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DISCOVERY OF A NEW KIND OF EXPLOSIVE X-RAY TRANSIENT NEAR M86

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ABSTRACT

We present the discovery of a new type of explosive X-ray flash in *Chandra* images of the old elliptical galaxy M86. This unique event is characterized by the peak luminosity of 6×10^{42} erg s^{-1} for the distance of M86, the presence of precursor events, the timescale between the precursors and the main event (∼4000 s), the absence of detectable hard X-ray and γ-ray emission, the total duration of the event, and the detection of a faint associated optical signal. The transient is located close to M86 in the Virgo cluster at the location where gas and stars are seen protruding from the galaxy probably due to an ongoing wet minor merger. We discuss the possible mechanisms for the transient and conclude that the X-ray flash could have been caused by the disruption of a compact white dwarf star by a $\sim 10^4\ M_\odot$ black hole. Alternative scenarios such that of a foreground neutron star accreting an asteroid or the detection of an off-axis (short) γ-ray burst cannot be excluded at present.

Key words: black hole physics – galaxies: individual (M86) – galaxies: interactions – X-rays: individual (XRT 000519)

Online-only material: color figures

1. INTRODUCTION

The universe is not static: optical, infrared, radio, X-ray, and γ-ray observations reveal a rich diversity in variability and explosions. In the X-ray band the observed variability on timescales of hours to days has been attributed to exploding massive stars (Mészáros 2006), the accretion of material onto neutron stars, or stellar-mass (Fender & Belloni 2012) or supermassive black holes (SMBHs) such as in active galactic nuclei (AGNs; Fabian 2012). The disruption of a star by an SMBH has also been observed (Komossa et al. 2004).

While stellar black holes up to $\sim 16\ M_\odot$ (for example, in M33 X-7; Orosz et al. 2007) and SMBHs in AGNs with masses of $>10^5\ M_\odot$ (Greene & Ho 2007) have been identified, black holes with masses of several hundred to a few thousand solar masses remain elusive. Ultra-luminous X-ray sources (ULXs) could harbor such black holes with masses in between the stellar-mass black holes found in X-ray binaries and the SMBHs ($\gtrsim 1 \times 10^5\ M_\odot$) found in the centers of galaxies. The ULX near ESO 243-49 is possibly the best intermediate-mass black hole (IMBH) candidate (Farrell et al. 2009).

Theoretically, the mass of a stellar-mass black hole, formed from the evolution of a massive star, depends on the initial mass of the progenitor, on the supernova explosion mechanism (Belczynski et al. 2010; Fryer et al. 2012), and on how much mass is lost during the progenitor's evolution, which, in turn, is a function of the metallicity of the black hole progenitor star. Mass is lost through stellar winds, and the mass-loss rate strongly depends on the metallicity of the star. For a low-metallicity star (∼0.01 solar metallicity) it is possible to leave a black hole of $\lesssim 70\ M_\odot$ (Belczynski et al. 2010). Thus, theories do allow for more massive stellar-mass black holes than have been found so far in our Galaxy (e.g., Özel et al. 2010).

In very massive stars ($\gtrsim 130\ M_\odot$) production of free electrons and positrons, due to increased γ-ray production, reduces thermal pressure inside the core. This eventually leads to a runaway thermonuclear explosion that completely disrupts the star without leaving a black hole, causing the upper limit for a stellar black hole of $\sim 100\ M_\odot$. It has been suggested that metal-free Population III stars could have had masses above this pair-instability limit and collapsed into IMBHs (Madau & Rees 2001). It has also been suggested that IMBHs may form in the centers of dense stellar clusters via the merger of stellar-mass black holes (e.g., Miller & Hamilton 2002), or from the collapse of merged supermassive stars in very dense star clusters (e.g., Portegies Zwart & McMillan 2002). These massive black holes could allow for the assembly of SMBHs early in the universe (e.g., Volonteri 2010, 2012).

Stellar dynamical models predict that once every 10^3–10^5 yr a star in a galaxy will pass within the tidal disruption radius of the central black hole and thus will be torn apart by tidal forces (Wang & Merritt 2004). The fall-back of debris onto the black hole produces a luminous electromagnetic flare that is detectable in UV and X-ray light. Several UV transients coincident with the center of a galaxy have been detected (e.g., Gezari et al. 2008). Candidates detected so far in X-rays using *ROSAT*, *XMM-Newton*, and *Chandra* had blackbody temperatures with $kT = 0.04$–0.12 keV (Komossa & Bade 1999; Komossa et al. 2004; Esquej et al. 2008). Tidal disruption events (TDEs) have a rise time of hours to weeks. The timescale for the light curve to peak depends on the black hole mass, with lower mass black holes having shorter rise times, and on the compactness of the disrupted star, with more compact stars, like white dwarfs, allowing for a shorter rise time. Recently, a new manifestation of TDEs was reported. The new extreme source discovered by *Swift* (Swift J164449.3+573451) is caused by

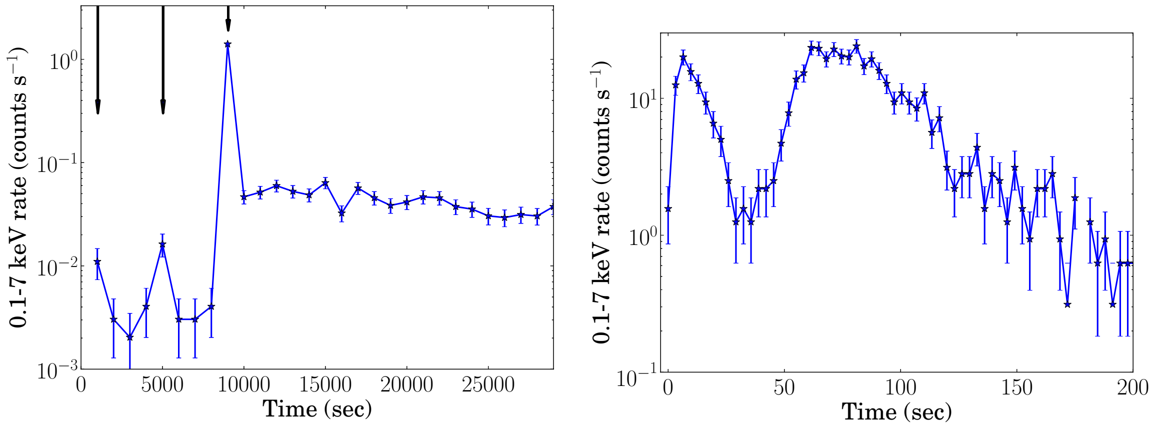

Figure 1. Left panel: the light curve of the transient X-ray event XRT 000519 in the 0.1–7 keV energy range at a resolution of 1000 s, to show the late-time power-law decay and the presence of the precursor events, taking place approximately 4000 s and 8000 s before the main event. The precursors and the main event are indicated by arrows separated by 4000 s. Time zero on the *X*-axis corresponds to the start of the *Chandra* observation. Right panel: zoom-in on the third (main) peak in the light curve of the transient X-ray event XRT 000519 in the 0.1–7 keV energy range at the full time resolution of 3.2 s afforded by the *Chandra* detector used. The peak count rate of the second bright peak corresponds to a 0.1–7 keV flux of 2×10^{-10} erg cm^{-2} s^{-1}. Zero on the *X*-axis corresponds to the start of the main X-ray event at $T = 9571$ s in the left panel.

(A color version of this figure is available in the online journal.)

relativistic jet emission launched due to a TDE (Levan et al. 2011; Bloom et al. 2011). The source had an extreme X-ray luminosity (10^{47} erg s^{-1}) that lasted for months. A power-law-like spectrum was detected in X-rays. During a possibly super-Eddington early phase in a TDE, the source can produce brief flares, of duration of order a thousand seconds. Whereas most TDEs are associated with the center of a galaxy, in principle one could find them also outside the core of a galaxy (see e.g., Jonker et al. 2012).

We here present the discovery of a new transient X-ray source. The properties of this transient event seem to be most compatible with those predicted for the tidal disruption of a compact (white dwarf) star by an IMBH.

2. OBSERVATIONS, ANALYSIS, AND RESULTS

2.1. *Chandra X-Ray Observation*

We identified a new type of X-ray transient in a *Chandra* observation that started on 2000 May 19 UT (universal time). We assign the name X-ray transient (XRT) 000519 to this event. The transient was discovered in *Chandra* images with observation identification number 803. The source position was covered by the S4 CCD of the ACIS-S array of CCD detectors (Garmire 1997). We reprocessed and analyzed the data using the CIAO 4.5 software developed by the *Chandra* X-Ray Center and employing CALDB version 4.5.5.1. The data telemetry mode was set to *very faint*, which allows for a thorough rejection of events caused by cosmic rays.

The ACIS-S4 CCD is known to be suffering from an error in the readout where charge unrelated to the arrival of X-ray photons is deposited during readout of the CCD. These events can be removed in the subsequent processing of the event file by using the DESTREAK command in the CIAO software suite provided by the *Chandra* X-Ray Center (Fruscione et al. 2006). XRT 000519 is still detected at a very high significance level after we run the DESTREAK command. However, given that this tool also removes some charge from genuine X-ray photons when the X-ray source is very bright, we extracted the data from the peak of XRT 000519 without applying the DESTREAK step.

Using the WAVDETECT tool on the X-ray image allows us to locate the event at (J2000) right ascension $12^{h}25^{m}31^{s}.64$ and declination $+13^{\circ}03'58''.8$ with an estimated 68% confidence uncertainty in the position of $1''$ due to the large angle of $13'.37$ between the optical axis of the *Chandra* mirrors and the location of the source on the detector. We investigated the point-spread function of the source by performing a MARX simulation for such an off-axis angle, and we find that the observed point-spread function is consistent with that expected on the basis of the simulation. Due to the large off-axis angle, the source photons were spread over hundreds of detector elements, making spectral distortion due to photon pileup minimal.

The light curve of the main event, plotted at the maximum time resolution of 3.24 s, is double peaked (see Figure 1). The source flux rises within 10 s from being undetected to a peak count rate of 20 counts s^{-1}, decays more slowly over a period of 20 s to a count rate just above 1 count s^{-1}, and rises again to the peak count rate of 24 counts s^{-1}. The second peak has a flat top that lasts around 20 s, before gradually decreasing on a timescale of about 100 s, followed by a slow power-law decay with an index of -0.3 ± 0.1 that could be followed for 2×10^{4} s until the end of the observation.

When investigating the X-ray light curve of the source, we found evidence for the presence of a precursor event of 16 X-ray photons about 4000 s before the main flare. In the same 1000 s interval of time of the precursor, we find four photons due to the background in a source-free region with the same size as the source region, on the same CCD and at a similar off-axis angle as XRT 000519. Thus, the chance of finding 16 photons due to random variations in the background is less than 1 in 250,000. Interestingly, there is evidence for another precursor event, again about 4000 s earlier. In that case, we find 11 photons in 1000 s where 3.7 are found in an off-source region over the same time; this should happen by chance in less than 1 in 650,000 cases. Therefore, we conclude that these two precursor events are likely to be real. The small number of events (three) does not allow us to conclude that the 4000 s timescale is periodic.

We extracted the source spectrum from photons in a circular region with radius of $30''$ centered on the source position of XRT 000519 in the energy range of 0.1–7 keV. Background events were extracted from an annulus centered on the position

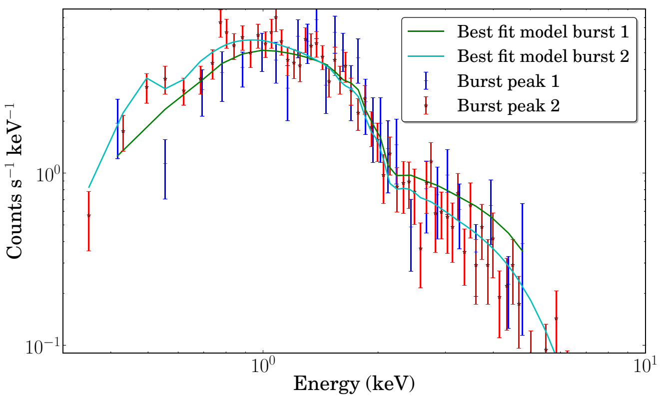

Figure 2. Observed soft X-ray spectral energy distribution for the two large peaks of the transient XRT 000519. The blue data points and the best-fitting power-law model (green drawn line) of the first large peak are plotted together with the data points (red) and the best-fitting model (light green) for the second large peak. The second peak is brighter and has a softer spectrum than the first bright peak.

of the source with an inner radius of 60″ and an outer radius of 105″. Using *xspec* version 12.4.0ad (Arnaud 1996), we have fitted the spectra of XRT 000519 using Cash statistics (Cash 1979) modified to account for the subtraction of background counts, the so-called W statistics.[9] We have used an absorbed power-law model (*pegpwrlw* in *xspec*) to describe the data. For the extraction of the X-ray spectral parameters we added an extinction of $N_{\rm H} = 2.6 \times 10^{20}$ cm^{-2} due to the Galactic foreground (Dickey & Lockman 1990). We did not detect enough counts to add a component to the fit function that could describe the influence of the potential presence of local material causing extinction in addition to that by the Galactic foreground. The X-ray spectrum of the first of the two bright peaks can be well described by a power law with photon index 1.6 ± 0.1 (68% confidence level), where we included the effect of the Galactic extinction in the direction of the source. The energy spectrum of the second of the two bright peaks is softer with a power-law photon index of 1.95 ± 0.05 (see Figure 2). The fact that the second peak has a higher peak count rate while it has a softer spectrum is in line with the inference that the X-ray spectrum is not distorted by the effects of photon pileup.

We further investigated the energy associated with each of the X-ray photons making up the precursor events. We find that most of their photons have an energy near 1–2 keV, which renders support for their interpretation as genuine source photons rather than background photons, as the spectrum agrees well with that found for the main event.

2.2. BATSE Observations

XRT 000519 was not detected by the Burst and Transient Source Experiment (BATSE), although the source was in the BATSE field of view at the time of the event (including the precursor events). Extrapolating the best-fitting X-ray spectrum at peak would have the source falling a factor of ∼50 below the BATSE threshold for detection. The nearly steady emission during the second half of the *Chandra* observation falls a factor of a few below the occultation technique's sensitivity limit.

2.3. XMM-Newton Observations of the Field

XMM-Newton X-ray observations of the region on the sky containing the position of XRT 000519 were obtained on 2002 July 1, 2004 December 27, and 2011 June 1 (the observation identification numbers for these observations are 0108260201, 0210270201, and 0673310101, respectively). Using the 2012 June 21 release of SAS, we cleaned the event lists for periods of enhanced background, leaving 78 and 79 ks for the MOS1 and MOS2 detectors in the 2002 observation, respectively. The source region falls off the pn CCD during the 2002 observation. The 2004 observation yielded 18 ks of cleaned pn exposure and 21.7 ks for both MOS1 and MOS2. Finally, the 2011 observation has 40 ks of cleaned pn exposure.

The source went undetected with a (0.5–10 keV) flux limit of $\approx 4 \times 10^{-14}$ erg cm^{-2} s^{-1} for an assumed incident power-law spectrum with index 1.7 for the first two observations and $\approx 3 \times 10^{-13}$ erg cm^{-2} s^{-1} for the last observation, giving a luminosity upper limit of 1×10^{39} erg s^{-1} for the first two and 9×10^{39} erg s^{-1} for the third observation, respectively, if the event took place at the distance of M86 of 16.2 Mpc.

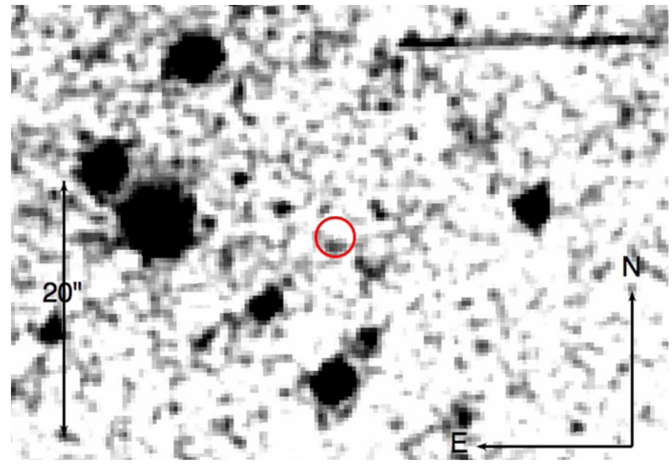

Figure 3. i'-band image of the field of XRT 000519 obtained using the Isaac Newton Telescope on 2001 March 22. The exposure time is 999 s, and the seeing is 1″. The red circle indicates the position of the *Chandra* X-ray event (for display purposes we increased the radius of the circle to 1.″5 instead of the 1″ formal 68% confidence uncertainty). We used a Gaussian smoothing with a kernel radius of 2 pixels to highlight the faint source. The larger number of sources toward the northeast of the image is due to the presence of a stream of stars protruding from M86 (see Section 3).

2.4. Ultraviolet, Optical, and Near-infrared Observations

We queried various data archives to search for archival ultraviolet, optical, and near-infrared images of the field of XRT 000519.

The *Galaxy Evolution Explorer* satellite observed the field of the transient on 2006 March 20 for 15,700 s with its near-ultraviolet camera and for 482 s with its far-ultraviolet camera. No source was detected in either the near-ultraviolet or the far-ultraviolet image down to a magnitude limit of 25.5 and 23.7, respectively.

We investigated a 999 s i'-band image ($\lambda_{\rm central} = 7743$ Å, $\Delta\lambda = 1519$ Å) from the Isaac Newton Telescope (INT) at La Palma, Spain, obtained on 2001 March 22 (see Figure 3). We found a faint optical star at a magnitude of $i' = 24.3 \pm 0.1$ mag. The source is located at (J2000) right ascension $12^{\rm h}25^{\rm m}31^{\rm s}.636$ and declination +13°03′58.″01, where the uncertainty in the position is 0.″1 in both right ascension and declination. The angular difference between the X-ray position of XRT 000519 and the position of this faint i'-band source is 0.″8. This is within the 1″ error circle of the *Chandra* X-ray position of the source.

[9] See http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec/manual/

Table 1
Optical Observations of the Field of XRT 000519 after Its Explosion on 2000 May 19

Telescope	Date	Exposure Time (s)	Band	Seeing (arcsec)	Magnitude Upper Limit/Detection
INT	2001 Mar 22	999	i'	1.0	24.3 ± 0.1
SDSS	2003 Mar 23	54	u'	1.6	>22
SDSS	2003 Mar 23	54	g'	1.6	>22.2
SDSS	2003 Mar 23	54	r'	1.2	>22.2
SDSS	2003 Mar 23	54	i'	1.3	>21.3
SDSS	2003 Mar 23	54	z'	1.3	>20.5
CFHT	2010 Jan 10–21	6402	u'	0.88	>27.2
CFHT	2009 May 22–25	3170	g'	0.69	26.8 ± 0.1[a]
CFHT	2009 May 14 and 15	2055	i'	0.54	>25.6
CFHT	2010 Jan 8–18	4400	z'	0.74	>25.3
CFHT	2005 Jan 17	1440	r'	1.0	>26

Note. [a] The location of this source is offset from the i'-band INT detection by 1″.6.

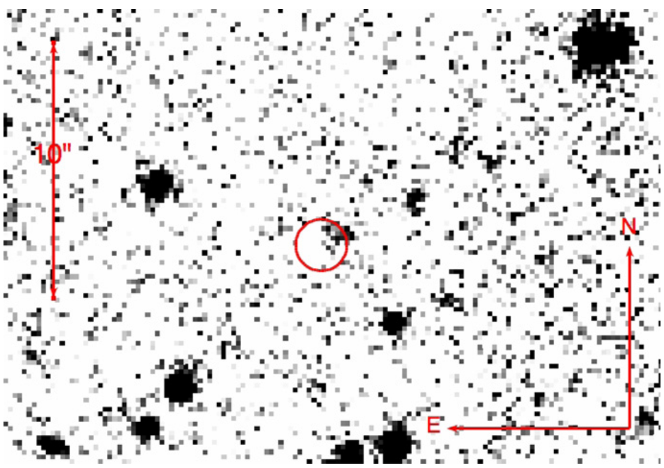

Figure 4. Optical g'-band image obtained at the Canada–France–Hawaii Telescope with a limiting magnitude of 27.2. The red circle of radius 1″ indicates the position and its 68% uncertainty due to the location of the X-ray event XRT 000519. A faint point source at $g' = 26.8 \pm 0.1$ is found close to but just outside the error circle of the position of the transient.

(A color version of this figure is available in the online journal.)

We found archival optical images in the u', g', i', and z' bands obtained in 2009 and 2010 by the Canada–France–Hawaii Telescope (CFHT) using the MegaPrime instrument (Ferrarese et al. 2012; see Table 1). In addition, we report on r' images obtained on 2005 January 17 with the same instrument–telescope combination. Using the Terapix data analysis results, we found no source down to the limiting magnitude of the images ($u' = 27.2$, $r' = 26$, $i' = 25.6$, and $z' = 25.3$). However, in the deep, median-combined g'-band image totaling 3170 s of exposure obtained between 2009 May 22 and 25, under seeing conditions of 0″.7, there is evidence for the presence of a faint unresolved source at a position of right ascension $12^h25^m31^s.56$ and declination $13°03'59''.2$ with $g' = 26.8 \pm 0.1$ (see Figure 4). This source position is 1″.2 away from the position of XRT 000519 and thus falls just outside the estimated error circle. The non-detection of the INT i'-band source in the deep CFHT i'-band image obtained a few years later in time (2009 May 14 and 15) down to a magnitude limit of 25.6 mag indicates that the source magnitude decayed by at least 1.2 mag, strengthening the association of the INT optical i'-band source with XRT 000519.

Sloan Digital Sky Survey (SDSS) images (Ahn et al. 2012) in the u', g', r', i', and z' bands were obtained closer in time to XRT 000519 than the CFHT observations, namely, on 2003 March 23 (see Table 1). In these images there is no evidence for a source in the error circle of the *Chandra* X-ray image down to the limiting magnitude of the SDSS images.

The source region was observed on 2007 May 3 by the UK Infrared Telescope (UKIRT) as part of the UKIRT Infrared Deep Sky Survey (Lawrence et al. 2007) in Y, J, H, and K, but no source was detected in the error region of XRT 000519 down to the survey limit of 18.3 mag in each of the bands. We obtained near-infrared K-band follow-up observations of the field of XRT 000519 in 2013 January using the 4.2 m William Herschel Telescope on La Palma. In 3750 s of exposure we find no source down to a limiting magnitude of $K > 20.3$.

2.5. Radio Observations

We also investigated archival images obtained by the Very Large Array (VLA) on 2005 August 15, 2009 August 3, and on 2012 May 1 and 2 (see Table 2). Although the pointing of the observations was centered on M84, the primary beam of the VLA provides a response of 55% at the position of the transient (12′.7 from the pointing center). The last, most sensitive observation was taken with a total bandwidth of 256 MHz, split into two 128 MHz sub-bands centered at 1452 and 1820 MHz. The primary calibrator was 3C 286, and the secondary calibrator was J1254+1141. The flux scale was set according to the coefficients derived at the VLA by NRAO staff as implemented in the 31DEC13 version of AIPS and CASA version 4.1.0. Data reduction was carried out according to standard procedures within AIPS and checked using CASA data reduction procedures. Images were made using Briggs weighting with a robust value of 0, to reduce the sidelobes from M84 (which has a peak of 130 mJy beam^{-1}), and no source was found at the transient position down to an upper limit of 0.18 mJy beam^{-1} (three times the rms noise of the image at the position of XRT 000519; for the upper limits of the other two observations see Table 2).

3. DISCUSSION

We found a new transient X-ray source in an archival *Chandra* observation. The source position is 12′.16 from the center of M86, and it does not fall in the M86 $\mu_B = 25$ mag arcsec^{-2} isophote area (de Vaucouleurs et al. 1991), which has an approximate radius of 8′.5 in the direction of the XRT 000519 location. However, it was found that M86 is falling into the

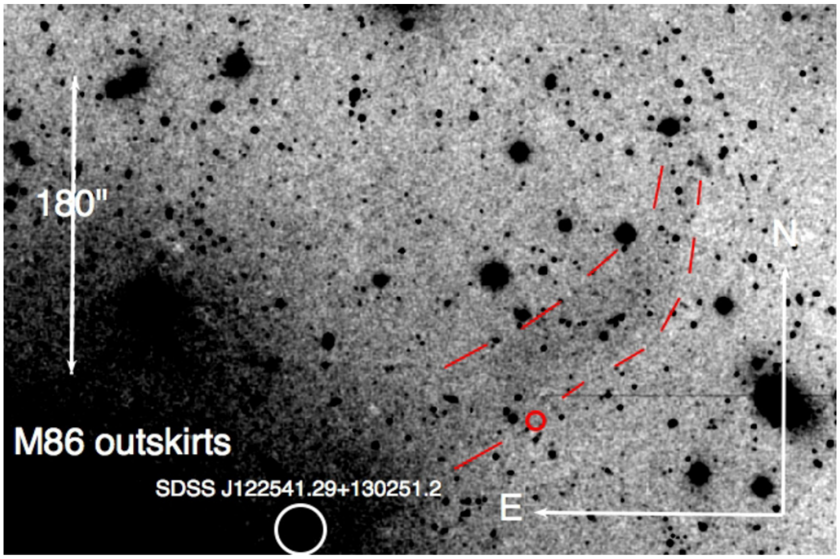

Figure 5. INT i'-band image around the field of the transient (which is indicated with the red circle). The cut levels are chosen to highlight the presence of the stream of stars (marked with dashed red lines on both sides of the stream of stars). Potentially, the stars are stripped from the galaxy SDSS J122541.29+130251.2, which in this representation is hidden in the glare of the stars of the outskirts of M86 (but its position is shown by the white circle). SDSS spectroscopy of this galaxy shows that it is a starburst galaxy that could well be associated with M86.

(A color version of this figure is available in the online journal.)

Table 2
VLA *L*-band 1.6 GHz Observations of the Field of XRT 000519 after Its Explosion on 2000 May 19

Program ID	Start Date	Exposure Time (s)	Configuration	Flux Limit (mJy)
AV 281	2005 Aug 15	2490	C	3
AM 989	2009 Aug 3	7180	C	3.6
12A-098	2012 May 1 and 2	17,770	C →CnB	0.18

Virgo cluster and that gas is stripped off the galaxy (Randall et al. 2008). The projected stripped gas lies close to the position of XRT 000519. Furthermore, the deep optical INT images we investigated show that stars, possibly stripped off the galaxy SDSS J122541.29+130251.2, follow the stripped gas, which suggests that M86 shows signs of a recent minor merger (see Figure 5). The small projected distance on the sky between the position of XRT 000519 and that of the stream of stripped stars strengthens the association between XRT 000519 and M86. The stream of stars falls between the wedge-shaped hot gas structure visible in the X-ray images of the field (Randall et al. 2008), suggesting that some or all of the gas may come from the infalling galaxy, making this a wet minor merger.

Whereas the source location is in the direction of the early-type galaxy M86, the source could in principle be a foreground object located in our own Galaxy, it could indeed be located at the distance of 16.2 Mpc of M86, or it could be located farther away, well behind M86. As the close proximity on the sky makes a scenario where the distance is consistent with that of M86 appealing, we discuss here a scenario for XRT 000519 that is borne out by the observations, where the source is associated with M86. Below we discuss other scenarios with the source placed at the distance of M86 or at other distances.

3.1. A Transient near M86?

If the transient event took place at the distance of M86, the peak luminosity would be 6×10^{42} erg s^{-1}. The late-time, slowly decaying, (0.5–10 keV) flux level is 4×10^{-13} erg cm^{-2} s^{-1}, which for the distance of M86 would be 10^{40} erg s^{-1}. If we interpret the peak flux as the Eddington luminosity, we derive a mass estimate of $4.6 \times 10^4\ M_{\odot}$.

The timescale and luminosity of the event and the occurrence in an old population limit the potential interpretations. We only know a few classes of events that can release so much energy over a short timescale. We favor the scenario where XRT 000519 is due to a TDE of a star by an IMBH near M86. The (quasi-)periodic recurrence time of the precursors of ≈4000 s is potentially related to the orbital period of the stellar material present around the black hole after the tidal disruption, with subsequent passages of a partially disrupted star (Guillochon & Ramirez-Ruiz 2013) or with variations in the fall-back rate after the white dwarf has been disrupted. The latter is likely to occur as the white dwarf will be disrupted in a strong gravitational field regime where the orbits of the fluid elements are not closed, giving rise to the possibility of multiple shocks; however, the current models are not yet calculated taking this into account (see the discussion in Rosswog et al. 2009). This short recurrence time of ≈4000 s and the inference that the peak flux is at or close to the Eddington luminosity would imply a $\sim 10^4\ M_{\odot}$ black hole tidally disrupting a white dwarf (see, e.g., Rosswog et al. 2009; Lodato & Rossi 2011). In the two observed passages prior to the main event, some of the material of the white dwarf star is accreted by the black hole, giving off X-rays with a peak luminosity of $\sim 6 \times 10^{39}$ erg s^{-1}. In a subsequent orbit the self-interaction of the accreting material increases the viscosity, giving rise to the bright peaks, in line with modeling (Luminet & Pichon 1989; Rosswog et al. 2009). It is unlikely that the white dwarf detonates: a detonating white dwarf would appear as a bright Type Ia supernova, and the absolute

i'-band magnitude during the INT observation is too low to be consistent with a Type Ia supernova less than one year after the explosion (Stritzinger & Sollerman 2007). The observed tail in the *Chandra* observation would be associated with the accretion of part of the material falling back (at super-Eddington rates) toward the IMBH (Strubbe & Quataert 2009; Lodato & Rossi 2011). The luminosity may well be limited to be below the Eddington limit. To explain the two-peak structure of the main event of XRT 000519, detailed hydrodynamical calculations have to be performed, which is beyond the scope of this paper.

In order for a star to be tidally disrupted by a black hole, it has to wander close enough. The rates for this to happen are low, except for instance in regions of high stellar density such as the centers of galaxies or in globular clusters (Baumgardt et al. 2006; Ramirez-Ruiz & Rosswog 2009). The photometry we have is consistent with a scenario where XRT 000519 originated in a globular cluster, although the globular cluster would have to be at the faint end of the globular cluster luminosity function (Harris 1996, 2010 edition).

Below, we discuss alternative scenarios for XRT 000519. The timescale and luminosity of XRT 000519 and the occurrence in an old population, if located at the distance of M86, suggest that XRT 000519 could, for instance, be due to two compact objects merging, such as a neutron star–neutron star merger. Given that we detect no hard X-ray or γ-ray emission, we would be observing the merger off-axis, unlike the short–hard γ-ray bursts (Rezzolla et al. 2011). Accretion from fall-back material onto the newly formed black hole would in this scenario account for the late-time X-ray emission. The non-detection of the source in the radio down to 0.18 mJy on 2012 May 1 and 2 (Karl G. Jansky VLA, central frequency 1636 MHz), thus nearly 12 yr after the event, only loosely constrains the circumstellar binary density in this scenario (for predictions for radio emission of off-axis γ-ray bursts see Nakar & Piran 2011; van Eerten & MacFadyen 2011). However, the precursor events are hard to explain in this scenario, making it less likely. An alternative, related scenario involves a neutron star overflowing its Roche lobe onto a black hole or another neutron star. The neutron star mass donor will eventually drop below the minimum mass for a neutron star. At that point, the star should explode, and some of the debris should be captured by the other compact object (Blinnikov et al. 1990; Colpi et al. 1993). The optical source could in this scenario be interpreted as the late-time fading counterpart at $M_{i'} = -6.7$ for a distance modulus of 31 for M86 (which converts to an i'-band luminosity of 8×10^{37} erg s^{-1}). However, again the precursor events require a special explanation in this scenario.

If the source is in M86, it could in principle be that we witnessed a Type Ia supernova shock break-out (Kasen 2010). A problem with this scenario is that the optical supernova was not discovered, which is unlikely given that the Virgo and M86 regions of the sky are well monitored (Akerlof et al. 2000) and given that Type Ia supernovae have an absolute magnitude of -19 in the V band (Hillebrandt & Niemeyer 2000), which means that the optical supernova would have reached $V \sim 12$, which is easily accessible also for amateur astronomers. The detection of the faint i' band at $M_{i'} = -6.7$ also makes this scenario improbable as typical Type Ia supernovae do not decay that fast in the i' band within a year (Stritzinger & Sollerman 2007).

3.2. A Foreground Object?

One could also envisage a scenario where the source is nearby, e.g., in our own Galaxy. For instance, the brightening in X-rays and the i' band could be due to an accretion event onto an isolated, old neutron star. The isolated neutron star is then possibly detected in the late-time CFHT g'-band observation. The two detections are offset by 1.″1 in right ascension and by −1.″2 in declination, giving a distance on the sky between the two positions of 1.″6. This would yield a proper motion of 0.″16 per year with respect to the i'-band variable source detected in 2001. For a typical transverse velocity of an isolated neutron star of 200 km s^{-1}, we derive a distance of 250 pc for the source. At that distance the fluence of the event would imply an accretion of around 5×10^{15} g onto the neutron star. The deep upper limits on the quiescent X-ray emission derived from the *XMM-Newton* observations imply a limit on the luminosity of 3×10^{29} erg s^{-1} for such a distance. This means that the quiescent neutron star luminosity is lower than what has been observed so far for isolated neutron stars (Page et al. 2004); however, the current observations favor young, hot neutron stars. Additionally, the cooler the neutron star, the more its emission peaks toward the soft X-rays or even the ultraviolet part of the energy spectrum. Additional, new, optical (e.g., *Hubble Space Telescope*) observations could test this scenario by checking whether the faint g'-band source indeed has a proper motion of 0.″16 per year.

In an alternative version of this scenario, where we do not ascribe the g'-band detection to the isolated neutron star, and thus we have no constraint on the proper motion or distance of the neutron star, we can place it at a larger distance. This would increase the total energy liberated in the transient event and thus the amount of accreted mass, but it alleviates the constraint on the quiescent X-ray luminosity of the isolated neutron star. However, in both these isolated neutron star scenarios the precursor events and their 4000 s timescale are difficult to understand. Furthermore, the accretion of asteroid-sized bodies onto a neutron star are thought to produce significant amounts of γ-ray emission (Campana et al. 2011), which is not detected from XRT 000519, implying that, for reasons unknown, the γ-ray emission is much reduced in this case, making this scenario less likely.

3.3. A Transient (Far) behind M86?

If we instead interpret XRT 000519 as coming from a redshift, z, between 0.23 and 1.5 in line with the g'-band non-detection of an unresolved faint dwarf galaxy of an absolute magnitude of $-14.5 > M_{g'} > -19.5$ (Blanton et al. 2005), then the luminosity of XRT 000519 would be between 3×10^{46} and 3×10^{48} erg s^{-1}.

Then, it could potentially be interpreted as an X-ray flash such as those found in X-rays, and which are probably related to γ-ray bursts (Campana et al. 2006; Sakamoto et al. 2005). However, with a peak energy, $E_{\rm p}$, of about 1.5 keV, the event has a softer X-ray spectrum than that of X-ray flashes known so far (Sakamoto et al. 2005). Nevertheless, if the event was indeed near $z = 1.5$, thus at a luminosity of $L = 3 \times 10^{48}$ erg s^{-1}, then the peak energy $E_{\rm p}$ of 1.5 keV and the isotropic peak energy at the peak flux, $E_{\rm iso}$, are consistent with those expected extrapolating the $E_{\rm p}$ and $E_{\rm iso}$ correlation of X-ray flashes and γ-ray bursts to lower values (the Amati et al. 2008 relation). Whereas we cannot rule out that XRT 000519 was due to an event similar to an X-ray flash, extending the peak energies and the isotropic luminosities for those events a factor of several below those that have been found for this class of flashes until now (Sakamoto et al. 2005), the presence of the precursor events is never seen in X-ray flashes so far, making the association unlikely. However, the latter could be due to the reduced sensitivity of the satellites that detected the X-ray flashes so far, compared with the *Chandra* sensitivity. A potential problem with this scenario and a distance of $z = 1.5$ is that even at 10 months after the event the absolute i'-band magnitude $M_{i'}$ would still have to be -20.9 mag. Furthermore, the projected co-location on the sky of an ongoing minor merger event and the X-ray transient would be a chance alignment in this scenario.

Interestingly, Shcherbakov et al. (2013) describe the X-ray flash reported by Campana et al. (2006) as a TDE of a white dwarf by an IMBH. This shows that the properties of these two classes of objects, X-ray flashes associated with stellar-mass black hole formation and X-ray flashes associated with TDEs by massive or IMBHs, overlap. The main reason for this is that TDEs cover X-ray luminosities ranging from as low as 10^{40} erg s^{-1} (Esquej et al. 2008; Gezari et al. 2008) up to 10^{48} erg s^{-1} for the blazar-like TDE Swift J1644+57 (Levan et al. 2011). The observed peak luminosity of XRT 000519 is in the range of distances we consider here. Thus, the properties of XRT 000519 are also consistent with a TDE in a dwarf galaxy at a distance between approximately 1.1 and 11 Gpc provided that the emission is strongly beamed toward us such as in Swift J1644+57 (Krolik & Piran 2011; Shcherbakov et al. 2013), although again the optical i'-band magnitude would favor distances closer to 1.1 Gpc over one close to 11 Gpc.

4. CONCLUSION

We discovered a peculiar transient (XRT 000519) in the direction of M86. Furthermore, we found evidence for an ongoing wet minor merger between M86 and the galaxy SDSS J122541.29+130251.2. This activity makes it conceivable that the transient is located at the distance of M86. If so, its properties are consistent with a scenario where the transient is due to the tidal disruption of a white dwarf by an IMBH. Alternative scenarios such as that of a foreground neutron star accreting an asteroid or the detection of an off-axis (short) γ-ray burst cannot be fully excluded at present. Future, high-resolution and deep *Hubble Space Telescope* imaging should reveal the host galaxy if it was due to an event in the background of M86 such as a TDE at larger distance or an off-axis γ-ray burst.

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