda = 2.449 \text{ Å}$ was used and the NPD data were analyzed using the Rietveld package FULLPROF SUITE and magnetic symmetry analysis using the BASIREPS software. The peak shape was modeled using the Thompson–Cox–Hastings pseudo-Voigt function. **μSR experiment and analysis.** Traverse and zero field μSR experiments were carried out at the nM3 beam line (low background GPS instrument) of the Swiss Muon Source (SmuS) of the Paul Scherrer Institute, using an intense beam (Qμ = 29 MeV/c) of 100% spin-polarized muons. Additional details can be found in Supplementary Note 4.

**Data availability**

Data supporting the findings of this study are available within the manuscript and the Supplementary Information.

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Author contributions

F.O.v.R. and S.L. designed the experiments. S.L. and C.W. synthesized the material. F.O.v.R. A.F.M. gratefully acknowledges financial support from the SNF and for the EU Graphene Flagship project. The authors acknowledge helpful discussions with Harald O. Jeschke and Vanessa Kronenberg for valuable experimental help during the synthesis of this material.

Competing interests

The authors declare no competing interests.

Additional information

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