In hierarchical structure formation, the growth of galaxy clusters results in accretion and merger of sub-halos. This leads to shock waves, which heat up the plasma, disturb its motion and accelerate cosmic rays12. Thus, galaxy clusters are an ideal celestial laboratory in which to study plasma physics; one such example is wide-angle tail (WAT) radio galaxies8,9. Another example is the so-called cold front, a density contact discontinuity of the intra-cluster medium (ICM)1,2, which results from gas motion, that naturally strips the gas by ram pressure13 and damps or amplifies magnetic fields14. Since their discovery, WAT sources and cold fronts have been the focus of many studies aimed at understanding their origins, their interaction with the ICM and the nature of the intra-cluster magnetic field15–19.

MRC 0600-399 was observed at 1.28 GHz with the MeerKAT telescope to investigate its morphology (Fig. 1). In the centre of Abell 3376 (hereafter, A3376), there are two prominent radio galaxies: MRC 0600-399 (redshift z = 0.04359) and galaxy B (z = 0.0480) (Fig. 1b). MRC 0600-399 also shows two-sided bent jets, but the collimated structures continue to the east over about 100 kpc and 50 kpc for the northern and southern jets, respectively, beyond the bend points (the locations indicated with red dashed circles in Fig. 1b). The radio fluxes of the jets (especially the northern jet) drastically decrease before the bend points. There are also diffuse faint structures (double-scythe jets) in the opposite (west) direction to the bent jets. At the southern boundary of the northern jet, some diffuse filaments are resolved. These filaments appear faint compared to the rest of the emission, but are detected well above the noise levels, and indicate real structure related to the northern jet. These features are very unusual for typical WAT sources. We confirmed that there is no other radio galaxy overlapping with MRC 0600-399 and causing the double-scythe structure; thus, we verified its association with the jets of MRC 0600-399.

A map of the spectral index α and one-dimensional profiles of α and the flux density (Fα, ν), where ν is the frequency, along the bent jets are shown in Fig. 2a. The spectral index values decrease gradually in areas N1 and S1 starting from MRC 0600-399. The spectral index decrease across 49 kpc (seven open circles) is about 0.76 for N1, and that across 25 kpc (four open circles) is about 0.44 for S1. The trend
then drastically changes, and these values become fairly constant in N2 and S2, suggesting reacceleration of relativistic electrons. Finally, these values again decrease in N3 with a decrease of about 0.69 across 30 kpc (six open circles). The flux density values show a similar trend to that of the spectral indices in each part. The flux densities of the radio emission of the jets gradually decrease, and in the bend regions the flux densities clearly increase.

The radial X-ray surface brightness profile across the northern bent jet (Fig. 3b, bottom inset) suggests a clear discontinuity, which we interpret as a cold front. Earlier numerical simulations have indicated that thick magnetic field layers can be formed around cold fronts. Indeed, some observational evidence of amplified magnetic fields across cold fronts has been reported. This unusual radio morphology is ascribed to (partly reaccelerated) relativistic electrons travelling galaxy in the optical band associated with MRC 0600-399. MRC 0600-399 has jets that are bent at 90° to the east and proceed in the east direction while keeping their collimated shapes. The arrows show the double-scythe structures, and the red dashed circles show the bend points. The yellow diamond point indicates the position of the optical source associated with galaxy B, which is a D-type elliptical galaxy of A3376. Galaxy B also has two-sided jets, but they bend gently, and the southern jet has a plume-like structure at the tail.

Fig. 1 | Multi-wavelength view of A3376 and MRC 0600-399. a, Composite image of A3376 (reddish colour, MeerKAT 1.28 GHz; light blue: X-rays; background: optical from Digitized Sky Survey). To handle high-dynamic-range images, the intensity of radio galaxies was scaled at 1/10. The radio galaxy MRC 0600-399 is located near the eastern tip of the X-ray emission. b, MeerKAT image of the total intensity of MRC 0600-399 at a central frequency of 1.28 GHz. The beam size, 5.80 × 5.48 arcsec², is shown in the bottom left corner. The magenta cross indicates the position of the second-brightest cluster galaxy in the optical band associated with MRC 0600-399. MRC 0600-399 has jets that are bent at 90° to the east and proceed in the east direction while keeping their collimated shapes. The arrows show the double-scythe structures, and the red dashed circles show the bend points. The yellow diamond point indicates the position of the optical source associated with galaxy B, which is a D-type elliptical galaxy of A3376. Galaxy B also has two-sided jets, but they bend gently, and the southern jet has a plume-like structure at the tail.

Fig. 2 | Radio properties derived from MeerKAT observation. a, Spectral index map derived from radio datasets obtained at 909–1,658 MHz. Pixels with intensities lower than three times the root-mean-square levels of the total intensity are blanked. Black circles on MRC 0600-399 indicate the regions in which the spectral index and flux density values are calculated and shown in b. The ellipse at the bottom left corner shows the image resolution of 9.50 × 8.50 arcsec². b, Plots of spectral indices (blue) and flux densities (red) of the regions at the northern (top) and southern (bottom) jets. The horizontal axes show the region numbers. Regions N1 and S1 of the northern and southern jets are above and below, respectively, the boundary line, shown in the spectral index map with a blue dashed line. The blue solid lines are the results of linear fitting of the spectral indices in N1 and S1.
along with the magnetic fields of jets and the ICM over 150 kpc. All observational evidence and previous numerical simulations point towards an interaction between jets and the intra-cluster magnetic field along the cold front.

To describe the bent jet quantitatively, we performed three-dimensional magneto-hydrodynamic (MHD) simulations of the interaction between the jet and the intra-cluster magnetic field using the CANS+ code\(^2\). We adopted an arch-shaped magnetic field to reproduce the magnetic layer of the cold front. A jet launched from MRC 0600-399 travels straight with supersonic speed and hits the magnetic arch. The motion of the jet across the arch is suppressed owing to the magnetic tension of the arch. The flow escapes along with the magnetic arch particularly towards the east direction, because the tension against the flow is weaker owing to the field inclination with respect to the jet injection direction; see Fig. 3a at 110 Myr after the interaction of the jet with the magnetic arch. The escaped flow has a sharp double-scythe shape because the Kelvin–Helmholtz instability is suppressed by the strong arch magnetic fields. These strong fields also produce a backflow of the jet. The backflow collides with the incoming jet and reduces its momentum, resulting in turbulence. As a result, the jet width reaches ten times the initial size around the bend point.

For the MRC 0600-399 case, a magnetic field of the order of 10 \(\mu\)G is required to reproduce the observed radio morphology.

The synchrotron radio image made with our simulation successfully reproduces major characteristic features of the northern jet (Fig. 3b). First, at the bend point, the simulation shows a double-scythe shape. Particularly, the eastern emission, which is produced by the greatest part of the escaped flow, has a close resemblance to the MeerKAT image, whereas the emission in the western area is more diffuse because of the presence of less gas along this direction. Second, the location of radio emission relative to the X-ray profile is consistent with the observed one (see Fig. 3b inset). Third, the simulation reproduces the profile of the radio flux across N1 to N2. For the southern jet, there are some consistencies, such as the double-scythe structure and an enhancement of the radio flux at the bend point, suggesting an interaction between the jet and ordered magnetic fields. However, the simulation shows a smoother arc-like structure at the tip of the jet. This difference could be due to the effect of the projection to a different viewing angle of the jet and/or a more complex structure of the magnetic fields.

Our MHD simulation reproduced a 50-kpc-long eastern scythe of the northern jet, and the observed emission extends up to 100 kpc from the bend point. This difference suggests that there may be some aspects of...
Upcoming polarization studies will shed light on the nature of the enhancement in the radio flux, spectral index and the double-scythe merger (25, 26). Because of its motion, the jets from MRC 0600-399 feel ram pressure from the sub-cluster and see their surrounding gas flowing to the east (slingshot would happen if MRC 0600-399 departs from the bulk motion of the cluster). As a galaxy cluster moves within the hot plasma sweeps the intra-cluster magnetic field, the magnetic field compresses along the contact discontinuity, forming a magnetic layer. The active galactic nucleus (AGN) jet ejected from the member galaxy of the cluster receives a ram pressure from the proper motion of the cluster. Because the central AGN is well inside the second brightest galaxy, MRC 0600-399, the ram pressure will not be applied directly on the jets. When the jet terminal region reaches the magnetic layer on the cold front, the jet flow diverges along with the magnetic layer, forming the double-scythe structure. Because the magnetic field in the AGN jet reconnects the magnetic layer, non-thermal particles accelerated by the magnetic reconnection propagate along with the magnetic layer. These particles emit synchrotron radiation. The northern part of the jet is located on the rim of the cold front, and the southern part hits it on the plane. The important aspect of our findings is that the bent jet in cold fronts could be a great probe to investigate the intra-cluster magnetic field. Ongoing/upcoming wide-field observations of galaxy clusters will reveal the nature of the intra-cluster magnetic field via the interaction with the jets.

Online content
Any methods, additional references, Nature Research reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41586-021-03434-1.
Methods

We assume that Hubble’s constant is $H_0 = 70 \text{ km s}^{-1} \text{Mpc}^{-1}$ and the density parameter for mass is $\Omega_m = 0.27$ and for dark energy is $\Omega_r = 0.7$ at $z = 0.046$, where 1 arcmin corresponds to 54.5 kpc. Unless otherwise stated, the errors correspond to 68% confidence for each parameter.

MeerKAT L-band observations and data reduction

A3376 East was observed with 60 antennas of the MeerKAT array on 1 June 2019 (project ID: SCI-20190418-JC-01) at the L-band (856 MHz to 1,712 MHz). The MeerKAT array, located in the Northern Karoo desert of South Africa, is made up of 64 13.5-m ‘offset Gregorian’ parabolic dish antennas. 48 of the 64 antennas are located in the inner core (within a 1-km radius), providing the shortest baseline of 29 m, whereas the other 16 antennas are spread outside the core, up to a maximum baseline of 8 km. Thus, MeerKAT is capable of recovering a wide range of angular scales (5° to 27°) at the central frequency of 1,283 MHz.

The primary flux and bandpass calibrator was fixed to J0408-6545 (total intensity of $I = 17$ Jy at 1,283 MHz), J0616-3456 ($I = 3.1$ Jy at 1,283 MHz, and 5.7° from the phase tracking centre of A3376 East) was used as the secondary gain calibrator. During the observations, we performed four 10-min scans of the primary calibrator, and we scanned the secondary calibrator every 2 min after the scan of the target. The flux, bandpass and gain calibrations were carried out reliably with these bright calibrators.

The data correlation was performed with the SKARAB correlator in 4k mode with 856 MHz bandwidth and 4,096 channels of $-209$ kHz per channel. Then, we reduced the data with the semi-automated MeerKAT data analysis pipeline OXKAT (https://ascl.net/code/v/2627).

OXKAT is a semi-automated pipeline used for MeerKAT data reduction and employs a collection of publicly available radio interferometry data flagging, calibration and imaging software packages. In the flagging process, the known radio frequency interference channels, 856–880 MHz, 1,658–1,800 MHz and 1,419.8–1,421.3 MHz, are usually flagged out. Then, other possible radio frequency interference channels are flagged using the autoflagger tricolour for the calibrators and AOF flagger for the target fields. The OXKAT pipeline uses the custom tasks from the CASA suite for cross-calibration.

To deconvolve and image the target data, the WSRClean imager with Briggs weighting and a robustness parameter of −0.3 was used, with the multi-scale and wide-band deconvolution algorithms enabled to facilitate imaging of diffuse emission present in the fields. Deconvolution was performed in ten sub-band images of each 107 MHz-wide band. WSRClean was used to generate the multi-frequency synthesis (MFS) map (full bandwidth map), in joined-channel deconvolution mode, with a central frequency of 1,283 MHz. The OXKAT pipeline uses the custom tasks from Cubical software for self-calibration.

We achieved a synthesized beam of $5.8 \times 5.8$ and the root-mean-square noise level in the MFS image was 4.2 mJy per beam. The central frequency of the sub-band images were 909, 1,016, 1,230, 1,337, 1,444, 1,551 and 1,658 MHz. To derive the spectral index map (Fig. 1b), we smoothed the resolutions of the sub-band images to the resolution (9″.5 × 8″.5) of the 909-MHz sub-band image using the CASA task imsmooth.

1-km radius), providing the shortest baseline of 29 m, whereas the other 16 antennas are spread outside the core, up to a maximum baseline of 8 km. Thus, MeerKAT is capable of recovering a wide range of angular scales (5° to 27°) at the central frequency of 1,283 MHz.

The primary flux and bandpass calibrator was fixed to J0408-6545 (total intensity of $I = 17$ Jy at 1,283 MHz), J0616-3456 ($I = 3.1$ Jy at 1,283 MHz, and 5.7° from the phase tracking centre of A3376 East) was used as the secondary gain calibrator. During the observations, we performed four 10-min scans of the primary calibrator, and we scanned the secondary calibrator every 2 min after the scan of the target. The flux, bandpass and gain calibrations were carried out reliably with these bright calibrators.

The data correlation was performed with the SKARAB correlator in 4k mode with 856 MHz bandwidth and 4,096 channels of $-209$ kHz per channel. Then, we reduced the data with the semi-automated MeerKAT data analysis pipeline OXKAT (https://ascl.net/code/v/2627).

OXKAT is a semi-automated pipeline used for MeerKAT data reduction and employs a collection of publicly available radio interferometry data flagging, calibration and imaging software packages. In the flagging process, the known radio frequency interference channels, 856–880 MHz, 1,658–1,800 MHz and 1,419.8–1,421.3 MHz, are usually flagged out. Then, other possible radio frequency interference channels are flagged using the autoflagger tricolour for the calibrators and AOF flagger for the target fields. The OXKAT pipeline uses the custom tasks from the CASA suite for cross-calibration.

To deconvolve and image the target data, the WSRClean imager with Briggs weighting and a robustness parameter of −0.3 was used, with the multi-scale and wide-band deconvolution algorithms enabled to facilitate imaging of diffuse emission present in the fields. Deconvolution was performed in ten sub-band images of each 107 MHz-wide band. WSRClean was used to generate the multi-frequency synthesis (MFS) map (full bandwidth map), in joined-channel deconvolution mode, with a central frequency of 1,283 MHz. The OXKAT pipeline uses the custom tasks from Cubical software for self-calibration.

We achieved a synthesized beam of $5.8 \times 5.8$ and the root-mean-square noise level in the MFS image was 4.2 mJy per beam. The central frequency of the sub-band images were 909, 1,016, 1,230, 1,337, 1,444, 1,551 and 1,658 MHz. To derive the spectral index map (Fig. 1b), we smoothed the resolutions of the sub-band images to the resolution (9″.5 × 8″.5) of the 909-MHz sub-band image using the CASA task imsmooth.

1-km radius), providing the shortest baseline of 29 m, whereas the other 16 antennas are spread outside the core, up to a maximum baseline of 8 km. Thus, MeerKAT is capable of recovering a wide range of angular scales (5° to 27°) at the central frequency of 1,283 MHz.

The primary flux and bandpass calibrator was fixed to J0408-6545 (total intensity of $I = 17$ Jy at 1,283 MHz), J0616-3456 ($I = 3.1$ Jy at 1,283 MHz, and 5.7° from the phase tracking centre of A3376 East) was used as the secondary gain calibrator. During the observations, we performed four 10-min scans of the primary calibrator, and we scanned the secondary calibrator every 2 min after the scan of the target. The flux, bandpass and gain calibrations were carried out reliably with these bright calibrators.

The data correlation was performed with the SKARAB correlator in 4k mode with 856 MHz bandwidth and 4,096 channels of $-209$ kHz per channel. Then, we reduced the data with the semi-automated MeerKAT data analysis pipeline OXKAT (https://ascl.net/code/v/2627).

OXKAT is a semi-automated pipeline used for MeerKAT data reduction and employs a collection of publicly available radio interferometry data flagging, calibration and imaging software packages. In the flagging process, the known radio frequency interference channels, 856–880 MHz, 1,658–1,800 MHz and 1,419.8–1,421.3 MHz, are usually flagged out. Then, other possible radio frequency interference channels are flagged using the autoflagger tricolour for the calibrators and AOF flagger for the target fields. The OXKAT pipeline uses the custom tasks from the CASA suite for cross-calibration.

To deconvolve and image the target data, the WSRClean imager with Briggs weighting and a robustness parameter of −0.3 was used, with the multi-scale and wide-band deconvolution algorithms enabled to facilitate imaging of diffuse emission present in the fields. Deconvolution was performed in ten sub-band images of each 107 MHz-wide band. WSRClean was used to generate the multi-frequency synthesis (MFS) map (full bandwidth map), in joined-channel deconvolution mode, with a central frequency of 1,283 MHz. The OXKAT pipeline uses the custom tasks from Cubical software for self-calibration.

We achieved a synthesized beam of $5.8 \times 5.8$ and the root-mean-square noise level in the MFS image was 4.2 mJy per beam. The central frequency of the sub-band images were 909, 1,016, 1,230, 1,337, 1,444, 1,551 and 1,658 MHz. To derive the spectral index map (Fig. 1b), we smoothed the resolutions of the sub-band images to the resolution (9″.5 × 8″.5) of the 909-MHz sub-band image using the CASA task imsmooth.
the arch. The average field of the magnetic arch is about 10 μG, which is consistent with a previous report on cold fronts. The ICM pressure profile is determined by the equilibrium condition:

$$p(r) = p(r = 0) = \frac{B_0^2(r)}{8\pi} - \int_0^r \frac{B_0^2(r')}{4\pi r'} dr,$$

where \( p(r = 0) = 5p_0 \). The ICM temperature is 5 keV inside the magnetic arch. The lowest value of plasma \( \beta (\beta = 8npB^2) \) is 1.3 at the top of the magnetic arch. To satisfy the equilibrium condition, the pressure in the magnetic arch is 50% lower than that of the inner area bounded by the arch. This is inconsistent with observations and theory, which indicate that the pressure does not change across the cold fronts. Although the thermal pressure gradient in our initial conditions may act to inflate the jets more easily than a realistic cluster, it does not have a role in the jet bending and collimating process.

The jet is injected at \((x, y, z) = (30R_o, 0, 0)\), with a radius of \( r_j = 3 \) kpc. The density, pressure and velocity of the injected flow are \( \rho_{jet} = 0.1p_{0}, p_{jet} = 5p_0 \) and \( v_{jet} = 1.5 \). The jet is injected with a purely toroidal magnetic field:

$$B = B_{jet} \sin^2(2\pi r/r_{jet}),$$

where \( B_{jet} = 5.6 \mu G \) and \( r' = \sqrt{(x - 30R_o)^2 + z^2} \). Therefore, the jet’s thermal, kinetic and magnetic energy luminosities are about \( 2 \times 10^{38} \) erg s\(^{-1}\), \( 2.5 \times 10^{38} \) erg s\(^{-1}\) and \( 6.8 \times 10^{38} \) erg s\(^{-1}\), respectively. The total energy of the jetted gas, \( E_{jet} = 0.5 \rho_{jet} v_{jet}^2 + (1 - 1) p_{jet} + B_{jet}^2/(8\pi) \), is \( 1.0 \times 10^{39} \) erg, where \( y \) is the adiabatic index and equals 5/3. By contrast, the maximum magnetic energy of the magnetic layer is \( 1.3 \times 10^{41} \) erg. Thus, the magnetic energy is weaker than the jet total energy (13% of the total energy).

We use a passive tracer function, \( f(x, y, z, t) \), which is injected with the jet to separate the jet material from that of the ICM. The tracer function has initially zero value elsewhere. To clarify the distribution of the jet to separate the jet material from that of the ICM, the tracer function takes the value of 1.0 in the injected region after the jet interacts with the magnetic arch, at \( t = 115 \) Myr.

We model the radio emission by integrating the emissivity along the line of sight. The synchrotron emissivity, without physical constants, is then given by:

$$\varepsilon_{sp} = N_{e}B_{z}^{3}(\alpha + 1),$$

where \( N_{e} \) and \( \alpha = 0.5 \) are the number density of relativistic electrons, the magnetic field perpendicular to the projection of the sky and the power-law synchrotron spectral index, respectively. We model the population of relativistic electrons assuming that it correlates with the product of the jet tracer function \( f \) (described above) and the pressure \( p \) of the gas as:

$$n_e = n_{e, \text{background}} \times \left( \frac{p}{p_{0}} \right)^{\alpha},$$

where \( n_{e, \text{background}} \) is the background density profile. We adopt the \( \beta \) model:

$$n_{e, \text{background}}(r) = \left( C_{n_{e}}[1 + (r/r_c)]^{1/2} \right), \quad r < r_{edge},$$

where \( r_c = \left[ x^2 + y^2 + z^2 \right]^{1/2} C_{e} = 1.6, n_{e, \text{background}} = 10^{-5} \text{cm}^{-3}, r_c = 25 \text{kpc} \) and \( r_{edge} = 110 \text{kpc} \).

To determine regions where the electric resistivity becomes anomalously high, we use the anomalous resistivity as follows:

$$\eta = \begin{cases} 1, & \nu_e > \nu_{\text{crit}}, \\ 0, & \nu_e < \nu_{\text{crit}}. \end{cases}$$

where \( \nu_e \) is the electron drift velocity and \( \nu_{\text{crit}} = 5v_{0} \) is the critical velocity. A high resistivity region appears inside the jet. Although an anomalous resistivity is assumed in our post-calculation, it becomes almost constant owing to the high magnetic field strength and velocity. The dissipation inside the jet functions as Ohmic dissipation, rather than magnetic reconnection.

**Data availability**
The raw MeerKAT data used in this work can be accessed at https://archive.sarao.ac.za (project ID: SCI-20190418-JC-OI). The calibrated MeerKAT data and images that support the findings of this study are available from the corresponding authors upon reasonable request.

27. Hickish, J. et al. A Decade of Developing Radio Astronomy Instrumentation using CASPER Open-Source Technology. J. Astron. Instrum. 5, 1641001-1641012 (2016).
28. Offringa, A. R., van de Gronde, J. J. & Roerdink, J. B. T. M. A morphological algorithm for improving radio-frequency interference detection. Astron. Astrophys. 539, A95 (2012).
29. McMullin, J. P., Waters, B., Schiebel, D., Young, W. & Golap, K. CASA architecture and applications. ASP Conf. Ser. 376, 127 (2007).
30. Offringa, A. R. et al. WSCLASS: an implementation of a fast, generic wide-field imager for radio astronomy. Mon. Not. R. Astron. Soc. 444, 606–618 (2014).
31. Kenyon, J. S., Smirnov, O. M., Grobler, T. L. & Perkins, S. J. CUBICAL: fast radio interferometric calibration suite exploiting complex optimization. Mon. Not. R. Astron. Soc. 478, 2399–2415 (2018).
32. Eckert, D. et al. The gas distribution in the outer regions of galaxy clusters. Astron. Astrophys. 541, A57 (2012).
33. Wang, Q. H. S., Markevitch, M. & Giacintucci, S. The merging galaxy cluster A2590—a broken-up cool core, a dark subcluster, and an X-ray channel. Astrophys. J. 833, 99 (2016).
34. Koide, S., Sakai, J.-I., Nishikawa, K.-i. & Mutel, R. L. Numerical simulation of bent jets: propagation into an oblique magnetic field. J. Geophys. Res. 101, 744 (1996).
35. Rybicki, G. B. and Lightman, A. P. Radiative Processes in Astrophysics (Wiley-VCH, 1985).
36. Bicknell, G. V., Mukherjee, D., Wagner, A. Y., Sutherland, R. S. & Nesvadba, N. P. H. Relativistic jet feedback: II. Relationship to gigahertz peak spectrum and compact steep spectrum radio galaxies. Mon. Not. R. Astron. Soc. 475, 3493–3501 (2018).
37. Komarov, S., Reynolds, C. & Churazov, E. Propagation of weak shocks in cool-core galaxy clusters. Mon. Not. R. Astron. Soc. 497, 1434–1442 (2020).
38. Cavagnolo, K. W., Donahue, M., Voit, G. M. & Sun, M. Intracluster medium entropy profiles for a Chandra archival sample of galaxy clusters. Astrophys. J. Suppl. Ser. 182, 12–32 (2009).
39. Tajima, T. & Shibata, K. Plasma Astrophysics (Basic Books, 1997).
their implementations. T.O. and M.M. constructed the theory and model and conducted the numerical simulations. H.A. performed X-ray data analysis and wrote the scientific discussion. T.A. contributed to the writing of the MeerKAT proposal and the scientific discussion. T.T.T., R.v.R. and H.N. contributed to the scientific discussions. All authors reviewed the manuscript.

**Competing interests** The authors declare no competing interests.

**Additional information**

**Supplementary information** The online version contains supplementary material available at https://doi.org/10.1038/s41586-021-03434-1.

**Correspondence and requests for materials** should be addressed to J.O.C., H.S. or T.O.

**Peer review information** Nature thanks Joydeep Bagchi and Maxim Markevitch for their contribution to the peer review of this work. Peer reviewer reports are available.

**Reprints and permissions information** is available at http://www.nature.com/reprints.