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Review

The Swift X-ray monitoring campaign of the center of the Milky Way

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A B S T R A C T

In 2006 February, shortly after its launch, *Swift* began monitoring the center of the Milky Way with the on board X-Ray Telescope using short 1-ks exposures performed every 1–4 days. Between 2006 and 2014 over 1200 observations have been obtained, accumulating to $\simeq 1.3$ Ms of exposure time. This has yielded a wealth of information about the long-term X-ray behavior of the supermassive black hole Sgr A*, and numerous transient X-ray binaries that are located within the $25' \times 25'$ region covered by the campaign. In this review we highlight the discoveries made during these first nine years, which include 1) the detection of seven bright X-ray flares from Sgr A*, 2) the discovery of the magnetar SGR J1745–29, 3) the first systematic analysis of the outburst light curves and energetics of the peculiar class of very-faint X-ray binaries, 4) the discovery of three new transient X-ray sources, 5) the exposure of low-level accretion in otherwise bright X-ray binaries, and 6) the identification of a candidate X-ray binary/millisecond radio pulsar transitional object. We also reflect on future science to be done by continuing this *Swift*'s legacy campaign, such as high-cadence monitoring to study how the interaction between the gaseous object 'G2' and Sgr A* plays out in the future.

1. Description of the program

Little over a year after the *Swift* satellite (Gehrels et al., 2004) was launched in November 2004, it embarked on a program to monitor the inner $\simeq 25' \times 25'$ of the Milky Way using the on board X-Ray Telescope (XRT; Burrows et al., 2005). Starting in February 2006, short $\simeq 1$ ks X-ray snapshots of the Galactic center have been taken once every 1–4 days (see Table 1). *Swift* can observe this region for $\simeq 250$ days per year; the field is too close to the Moon for $\simeq 2$–3 days per month and in November/December/January it is too proximate to the Sun. In 2006–2014 over 1200 X-ray observations were obtained in photon counting (PC) mode, amounting to $\simeq 1.3$ Ms of exposure time (Table 1). Fig. 1 displays an accumulated three-color XRT image of the Galactic center monitoring program.

The central part of the Milky Way has always been a prime target for X-ray missions as it is a very rich environment to study accretion onto compact objects. Not only does it harbor the central supermassive black hole Sagittarius A* (Sgr A*), there is also a large concentration of X-ray point sources toward the inner part of the Galaxy (e.g., Muno et al., 2009). Many of these are X-ray binaries; binary star systems in which a stellar-mass black hole or a neutron star accretes matter from its companion. These are excellent laboratories to further our understanding of the physics of accretion, the properties of black holes and neutron stars, and stellar/binary evolution.

Over the past decades, many different observing campaigns and many different satellites have targeted the Galactic center (e.g., Watson et al., 1981; Pavlinsky et al., 1994; Sidoli et al., 1999, 2001; Swank and Markwardt, 2001; Sakano et al., 2002; 't Zand et al., 2004; Wijnands et al., 2006; Kuulkers et al., 2007; Muno et al., 2009; Degenaar et al., 2012, 2013a). However, the Swift monitoring program is unique in many ways, and important for a variety of scientific goals. Firstly, the XRT provides better spatial resolution (arcseconds) and X-ray sensitivity (down to a 2–10 keV luminosity of $L_X \simeq 10^{34}$ erg s^{-1} in a single 1-ks pointing) than wide-field monitors (e.g., *Integral*, *MAXI*, *RXTE*, *Swift*/BAT; arcminute resolution and a sensitivity of $L_X \simeq 10^{36}$ erg s^{-1}). Secondly, *Swift* is very flexible (compared to, e.g., *Chandra*, *XMM-Newton*, *Suzaku*), allowing for many repeated observations and thereby providing unprecedented dense time coverage.

During its nine-year runtime, *Swift*'s monitoring campaign of the Galactic center has led to many remarkable discoveries, which

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Table 1
Overview of *Swift*/XRT monitoring observations of the Galactic center.

Year	Start date	End date	Total observations	Total exposure (ks)	Cadence (obs day^{-1})	Average exposure (ks obs^{-1})
1	2006 Feb. 24	2006 Nov. 1	197	262	0.8	1.3
2	2007 Feb. 17	2007 Nov. 1	173	172	0.8	1.0
3	2008 Feb. 19	2008 Oct. 30	162	200	0.6	1.2
4	2009 May 17	2009 Nov. 1	39	40	0.2	1.0
5	2010 Apr. 7	2010 Oct. 31	64	71	0.3	1.1
6	2011 Feb. 4	2011 Oct. 25	80	76	0.3	1.0
7	2012 Feb. 5	2012 Oct. 31	80	74	0.3	0.9
8	2013 Feb. 3	2013 Oct. 31	190	174	0.7	0.9
9	2014 Feb. 2	2014 Nov. 2	240	234	0.9	1.0
1–9	2006 Feb. 24	2014 Nov. 2	1226	1304	0.5	1.0

This overview concerns observations obtained in PC mode (updated from Degenaar et al., 2013a). In 2007 the daily monitoring observations were interrupted for 46 days between August 11 and September 26 (Gehrels, 2007a, 2007b).

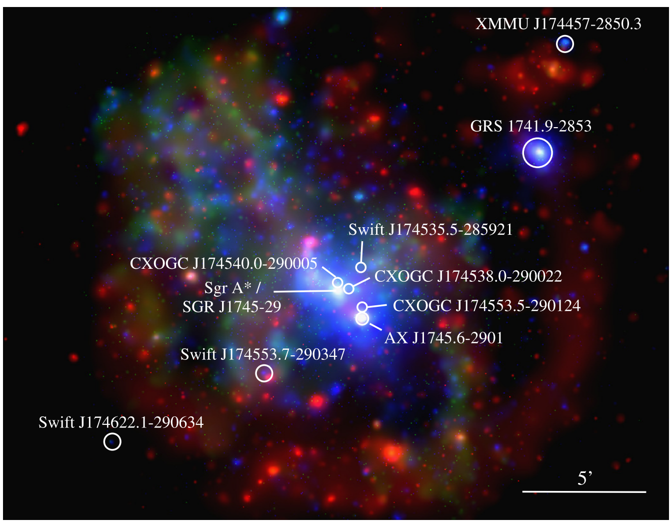

Fig. 1. Accumulated image of the XRT-PC data of the Galactic center using 1.3 Ms of data collected in 2006–2014 ($\simeq 25'$ square). This representative-color image was constructed from 0.3–1.5 keV (red), 1.5–3.0 keV (green), and 3.0–10 keV (blue) images that were smoothed using the CIAO tool CSMOOTH and then combined with DS9. The markers indicate the location of the supermassive black hole Sgr A* and the magnetar SGR J1745–29, as well as the 9 transient X-ray binaries that were seen active during the campaign. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

are reviewed in this article. For instance, the program allowed the detection of seven bright X-ray flares from Sgr A* (Section 2.1) and the discovery of the nearby (separated by only $\simeq 2.4''$) magnetar SGR J1745–29 (Section 2.2). Furthermore, a total of 24 distinct accretion outbursts were detected from nine different transient X-ray binaries, of which three were newly discovered sources (Section 2.4). The majority of these outbursts had peak luminosities of $L_X \lesssim 10^{36}$ erg s^{-1}, tracing a relatively poorly understood regime of accretion. The *Swift* program has allowed for the first detailed and systematic analysis of such low-level accretion events (Sections 2.3 and 2.5). Moreover, the remarkable X-ray variability of one of these X-ray binaries suggests that it could possibly be a member of the recently emerged class of "transitional" neutron stars that switch between millisecond radio pulsar and X-ray binary manifestations (Section 2.6). In the next sections we describe these discovery highlights of *Swift*'s Galactic center monitoring campaign in more detail, and we conclude with future prospects in Section 3.[1]

2. Discovery highlights

2.1. Seven bright X-ray flares from Sgr A*

Forming the dynamical center of the Milky Way, located at a distance of $\simeq 8$ kpc, Sgr A* is the most nearby supermassive black hole (e.g., Reid and Brunthaler, 2004; Ghez et al., 2008; Gillessen et al., 2009). As such it allows for an unparalleled study of how galactic nuclei accrete and supply feedback to their environment. Most remarkably, despite having an estimated mass of $\simeq 4 \times 10^6$ M$_\odot$, the bolometric luminosity output of Sgr A* is only a factor of $\simeq 550$ higher than that of the Sun. This is $\simeq 10^9$ times fainter than expected for Eddington-limited accretion onto a black hole of this mass (e.g., Melia and Falcke, 2001; Genzel et al., 2010; Morris et al., 2012 for reviews). Sgr A* likely feeds off the winds of nearby massive stars (e.g., Coker and Melia, 1997; Quataert et al., 1999; Cuadra et al., 2008), but only $\simeq 1\%$ of the matter captured at the Bondi radius seems to reach the supermassive black hole (Wang et al., 2013). Its puzzling sub-luminous character can be explained if the majority of the matter is ejected and the accretion flow is radiatively inefficient. This may well be the dominant form of accretion onto supermassive black holes throughout the Universe (e.g., Ho, 1999; Nagar et al., 2005), and it is therefore of great interest to understand the fueling process of our Galactic nucleus.

Despite its faint persistent X-ray emission of $L_X \simeq 3 \times 10^{33}$ erg s^{-1} (2–10 keV; Baganoff et al., 2001, 2003), Sgr A* is not completely inactive; roughly daily its X-ray emission flares up by a factor of $\simeq 5$–150 for tens of minutes to a few hours. Several tens of such X-ray flares have been detected to date with different satellites (e.g., Baganoff et al., 2001, 2003; Goldwurm et al., 2003; Bélanger et al., 2005; Porquet et al., 2003, 2008; Trap et al., 2011; Nowak et al., 2012; Degenaar et al., 2013a; Neilsen et al., 2013; Barrière et al., 2014; Mossoux et al., 2015).[2] Most have an intensity of $L_X \lesssim 10^{35}$ erg s^{-1} in the 2–10 keV band; such weak X-ray flares occur approximately once every day (Neilsen et al., 2013). On a few occasions, however, bright flares with $L_X \simeq (1–5) \times 10^{35}$ erg s^{-1} have been detected (Baganoff et al., 2001; Porquet et al., 2003, 2008; Nowak et al., 2012; Degenaar et al., 2013a; Barrière et al., 2014; Reynolds et al., 2014). The overall duration and short-timescale variability of the X-ray flares suggests that the emission originates close to the black hole, within $\simeq 10$ R_s (where $R_s = 2GM/c^2$ is the Schwarzschild radius, e.g., Baganoff et al., 2001; Porquet et al., 2003; Barrière et al., 2014; Mossoux et al., 2015). These events therefore provide excellent means to investigate the inner accretion flow, offering a new view

[1] Throughout this work we quote uncertainties as 90% confidence levels and assume source distances of 8 kpc unless noted otherwise.

[2] Similar (often associated) flaring activity is observed at near-infrared wavelengths (see e.g., Witzel et al., 2012 and references therein).

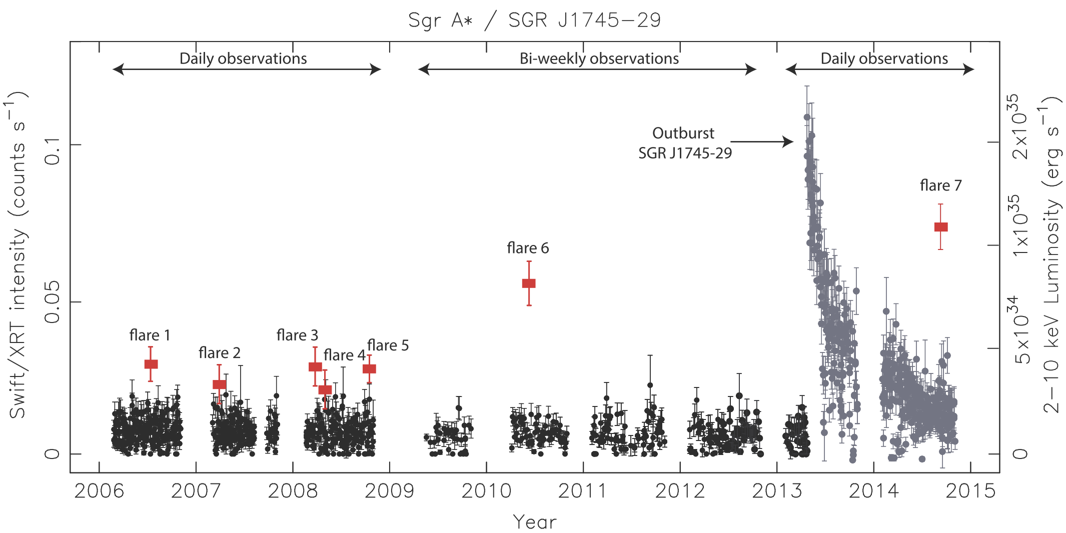

Fig. 2. Long-term XRT-PC count rate light curve of Sgr A*/SGR J1745–29. The red squares indicate the seven X-ray flares detected from Sgr A* and the discovery outburst of SGR J1745–29 is indicated by the grey data points. The typical sampling rate along the campaign is indicated on top. Data gaps at the beginning/end of a year correspond to the Sun-constrained window and the interruption in 2007 corresponds to a short episode during which no observations could be obtained (Gehrels, 2007a, 2007b). Note that this graph is binned per observation, whereas X-ray flares 1–5 were detected only during smaller data segments (Degenaar et al., 2013a). Hence their true peak intensity was higher than reflected here. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

of the feeding processes of Sgr A*. Different mechanisms have been proposed to explain the flares, including magnetic reconnection and particle acceleration processes (e.g., Markoff et al., 2001; Yuan et al., 2003; Liu et al., 2004, 2006), as well as the infall of gas clumps or disruption of small bodies such as asteroids or comets (e.g., Čadež et al., 2006; Tagger and Melia, 2006). Constraining the repetition rate and spectral properties of X-ray flares is an important aspect of understanding their origin (e.g., Porquet et al., 2008; Trap et al., 2010).

Swift's X-ray monitoring campaign of the Galactic center has proven to be a powerful tool to catch and study X-ray flares from Sgr A*; out of the 13 bright X-ray flares ($L_X \gtrsim 1 \times 10^{35}$ erg s^{-1}) reported to date, seven were detected by *Swift*. The spatial resolution of the XRT does not allow us to separate Sgr A* from its dense environment; in a 10″ aperture centered at the radio position of the supermassive black hole we detect a continuum emission of $L_X \simeq 2 \times 10^{34}$ erg s^{-1} (2–10 keV). This is a factor of $\simeq 10$ higher than the quiescent emission of Sgr A* and is dominated by the X-ray emission of diffuse structures and a number of faint X-ray point sources (Baganoff et al., 2003; Degenaar et al., 2013a). Nevertheless, the XRT can pick up X-ray flares since these can be an order of magnitude brighter. Indeed, in an initial study using all XRT-PC data obtained in 2006–2011, a total of six flares with intensities of $L_X \simeq (1\text{–}2) \times 10^{35}$ erg s^{-1} were identified (Degenaar et al., 2013a). This is illustrated in Fig. 2, which shows the long-term XRT count rate light curve of Sgr A*. The background-subtracted X-ray spectrum of the flare that collected the most photons (number 6, 2010 June 12), is shown in Fig. 3. All *Swift*-detected flares are positionally coincident with Sgr A* and their duration, spectra, and peak luminosities are similar to flares detected from the supermassive black hole with *Chandra* and *XMM-Newton*. None of the other X-ray point sources located within the XRT extraction region (e.g., accreting white dwarfs and X-ray binaries) have ever been seen to display such short (hours) X-ray variability peaking at $L_X \simeq 10^{35}$ erg s^{-1}. Therefore, it is highly likely that all six events were X-ray flares from Sgr A* (Degenaar et al., 2013a).

The *Swift* study of Sgr A* more than doubled the number of bright X-ray flares observed at that time. Furthermore, the unprecedented 6-year long baseline of daily–weekly observations allowed for an estimate of the occurrence rate of bright X-ray flares; we found Sgr A* fires off one such event every $\simeq$ 5–10 days

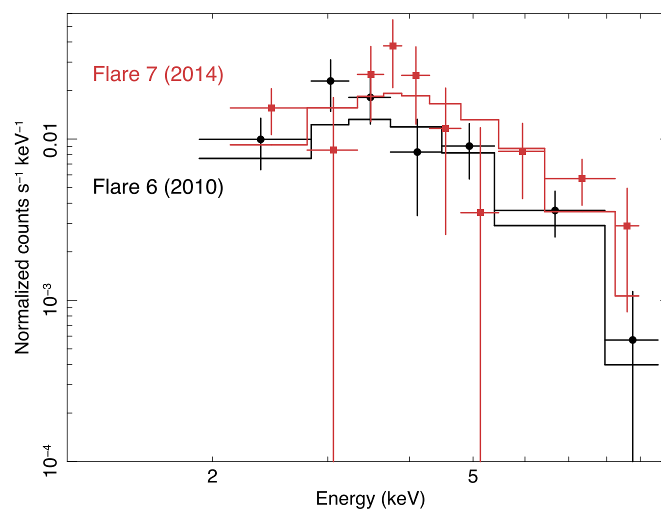

Fig. 3. Comparison between the two brightest flares detected from Sgr A* with *Swift*: the new 2014 X-ray flare (red, squares; Reynolds et al., 2014) and the one observed in 2010 (black, circles; Degenaar et al., 2013a). The solid lines correspond to a fit with an absorbed power-law model, where the hydrogen column density was kept fixed at $N_H = 9.1 \times 10^{22}$ cm^{-2}. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(Degenaar et al., 2013a). Finally, with such a large number of X-ray flares detected by a single instrument, we were able to perform a comparative study of their spectral properties unbiased by instrumental effects that are present when flares detected by different observatories are compared. Our analysis suggested that despite their similar intensities, one of the flares (the sixth, shown in Fig. 3) possibly had a different spectral shape than the other five. Although this was a stand-alone and low-significance result at the time, similar findings were recently reported from comparing two bright X-ray flares detected with *NuSTAR* (Barrière et al., 2014). Taken together, this may indicate that X-ray flares can have different spectral shapes, which may give further insight into their nature. For instance, different spectral shapes can naturally be explained if the X-ray flares are related to magnetic reconnection events, which create turbulence and stochastic acceleration of electrons, leading to a range of particle distribution slopes

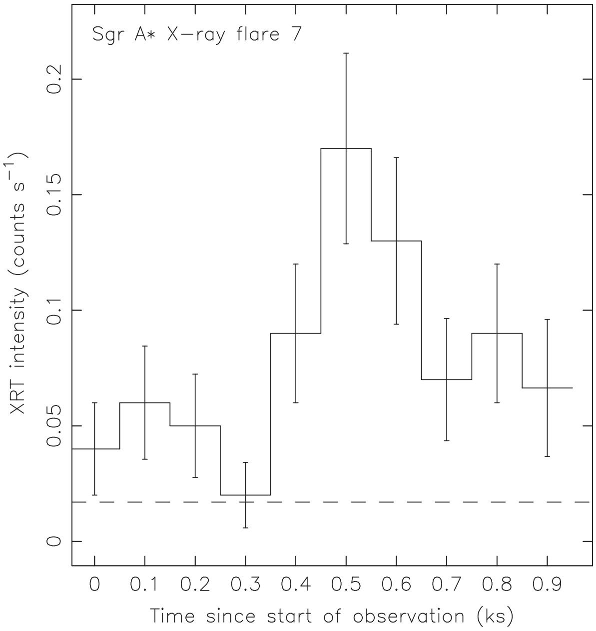

Fig. 4. Light curve of the 2014 *Swift* X-ray flare observation, at 100-s resolution. The dashed horizontal line indicates the average count rate observed in the preceding and subsequent observation.

(e.g., Liu et al., 2004; Zharkova et al., 2011). Nevertheless, analysis of 39 X-ray flares caught by *Chandra*, including one bright, did not reveal spectral differences between individual flares (Neilsen et al., 2013). Continued investigation is therefore warranted.

In 2013 April, *Swift* lost its view of Sgr A* due to sudden activity of the nearby magnetar SGR J1745–29, with an angular separation of only 2.4″ and a 2–10 keV X-ray luminosity a factor $\simeq 100$ higher than the quiescent emission of the supermassive black hole (see Section 2.2). This put *Swift*'s detection of X-ray flares temporarily on hold. However, the X-ray emission of the magnetar steadily faded and became faint enough for the XRT to pick up a bright X-ray flare from Sgr A* again in 2014 September (Reynolds et al., 2014; Degenaar et al., 2014a).

2.1.1. The seventh X-ray flare detected in 2014 September

Reynolds et al. (2014) reported the detection of a new X-ray flare from Sgr A*, which occurred during a $\simeq$ 1-ks observation that started on 2014 September 9 at 11:41 UT (obsID 91906150). Fig. 4 shows the XRT light curve of this observation. The count rate varied between $\simeq (2\text{–}20) \times 10^{-2}$ c s^{-1}, with a mean value of $(8 \pm 1) \times 10^{-2}$ c s^{-1}. As can be seen in Fig. 4, this is significantly higher than the count rate detected at this position in the preceding observation on September 8 at 04:01–05:49 UT, i.e., $\simeq$ 30 h earlier (obsID 91906149; $(1.8 \pm 0.4) \times 10^{-2}$ c s^{-1}), and the subsequent pointing on September at 10 06:52–07:10 UT, i.e., $\simeq$ 19 h after the flare detection (obsID 91906151, $(1.6 \pm 0.4) \times 10^{-2}$ c s^{-1}; Degenaar et al., 2014a). The event thus had a duration of $\gtrsim$16 min, but $\lesssim$49 h. The timescale, intensity and spectrum (see below), are similar to X-ray flares detected previously from Sgr A* with *Swift*, strongly suggesting that this event too was an X-ray flare from the supermassive black hole (Reynolds et al., 2014; Degenaar et al., 2014a).

Extracting a single spectrum from a 10″ circular region yielded 79 counts, i.e., sufficient to carry out basic spectral fitting. We used the same data reduction and analysis approach as outlined in Degenaar et al. (2013a). However, given that the magnetar SGR J1745–29 was likely still contributing to the local background of Sgr A* in 2014 (see Section 2.2), we cannot use the same background model as used for previous X-ray flares. To model the background for the 2014 flare we therefore extracted a spectrum using the 10 observations preceding the detection (obsIDs 91906140–149) and 10 observations following it (obsIDs 91906151–160). This averaged continuum background spectrum can be described by an absorbed power-law model (where we fixed $N_H = 9.1 \times 10^{22}$ cm^{-2} as found from analyzing the non-flaring emission in 2006–2011; Degenaar et al., 2013a) with $\Gamma = 1.9 \pm 0.2$, and a 2–10 keV (absorbed) flux of $F_X^{abs} = (2.2 \pm 0.1) \times 10^{-12}$ erg cm^{-2} s^{-1}. We then fitted the flare spectrum including background to a double power-law model, with the parameters for the continuum fixed to these values. The results are given in Table 2.

Table 2
Properties of the seventh bright X-ray flare from Sgr A*.

Parameter	Value
ObsID	91906150
Date	2014 September 09
Obs start time (UTC; hh:mm:ss.s)	11:41:29.5
Flare duration (h)	$0.27 \lesssim t \lesssim 49$
Rate (c s^{-1})	$(8 \pm 1) \times 10^{-2}$
HR	1.51 ± 0.23
Γ	0.9 ± 0.8
Cstat/dof	46.46/69
F_X^{abs} (erg cm^{-2} s^{-1})	$(2.6 \pm 0.7) \times 10^{-11}$
L_X (erg s^{-1})	$(1.4 \pm 0.4) \times 10^{35}$

The spectrum of the flare, including background, was fitted with a double power-law model where the parameters for the power-law describing the continuum emission were fixed (see text). The hardness HR gives the ratio of counts in the 2–4 and 4–10 keV bands. F_X^{abs} is the *absorbed* 2–10 keV flux ($N_H = 9.1 \times 10^{22}$ cm^{-2} was fixed), whereas L_X gives the 2–10 keV luminosity corrected for absorption, assuming $D = 8$ kpc. Errors are 90% confidence levels.

The estimated luminosity of $L_X \simeq 1 \times 10^{35}$ erg s^{-1} for the 2014 flare is similar to the brightest one detected previously with *Swift* on 2010 June 12 (see Fig. 2). This makes it interesting to model the two events together, to see if there are any spectral differences as hinted previously (Degenaar et al., 2013a). Given the different background emission for the two flares (see above),[3] we opted for both flares to subtract a spectrum obtained from the preceding observation, rather than modeling the background emission. This way we obtained $\Gamma = 1.9 \pm 0.9$ for 2010 and $\Gamma = 1.1 \pm 1.1$ for 2014 (with $N_H = 9.1 \times 10^{22}$ cm^{-2} fixed). The spectral indices are consistent within the 90% confidence errors, i.e., we find no spectral differences between these two flares.

2.1.2. Possible future re-activation of Sgr A*

The detection of Fermi bubbles, relic jets, and time-variable fluorescent light echoes from giant molecular clouds in the Galactic center, suggest that Sgr A* may have been much more active and orders of magnitude brighter in the (recent) past (see, e.g., Ponti et al., 2013; Yusef-Zadeh et al., 2012; Li et al., 2013; Ryu et al., 2013 for recent studies and reviews). Therefore it is plausible that our supermassive black hole reactivates again in the future. This idea got revived when in 2012 the discovery was announced that a gaseous object denoted as 'G2' was on a collision course with Sgr A*, passing as close as *few* $\times 10^3 R_s$ (e.g., Gillessen et al., 2012; Eckart et al., 2014; Ghez et al., 2014; Pfuhl et al., 2015). This is well within the Bondi accretion radius of $\simeq 10^5 R_s$, suggesting that G2 could interact with the ambient hot medium, perhaps creating a bowshock (e.g., Sądowski et al., 2013). Its estimated mass of a few Earth masses is comparable to that present in the accretion flow around Sgr A* (e.g., Yuan et al., 2003). Therefore, if G2 would become disrupted due tidal forces and a significant fraction of the shredded gas would accrete onto the supermassive black

[3] SGR J1745–29 very likely resided in quiescence in 2010, implying an X-ray luminosity of $L_X \lesssim 10^{32}$ erg s^{-1} (Mori et al., 2013).

hole, that could lead to a significant brightening unfolding over the next decade (e.g., Anninos et al., 2012; Gillessen et al., 2013; Schartmann et al., 2012). Ever since this discovery, however, there has been considerable debate about the nature and origin of G2 – whether it is a pure gas cloud or whether there is a hidden central object that could keep it gravitationally bound – resulting in a wide range of predictions how the activity of Sgr A* would be affected (e.g., Burkert et al., 2012; Schartmann et al., 2012; Meyer and Meyer-Hofmeister, 2012; Miralda-Escudé, 2012; Phifer et al., 2013; Scoville and Burkert, 2013; De Colle et al., 2014; Guillochon et al., 2014).

The prospective interaction between G2 and Sgr A* spurred great interest, because X-ray brightening of the supermassive black hole could give more insight into the physics of Bondi accretion. Dedicated monitoring and target-of-opportunity programs have therefore been set up accordingly, covering almost the entire electromagnetic spectrum. *Swift* plays a central role in this effort since enhanced accretion activity of Sgr A* should manifest itself in the X-ray band. Given that the *Swift*/XRT monitoring program is a factor $\simeq 10$–100 more sensitive than daily scans from *MAXI* and *Swift*/BAT, but can still target the Galactic center almost every day, it has been widely recognized that this *Swift* program would serve as an important trigger for other observatories in case the interaction with G2 were to affect the supermassive black hole. In this respect, having mapped out the years-long X-ray activity of Sgr A* with *Swift* provides an important calibration point, allowing us to detect any possible changes in its accretion activity (e.g., not only an increase in its persistent emission, but also in its X-ray flaring activity; Degenaar et al., 2013a).

Deep near-infrared observations have shown that G2 completed its closest approach in mid-2014, although it is debated whether there are signs of disruption (Pfuhl et al., 2015; Witzel et al., 2014). At the time of writing, no enhanced activity of Sgr A* has been detected in the X-ray band, nor at other wavelengths (Crumley and Kumar, 2013; Sądowski et al., 2013; Chandler and Sjouwerman, 2014; Haggard et al., 2014; Hora et al., 2014; Tsuboi et al., 2015). Nevertheless, transporting gas out from $\simeq 10^3 R_s$ to the inner accretion flow would take a viscous time scale, which is estimated to be years for Sgr A* (e.g., Burkert et al., 2012; Schartmann et al., 2012; Mościbrodzka et al., 2012). Continued, frequent monitoring in X-ray band is therefore highly desired to keep on watch for any possible enhancement in the activity of the supermassive black hole. Only *Swift* can accommodate high-cadence, sensitive X-ray monitoring to explore the interaction with G2 and its future consequences.

2.2. The Galactic center magnetar SGR J1745–29

On 2013 April 24, *Swift* detected sustained X-ray activity at the position on Sgr A* (Degenaar et al., 2013b), which was initially thought to be linked to the anticipated interaction between the supermassive black hole and G2 (Section 2.1.2). However, a very brief and highly energetic burst seen by *Swift*/BAT and 3.76-s coherent X-ray pulsations detected by *NuSTAR* revealed that instead of Sgr A* it was a nearby (angular separation of only 2.4″; Rea et al., 2013), highly-magnetized neutron star that had suddenly become X-ray active: SGR J1745–29 (Mori et al., 2013; Kennea et al., 2013). This has been an interesting discovery because the neutron star may be in a bound orbit around the supermassive black hole (Rea et al., 2013; Bower et al., 2015), and its long-term X-ray flux evolution can give insight into the physics of neutron star magnetospheres and the composition/structure of their interior (Kaspi et al., 2014; Coti Zelati et al., 2015). Moreover, SGR J1745–29 was also detected as a radio pulsar (Shannon and Johnston, 2013), and its polarized radio emission provided a measurement of the magnetic field near Sgr A* (Eatough et al., 2013). Finally, its discovery provided new strategies for finding other radio pulsars near Sgr A* that could probe space–time deformations around the supermassive black hole (Bower et al., 2014).

Quite remarkably, the X-ray outburst of SGR J1745–29 faded much more slowly than typically seen for transient magnetars (Kennea et al., 2013; Kaspi et al., 2014; Coti Zelati et al., 2015); the source continued to be detected in the 2–10 keV band over 1.5 years after it switched on (see Fig. 2). Fitting the XRT light curve of SGR J1745–29 to a simple exponential decay yields an e-folding time of $\tau = 152 \pm 6$ days (with a normalization of $(8 \pm 1) \times 10^{-2}$ c s^{-1}), suggesting that it should fade into the local X-ray background roughly 800 days after its onset, which would correspond to mid-2015. Indeed, in a 10″ extraction region around Sgr A* the average count rate in the last 10 observations of 2014 (October 21–November 2) was $(1.8 \pm 0.1) \times 10^{-2}$ c s^{-1}, i.e., higher than the average intensity of $(1.1 \pm 0.1) \times 10^{-2}$ c s^{-1} in 2006–2011 (Degenaar et al., 2013a). Nevertheless, by late 2014 the magnetar had already faded sufficiently to allow the detection of X-ray flares from Sgr A* with the XRT again (Section 2.1.1).

2.3. The outburst properties of very-faint X-ray binaries

In addition to the central supermassive black hole Sgr A* and the Galactic center magnetar SGR J1745–29, the 25′ × 25′ region covered by *Swift* also includes the position of 14 transient X-ray point sources, 9 of which were seen active in 2006–2014 (Table 3). The locations of these active sources are indicated in Fig. 1, and their long-term XRT light curves are shown in Fig. 5. Three of these active sources were previously unknown X-ray transients, uniquely discovered by *Swift* (see Section 2.4).

The Galactic center X-ray transients are usually very dim ($L_X \simeq 10^{30-33}$ erg s^{-1}; Degenaar et al., 2012) and undetected by *Swift*, but become visible during occasional X-ray outbursts when the 2–10 keV X-ray luminosity rises to $L_X \gtrsim 10^{34}$ erg s^{-1} for a duration of $t_{ob} \gtrsim 1$ week (see Table 3). The amplitude, duration and energy output indicates that these X-ray outbursts are powered by accretion onto a neutron star or stellar-mass black hole in an X-ray binary. Indeed three of these sources (AX J1745.6–2901, GRS 1741–2853, and XMM J174457–2850.3) have displayed Type-I X-ray bursts; bright flashes of X-ray emission caused by thermonuclear runaway on the surface of an accreting neutron star (e.g., Galloway et al., 2008). These are generally assumed to have low-mass companion stars and are therefore denoted as low-mass X-ray binaries (LMXBs).

In LMXBs matter is transferred to the compact primary via an accretion disk and transient behavior is ascribed to thermal-viscous instabilities in this disk (e.g., Lasota, 2001, for a review). During the X-ray dim episodes, called quiescence, gas flows from the companion into a cold accretion disk but little of this matter reaches the neutron star/black hole. However, as more material accumulates in the disk the temperature and pressure rise, eventually crossing the threshold for the disk to become hot and ionized. This strongly increases the viscosity and causes matter to rapidly accrete onto the compact primary, resulting in an X-ray outburst. As matter is more rapidly consumed than it is supplied by the companion, the disk becomes depleted and eventually switches back to its cold, quiescent state until a new outburst commences.

The outburst energetics serve as a probe of the amount of matter that was accreted and the detailed shape of the light curve can be used to determine if this was a large or a small portion of the entire disk (e.g., King and Ritter, 1998). Transient X-ray binaries are often further classified according to their 2–10 keV peak luminosity L_X^{peak} (Wijnands et al., 2006). The brightest sources exhibit $L_X^{peak} \simeq 10^{36-39}$ erg s^{-1}, but some objects never become brighter than $L_X^{peak} \simeq 10^{34-36}$ erg s^{-1}. These are therefore denoted

Table 3
Transient X-ray binaries covered by the *Swift* Galactic center monitoring campaign.

Source name	Year	L_X (10^{35} erg s^{-1})	L_X^{peak} (10^{35} erg s^{-1})	t_{ob} (weeks)	Classification	Reference
1. AX J1745.6–2901	2006	4.1×10^{35}	9.2×10^{35}	> 16	Neutron star LMXB	(Degenaar and Wijnands, 2009)
	2007–2008	1.1×10^{36}	5.1×10^{36}	> 80		(Degenaar and Wijnands, 2009, 2010)
	2010	2.7×10^{35}	5.6×10^{35}	20–34		(Degenaar et al., 2014b)
	2013–2015*	2.5×10^{36}	4.7×10^{36}	> 84		(Degenaar et al., 2014b)
2. CXOGC J174535.5–290124	2006	1.6×10^{34}	4.0×10^{34}	> 8	VFXB	(Degenaar and Wijnands, 2009)
	2008	1.1×10^{34}	3.0×10^{34}	> 12		(Degenaar and Wijnands, 2010)
3. CXOGC J174540.0–290005	2006	9.6×10^{34}	2.3×10^{35}	2	VFXB	(Degenaar and Wijnands, 2009)
	2013	1.5×10^{35}	4.0×10^{35}	4		(Koch et al., 2014)
4. Swift J174553.7–290347	2006	6.0×10^{34}	1.5×10^{35}	2	VFXB	(Degenaar and Wijnands, 2009)
5. Swift J174622.1–290634	2006	1.2×10^{34}	5.0×10^{34}	5	VFXB	(Degenaar and Wijnands, 2009)
6. GRS 1741–2853	2006	3.0×10^{34}	5.0×10^{34}	1	Neutron star LMXB	(Degenaar and Wijnands, 2009)
	2007	1.1×10^{36}	2.0×10^{36}	> 13		(Degenaar and Wijnands, 2009)
	2009	1.8×10^{36}	1.3×10^{37}	4–5		(Degenaar and Wijnands, 2010)
	2010	6.3×10^{35}	1.4×10^{36}	13		(Degenaar et al., 2014b)
	2013	4.4×10^{36}	2.3×10^{37}	6		(Degenaar et al., 2014b)
7. XMM J174457–2850.3	2007	2.6×10^{33}	7.3×10^{33}	< 12	Neutron star LMXB	(Degenaar and Wijnands, 2009)
	2008	1.7×10^{35}	1.4×10^{36}	1–7		(Degenaar and Wijnands, 2010)
	2009	1.0×10^{34}	1.1×10^{35}	< 2		(Degenaar and Wijnands, 2010)
	2010	2.6×10^{34}	1.9×10^{35}	1–3		(Degenaar et al., 2014c)
	2012	3.4×10^{35}	9.8×10^{35}	3		(Degenaar et al., 2014c)
	2013	3.0×10^{34}	4.5×10^{34}	1		this work
	2014	1.0×10^{34}	1.1×10^{34}	1–2		this work
8. CXOGC J174538.0–290022	2009	3.8×10^{34}	1.7×10^{35}	30–52	VFXB	(Degenaar and Wijnands, 2010)
9. Swift J174535.5–285921	2011	5.1×10^{34}	1.1×10^{35}	1–2	VFXB	this work
CXOGC J174540.0–290031	2004–2005	–	1×10^{35}	–	Black hole LMXB?	(Muno et al., 2005b; Muno et al., 2005a; Porquet et al., 2005a)
CXOGC J174541.0–290014	1999–2005	–	1×10^{34}	–	VFXB	(Muno et al., 2005a)
1A 1742–289	1975	–	7×10^{38}	–	Black hole LMXB?	(Davies et al., 1976; Branduardi et al., 1976; Muno et al., 2009)
XMMU J174554.4–285456	2002	–	8×10^{34}	–	VFXB	(Muno et al., 2005a; Porquet et al., 2005b)
XMM J174544–2913.0	2000	–	5×10^{34}	–	VFXB	(Sakano et al., 2005)

[*] The latest outburst of AX J1745.6–2901 was ongoing at the time of writing (2015 March). This overview is collected from the literature except for the 2011 outburst of Swift J174535.5–285921 and the 2013/2014 activity of XMM J174457–2850.3, which are reported here. Sources are numbered in the order that they appeared active during the campaign. For XMM J174457–2850.3 we list only outbursts for which a rise and/or decay could be determined, i.e., we do not list extended periods of low-level activity such as seen from this source in 2008 (Degenaar and Wijnands, 2010) and 2011 (Degenaar et al., 2014c). L_X gives the average 2–10 keV outburst luminosity and L_X^{peak} the estimated peak luminosity in that band. We assumed distances of $D = 6.7$ kpc for GRS 1741–2853 and $D = 6.5$ kpc for XMM J174457–2850.3 as inferred from Type-I X-ray burst analysis (Trap et al., 2010 and Degenaar et al., 2014c, respectively), whereas $D = 8$ kpc was used for all other sources. The bottom five are known X-ray transients within the FOV that were not active between 2006–2014; for reference we list their peak L_X reported for previous outbursts.

as 'very-faint X-ray binaries' (VFXBs; e.g., Muno et al., 2005a; Wijnands et al., 2006; Degenaar and Wijnands, 2009; Campana, 2009). This classification is not necessarily strict, however, since several bright LMXBs also exhibit very-faint outbursts (see Section 2.5).

As can be seen in Table 3, only four out of 14 X-ray transients covered by the *Swift* campaign have displayed outbursts with $L_X^{peak} > 10^{36}$ erg s^{-1}; the majority of sources remain below that level and can thus be classified as VFXBs. Although the VFXBs thus seem to outnumber the brighter LMXBs in the Galactic center region (see also Muno et al., 2005a; Degenaar et al., 2012), their sub-luminous character remains a puzzle. One proposed explanation is that these objects have degenerate (white dwarf) donor stars and short orbital periods, so that their accretion disks are small and hence only little material is accreted over an outburst (e.g., King and Wijnands, 2006; 't Zand et al., 2007; Heinke et al., 2015). Another possibility is that these neutron stars have relatively strong magnetic fields that choke the accretion flow (e.g., Wijnands, 2008; Patruno, 2010; Degenaar et al., 2014c; Heinke et al., 2015), or are feeding off the wind of their companion rather than from a disk (Pfahl et al., 2002; Degenaar and Wijnands, 2010; Maccarone and Patruno, 2013). It is also possible that the VFXBs are just bright X-ray binaries that exhibit low-level accretion activity and for which a bright outburst has not been observed yet (e.g., Wijnands et al., 2013; Heinke et al., 2015, see also Section 2.5).

The *Swift* Galactic center monitoring program has not only been important to discover new VFXBs (see Section 2.4), but it also allowed for the first detailed, systematic study of the outburst energetics and recurrence time of these peculiar objects. For instance, the mass-accretion rate averaged over thousands of years, $\langle \dot{M}_{long} \rangle$, is an important parameter for understanding the evolution of LMXBs. The excellent, long baseline provided by the *Swift* program has allowed to determine the duration (t_{ob}), recurrence time (t_{rec}), and mass-accretion rate of the outbursts of VFXBs ($\dot{M}_{ob}$), which can then be used to estimate $\langle \dot{M}_{long} \rangle$ (Degenaar and Wijnands, 2009, 2010, Koch et al., 2014, see also Section 2.4). The resulting long-term averaged low mass-accretion rates suggest that some VFXBs may indeed have white dwarf companions and hence small orbits/disks (see also Heinke et al., 2015).

Furthermore, the *Swift* program has provided the first detailed light curves of the (often short) outbursts of VFXBs, which can be compared to accretion disk models to gain information about their disk size (Heinke et al., 2015). Studying the light curves of three outbursts of two different sources (CXOGC J174540.0–290005 and XMM J174457–2850.3) revealed that these sources likely have orbital periods of order $\simeq 1$ h and thus indeed have small accretion disks. Such light curve modeling also allows to distinguish between true VFXBs and bright X-ray binaries showing low-level accretion

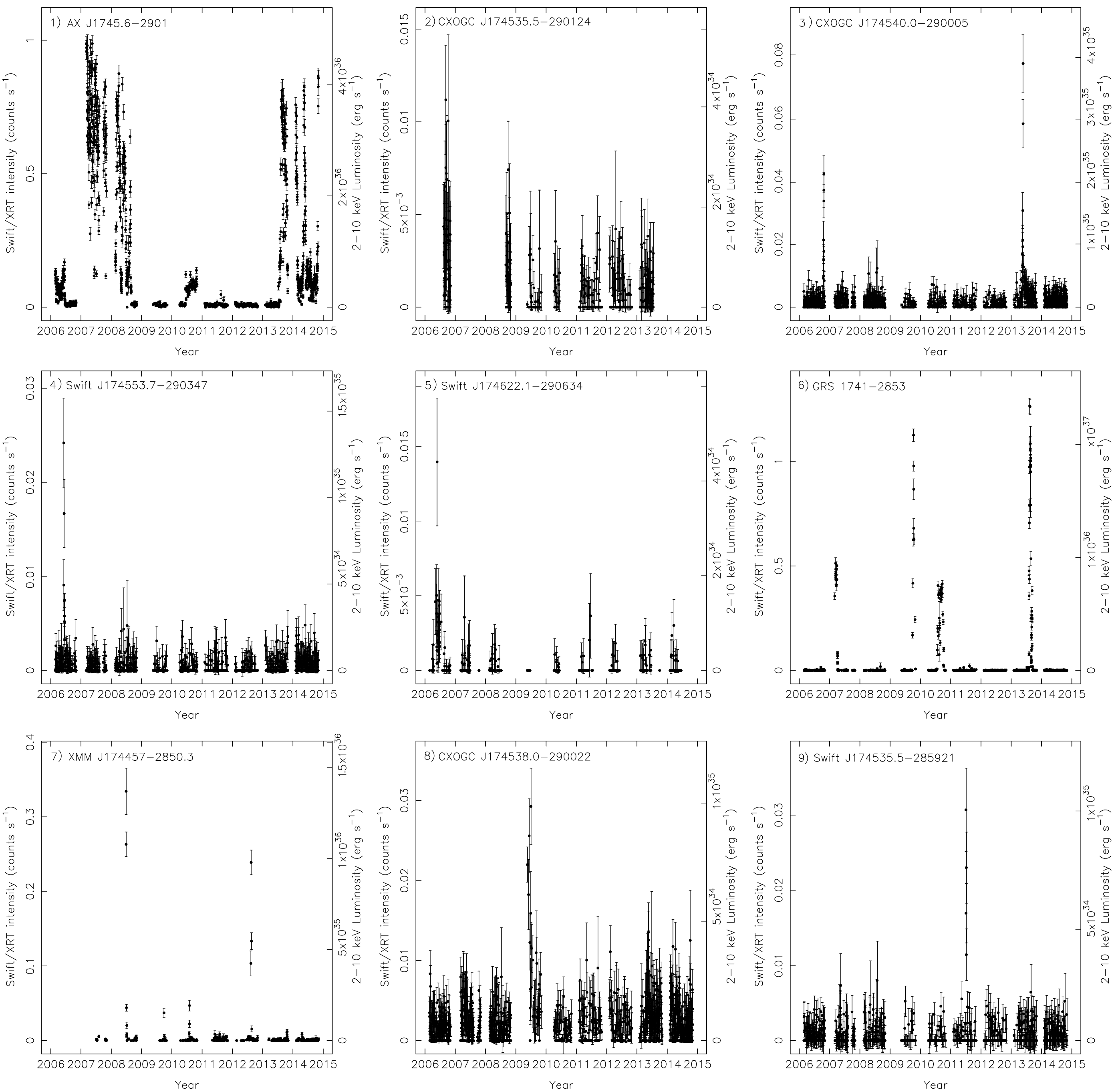

Fig. 5. Background corrected long-term 0.3–10 keV *Swift*/XRT count rate light curves of the 9 transient X-ray binaries that were active in 2006–2014 (PC mode data only, binned per observation). More detailed light curves of selected individual outbursts are presented in Fig. 6. Distances were assumed to be $D = 8$ kpc, except for GRS 1741–2853 and XMM J174457–2850.3, for which we adopted the estimates from Type-I X-ray burst analysis ($D = 6.7$ kpc and $D = 6.5$ kpc, respectively; Trap et al., 2010; Degenaar et al., 2014c).

activity (see also Section 2.5): In the former case the entire (albeit small) disk would be accreted and result in an exponential outburst decay followed by a linear trend, whereas in the latter case only a portion of the disk would be accreted and the resulting decay would only show a linear trend (Heinke et al., 2015). Importantly, this study demonstrated that daily, sensitive X-ray observations are instrumental; less dense sampling does not allow for good constraints on the outburst decays so that no conclusions can be drawn on the disk size. This study of VFXB light curves has not been possible prior to *Swift*, because all-sky monitors lack the required sensitivity, and other pointed telescopes are not flexible enough to obtain dense sampling of the often short (<1 month) outbursts. It is of note that *Swift* also uncovered sustained long periods of low-level accretion activity in one particular source (XMM J174457–2850.3), which may point toward the magnetic field of the neutron star choking the accretion flow (see Section 2.6).

2.4. Newly discovered (candidate) transient X-ray binaries

Three of the sources that exhibited an outburst during the *Swift* campaign had previously been identified as dim, non-variable X-ray sources in a deep *Chandra* survey (Muno et al., 2009), but were not known to be transient; Swift J174553.7–290347, Swift J174622.1–290634 (Degenaar and Wijnands, 2009), and Swift

Table 4
The new X-ray transient Swift J174535.5–285921.

Parameter	Value
N_H (cm^{-2})	$(1.1 \pm 0.7) \times 10^{23}$
Γ	1.1 ± 0.7
F_X (erg cm^{-2} s^{-1})	$(6.6 \pm 2.0) \times 10^{-11}$
L_X (erg s^{-1})	$(5.1 \pm 1.5) \times 10^{34}$
L_X^{peak} (erg s^{-1})	1.1×10^{35}
t_{ob} (weeks)	1–2
f (erg cm^{-2})	$(3–9) \times 10^{-6}$
$\dot{M}_{ob}$ (M$_\odot$ yr^{-1})	1.3×10^{-11}
$\langle \dot{M}_{long} \rangle$ (M$_\odot$ yr^{-1})	$< 3 \times 10^{-13}$

F_X is the average unabsorbed flux and L_X is the corresponding luminosity for $D = 8$ kpc (2–10 keV). The outburst fluence f is the product of F_X and the outburst duration t_{ob}. $\dot{M}_{ob}$ is the estimated mass-accretion during outburst and $\langle \dot{M}_{long} \rangle$ the long-term averaged mass-accretion rate (for details, see Degenaar and Wijnands, 2009). Errors are 90% confidence.

J174535.5–285921 (Degenaar et al., 2011a). All three exhibited very brief ($\lesssim$5 weeks), and very faint ($L_X \lesssim 10^{35}$ erg s^{-1}) outbursts that are easily missed and have only been detected by the advent of *Swift*'s frequent, sensitive X-ray observations (see Fig. 5 and Table 3). The detailed properties of the newly discovered transients Swift J174553.7–290347 and Swift J174622.1–290634 (both active in 2006) were reported in Degenaar and Wijnands (2009), but we discuss the 2011 discovery outburst of Swift J174535.5–285921 here.

Swift J174535.5–285921. This transient X-ray source is located $\simeq 1.3'$ NE of Sgr A* (see Fig. 1) and was first detected on 2011 July 3, while it had not been seen prior to June 30 (Degenaar et al., 2011a). The source remained visible in subsequent observations performed on July 6, 8, and 9, was not seen on July 15, 17, and 18, but reappeared during a single observation on July 21 (Degenaar et al., 2011b). The source remained dormant after that (July 24 onwards). The long-term XRT light curve of this new X-ray transient is shown in Fig. 5, whereas a zoom of its 2011 outburst is shown at the bottom left in Fig. 6. The results of fitting the average outburst spectrum (using obsID 91095027–29, 91095032, and 35650234; 5.1 ks of data), are listed in Table 4.

Chandra observations performed on July 21 (i.e., during the reflare) provided a sub-arcsecond localization of the new Galactic transient and allowed for the identification of the likely quiescent counterpart: CXOGC J174535.6–285928 (Chakrabarty et al., 2011). This is a faint object that was persistently detected at an intensity of $L_X \simeq 2 \times 10^{31}$ erg s^{-1} during a *Chandra* monitoring campaign of the Galactic center carried out in 2005–2008 (source number 1680; Muno et al., 2009).

The main outburst of Swift J174535.5–285921 had a duration of $6 \lesssim t_{ob} \lesssim 15$ days, whereas the small re-flare cannot have been longer than 6 days. The average luminosity during the main outburst was $L_X \simeq 5 \times 10^{34}$ erg s^{-1}, whereas we estimate $L_X \simeq 8 \times 10^{33}$ erg s^{-1} for the July 21 observation (see also Chakrabarty et al., 2011). It seems likely that most of the energy was released during the main outburst. With an estimated outburst peak of $L_X^{peak} \simeq 1 \times 10^{35}$ erg s^{-1}, Swift J174535.5–285921 falls into the class of VFXBs, just like the other two newly discovered transients Swift J174553.7–290347 and Swift J174622.1–290634 (see Table 3).

From the observed outburst properties we can estimate the long-term average mass-accretion rate onto the compact primary (see Section 2.3). We estimate an average mass-accretion rate during outburst of $\dot{M}_{ob} = RL_{acc}/GM \simeq 1.3 \times 10^{-11}$ M$_\odot$ yr^{-1}. In this relation $L_{acc} \simeq 3L_X$ is the estimated bolometric accretion luminosity ('t Zand et al., 2007), G is the gravitational constant, and R and M are the radius and mass of the compact primary, respectively. Here we assumed a neutron star primary with $R = 10$ km and $M = 1.4$ M$_\odot$ (see Degenaar and Wijnands, 2009 for caveats).

The long-term average accretion rate can be estimated as $\langle \dot{M}_{long} \rangle = \dot{M}_{ob} \times t_{ob}/t_{rec}$, where $t_{rec} = t_{ob} + t_q$ is the recurrence time, i.e., the sum of the quiescent and outburst intervals. In 2014 the source position was covered for 39 consecutive weeks with no data gaps exceeding 5 days. We can therefore take this as a lower limit on the time it spends in quiescence, i.e., $t_q > 39$ weeks and $t_{rec} > 40$ weeks. The duty cycle is then $t_{ob}/t_{rec} < 0.022$ (2.2%), giving $\langle \dot{M}_{long} \rangle < 3 \times 10^{-13}$ M$_\odot$ yr^{-1}. This low value may indicate that Swift J174535.5–285921 also harbors an old degenerate companion and a small orbit (cf. Degenaar and Wijnands, 2009; Heinke et al., 2015).

2.5. Low-level accretion in bright X-ray binaries

Remarkably, the *Swift* Galactic center monitoring campaign has also exposed very-faint X-ray activity from LMXBs that normally exhibit brighter outbursts. AX J1745.6–2901, for instance, exhibited four different outbursts between 2006–2014; in 2007–2008 and 2013–2014 it showed long (>1.5 yr) and bright ($L_X^{peak} \simeq 6–7 \times 10^{36}$ erg s^{-1}) outbursts (Table 3). However, its 2006 and 2010 outbursts were both shorter (few months) and an order of magnitude fainter (Degenaar and Wijnands, 2009; Degenaar et al., 2014b, see also Fig. 5). Moreover, in 2006 *Swift* uncovered a very brief ($\simeq$ 1 week) and very faint ($L_X^{peak} \lesssim 7 \times 10^{34}$ $(D/6.7$ kpc$)^2$ erg s^{-1}) outburst from GRS 1741–2853 (see Fig. 6), whereas it normally displays weeks-long outbursts that peak at $L_X^{peak} \simeq \times 10^{36–37}$ $(D/6.7$ kpc$)^2$ erg s^{-1} (Degenaar and Wijnands, 2009, see Table 3).

A strikingly similar mini-outburst as that from GRS 1741–2853 was detected with *Swift* from XMM J174457–2850.3 in 2013; a clear excess of photons was found at the source position in five consecutive observations performed on October 19, 20, 21, 22, and 23, whereas it went undetected on October 18 and 24, i.e., $t_{ob} = 5–6$ days. The averaged spectrum of these five observations can be described by an absorbed power-law model with an index of $\Gamma = 0.8 \pm 0.8$ (for a fixed $N_H = 1.1 \times 10^{23}$ cm^{-2}; Degenaar et al., 2014c), yielding a 2–10 keV unabsorbed flux of $F_X = (5.9 \pm 2.2) \times 10^{-12}$ erg cm^{-2} s^{-1}. This translates into an average luminosity of $L_X = (3.0 \pm 1.1) \times 10^{34}$ $(D/6.5$ kpc$)^2$ erg s^{-1}, whereas we estimate a peak luminosity of $L_X^{peak} = 4.5 \times 10^{34}$ $(D/6.5$ kpc$)^2$ erg s^{-1}. The light curve of this short, faint outburst of XMM J174457–2850.3 is shown in Fig. 6 (top right), where it is compared to mini-outburst of GRS 1741–2853 in 2006 (top left; Degenaar and Wijnands, 2009).

For comparison, we also show in Fig. 6 two example light curves of the activity of VFXBs; the 2006 outburst of CXOGC J174540.0–290005 (lower right), and the 2011 discovery outburst of Swift J174535.5–285921 (lower left). This plot illustrates that the mini-outbursts of the otherwise bright LMXBs are very similar in terms of duration, peak intensity, and energetics to some outbursts of VFXBs. Since GRS 1741–2853 and XMM J174457–2850.3 also show longer and brighter outbursts, it is likely that their mini-outbursts are the result of accreting only a (small) portion of the entire disk (Degenaar and Wijnands, 2010; Heinke et al., 2015). Similar events have also been detected from a few other bright neutron star LMXBs (e.g., XTE J1701–462, KS 1741–293, SAX J1750.8–2900, and MAXI J0556–332; Fridriksson et al., 2011; Degenaar and Wijnands, 2013; Wijnands and Degenaar, 2013; Homan et al., 2014). It can therefore be hypothesized that some of the VFXBs could be bright LMXBs that exhibited low-level accretion activity (e.g., Wijnands et al., 2013; Heinke et al., 2015, see also Fridriksson et al., 2011).

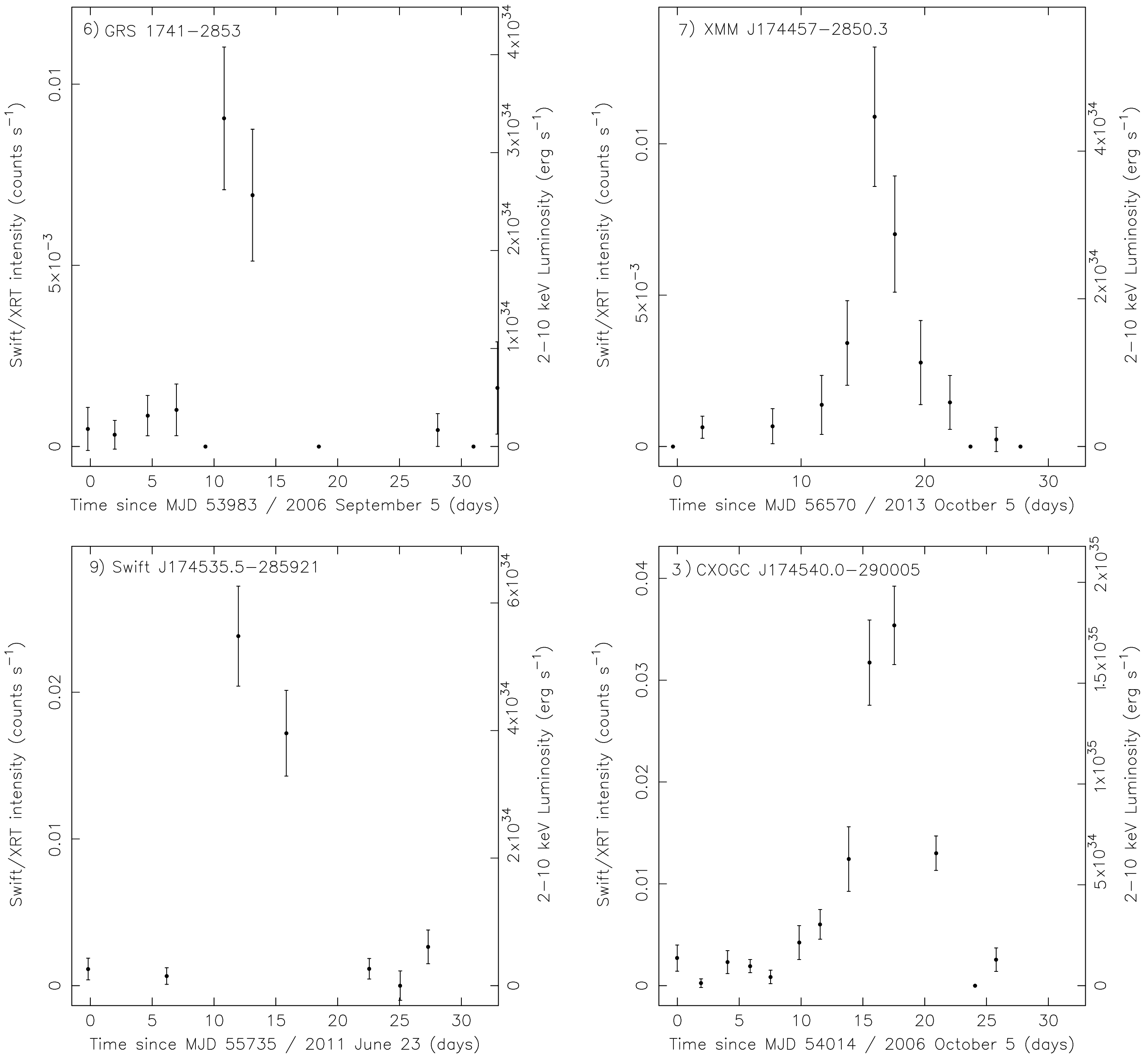

Fig. 6. Comparison between the light curves of low-level accretion activity in the bright neutron star LMXBs GRS 1741–2853 (2006) and XMM J174457–2850.3 (2013) on top, and illustrative examples of the light curves of VFXBs in outburst, Swift J174535.5–285921 (2011) and CXOGC J174540.0–290005 (2006), at the bottom. All displayed light curves were binned per two observations. Distances were assumed to be $D = 8$ kpc for CXOGC J174540.0–290005 and Swift J174535.5–285921, but based on Type-I X-ray burst analysis we took $D = 6.7$ kpc for GRS 1741–2853 (Trap et al., 2010) and $D = 6.5$ kpc for XMM J174457–2850.3 (Degenaar et al., 2014c).

2.6. LMXB/millisecond radio pulsar transitional object

Apart from short, faint accretion outbursts such as seen in 2013 (see Fig. 5 and Section 2.5), the *Swift* Galactic center monitoring program revealed that XMM J174457–2850.3 also displays much longer (months) periods of sustained low-level activity, sometimes without an associated outburst (Degenaar et al., 2014c). In fact, combining the *Swift* data with archival *Chandra* and *XMM-Newton* observations, it was demonstrated that the source appears to exhibit three different luminosity regimes; 1) it regularly displays accretion outbursts with $L_X \simeq 10^{34}$–10^{36} $(D/6.5\ \text{kpc})^2$ erg s^{-1}, 2) on rare occasions it has been found in deep quiescence with $L_X \lesssim 10^{33}$ $(D/6.5\ \text{kpc})^2$ erg s^{-1}, and 3) most often it is detected at an intermediate regime of $L_X \simeq 10^{33}$–10^{34} $(D/6.5\ \text{kpc})^2$ erg s^{-1}. There appears to be little variation in the X-ray spectrum despite this orders of magnitude change in luminosity (Degenaar et al., 2014c).

This behavior is difficult to explain as thermal-viscous instabilities in the accretion disk, since the mass-accretion rate during these low-activity periods should not be sufficient to irradiate the disk and keep the mass-flow going (Degenaar and Wijnands, 2010). However, the detection of an energetic Type-I X-ray burst in 2012 makes it unlikely that the neutron star is feeding off the wind of its companion, hence increasing the mystery of its peculiar X-ray properties (Degenaar et al., 2014c).

The flux variability of XMM J174457–2850.3, and the lack of strong spectral changes between different luminosity states, is remarkably similar to that of a neutron star in the globular cluster M28, PSR J1824–24521 (Linares et al., 2014a). This source was known to be a millisecond radio pulsar (MSRP), but in 2012 suddenly exhibited an accretion outburst like that seen

LMXBs (Papitto et al., 2013). It had long been suspected that MSRPs are the descendants of LMXBs (e.g., Alpar et al., 1982; Bhattacharya and van den Heuvel, 1991; Strohmayer et al., 1996; Wijnands and van der Klis, 1998), and the discovery of a neutron star directly switching between these two different manifestations has opened up a new opportunity to investigate their evolutionary link. Two other MSRPs display similar behavior, PSR J1023+0038 (e.g., Archibald et al., 2009, 2014; Stappers et al., 2014; Patruno et al., 2014; Deller et al., 2014) and XSS J12270–4859 (e.g., de Martino et al., 2013; Bassa et al., 2014; Roy et al., 2014; Papitto et al., 2015), and together these three are referred to as the 'MSRP/LMXB transitional objects'. Discovering more of such neutron stars, either drawn from the MSRP or from the LMXB population, is highly desired to further investigate their connection. Based on seven years of *Swift* Galactic center monitoring, we demonstrated that the peculiar neutron star XMM J174457–2850.3 may be another member of this class (Degenaar et al., 2014c).

3. Summary and outlook

We have reviewed the main discoveries of nine years of *Swift* X-ray monitoring of the center of the Milky Way Galaxy, in which short 1-ks exposures have been taken almost daily since 2006. The *Swift* detection of seven bright ($L_X \gtrsim 10^{35}$ erg s^{-1}) X-ray flares from Sgr A* constitutes more than half of the current number of such bright flares observed, and has allowed for an estimate of their recurrence time (once per 5–10 days) as well as a comparison of their spectral properties (hinting that flares of similar brightness may have different spectral shapes; Section 2.1). Moreover, the discovery of the magnetar SGR J1745–29, which seems to be orbiting the supermassive black hole, has provided a measurement of the magnetic field near Sgr A* and has led to new observing strategies for finding other radio pulsars in the same region (Section 2.2).

In addition, the unique combination of sensitive observations and dense sampling of the *Swift* program allowed for a first detailed, systematic study of the peculiar class of VFXBs, X-ray binaries with very dim outbursts and unusually low mass-accretion rates, providing more insight into their nature (Section 2.3). In nine years time, *Swift* discovered three new transient VFXBs near the Galactic center (Section 2.4). Furthermore, *Swift* exposed that bright LMXBs can display low-level accretion activity that looks similar to the outbursts of VFXBs (Section 2.5). Finally, owing to this *Swift* program it was found that XMM J174457–2850.3 displays peculiar X-ray flux variability and could be a member of the recently discovered class of LMXB/MSRP transitional objects, which hold great potential to further our knowledge of the evolutionary link between these two different neutron star manifestations (Section 2.6).

Building and following-up on this exciting series of discoveries, continuing this *Swift* legacy allows us to:

1. **Continue catching Sgr A* X-ray flares**
   Confirming that X-ray flares from Sgr A* can have different spectral shapes would give important insight into their underlying emission and production mechanism (e.g., Degenaar et al., 2013a; Barrière et al., 2014). *Swift* has provided a first glimpse in this direction, by finding that one of the six flares detected in 2006–2011 may have had a different spectral shape (Degenaar et al., 2013a). However, the result was of only low significance, so further confirmation is required. By continuing the *Swift* monitoring campaign we can collect more X-ray flares from Sgr A* and increase the sample available for a comparative study.
2. **Keep watch for changing activity of Sgr A***
   Now that G2 has swung by Sgr A* (Witzel et al., 2014; Pfuhl et al., 2015), its possible disruption and accretion could increase the X-ray emission of the supermassive black hole. Dedicated monitoring and target-of-opportunity programs remain in line to study this rare phenomenon. It is widely recognized that *Swift*'s Galactic center monitoring program is of vital importance to promptly detect any changes in the (persistent or flaring) emission from Sgr A*, and to trigger follow-up observations with other observatories and at other wavelengths.
3. **Further study very-faint accretion outbursts**
   In 2006–2014, *Swift* detected 16 very-faint accretion outbursts from 9 X-ray binaries. The daily, sensitive XRT observations have yielded a wealth of information about their outburst profiles and energetics, which cannot be obtained with any other X-ray satellite. Continuation of this program is guaranteed to capture new outbursts of VFXBs, giving further insight into the nature of this peculiar (yet perhaps dominant) sub-class of X-ray binaries.
4. **Test the nature of XMM J174457–2850.3**
   A distinguishing property of the recently discovered LMXB/MSRP transitional objects is that these occupy different X-ray luminosity regimes, most likely governed by the interaction between the accretion flow and the magnetic field (e.g., Linares et al., 2014b; Patruno et al., 2014; Bassa et al., 2014). By virtue of the *Swift* Galactic center monitoring campaign, we found that XMM J174457–2850.3 may display similar behavior (Degenaar et al., 2014c). However, due to its location $\simeq 14'$ from Sgr A*, it was only covered during a fraction of the time. In 2015–2016 the observations will be offset by $\simeq 2'$ from the nominal aimpoint, to ensure that XMM J174457–2850.3 is covered by every pointing. Following this source daily for a year allows us to establish if it indeed exhibits three distinct accretion regimes, strengthening its LMXB/MSRP candidacy.

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