A likely decade-long sustained tidal disruption event

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Multiwavelength flares from tidal disruption and accretion of stars can be used to find and study otherwise dormant massive black holes in galactic nuclei1. Previous well-monitored candidate flares were short-lived, with most emission confined to within ~1 year25. Here we report the discovery of a well-observed super-long (>11 years) luminous X-ray flare from the nuclear region of a dwarf starburst galaxy. After an apparently fast rise within ~4 months a decade ago, the X-ray luminosity, though showing a weak trend of decay, has been persistently high at around the Eddington limit (when the radiation pressure balances the gravitational force). The X-ray spectra are soft — steeply declining towards higher energies — and can be described with Comptonized emission from an optically thick low-temperature corona, a super-Eddington accretion signature often observed in accreting stellar-mass black holes4. Dramatic spectral softening was also caught in one recent observation, implying either a temporary transition from the super-Eddington accretion state to the standard thermal state, or the presence of a transient highly blueshifted (~0.36c) warm absorber. All these properties in concert suggest a tidal disruption event with an unusually long super-Eddington accretion phase that has never before been observed.

The X-ray source 3XMM J150052.0+015452 (referred to as XJ1500+0154 hereafter) was serendipitously detected in frequent observations2 of the foreground galaxy group NGC 5813 by the X-ray observatories Chandra and XMM-Newton from 2005 to 2011. Our best fits to the spectra with sufficient counts are shown in the lower panel and are also given in Table 1. The upper panel in Fig. 2 shows the long-term evolution of the X-ray luminosity LX. Our best fits to the spectra with sufficient counts are shown in the lower panel and are also given in Table 1. One striking property of the source is the fast-rise-very-slow-decay outburst profile. It was not detected in the first Chandra observation on 2 April 2005, with LX < 4.3 × 10^41 erg s⁻¹ (3σ upper limit, assuming a powerlaw source spectrum of photon index 2.0). Less than 4 months later (23 July 2005), the source was detected in the first XMM-Newton observation, with LX ≈ 5.5 × 10^41 erg s⁻¹. It was detected at an even higher luminosity 3 years later, in one Chandra observation on 5 June 2008 and two XMM-Newton observations in February 2009, with LX ≈ 7.0 × 10^41 erg s⁻¹. The luminosity decreased slightly to ~3.0 × 10^41 erg s⁻¹ in seven Chandra observations in March–April 2011. Similar luminosities were seen in our follow-up observations later, one by Swift on 28 March 2014, one by Chandra on 23 February 2015, and seven by Swift in February 2016. Given the probably small central SMBH and correcting for emission outside the X-ray band, the source luminosity has been most likely at around the Eddington limit since it went into the outburst.

Another special property of the source is the generally quasistatic X-ray spectra, most evident in the XMM-Newton and Chandra observations in 2008–2011. These spectra can be roughly described as a dominant thermal disk of apparent maximum disk temperature kTdisk~0.3 keV plus a weak powerlaw (see Supplementary Information). However, such a model is physically unacceptable, because the standard thin accretion disk around a SMBH is expected to produce much cooler thermal emission (kTdisk~0.1 keV)9. Instead, the spectra can be described well with the Comptonization model CompTT10, with an optically thick (τ~4–11) low-temperature (kT~0.4–1.3 keV) corona (see Supplementary Information). Such spectral parameters are commonly seen in ultraluminous X-ray sources (ULXs)11,12, most of which are believed to be super-Eddington accreting stellar-mass black holes — except that XJ1500+0154 had orders of magnitude higher luminosities.
Therefore, we identified the observations in 2008–2011 as being in the super-Eddington accretion state.

Surprisingly, we obtained a much softer X-ray spectrum in the Chandra observation in 2015, mostly due to a drop (by a factor of 7.0) in the count rate above ~1 keV (Fig. 2) compared with the observations in 2008–2011. This super-soft spectrum can be described as a dominant thermal disk of $kT_{\text{disk}} \sim 0.13 \pm 0.01$ keV plus a very weak powerlaw (Fig. 2). Such a cool thermal disk is expected from accretion onto a SMBH below the Eddington limit. The source could then be in the super-Eddington accretion state with the identification of the super-Eddington accretion state in previous observations. In this case, the X-ray spectral evolution of XJ1500+0154 is very similar to a transient ULX in M31, which changed from a super-Eddington accretion state to a thermal state within 20 days with the X-ray luminosity decreasing only slightly. However, we find that the spectrum can be described equally well with the CompTT model that fits the Chandra observations in 2011, except for additional absorption by a strong ($N_a \approx 6 \times 10^{21}$ cm$^{-2}$) ionized ($\log(\xi) = 2.8$) absorber with a blueshifted velocity of 0.36c. Powerful sub-relativistic winds are expected in super-Eddington accreting black holes, and highly blueshifted warm absorbers have been detected in ULXs. Therefore, this interpretation for the Chandra observation in 2015 also supports the identification of the super-Eddington accretion state in previous observations. The recent Swift observations in 2016 have poor statistics, but some of them did not seem to show similar super-soft X-ray spectra. Therefore, the source has not completely settled to a new state of super-soft X-ray spectra, and the super-Eddington accretion seems to have lasted for >11 years (see Supplementary Information).

No sign of persistent nuclear activity is seen in the optical emission lines of the host galaxy, whose ratios are fully consistent with those expected from a starburst galaxy. There are many other properties of the source that argue against the possibility that it is a standard active galactic nucleus (AGN; see Supplementary Information). In particular, no AGN is known to show X-ray spectra as soft as XJ1500+0154 within the 1–4.5 keV energy band, or show dramatic quasi-soft to super-soft X-ray spectral change. The large X-ray variability (a factor of >97) is also extremely rare among AGNs. Therefore, although we cannot yet completely rule out that XJ1500+0154 is a highly variable AGN, its X-ray outburst is best explained as tidal disruption of a star by the central black hole. This interpretation is strongly supported by our new discovery of two other sources that seemed to be in X-ray outbursts with similar quasi-soft X-ray spectra as XJ1500+0154 but have host galaxies showing no sign of nuclear activity in optical (see Supplementary Information).

The super-Eddington accretion phase from tidal disruption of a solar-type star by a $10^6 M_\odot$ black hole can last approximately 2 years ($t_{\text{tid}}$), with the peak mass accretion rate highly super-Eddington, $M_{\text{Edd}}$. One main property of a super-Eddington accretion disk is a lower radiative efficiency than a standard thermal thin disk, due to significant super-Eddington effects of photon trapping and outflows in...
Table 1 | Spectral fit results for high-quality spectra.

| Obs. | Model                  | Parameters               | $\chi^2$/d.o.f. | $L_{\text{abs}}$ | $L_{\text{unabs}}$ |
|------|------------------------|--------------------------|----------------|-----------------|------------------|
| X1   | diskbb+PL              | $k_{\text{diskbb}} = 0.10^{+0.05}_{-0.04}$ keV, $N_{\text{diskbb}} = 210^{+27841}_{-204}$, $\Gamma_{\text{diskbb}} = 2.5$, $N_{\text{PL}} = 4.6^{+3.9}_{-2.3} \times 10^{-6}$ | ... | $0.08^{+0.04}_{-0.03}$ | $5.5^{+10.9}_{-3.1}$ |
| X2   | CompTT                 | $k_{T_0} = 0.04$ keV, $k_{T_1} = 0.35^{+0.01}_{-0.02}$ keV, $r = 10.8^{+2.4}_{-2.1}$ | 1.09 (106) | $1.16^{+0.02}_{-0.03}$ | $6.18^{+0.65}_{-0.40}$ |
| X3   | CompTT                 | $k_{T_0} = 0.04$ keV, $k_{T_1} = 0.5^{+0.1}_{-0.2}$ keV, $r = 7.3^{+2.2}_{-2.2}$ | 0.90 (99) | $1.3^{+0.06}_{-0.05}$ | $7.03^{+0.71}_{-0.66}$ |
| C2   | CompTT                 | $k_{T_0} = 0.04$ keV, $k_{T_1} = 0.5^{+0.2}_{-0.1}$ keV, $r = 7.6^{+3.5}_{-2.5}$ | 0.90 (43) | $1.08^{+0.09}_{-0.09}$ | $6.2^{+1.55}_{-1.32}$ |
| C3-C9| CompTT                 | $k_{T_0} = 0.04$ keV, $k_{T_1} = 1.3^{+0.4}_{-0.5}$ keV, $r = 3.9^{+12}_{-17}$ | 0.83 (138) | $0.6^{+0.02}_{-0.02}$ | $3.3^{+0.23}_{-0.21}$ |
| C10  | diskbb+PL              | $k_{\text{diskbb}} = 0.13^{+0.05}_{-0.04}$ keV, $N_{\text{diskbb}} = 312^{+72}_{-70}$, $\Gamma_{\text{diskbb}} = 2.5$, $N_{\text{PL}} = 2.2^{+0.1}_{-0.09} \times 10^{-6}$ | $0.31^{+0.05}_{-0.04}$ | $2.8^{+0.86}_{-0.66}$ | $3.3^{+0.23}_{-0.21}$ |
|      | zxipcf(CompTT)         | $k_{T_0} = 0.04$ keV, $k_{T_1} = 1.33^{+0.12}_{-0.11}$ keV, $r = 3.9^{+3.9}_{-1.1}$ | ... | $0.6^{+0.02}_{-0.02}$ | $3.3^{+0.23}_{-0.21}$ |

The $X$ and $C10$ spectra were rebinned to have at least one count per bin and were fitted by minimizing the C statistic, while the $X2$, $X3$, $C2$, and $C3-C9$ spectra were rebinned to have at least 20 counts per bin and were fitted by minimizing the $\chi^2$ statistic. The fits used energy channels within 0.3-10 keV for XMM-Newton and energy channels within 0.3-7 keV for Chandra. All models include Galactic absorption of column density $N_{\text{H,Gal}} = 4.4 \times 10^{20}$ cm$^{-2}$. The absorption intrinsic to the X-ray source at redshift $z = 0.154$ was also included and fixed at $N_{\text{H,inf}} = 4.2 \times 10^{20}$ cm$^{-2}$, which was the best-fitting value from the simultaneous fit to the $X$, $C2$, $X3$, and $C3-C9$ spectra. $\xi_{\text{diskbb}}$ is the source rest-frame 0.3-4.5 keV luminosity, corrected for both Galactic and intrinsic absorption. Both $L_{\text{abs}}$ and $L_{\text{unabs}}$ are in units of 10$^{41}$ erg s$^{-1}$. All errors are at the 90% confidence level. Parameters without errors were fixed in the fits. For $C10$, two models were tested: diskbb+PL, where PL is the powerlaw model in XSPEC, and zxipcf(CompTT). For the latter model, the CompTT component was fixed at the best fit of this model to C3-C9, and the luminosities $L_{\text{abs}}$ and $L_{\text{unabs}}$ was simply copied from those of C3-C9. The reduced $\chi^2$ values are given for fits using the $\chi^2$ statistic, but not for those using the C statistic.

The inner disk region is another major region of interest. These effects are more serious at higher accretion rates, with the disk luminosity sustained at the Eddington limit. The Eddington-limited slow decay of our source thus agrees well with the super-Eddington accretion signatures suggested by the X-ray spectra. The super-Eddington accretion phase of $\gtrsim 11$ years in our event would imply disruption of a very massive star ($10^6 M_\odot$) based on the standard theory. However, it has been realized that the evolution of tidal disruption events (TDEs) depends heavily on how the streams of tidal debris intersect each other. For simplicity, it should be common for circularization of the fallback mass onto the accretion disk to occur at a much larger distance than predicted from the standard theory, resulting in a much longer viscous timescale. Therefore, $t_{\text{circ}}$ can be very long in a slow circularization process, unless the circularization is so slow that the peak accretion rate drops to be sub-Eddington. The duration of the super-Eddington accretion phase is expected to be well sub-Eddington in the next 10 years, based on our model.

Figure 2 shows the evolution of the luminosity from a full disruption of a $2 M_\odot$ star by a $10^6 M_\odot$ black hole, with the accretion of the mass slowed relative to the fallback time by 3 years. The super-Eddington effects were taken into account by introducing a logarithmic dependence of the radiative efficiency on the accretion rate above the Eddington limit (see Supplementary Information). We assumed that 25% of the radiation is in X-rays, as inferred from the spectral modelling. The model describes the data well. The total energy release and the total mass accreted onto the black hole until the last Swift observation would then be $6.4 \times 10^{42}$ erg and $0.89 M_\odot$, respectively, which are orders of magnitude higher than seen in other known events.

Although disruption of a very massive star of $10^6 M_\odot$ with prompt circularization can also describe the data, such disruption is expected to be orders of magnitude rarer than disrupting a star of $2 M_\odot$ with slow circularization (see Supplementary Information). Therefore our event provides the first convincing evidence of slow circularization effects in TDEs, which are expected to be very common when the black holes are small ($\sim 10^2 M_\odot$), but have not yet been clearly observed (probably due to observational bias).

We calculated the rate of events similar to XJ1500+0154 to be $\sim 4 \times 10^{-7}$ per galaxy per year (see Supplementary Information), which is about two orders of magnitude lower than estimated for short TDEs. One main reason for the low rate of events such as XJ1500+0154 could be the relatively large mass ($2 M_\odot$) required of the disrupted stars, which is only possible in starburst galaxies. Although events such as XJ1500+0154 are rare, their extreme duration and radiative inefficiency mean that their contributions to the luminosity function of active galactic nuclei and to the growth of the black holes are comparable to (or even higher than) those of short events. TDEs with a shorter super-Eddington accretion phase than XJ1500+0154 could be more common. The discovery of our event opens up a new realm in which to search for super-Eddington accreting TDEs, that is, by investigating sources with quasi-soft X-ray spectra. Our discovery of the other two candidates is the result of applying this scheme.

This is the first time that X-ray spectra resembling typical super-Eddington accreting stellar-mass black holes were observed in an accreting SMBH. If our interpretation of a super-Eddington accreting TDE for XJ1500+0154 is correct, it would have important implications for the growth of massive black holes. The detection of quasars at redshift $z > 6$ with black hole masses of $\sim 10^9 M_\odot$ poses a problem to explain their growth with accretion via a standard thin disk at the Eddington rate. However, their formation would be possible if the black holes can accrete at a super-Eddington rate during an early phase. Our event shows that super-Eddington accretion onto massive black holes can occur, giving strong observational support to this model. The high absorption in these systems would mean that radio and infrared should be used to search for them, because their X-ray spectra, if as soft as XJ1500+0154, would be completely absorbed.

We expect the accretion rate to drop by an order of magnitude to be well sub-Eddington in the next 10 years, based on our model of full disruption of a $2 M_\odot$ star. By continued monitoring of the event, we will be able to test our TDE interpretation and determine the duration of the super-Eddington accretion phase and the origin of spectral softening. We will also be given a rare opportunity to observe the spectral evolution of the event across different accretion regimes and to investigate its connection with short super-soft events that are mostly believed to accrete below the Eddington limit.

**Methods**

*XMM-Newton observations and data analysis.* XJ1500+0154 was serendipitously detected at off-axis angles of $\sim 13^\circ$ in three XMM-Newton observations (X1–X3 hereafter; see Supplementary Table 1) of NGC 5813. X1 was made in July 2005, while X2 and X3 were made in February 2009, only six days apart. The source was detected in all three European Photon Imaging Cameras (that is, pn, MOS1/M2 and MOS2/M2), in the imaging mode in X1, but only in pn and MOS2 in X2 and X3 because the source is outside the field of view (FOV) of MOS1 in these two observations. We used SAS 15.0.0 and
The calibration files of 2016 February for reprocessing the X-ray event files and follow-up analysis. The data in strong background flare intervals, seen in all cameras in all observations, were excluded following the SAS thread for the filtering against high backgrounds. The final clean exposures are used in Supplementary Table 1. We extracted the source spectra from all available cameras using a circular region of radius 20″. The background spectra were extracted from a large circular region near the source, using a radius of 100″ for MOS1 and MOS2 and a radius of 50″ for the event selection threshold values in the pipeline. For X2 and X3, in which the source was bright, we also extracted the pn light curves binned at 500 s using the SAS tool epiclccorr and performed variability tests using the ekstest tool. We used the 0.3–3 keV band, where the source counts dominated over those of the background.

Chandra observations and data analysis. XJ1500+0154 was serendipitously covered in nine Chandra observations (C1–C9 hereafter; see Supplementary Table 1) of NGC 5813, but all at large pointing offsets (11″–15″). The dense observations in 2011 (C3–C9, ∼0.5 Mx) are from a Large Program (LP; principal investigator: S. Randall, Harvard-Smithsonian Center for Astrophysics, Massachusetts, USA) on NGC 5813. All nine observations used the imaging array of the AXAF CCD Imaging Spectrometer (ACIS), and X1500+0154 fell in the back-illuminated chip S1 in all observations except C2, in which it fell in the front-illuminated chip I3. We had a Chandra follow-up observation of the source for 37 ks in February 2015 (C10 hereafter), with the aim point at the back-illuminated chip S3. We reprocessed all the data to apply the latest calibration (CALDB 4.6.7) using the script chandra_repro in the Chandra Interactive Analysis of Observations (CIAO) version 4.7 package. No clear background flares were seen, and we used all data for all observations.

The spectra of XJ1500+0154 were extracted for each observation. We used a circular source region enclosing 90% of the point spread function (PSF) at 1.0 keV and a circular background region of a radius of 50″ near the source. However, there are three exceptions. For observations C1 and C2, we used the 70% PSF radius for the source region, as the source was not detected in C1 and was near the CCD edge in C2. For our follow-up observation C10, in which the source is near the aim point with minimum background contamination, we used the 95% PSF radius for the source region. We used the CIAO task mkacisrmf to create the response matrix files, and the CIAO tasks mkarf and arfcor to generate the source- and auxiliary-response matrices. Considering no significant difference between LP observations, which were taken within 13 days, and in order to improve the statistics for spectral modelling, we created a single spectrum combining LP observations. For observation C1, in which the source was not detected, we used the CIAO task aprates to determine confidence bounds of the flux. We used the 0.4–3 keV band, adopting the Gregory-Loredo algorithm implemented by the CIAO tool glvary. It splits the events into multiple time bins and looks for significant deviations. The variation of the effective area with time was taken into account and was obtained by another CIAO tool dither_region. The different degrees of confidence are indicated by the parameter of ‘variability index’, which spans values within [0,10] and is larger for variability of higher confidence.

Our C10 observation was intended to provide an accurate position of XJ1500+0154, utilizing the sub-arcsec resolution of Chandra near the aimpoint. We performed the source detection by applying the CIAO wavdetect wavelet-based source detection algorithm on the 0.3–7 keV image binned at single pixel size resolution. We then carried out the absolute astrometric correction for the X-ray sources by cross-correlating them with optical sources in the Canada-France-Hawaii Telescope (CFHT) MegaPrime/MegaCam r’-band stacked images. We only used 19 matches that are outside the strong diffuse gas contamination, we used the 95% PSF radius for the source region. We used the CIAO task mkacisrmf to create the response matrix files, and the CIAO tasks mkarf and arfcor to generate the source- and auxiliary-response matrices. Considering no significant difference between LP observations, which were taken within 13 days, and in order to improve the statistics for spectral modelling, we created a single spectrum combining LP observations. For observation C1, in which the source was not detected, we used the CIAO task aprates to determine confidence bounds of the flux. We used the 0.4–3 keV band, adopting the Gregory-Loredo algorithm implemented by the CIAO tool glvary. It splits the events into multiple time bins and looks for significant deviations. The variation of the effective area with time was taken into account and was obtained by another CIAO tool dither_region. The different degrees of confidence are indicated by the parameter of ‘variability index’, which spans values within [0,10] and is larger for variability of higher confidence.

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X-ray spectral fits. The X-ray activity of XJ1500+0154 should be due to accretion onto a black hole, and we fitted the X-ray spectra with several models typically used to study such an object. Given that XJ1500+0154 is most likely to be associated with a galaxy at z = 0.1452, we applied this redshift to all the spectral models that we tested with the convolution model starchip in XSPEC. All models included the Galactic absorption fixed at N_H = 4.4 × 10²² cm⁻² using the tbabs model. Possible absorption intrinsic to the source was accounted for using the ztbabs model. The abundance tables from ref. 41 were used.

Data availability statement. The data that support the plots within this paper and other findings of this study are available from the corresponding author upon reasonable request.
14. Pinto, C., Middleton, M. J. & Fabian, A. C. Resolved atomic lines reveal outflows in two ultraluminous X-ray sources. Nature 553, 64–67 (2016).
15. Ulmer, A. Flares from the tidal disruption of stars by massive black holes. Astrophys. J. 514, 180–187 (1999).
16. Ohsuga, K. & Mineshige, S. Why is supercritical disk accretion feasible? Astrophys. J. 670, 1283–1290 (2007).
17. Krolik, J. H. & Piran, T. Jets from tidal disruptions of stars by black holes. Astrophys. J. 749, 92 (2012).
18. Kochanek, C. S. Tidal disruption event demographics. Astrophys. J. 809, 166 (2015).
19. Shiokawa, H., Krolik, J. H., Cheng, R. M., Piran, T. & Noble, S. C. General relativistic hydrodynamic simulation of accretion flow from a stellar tidal disruption. Astrophys. J. 804, 85 (2015).
20. Hayasaki, K., Stone, N. & Loeb, A. Circularization of tidally disrupted stars around spinning supermassive black holes. Mon. Not. R. Astron. Soc. 461, 3760–3780 (2016).
21. Li, L.-X., Narayan, R. & Menou, K. The giant X-ray flare of NGC 5905: tidal disruption of a star, a brown dwarf, or a planet? Astrophys. J. 576, 753–761 (2002).
22. Komossa, S. et al. A huge drop in the X-ray luminosity of the nonactive galaxy RX J1242.6-1119A, and the first postflare spectrum: testing the tidal disruption scenario. Astrophys. J. 603, L17–L20 (2004).
23. Donley, J. L., Brandt, W. N., Eracleous, M. & Boller, T. Large-amplitude X-ray outbursts from galactic nuclei: a systematic survey using ROSAT archival data. Astron. J. 124, 1308–1321 (2002).
24. Kochanek, C. S. Tidal disruption event demographics. Mon. Not. R. Astron. Soc. 461, 371–384 (2016).
25. Mortlock, D. J. et al. A luminous quasar at a redshift of z = 7.085. Nature 474, 616–619 (2011).
26. Volonteri, M. & Rees, M. J. Rapid growth of high-redshift black holes. Astrophys. J. 633, 624–629 (2005).
27. Martinez-Sansigre, A. et al. The obscuration by dust of most of the growth of supermassive black holes. Nature 436, 666–669 (2005).
28. Maksym, W. P., Ulmer, M. P., Eracleous, M. C., Guennou, L. & Ho, L. C. A tidal flare candidate in Abell 1795. Mon. Not. R. Astron. Soc. 435, 1904–1927 (2013).
29. Janzen, F. et al. XMM-Newton observatory. I. The spacecraft and operations. Astron. Astrophys. 365, L1–L6 (2001).
30. Strüder, L. et al. The European Photon Imaging Camera on XMM-Newton: the pn–CCD camera. Astron. Astrophys. 365, L18–L26 (2001).
31. Turner, M. J. L. et al. The European Photon Imaging Camera on XMM-Newton: the MOS cameras. Astron. Astrophys. 365, L27–L35 (2001).
32. Watson, M. G. et al. The XMM-Newton serendipitous source catalogue. A. The Second XMM-Newton serendipitous source catalogue. Astron. Astrophys. 493, 339–373 (2009).
33. Bautz, M. W. et al. in Society of Photo-Optical Instrumentation Engineers Conference Series Vol. 3444 (eds Hooyer, R. B. & Walker, A. B.) 210–224 (SPIE, 1998).
34. Gregory, P. C. & Loredo, T. J. A new method for the detection of a periodic signal of unknown shape and period. Astrophys. J. 398, 146–168 (1992).
35. Evans, I. N. et al. The Chandra source catalog. Astrophys. J. Suppl. Ser. 189, 37–82 (2010).
36. Freeman, P. E., Kashyap, V., Rosner, R. & Lamb, D. Q. A wavelet-based algorithm for the spatial analysis of Poisson data. Astrophys. J. Suppl. Ser. 138, 185–218 (2002).
37. Boulade, O. et al. in Instrument Design and Performance for Optical/Infrared Ground-based Telescopes (eds Iye, M. & Moorwood, A. F. M.) 72–81 (Society of Photo-Optical Instrumentation Engineers Conference Series Vol. 4841, 2003).
38. Randall, S. W. et al. Shocks and cavities from multiple outbursts in the galaxy group NGC 5813: a window to active galactic nucleus feedback. Astrophys. J. 726, 86 (2011).
39. Kim, M. et al. Chandra multwavelength project X-ray point source catalog. Astrophys. J. Suppl. Ser. 169, 401–429 (2007).
40. Lin, D. et al. Discovery of the candidate off-nuclear ultrasoft hyper-luminous X-ray source 3XMM J141711.1+522541. Astrophys. J. 821, 25 (2016).
41. Gehrels, N. et al. The Swift gamma-ray burst mission. Astrophys. J. 611, 1005–1020 (2004).
42. Burrows, D. N. et al. The Swift X-ray telescope. Space Sci. Rev. 120, 165–195 (2005).
43. Roming, P. W. A. et al. The Swift ultra-violet/optical telescope. Space Sci. Rev. 120, 95–142 (2005).
44. Gwym, S. D. J. MegaPipe: the MegaCam image stacking pipeline at the Canadian Astronomical Data Centre. Publ. Astron. Soc. Pacif. 120, 212–223 (2008).
45. Abazajian, K. N. et al. The seventh data release of the Sloan Digital Sky Survey. Astrophys. J. Suppl. Ser. 182, 543–558 (2009).
46. Peng, C. Y., Ho, L. C., Impey, C. D. & Rix, H.-W. Detailed decomposition of galaxy images. II. Beyond axisymmetric models. Astron. J. 139, 2097–2129 (2010).
47. Arnaud, K. A. in Astronomical Data Analysis Software and Systems V (eds Jacoby, G. H. & Barnes, J.) 17 (Astronomical Society of the Pacific Conference Series, Vol. 101, 1996).
48. Kalberla, P. M. W. et al. The Leiden/Argentine/Bonn (LAB) Survey of Galactic HI. Final data release of the combined LDS and IAR surveys with improved stray-rejection corrections. Astron. Astrophys. 440, 775–782 (2005).
49. Wilms, J., Allen, A. & McCray, R. On the absorption of X-rays in the interstellar medium. Astrophys. J. 542, 914–924 (2000).

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Author contributions
D.L. wrote the main manuscript and led the data analysis. J.G. helped with the modelling of the long-term X-ray light curve and wrote the text on the modelling in the Supplementary Information. S.G. stacked the CFHT images. All authors discussed the results and commented on the manuscript.

Additional information
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Competing interests
The authors declare no competing financial interests.