Mergers of neutron stars are known to be associated with short γ-ray bursts1–4. If the neutron-star equation of state is sufficiently stiff (that is, the pressure increases sharply as the density increases), at least some such mergers will leave behind a supramassive or even a stable neutron star that spins rapidly with a strong magnetic field5–8 (that is, a magnetar). Such a magnetar signature may have been observed in the form of the X-ray plateau that follows up to half of observed short γ-ray bursts9,10. However, it has been expected that some X-ray transients powered by binary neutron-star mergers may not be associated with a short γ-ray burst11,12. A fast X-ray transient (CDF-S XT1) was recently found to be associated with a faint host galaxy, the redshift of which is unknown13. Its X-ray and host-galaxy properties allow several possible explanations including a short γ-ray burst seen off-axis, a low-luminosity γ-ray burst at high redshift, or a tidal disruption event involving an intermediate-mass black hole and a white dwarf13. Here we report a second X-ray transient, CDF-S XT2, that is associated with a galaxy at redshift $z = 0.738$ (ref. 14). The measured light curve is fully consistent with the X-ray transient being powered by a millisecond magnetar. More intriguingly, CDF-S XT2 lies in the outskirts of its star-forming host galaxy with a moderate offset from the galaxy centre, as short γ-ray bursts often do13,14. The estimated event-rate density of similar X-ray transients, when corrected to the local value, is consistent with the event-rate density of binary neutron-star mergers that is robustly inferred from the detection of the gravitational-wave event GW170817.15.

Upon the completion of the deepest X-ray survey to date, the 7-Ms Chandra Deep Field-South survey (CDF-S), which consists of 102 individual Chandra/Advanced CCD Imaging Spectrometer imaging array (ACIS-I) observations spanning 16.4 yr (refs 17,18), we performed a search for X-ray transient events and discovered two notable fast outbursts13,14, CDF-S XT1, reported elsewhere13, and CDF-S XT2, which is our focus here. The Chandra X-ray position of CDF-S XT2 is right ascension RA $= 03 h 32 min 18.38 s$ and declination dec. $= − 27° 52′ 24.2″$ (using J2000.0 coordinates, with a 1σ positional uncertainty of 0.11″; see Methods). This X-ray outburst started at about 07:02:45 Universal Time on 22 March 2015 ($T_0$) and lasted for about 20 ks during an observation approximately 70 ks long (Chandra Observation ID: ObsID 16453). CDF-S XT2 did not trigger the Gamma-ray Burst Monitor (GBM; 8 keV–30 MeV), the Large Area Telescope (LAT; 20 MeV–300 GeV) onboard the Fermi Gamma-ray Space Telescope, the Burst Alert Telescope (BAT) onboard the Neil Gehrels Swift Observatory or the International Gamma-Ray Astrophysics Laboratory/Spectrometer Anticoincidence Shield (INTEGRAL/ACS; 20 keV–8 MeV) (see Methods and also personal communication with A. Lien). It was not detected by KONUS onboard Wind or by the Interplanetary Network (IPN3), which examines high-energy data from a number of space observatories including Fermi, Swift and INTEGRAL (K. Hurley and D. Svininkin, personal communication). Aside from the Chandra observations, no contemporaneous observational data have been identified at any other wavelengths for CDF-S XT2, spanning approximately one month before the outburst to about four months thereafter.

We present the binned Chandra 0.5–7 keV light curves and the spectra of CDF-S XT2 in Fig. 1 for viewing purposes, and we fitted the unbinned light curves and spectra for physical constraints (see Methods). The light curve of CDF-S XT2 (listed in Extended Data Table 1) contains a total of 136 photons, with the $T_0$ parameter estimated to be 11.1±0.6 ks (that is, the timespan from the 5th to the 95th percentile of the total measured counts; throughout this paper, we quote 1σ errors unless stated otherwise). The light curve is well fitted by a broken power-law model using the Markov Chain Monte Carlo code emcee19, with the best-fitting power-law slopes being $−0.14±0.03$ before the break (at $T_0 = 2.3_{−0.4}^{+0.3}$ ks) and $−2.16_{−0.29}^{+0.27}$ after the break, respectively (see Fig. 1a). We define the hardness ratio $HR = (H − S)/(H + S)$, where $H$ and $S$ are the count rates in the 2–7 keV and 0.5–2 keV bands, respectively, and derive its errors based on the Bayesian code BEHR20. A simple hardness-ratio analysis reveals an overall softening spectral trend of the source, which is confirmed by a detailed spectral analysis, that is, the best-fitting power-law spectral indexes being $Γ = 1.59_{−0.55}^{+0.49}$ before the break and $Γ = 2.53_{−0.74}^{+0.10}$ after the break, respectively (see Fig. 1b, c and Methods). Given the fact that the light curve of CDF-S XT2 peaked quickly (with a rest-frame peak luminosity $L_\text{X} \approx 3 \times 10^{45} \text{ erg s}^{-1}$ given our adopted cosmology21; see Extended Data Table 1) with a slower decay, we estimate a very short rise time ($\lesssim 45$ s) for this outburst (see Methods).

Figure 2a compares the X-ray luminosity light curve of CDF-S XT2 with the X-ray afterglow light curves of short γ-ray bursts (SGRBs) with known redshifts. We can see that CDF-S XT2 is abnormal underluminous compared with SGRB afterglows, especially at early times. Figure 2b presents the isotropic rest-frame 1–100 keV 1-s peak luminosity $(L_{1−100} \text{ keV})$ of SGRB prompt emission against X-ray luminosity at $t = 100$ s after the trigger, with CDF-S XT2 overplotted for comparison. The chosen time of $t = 100$ s is typical during the X-ray plateau phase9,10. It is clear that if CDF-S XT2 originates from the afterglow of an SGRB, at such a low luminosity, the expected $L_{1−100} \text{ keV}$ should be well below the upper limit set by Fermi/GBM. These properties leave
open the intriguing possibility that CDF-S XT2 could be associated with an undetected low-luminosity SGRB.

The accurate Chandra X-ray position of CDF-S XT2 guarantees a robust identification of its host galaxy, which has a secure spectroscopic redshift of $z = 0.738$ and an apparent AB magnitude of $m_{F160W} \approx 24$ mag (refs. 22,23), with an offset of $0.44'' \pm 0.25''$ (that is, a projected distance of $3.3 \pm 1.9$ kpc; the error is computed as the root of the quadratic sum of the Chandra and Hubble Space Telescope (HST) positional uncertainties as well as the uncertainty of astrometric registration between these two sets of data) considering the peak-flux position of the host galaxy or $0.45'' \pm 0.25'' (3.3 \pm 1.8$ kpc) considering the position derived using SExtractor (https://www.astromatic.net/software/sextractor or https://sextractor.readthedocs.io/en/latest/) (see Fig. 3a and Methods). From the galaxy surface density derived from the HST/CANDELS F160W DR1 catalogue 22, we estimate that the probability of a coincident match between CDF-S XT2 and a galaxy brighter than $m_{F160W} \approx 24$ mag within $0.44''$ is only about 1%. We adopt the median stellar mass ($M_\star = 1.17 \times 10^9 M_\odot$), star-formation rate ($SFR = 0.81 M_\odot$ yr$^{-1}$), and metallicity ($Z = 2.0 Z_\odot$) of the host galaxy from the five independent and consistent estimates derived from spectral energy distribution fitting 24, which used the same photometry, galaxy templates and initial mass function 24 as well as different

![Fig. 1 | Timing and spectral evolution of CDF-S XT2. a. Light curves (see Extended Data Table 1 for additional information) and best-fit broken power-law model, the ratio between data and best-fit model, and the evolution of the hardness ratio (HR) of CDF-S XT2. The downward dashed arrow indicates no photons being detected from CDF-S XT2 at $t < 10$ s, and the corresponding 1σ flux upper limit is $3.1 \times 10^{-16}$ erg cm$^{-2}$ s$^{-1}$ (see Methods). The vertical dotted line ($t = 2,000$ s) roughly indicates the break time that divides the outburst into two segments. Three different binning schemes are presented to show the details around the break. b. Spectra and best-fit models of the entire outburst and the two segments. Vertical error bars plotted in both a and b are 1σ; in a, the horizontal ‘errors’ that indicate the binned time ranges are not shown for clarity (the log-binned time ranges can be found in Extended Data Table 1) and in b, the horizontal ‘errors’ indicate the binned energy ranges for viewing purposes. c. Corresponding best-fit values of photon index $\Gamma$ and hydrogen column density $N_H$ as well as the respective 1σ (solid curves) and the 2σ (dashed curves) confidence contours.](image1)

![Fig. 2 | X-ray and γ-ray luminosity-related information for CDF-S XT2. a. X-ray luminosity light curve and X-ray luminosity at rest-frame $t = 100$ s of CDF-S XT2 (in red), in comparison with that of known SGRB X-ray afterglows (in blue) that have redshift information. b. Isotropic rest-frame $1-10^5$-keV 1-s peak luminosities of SGRB prompt emission versus X-ray luminosities at rest-frame $t = 100$ s after the trigger, with CDF-S XT2 overplotted for comparison. In a, the vertical error bars are 1σ and the horizontal ‘errors’ are the binned time ranges; in b, the vertical error bars are 90% (corresponding to γ-ray data from ref. 25) and the horizontal errors (corresponding to X-ray data) are 1σ; upper limits are quoted at the 1σ level.](image2)
star-formation history models and extinction laws. The values of the redshift, stellar mass, and SFR indicate that the host galaxy is located within the lower part of the galaxy main sequence \(^{25}\), that is, it has a relatively low SFR given its stellar mass and is close to the lower bound of the main sequence.

We present additional host-galaxy-related properties of CDF-S XT2 in Fig. 3. Using the HST F125W-band image, we compute the offset between CDF-S XT2 and the host galaxy in units of galaxy half-light radius \((R_0 = 0.38''\)\), and find that it is well within the distribution of known SGRB–host-galaxy offsets \(^{15,16}\) (see Fig. 3b). We also calculate the light fraction \(F_{\text{light}}\) which indicates how bright the CDF-S XT2 region (that is, the red circle with \(r = 0.11''\)) is relative to the other parts of the host galaxy, with \(F_{\text{light}} = 1\) (or 0) standing for the brightest (or faintest) region. We use the segmentation given by SExtractor to define the host-galaxy region, and compute \(F_{\text{light}}\) as the ratio of the total light of the galaxy region with surface brightness smaller than the median value within the CDF-S XT2 region to the entire galaxy region. We obtain \(F_{\text{light}} = 0.0\) for CDF-S XT2, which is consistent with \(F_{\text{light}}\) values of the majority of known SGRBs (see Fig. 3c).

To better discern whether the origin of CDF-S XT2 is a merger of neutron stars, we calculate the probability, \(O(\text{II:I})_{\text{host}}\), of the source being similar to long GRB (LGRB) (massive-star collapse type, or type II) versus SGRB (compact-star merger type, or type I) populations based on the statistical properties of the host-galaxy data of the two types \(^{15,26,27}\). The criteria used include how each of the following observed parameters compares with the distributions of both LGRBs and SGRBs collected \(^{27}\): stellar mass, SFR, metallicity, offset and galaxy size. The probability for each criterion for each category is calculated, and \(O(\text{II:I})_{\text{host}}\) is defined as the product of the LGRB-to-SGRB probability ratios for all criteria. By definition, a negative (or positive) \(\log[O(\text{II:I})_{\text{host}}]\) value indicates a merger (or collapsar) origin. We obtain \(\log[O(\text{II:I})_{\text{host}}] = -0.8\), which is roughly the median value of known SGRBs and is smaller than that of 98% of known LGRBs (see Fig. 3d). This indicates that CDF-S XT2 is very likely to be of compact-star merger origin.

A rapidly spinning magnetar has a spindown luminosity that evolves with time as \(L_{\text{sd}} \propto t_0/(1 + t_0/t_{\text{sd}})^2\). This can be approximated as \(L_{\text{sd}} \propto t_0^2\) for \(t \ll t_{\text{sd}}\) and \(L_{\text{sd}} \propto t_{\text{sd}}^2\) for \(t \gg t_{\text{sd}}\) (refs \(^{28,29}\)). The observed light curve is consistent with such an evolution (see Fig. 1a and Methods). At \(z = 0.738\), an SGRB with \(L_{1-10^6\text{ keV}} < 1.5 \times 10^{41}\) erg s\(^{-1}\) (including 170817A-like GRBs) would be too faint to trigger Fermi/GBM and other GRB detectors (see Methods). Therefore, CDF-S XT2 could be, in principle, associated with a low-luminosity SGRB below the Fermi and INTEGRAL detection limits. In any case, the lack of a detectable SGRB is consistent with an off-axis jet configuration. Such a geometry has a larger probability of being detected, consistent with the possibility that CDF-S XT2 is the first such event detected.

We estimate the event-rate density (or the volumetric rate) of CDF-S XT2-like events to be \(1.3^{+2.8}_{-1.8} \times 10^3\) Gpc\(^{-3}\) yr\(^{-1}\), taking into account a number of factors that include, for example, the event searching procedure, varying sensitivities across the Chandra/ACIS-I field of view (FOV), and the X-ray spectral shape and peak luminosity of CDF-S XT2 (see Methods). We note that CDF-S XT1 is not included in the estimation of the rate, because its observational properties are different from CDF-S XT2 and it probably belongs to a different type of transient (see Methods). From the redshift evolution of the event-rate density of SGRBs given three different merger delay models \(^{30}\), one can derive the corresponding local event-rate density of CDF-S XT2-like events, which is \(1.8^{+1.3}_{-1.8} \times 10^3\) Gpc\(^{-3}\) yr\(^{-1}\). This is consistent with the event-rate density for neutron-star mergers inferred from the detection of

![Fig. 3](image-url)
GW170817 by the LIGO–Virgo Collaboration1, that is, $1.5^{+2.2}_{-1.0} \times 10^{5}$ Gpc$^{-3}$ yr$^{-1}$. The lower limit on the event-rate density remains consistent with that of 170817A-like SGRBs (that is, $190^{+440}_{-160}$ Gpc$^{-3}$ yr$^{-1}$) inferred from the Fermi/GBM detection4. This leaves open the possibility that the viewing angle of CDF-S XT2 could be comparable to or even smaller than that of GW170817/GRB 170817A, even if the viewing angle of the former is probably larger.

The Thomson optical depth for X-rays should be below unity so that they can escape from the ejecta surrounding the magnetar. This requires that the viewing angle is in the so-called ‘free zone’12 if the merger occurred immediately before the onset of X-ray emission, which requires the line of sight to have been cleared by a low-luminosity jet-like outflow7,8. Numerical simulations8 showed that a magnetar can open a funnel with a moderate opening angle of about one radian within approximately 100 s, and a possible undetected low-luminosity SGRB could also help to open the gap. The required magnetar parameters can be made consistent with those inferred from the observations (see Methods).

Other mechanisms to produce cosmological X-ray transients are disfavoured by the observational data of CDF-S XT2 (see Methods). Low-luminosity LGRBs or massive-star shock breakout events are typically associated with active star formation. This is inconsistent with the host-galaxy type of CDF-S XT2 and its large offset with respect to the host-galaxy centre. GRB orphan afterglows and tidal disruption events typically have much longer durations and very different light-curve shapes. Comparison of CDF-S XT2 with future multi-messenger observations of X-ray transients directly detectable by gravitational wave detectors will help to verify its origin as a merger of neutron stars, and provide unprecedented insight into the physics of mergers of neutron stars.

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Correspondence and requests for materials should be addressed to Y.Q.X., X.C.Z. or B.Z.

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METHODS

Chandra data reduction and extraction of light curves and spectra. We reduced and analysed the 7-Ms CDF-S observations17 using the Chandra Interactive Analysis of Observations (CIAO version 4.8; http://cxc.harvard.edu/ciao/) tools, the MARX-ray-tracing simulator (version 5.3; https://space.mit.edu/cxc/marx/), ACIS Extract (AE version 2016May25)19, and custom software. In brief, we applied charge transfer inefficiency corrections, removed bad pixels, flagged cosmic-ray background events, discarded faint afterglow events with ≥3 total counts that fall onto the same pixel within 20 s, and rejected background flares in an appropriate way15 to obtain a cleaned event file for each individual observation. We then registered and aligned all individual observations to a common accurate astrometric frame (that is, the TENIS Ks-band catalogue20) and merged them into a combined master event file that is ready for the extraction of images, light curves, spectra and so on. Our procedure of data reduction ensures the best possible X-ray source positions and reliable photometry, which is particularly critical for faint sources.

Using the cleaned master event file, we extracted the 0.5–7-keV light curves and spectra of CDF-S XT2 (see Fig. 1) within a r = 3.5″ (corresponding to an encircled energy fraction of about 95% given its off-axis angle of 4.5″ in ObsID 16453) circular source region centred at its position. Its photons were detected only within ObsID 16453 and aggregated 136 in total (see Extended Data Table 1), which enabled AE to derive an accurate X-ray position of the source by taking the local ACIS-I point spread function into account. The source position and associated uncertainty are given by the AE keywords of RA_DATA, DEC_DATA, and ERR_DATA, which are the mean/centroid data position and corresponding standard error that is computed using the variances of the point spread function and that background within the extraction region, respectively. Over the duration of CDF-S XT2, the individual pixels that recorded the detected photons traced out portions of the Lissajous pattern expected as a result of Chandra dither, indicating that the source is indeed celestial. The background level is very low in the source region, indicating a highly significant detection: we extracted the background in a source-free annulus centred around the source whose area is ten times that of the source region, and found only seven background photons during the outburst, which indicates 0.7 photons expected in the source region. This background level is consistent with the mean background level of 0.184 photons Ms−1 pixel−1 in the 7-Ms CDF-S20, and there was no sign of a peak of the background flux throughout the outburst. Hence, we conclude that we can ignore the influence of the background in our analysis.

No high-energy (γ-ray) trigger. CDF-S XT2 was in the FOV of Fermi/GBM during Tp = ±1,000 s. We examined the light curves of the eight GBM detectors around Tp, the pointing angles of which were within 60 degrees with respect to the source location. We found no relevant source-like γ-ray emission signal above background. We then extracted the spectra of GBM detectors n4, n5 and b0 during Tp = ±25 s, confirming that the extracted spectra are consistent with the background spectrum. Subsequently, we calculated the source count limits26 at the 90% confidence level (SLL(SLL)) in each energy channel i based on the corresponding observed counts and background counts, and obtained the flux upper limits by fitting the power-law model to a simulated spectrum realized based on (SLL, SLL). The flux upper limits are Γ0,1−30 keV = 6.0×10−7 erg cm−2 s−1, f0,3−10 keV = 2.4×10−9 erg cm−2 s−1 and f0,100 keV = 1.4×10−8 erg cm−2 s−1, respectively, with the corresponding isotropic rest-frame luminosity upper limits being L0,1−30 keV = 1.5×1048 erg s−1, f0,3−10 keV = 6.1×1039 erg s−1 and f0,100 keV = 3.5×1040 erg s−1, respectively. We also estimated the Fermi/LAT flux and isotropic rest-frame luminosity upper limits, during Tp = ±10 s, to be f0,100 MeV−30 GeV = 6.0×10−10 erg cm−2 s−1 and L0,MeV−30 GeV = 1.5×1048 erg s−1, respectively.

A search for a γ-ray component temporally and spatially coincident with CDF-S XT2 with the Swift/BAT data also led to a negative result (A. Lien, personal communication). This is consistent with the facts that Fermi/GBM is more sensitive than Swift/BAT in detecting SGRBs and that the BAT SGRB population is consistent with the GBM SGRB population15.

X-ray spectral fitting. To inspect the spectral variation, we not only used XSPEC35 to fit the entire unbinned spectrum (Spec_0) throughout the event, but also fitted the unbinned spectrum before (Spec_1) and after 2,000 s (Spec_2) with the Cash statistic (C), which is the dividing point close to the break time (see Fig. 1a) and can balance the total counts in the two segments. The model we used was phabs (x (zphabs xpow)), which includes the Galactic absorption (fixed to a column density of 8.8×1020 cm−2)20, the intrinsic absorption (NHI), and the intrinsic power-law component (Γ), and fits all the spectra well (see Extended Data Table 2 for details). We obtained Γ = 1.93 ± 0.60 and NHI = 0.61 ± 0.10 × 1021 cm−2 for Spec_0 and 1.92 ± 0.60 and NHI = 0.62 ± 0.10 × 1021 cm−2 for Spec_2, respectively. To derive an luminosity-equivalent energy emission in the 0.3–10-keV band of flux38×10−15 erg cm−2 s−1, we estimated the spectral profile and linked NHI, and Case D (linked Γ and linked NHI), and adopted the Akaike information criterion39 (AIC = C + 2k, where k is the number of free parameters in the model) to identify which model fits the data best.

According to Extended Data Table 2, Case B has the smallest AIC and therefore describes Spec_1 and Spec_2 best, indicating that NHI is probably constant throughout the outburst and that Γ increases from Spec_1 to Spec_2 (that is, spectral softening, which is significant at a confidence level of about 99% given exp(AICN − AICN0) = 0.11; see also Fig. 1c). This likely spectral evolution cannot be compared with the magnetor model predictions because the latter are currently unavailable.

Estimation of rise time. In Fig. 1a, it is clear that the flux reaches its peak at the very beginning, which implies an extremely short rise time. However, because of the small number of counts in the first few bins, we cannot easily determine the exact position of the peak. There are two possibilities: the first photon is in the rising period of the light curve, and hence the high flux is due only to our binning strategy, or the first photon is really at the peak. If the first scenario is true, we should find some clues in the analysis of the intervals between the recorded arrival times of the photons during the beginning of the light curve, but we found that the intervals between the first few photons do not show any particular pattern. We also inspected the relative positions of the first 19 photons arriving within the first six bins in the event (see Extended Data Table 1) and found that each pair of neighbouring photons is well separated, which excludes the possibility of any residual cosmic-ray effect during the period. We take this as evidence that the first photon is at the peak or at least near the peak.

For the case of not detecting any photons in the rising period, we can estimate the rise time based on the Poisson distribution. Assuming that the rise profile is linear and the rise time is Tr, we can write the probability that we do not observe any photon at the ith frame since the event occurs:

$$P_{T_r}(i) = e^{-\frac{f_{i}}{T_r}}$$

and

$$P(n) = e^{-\frac{n f_{i}}{T_r}} \frac{(n f_{i})^n}{n!}$$

From equation (3), we can obtain the 1σ upper limit on the rise time, approximately 45 s (that is, about 26 s in the rest frame).

During the period from the start time of ObsID 16453 to the arrival of the first photon of CDF-S XT2, we estimate a background photon flux level of (2.4 ± 0.6) × 10−10 counts s−1, which corresponds to a flux upper limit of (3.1 ± 0.8) × 10−15 erg cm−2 s−1 (assuming Γ = 1.4, that is, the spectral slope of the cosmic X-ray background) before the onset of the outburst.

Determination of the offset between CDF-S XT2 and its host galaxy. There are 18 HST/WFC3 F125W-band exposures that cover CDF-S XT2 during 12 visits. For each observation, we consider only the portion of the image that is local to CDF-S XT2, that is, within a roughly circular area with r = 2″ around CDF-S XT2, in order to reduce the likely effect of astrometric variation across the FOV. We use SExtractor to find sources in the 18 local images that are free of cosmic-ray events, and then register and combine them using the standard commands tweakreg and AstroDrizzle, respectively. The root mean squares of the registrations between different images are about 0.1 pixel (with a pixel size of 0.06″), which indicates good astrometric registrations. Subsequently, we use SExtractor to find sources in the local combined F125W image and register it to the astrometric frame of the 7-Ms CDF-S main catalogue40. By doing this, we ensure that the X-ray image of CDF-S XT2 from ObsID 16453 and the local combined F125W image have the same astrometric frame (accurate to about 0.2″), which guarantees a reliable determination of the offset between CDF-S XT2 and its host galaxy (see Fig. 3a).

We also perform the above procedures using the 16 HST/WFC3 F160W-band observations that cover CDF-S XT2 and obtain essentially the same results. Here we choose to report the F125W-band results, given that the F125W-band probes a median rest-frame wavelength of about 7,200 Å and traces the stellar distribution of the galaxy better than the F160W band (corresponding to about 9,200 Å).
Multimwavelength observations in the CDF-S XT2 neighbourhood. We display in Extended Data Fig. 1 the 0.5–7-keV image (ref. 17) and the HST/CANDELS F160W-band image29 of the CDF-S XT2 neighbourhood. We show in Extended Data Table 3 the properties of the six closest galaxies31 within a radius of 5′ around CDF-S XT2 in the HST/CANDELS F160W DR1 catalogue29.

The X-ray position of CDF-S XT2 (with a total of 136 photons detected) is solely determined by ObsID 16453, within which its outburst occurred, which is slightly (about 0.3″, being smaller than the X-ray image pixel size of 0.49″) northeastward of the X-ray position of the source XIDM391, reported in the 7-Ms CDF-S main catalogue31. XIDM391 was initially identified as being the same source as XIDM391 in the 4-Ms CDF-S main catalogue31. XIDM391 was also the mean background count rate of the 7-Ms CDF-S17. The fluctuation is smaller than the X-ray image pixel size of 0.49″, and we divide the central survey. Since the detection limit of the 7-Ms CDF-S is a function of off-axis angle, which limits the actual FOV considered to the central 5′. We discuss other X-ray transient types that might be considered when interpreting CDF-S XT2 as is clearly shown in Extended Data Fig. 1 and Extended Data Table 3.

The host galaxy of CDF-S XT2 is a dwarf galaxy (labelled 1 in Extended Data Fig. 1) with a secure spectroscopic redshift of 0.738 and an irregular-disk morphology, while the X-ray photons of XIDM391 were from an elliptical galaxy (labelled 2) with a secure spectroscopic redshift of 0.740 and a pure-bulge morphology. These two galaxies probably belong to the same prominent large-scale structure at z ≈ 0.73 in the Extended-CDF55,60. Given that XIDM391 was reported with a low count rate of 7.5 × 10^−3 counts s^−1, similar to the average level of XIDM391, the expected contribution from the elliptical during the outburst of CDF-S XT2 is ≤ 0.2 photons, and can be ignored when analysing the Chandra data of CDF-S XT2.

**Magnetar parameters.** Assuming dipolar spindown, the magnetar parameters may be estimated using the relations:

\[ L_x = 10^{45} \text{erg s}^{-1} \]

\[ \eta = 10^{-3} \text{ yr}^{-1} \]

\[ R_n = \frac{1.6 \times 10^{12} \text{ cm}}{3 \times 10^{15} \text{ erg s}^{-1}} \]

\[ D_{\text{c}} = 10^{11} \text{ yr} \]

\[ D_{\text{z}} = 10^{11} \text{ yr} \]

where \( L_x \) is the X-ray luminosity, \( \eta \) the efficiency of converting spindown luminosity to X-ray luminosity (\( \eta = 10^{-3} \)), and noting that \( L_x \approx 1.9 \) for a supramassive neutron star after the merger of two neutron stars, we obtain:

\[ B_{p,15} = 1.6 \eta_{12}^{1/2} \]

\[ R_{n,30} = 1.7 \eta_{12}^{1/2} \]

if we scale \( L_x \) to the CDF-S XT2 peak luminosity and assume that \( t_{\text{fo}} = t_{\text{ad}} = 3.2 \times 10^3 \) ks. Reasonable magnetar parameters can be obtained if \( \eta \) is of the order of 10^−3. With such parameters and assuming that the ejecta mass is \( M_{\text{ej}} \approx 0.01 M_{\odot} \), we obtain a magnetar–ejecta interaction parameter \( E/M_{\text{ej}} = 3 \times 10^{16} \text{ erg} \), which is between the “low” and “average” cases studied in figure 2 of ref. 8. Given such parameters, the magnetar wind could open a reasonably large funnel within approximately 100 s, so that X-rays can be detected at a relatively large viewing angle, as might be the case for CDF-S XT2.

**Estimation of event-rate density.** While searching for transient events in the 7-Ms CDF-S, we required the sources to be covered by all the 102 CDF-S observations, which limits the actual FOV considered to the central \( r = 8′ \) area of the CDF-S survey. Since the detection limit of the 7-Ms CDF-S is a function of off-axis angle, we divide the central \( r = 8′ \) FOV into a series of narrow concentric annuli with a width of \( \Delta r \) to determine the minimum 0.5–7-keV counts of an X-ray source required for a detection in each annulus, that is, the detection limit in each annular region. Following the original transient-searching procedure34 and considering that the background of the 7-Ms CDF-S is stable31, we assume a background region ten times that of the source region and estimate the expected background counts for the source in a 70-ks observation (that is, the exposure of ObsID 16453) using the mean background count rate of the 7-Ms CDF-S. The fluctuation (\( \sigma \)) of the background counts is given by the Poisson distribution. For short events like CDF-S XT2, we assume that all the photons during the outburst can be caught in a single

Chandra observation of typical exposure. If the net counts of the source exceed the mean background level by 3\( \sigma \), then we consider it to be a detected X-ray transient. For events with a spectral shape and peak luminosity similar to that of CDF-S XT2, we can then use the 3\( \sigma \) counts limit to derive the maximum redshift \( z_{\text{max}} \) to which we may detect such an event. Combining the FOV size being considered and the rest-frame monitoring time, we finally estimate the observed event rate density as follows:

\[ \frac{dN}{dt} = \frac{1}{t_{\text{bur}}^2} \int_{z_{\text{min}}}^{z_{\text{max}}} \frac{dN}{dz} \]
a relatively low SFR. The large offset of the source from the host galaxy is also at odds with an LGRB origin.

(4) Shock breakout events such as the X-ray Outburst XRO 080109\(^ {36} \) have a luminosity 1–2 orders of magnitude lower than that of CDF-S XT2. The shape of the light curve of XRO 080109 is very different from that of CDF-S XT2, which shows no evidence of a magnetar-powered plateau. Even though the host galaxy of XRO 080109 (that is, NGC 2770) is a regular spiral galaxy, the transient occurred in the brightest region of the host galaxy, being consistent with a massive star core collapse origin. Indeed, it was associated with a type Ibc supernova, SN 2008D. In contrast, the location of CDF-S XT2 is offset from the host galaxy, with little evidence of star formation in the neighbourhood. Therefore, a shock breakout origin is disfavoured.

Data availability
The data that support the plots within this paper and other findings of this study are available from the corresponding authors upon reasonable request.

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Extended Data Fig. 1 | Multiwavelength images of the CDF-S XT2 neighbourhood. a, Merged Chandra 0.5–7-keV image including the entire 7-Ms CDF-S survey. b, Same as a, but excluding ObsID 16453.

Data correspond to 0.5–7-keV image from ObsID 16453 alone. The large dashed circle marks the source region (r = 3.5″) for the extraction of light curves and spectra. The X-ray images in a–c are rendered in counts using the same linear scale, with pixel values ranging from 0 to 8. d, HST/CANDELS F160W image. In each panel, the small red circle marks the position and 1σ positional uncertainty of the source with XID_{7Ms} 330 reported in the 7-Ms CDF-S main catalogue17, while the cyan circle denotes that of the source with XID_{4Ms} 256 reported in the 4-Ms CDF-S main catalogue38. The magenta numbers and crosses mark the object numbers of the six closest galaxies to CDF-S XT2 (see Extended Data Table 2) and their positions in the CANDELS F160W DR1 catalogue22, respectively. For clarity, the position of CDF-S XT2 is not annotated; it is slightly (about 0.3″) northeastern to that of XID_{7Ms} 330.
### Extended Data Table 1 | Light curve of CDF-S XT2 in logarithmic bins

| Time (s) | Bin width (s) | Counts | Count rate \( \text{(count s}^{-1}) \) | \( F_{0.5-7 \text{ keV}} \) \( \text{\( \text{(erg s}^{-1} \text{ cm}^{-2}) \)} \) | \( L_{0.3-10 \text{ keV}} \) \( \text{\( \text{(erg s}^{-1}) \)} \) |
|----------|---------------|--------|-------------------------------|---------------------------------|---------------------------------|
| 4        | 8             | 0      | 0.0                           | \( 0.0^{+2.9}_{-0.0} \times 10^{-12} \) | \( 0.0^{+1.0}_{-0.0} \times 10^{46} \) |
| 16       | 16            | 1 \( 6.3^{+10.5}_{-5.2} \times 10^{-2} \) | \( 7.8^{+18.3}_{-6.5} \times 10^{-13} \) | \( 2.7^{+6.3}_{-2.3} \times 10^{45} \) |
| 40       | 32            | 2 \( 6.3^{+8.3}_{-4.0} \times 10^{-2} \) | \( 7.8^{+10.4}_{-5.0} \times 10^{-13} \) | \( 2.7^{+3.6}_{-1.8} \times 10^{45} \) |
| 88       | 64            | 3 \( 4.7^{+4.6}_{-2.5} \times 10^{-2} \) | \( 5.9^{+5.7}_{-2.9} \times 10^{-13} \) | \( 2.0^{+2.0}_{-1.1} \times 10^{45} \) |
| 184      | 128           | 3 \( 2.3^{+2.3}_{-1.3} \times 10^{-2} \) | \( 2.9^{+2.9}_{-1.6} \times 10^{-13} \) | \( 1.0^{+1.0}_{-0.6} \times 10^{45} \) |
| 376      | 256           | 10 \( 3.9^{+1.7}_{-1.2} \times 10^{-2} \) | \( 4.9^{+2.1}_{-1.5} \times 10^{-13} \) | \( 1.7^{+0.7}_{-0.5} \times 10^{45} \) |
| 760      | 512           | 15 \( 2.9^{+1.0}_{-0.7} \times 10^{-2} \) | \( 3.7^{+1.2}_{-0.9} \times 10^{-13} \) | \( 1.3^{+0.4}_{-0.3} \times 10^{45} \) |
| 1528     | 1024          | 36 \( 3.5^{+0.6}_{-0.6} \times 10^{-2} \) | \( 4.4^{+0.7}_{-0.7} \times 10^{-13} \) | \( 1.5^{+0.3}_{-0.3} \times 10^{45} \) |
| 3064     | 2048          | 42 \( 2.1^{+0.4}_{-0.3} \times 10^{-2} \) | \( 2.6^{+0.5}_{-0.4} \times 10^{-13} \) | \( 8.9^{+1.6}_{-1.4} \times 10^{44} \) |
| 6136     | 4096          | 13 \( 3.2^{+1.2}_{-0.9} \times 10^{-3} \) | \( 4.0^{+1.4}_{-1.1} \times 10^{-14} \) | \( 1.4^{+0.5}_{-0.4} \times 10^{44} \) |
| 12280    | 8192          | 9 \( 1.1^{+0.5}_{-0.5} \times 10^{-3} \) | \( 1.4^{+0.6}_{-0.4} \times 10^{-14} \) | \( 4.8^{+2.2}_{-1.6} \times 10^{43} \) |
| 24568    | 16384         | 2 \( 1.2^{+1.6}_{-0.8} \times 10^{-4} \) | \( 1.5^{+2.0}_{-1.0} \times 10^{-15} \) | \( 5.3^{+7.1}_{-3.4} \times 10^{42} \) |

*The time value is the middle time in each bin (t = 0 s is set to be 10 s before the arrival of the first photon).
†These relatively low count rates essentially eliminate the pile-up issue (that is, when two or more photon events overlap in a single frame and are read as a single event, which becomes problematic only for very bright (high count rate) sources).
‡The flux and luminosity values are obtained based on the count rate, exposure time and overall power-law spectral slope of CDF-S XT2.
Extended Data Table 2 | X-ray spectral fitting results for CDF-S XT2

| Case (Spec_1 & Spec_2) | Spectral fitting results | C/d.o.f | goodness | AIC |
|------------------------|--------------------------|---------|----------|-----|
| A: free $\Gamma$ & free $N_H$ | $\Gamma_1 = 1.45^{+0.68}_{-0.56}$, $\Gamma_2 = 2.67^{+0.92}_{-0.74}$, $N_{H1} = 0.45^{+1.60}_{-0.45}$, $N_{H2} = 1.03^{+1.54}_{-1.03}$ | 361.61/882 | 53% | 373.61 |
| B: free $\Gamma$ & linked $N_H$ | $\Gamma_1 = 1.57^{+0.55}_{-0.50}$, $\Gamma_2 = 2.53^{+0.74}_{-0.64}$, $N_{H1} = N_{H2} = 0.77^{+1.06}_{-0.77}$ | 361.81/883 | 49% | 371.81 |
| C: linked $\Gamma$ & free $N_H$ | $\Gamma_1 = \Gamma_2 = 2.01^{+0.54}_{-0.42}$, $N_{H1} = 1.45^{+1.65}_{-1.19}$, $N_{H2} = 0.25^{+0.99}_{-0.25}$ | 365.35/883 | 48% | 375.35 |
| D: linked $\Gamma$ & linked $N_H$ | $\Gamma_1 = \Gamma_2 = 1.93^{+0.52}_{-0.46}$, $N_{H1} = N_{H2} = 0.61^{+1.00}_{-0.61}$ | 368.14/884 | 44% | 376.14 |

Spec_0 | $\Gamma = 1.93^{+0.52}_{-0.47}$, $N_H = 0.61^{+1.00}_{-0.61}$ | 261.99/441 | 44% | — |

$\Gamma_1$ and $N_{H1}$ are for Spec_1; $\Gamma_2$ and $N_{H2}$ are for Spec_2; $N_H$ values are in units of $10^{22}$ cm$^{-2}$; d.o.f, degrees of freedom; all goodness-of-fit values (obtained using the goodness command in XSPEC) are around 50%, which indicates that the fits are good. C is the Cash statistic.
Extended Data Table 3 | Properties of the six closest galaxies to CDF-S XT2

| #  | CANDELS ID | RA (°) | DEC (°) | Offset (") | $m_{F606W}$ | $m_{F160W}$ | z_{best} | $M_{F606W}$ | log($M_*/M_\odot$) | SFR ($M_\odot$ yr$^{-1}$) | Morphology |
|----|------------|--------|---------|------------|-------------|-------------|----------|-------------|----------------|-------------------|------------|
| 1  | 4167       | 53.0765804 | -27.8738154 | 0.42 | 25.35 | 23.85 | 0.738 | -17.93 | 9.07 | 0.81 | Irregular disk |
| 2  | 4210       | 53.0760576 | -27.8736135 | 1.57 | 23.15 | 21.49 | 0.740 | -20.14 | 9.77 | 15.49 | Pure bulge |
| 3  | 4059       | 53.0765953 | -27.8738338 | 1.63 | 25.45 | 24.82 | 3.140 (3.06–3.20) | -21.68 | 8.83 | 19.50 | N/A |
| 4  | 4032       | 53.0766334 | -27.8742376 | 3.07 | 25.85 | 24.61 | 1.218 (1.15–1.29) | -18.78 | 8.75 | 0.52 | N/A |
| 5  | 28140      | 53.0775843 | -27.8727073 | 4.29 | 27.13 | 26.75 | 1.638 (1.49–1.78) | -18.28 | 8.04 | 0.37 | N/A |
| 6  | 28134      | 53.0751600 | -27.8730197 | 4.42 | 29.00 | 26.88 | 1.688 (0.73–3.15) | -16.50 | 8.42 | 0.78 | N/A |

(1) Object number. (2) CANDELS ID. (3, 4) F160W-band position (right ascension and declination)$^{22}$. (5) Nominal offset between the F160W-band position and the X-ray position of XID_\text{X} 330$^{17}$. Without performing a careful astrometric alignment between the two catalogues$^{17,22}$, (6, 7) Apparent AB magnitudes in the F606W and F160W bands. (8) Best redshift estimate$^{23}$. The redshifts of 4167 and 4210 are spectroscopic, while the other four are photometric, with their 1σ confidence ranges shown in parentheses. (9) Absolute F606W-band AB magnitude based on the best redshift. (10, 11) Median stellar mass and SFR of the spectral energy distribution fitting results from five teams$^{23}$. (12) Morphology measurement$^{17}$. 