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Swift: the science across the rainbow

Mission Overview and Highlights of Results

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Abstract. I present an overview of the *Swift* mission, which was launched on November 20, 2004 to discover and observe the most energetic of astrophysical phenomena, γ–ray bursts (GRBs). After almost 6 years in space the Observatory is in excellent shape, with all systems and instruments performing nominally and in burst chasing mode for an average of 97 % of the time. *Swift* is also a multi-purpose multi-frequency mission with the observing time evolving from mostly GRB targets, to mainly secondary science ones such as supernovae, cataclysmic variables and novae, active galactic nuclei, Galactic transients, active stars and comets. I present the most recent science highlights.

Key words. gamma rays: general - gamma rays: bursts - space vehicles: instruments - telescopes - ultraviolet: general

1. Introduction

The *Swift* Gamma-Ray Burst Explorer (Gehrels et al. 2004) is a MIDEX NASA mission, whose instruments were built with the participation of the United Kingdom and Italy, that was successfully launched on 2004 Nov. 20. It is a first-of-its-kind autonomous rapid-slewing mission to discover and observe the most energetic of astrophysical phenomena, γ–ray bursts (GRBs), and pioneers the way for future rapid-reaction and multi-wavelength missions, such as *Fermi*. The nominal lifetime was of two years, but has subsequently been extended in 2006, 2008, and 2010.

The scientific goals of the mission are to determine the origin of GRBs, to classify them and search for new types, to determine how the GRB blast-wave evolves and interacts with the surroundings, to use GRBs to study the early universe, and to perform a sensitive hard X-ray survey.

In order to tackle these goals, *Swift* carries three co-aligned telescopes (see Fig. 1): one wide-field instrument, the gamma-ray Burst Alert Telescope (BAT, 15-150 keV, Barthelmy et al. 2005), which is the coded aperture mask telescope that provides the initial GRB trigger, and two narrow-field instruments (NFI), the X–ray Telescope (XRT, 0.2–10 keV, Burrows et al. 2005a), and the UV/Optical Telescope (UVOT, 1700–6500Å, Roming et al. 2005). The main characteristics of the payload are reported in Table 1 (see Gehrels et al. 2004, for a complete description).

Much of the mission's success is undoubtedly due to the GRB observing strategy. The

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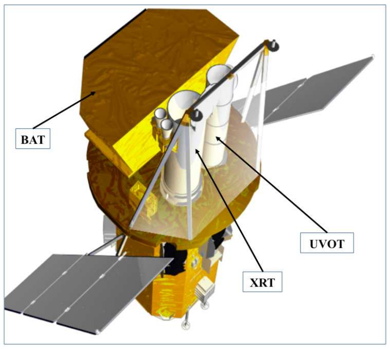

Fig. 1. The *Swift* satellite.

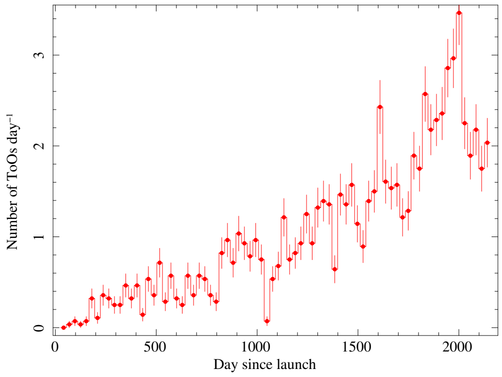

Fig. 2. ToO observation requests as a function of time, on a monthly basis, since the start of the mission. Courtesy of J.A. Kennea.

Table 1. *Swift* in-flight performance.

BAT		
	FOV	1.4 sr (half-coded)
	Energy range	15–150 keV
	Position precision	2'–3'
XRT		
	FOV	23.6'×23.6'
	Energy range	0.2–10 keV
	Position precision	5"
UVOT		
	FOV	17'×17'
	Energy range	1700–6500Å
	Position precision	0.5'

BAT detects a GRB and calculates the source location down to 2'–3', depending on the source brightness, and triggers an autonomous slew of the whole Observatory, so that the NFIs can image the GRB location, generally within a minute or so. The BAT position is sent to the ground within 15 s of the localization, so that the ground-based facilities can start observing the transient at once and attempt to determine its redshift. Subsequently, the XRT can improve the GRB localization down to ~ 5", while the UVOT can further refine it to ~ 0.5". In about 5 minutes, *Swift* can generally provide a ~ 0.5" position for the GRB, and allows the investigation of the initial phases of the afterglow starting as early as one minute after the BAT trigger. All this happens during a time span comparable to the one it takes to read this last paragraph.

1.1. Status of the Mission

The *Swift* mission is in excellent shape, with an expected orbital life of more than 15 years. After almost 6 years (as of 2010-09-30) in space all systems are performing nominally with a science uptime of 97.5 %. We performed about 180,000 slews and have responded to the more than 500 bursts within an hour since the onset of the event with GCN circulars, so that the Flight Operation Team and Science Operation Team response has been excellent. Both the ground station and Observatory are in nominal condition. The same applies for the three instruments, BAT, XRT, and UVOT. BAT is burst chasing for 97 % of the time, with a GRB discovery rate consistent with pre-flight predictions; XRT detects about 97 % of afterglows with a prompt response.

Swift is also a multi-purpose multi-frequency mission whose observing time is evolving from an initial (as of 2006) 60 % of the time dedicated to GRB observations, and 30 % divided between target of opportunity (ToO, 10 %) and Fill-in observations (18 %), to a current 27 % dedicated to GRBs, 29 % to ToOs, and 26 % to Fill-in observations (2010). Figure 2 shows the number of ToOs received per day on a monthly basis since the start of

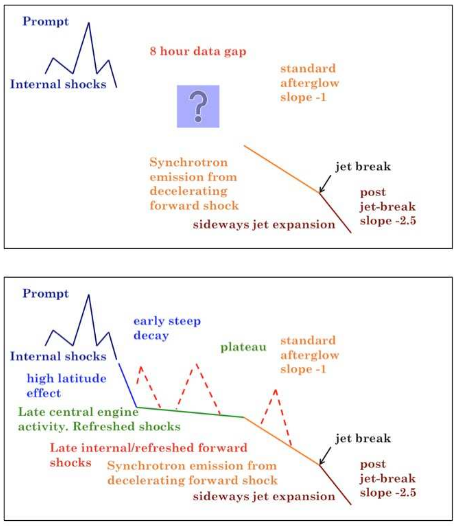

Fig. 3. GRB light curves before (top) and after (bottom) *Swift*.

the mission, which is an ever-increasing function of time.

2. Science Highlights: GRBs

Swift has opened a new avenue of research in GRBs as, for the first time, we can study them in a continuous way, from prompt emission to all phases of the afterglow (AG). This is exemplified in Fig. 3 (top): at the times of *BeppoSAX* it used to take about 6–10 hours from the detection of a new GRB to the moment it could be imaged with lower-energy narrow-field instruments. As the AG decays quite fast, this implied that at that point, the AG was a few orders of magnitude fainter, hence its localization more difficult to obtain, and its study at lower energies much more complicated to perform.

Swift has now observed more than 500 GRBs (Fig. 4) panchromatically. At the date of writing (2010-09-30) *Swift* has detected 544 GRBs, 84 % of which have an XRT-detected AG (this percentage rises to 97 % if the slew was performed immediately after the BAT trigger), 57 % with optical detection. Nowadays, about 88 % of the total number of AGs is due to *Swift*. Of all *Swift* GRBs, 174 have a redshift determination when only 41 existed before.

These data have yielded a few surprises, the first being the fact that X–ray AGs do not follow the initial prompt decay to smoothly join the 'standard' X–ray AG. On the contrary, the X–ray AG light curve has now a well-defined 'canonical' shape, which can be divided in distinct phases (noted above the curve in Fig. 3, bottom) for which several responsible mechanisms are invoked (reported below the curve). This 'canonical' (Zhang et al. 2006; Nousek et al. 2006; O'Brien et al. 2006) light curve is characterized by a steep/flat/steep/steeper shape, of which only the latter two were known before the launch of *Swift*. Many light curves also show flares (Burrows et al. 2005b; Romano et al. 2006; Falcone et al. 2006; Chincarini et al. 2007) that imply central engine long-lasting activity. A full review of the *Swift* results on GRBs can be found in Gehrels et al. (2009). Here I shall mention only a few.

GRB 080319B ($z = 0.937$) has been dubbed 'the naked-eye burst' (Racusin et al. 2008, and references therein) since it reached the uniquely bright visual magnitude of 5.3 mag, offered the brightest optical and X–ray fluxes, and had one of highest γ–ray fluences ever recorded for a GRB ($\sim 6.3 \times 10^{-4}$ erg cm^{-2}, 20 keV–7 MeV). It has proven to be a powerful diagnostic of the detailed physics of this explosion within seconds of its formation.

GRB 090423, with its redshift of 8.2 (Salvaterra et al. 2009), is not only the most distant GRB, but also the most distant object ever observed in the universe, and it has allowed us to establish that the the mechanisms and progenitors that gave rise to this burst about 600 million years after the Big Bang are not markedly different from those producing GRBs 10 billion years later. The previous record-holders were GRB 050904 ($z = 6.3$ Cusumano et al. 2006), GRB 080913 ($z = 6.7$ Greiner et al. 2009).

Swift has detected 46 short GRBs, 70 % of which localized to arcsecond precision (none were available before *Swift*, see, e.g. Gehrels et al. 2005), and about half with host identifi-

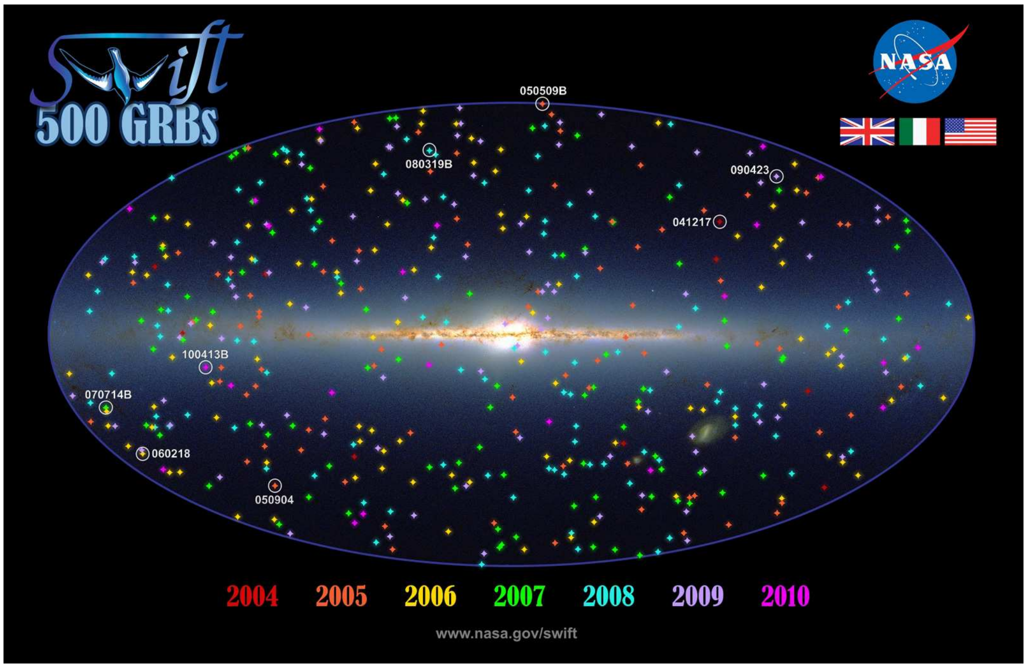

Fig. 4. The first 500 GRBs observed by *Swift*. Credit: NASA/Goddard Space Flight Center/*Swift*.

cation and/or redshifts. The main implication is that the progenitors are likely binary mergers, as opposed to the death of massive stars, which are the likely progenitors of long GRBs. Short GRBs show X–ray light curves similar to the ones of long GRBs, including the presence of flares.

The link between long GRBs and supernovae (SN) dates back before the *Swift* era, with a firm association established between an almost-simultaneous Type Ib/Ic SN, so that long GRBs can be the high-energy counterpart of such SN events. However, it was only with GRB 060218 that we could actually observe the beginning of a SN explosion and its intimate link with a GRB. Campana et al. (2006) describe how, in addition to the classical non-thermal emission, GRB 060218 showed a thermal component in its X-ray spectrum, which cooled and shifted into the optical/UV band as time passed, and interpreted these features as arising from the break-out of a shock wave driven by a mildly relativistic shell into the dense wind surrounding the progenitor, which was probably a Wolf-Rayet star.

Swift has been studying SNe extensively (see Fig. 5). In particular, Brown et al. (2009) present more that 100 SNe light curves in the UV and X–rays, more than those obtained with all previous missions combined. This large sample has allowed characterization of light curve shapes and the classification of SNe based on UV-optical photometry and can also be compared with rest-frame UV observations of high-redshift SNe observed at optical wavelengths. *Swift* is also surveying nearby galaxies like M 31 (Fig. 6) in order to understand the star-formation conditions and relate them to the conditions in the distant galaxies where GRB are occurring.

3. Science Highlights: secondary science

Swift's multi-wavelength capability and flexible observing schedule make it perfectly suited for studies of comets, cataclysmic variables

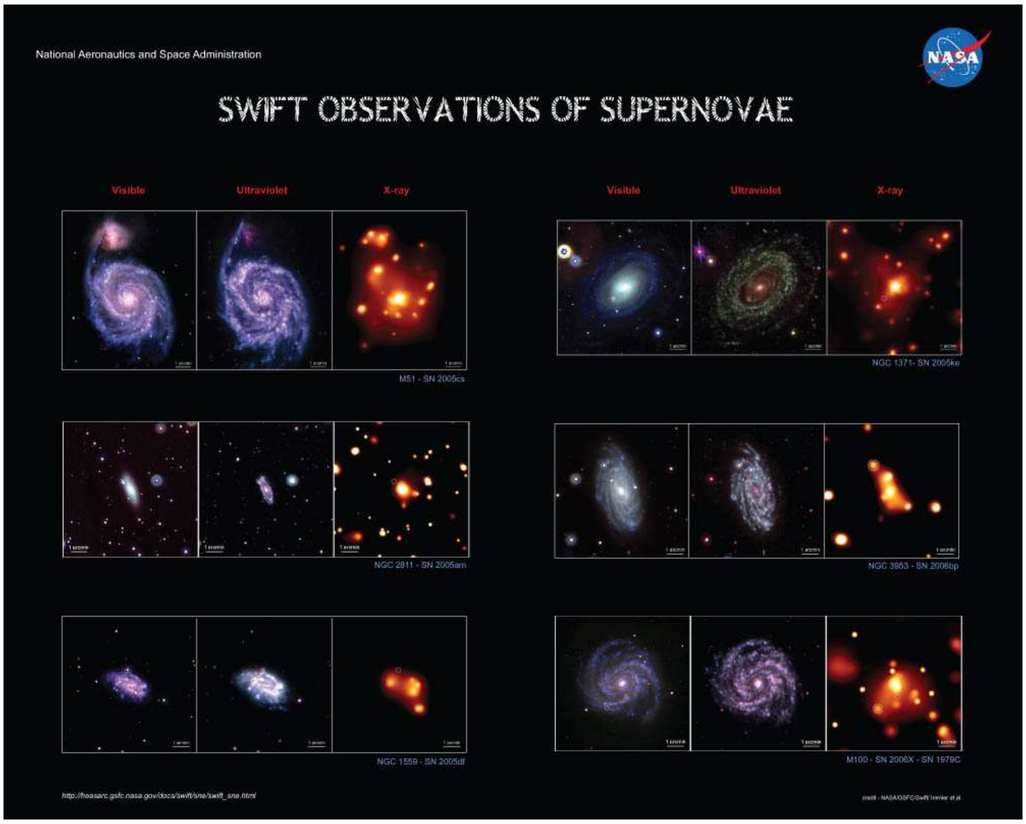

Fig. 5. *Swift* optical (left), ultraviolet (middle), and X-ray images (right) of nearby SN host galaxies. The visible (V, B, and U filters) and ultraviolet ($UVW1$, $UVM2$ $UVW2$ filters) images were obtained with UVOT. The X-ray images (0.2–10 keV) were obtained simultaneously with XRT. Credit: NASA/*Swift*/S. Immler.

(CVs) and novae, active stars, active galactic nuclei (AGN), and Galactic transients. The increasing number of ToO requests is an indication that the astronomical community has realized this and is exploiting the potentiality of this Observatory for non-GRB science.

Among the most interesting objects that *Swift* has observed we can find several comets. These objects are uncontaminated fossils from the early days of the Solar system, hence precious tools in studying cosmogony. Comets are difficult to observe in that they are fast-moving targets, hence requiring a fast accurate pointing, and are often too bright for *XMM-Newton* and *Chandra*. *Swift* has allowed to study the composition (with the UVOT grisms), the chemistry (UVOT grisms), the evolution of the gas surrounding the comet (UVOT imaging), and the interaction of this gas with the Solar wind (XRT). Some of the main results can be found in Bodewits et al. (2010).

A true renaissance has occurred in the field of accreting white dwarfs and novae because of the availability of simultaneous optical to hard X-ray observations. *Swift* has made unique observations, collecting whole-outburst light curves showing the rise and fall of the super-soft emission. As an example, it has been possible to study the rare outburst of the dwarf nova GW Lib (Byckling et al. 2009), and to find that its long inter-outburst time-scale with no observed normal outbursts is consistent with the idea that the inner disc is evacuated or the disc viscosity is very low. On the

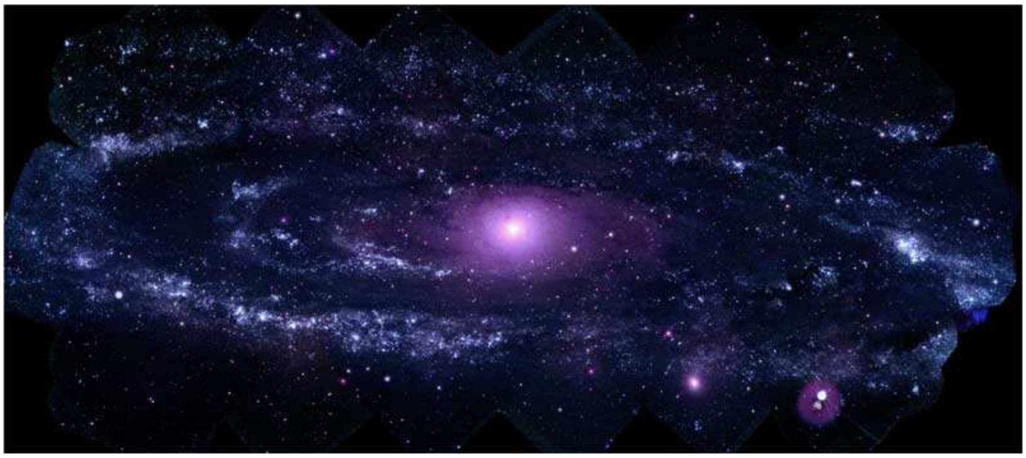

Fig. 6. The highest-resolution ultraviolet image of the Andromeda Galaxy obtained by *Swift*. The image is a mosaic of 330 images acquired between May 25 and July 26 2008, for a total exposure time of 24 hours, by UVOT. UVOT revealed about 20,000 ultraviolet sources in a region 200,000 light-years wide. Several features are apparent in the new mosaic like the striking difference between the galaxy's central bulge and its spiral arms. Credit: NASA/*Swift*/Stefan Immler (GSFC) and Erin Grand (UMCP).

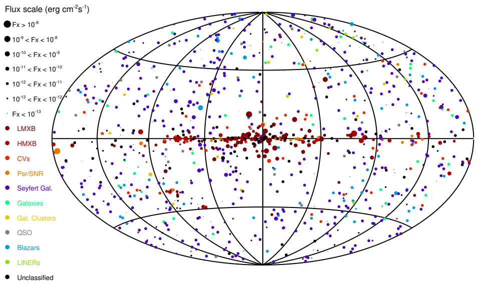

Fig. 7. Map (Galactic coordinates) of the sources detected and associated with a counterpart, during the first 54 months of survey performed by BAT. Different colors indicate different kinds of sources, while the symbol dimension is proportional to the 15-150 keV flux of the source. Adapted from Cusumano et al. (2010).

other hand, Evans et al. (2009) show that the large disc in the dwarf nova-like GK Per is able to maintain a long-term memory of the mass transfer rate from the secondary.

Swift's contribution to the AGN field is considerable, since it covers the critical optical/UV to hard X-ray range of the spectral energy distribution (SED) where the transition between the synchrotron and inverse Compton emission usually occurs. AGN are notoriously highly variable sources in the UV as well as in X-rays, so the requirement is simultaneity of such observations. This allows researchers to determine the physical conditions in individual AGNs, and to treat AGN as a class, studying their evolution and formation. Furthermore, *Swift* has allowed to study particle acceleration mechanisms in blazar jets. As an example, Abdo et al. (2010) study the SED of Fermi bright blazars, and propose a new classification scheme based on the position of the peaks of the SED. In Fig. 7 I show the results based on a 54-month survey of the sky (Cusumano et al. 2010). The BAT, because of its large field of view and detector area, offers the opportunity to significantly increase the number of detections contributing to the luminosity of the sky in the hard X-rays allowing a substantial improvement of our knowledge of the AGN and of the cosmic hard X-ray background.

Finally, a mention should be made to Galactic transients, among them the Very Faint X–Ray Transients and Supergiant Fast X–Ray Transients. The latter are an ideal test-case that shows the potentials of *Swift* in the field of transients. On one hand *Swift* is the only observatory which can detect their outbursts (see

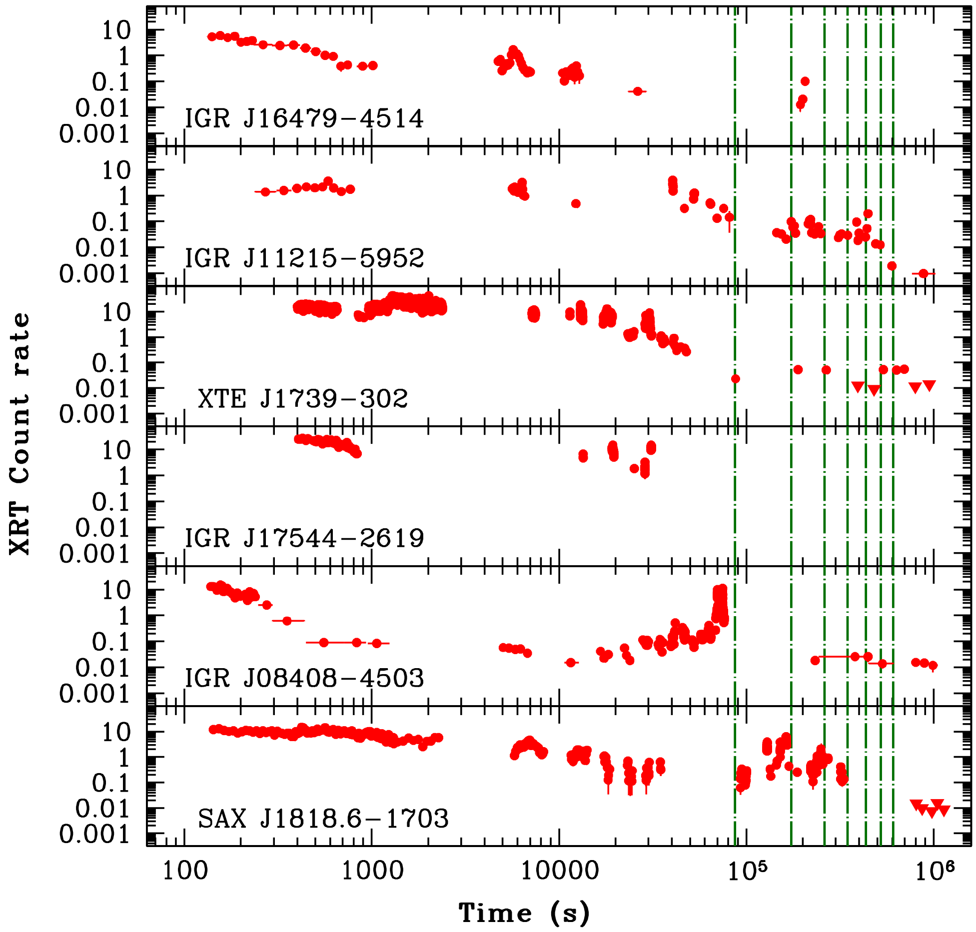

Fig. 8. Light curves of the outbursts of SFXTs followed by Swift/XRT referred to their respective triggers. Points denote detections, triangles 3σ upper limits. Note that where no data are plotted, no data were collected. Vertical dashed lines mark time intervals equal to 1 day, up to a week.

Fig. 8) in their very early stages and study them panchromatically as they evolve, as is done for GRBs. On the other hand, *Swift*'s flexible observing scheduling makes a monitoring cost-effective, so that *Swift* has given SFXTs the first non serendipitous attention through monitoring campaigns that cover all phases of their lives with a high sensitivity in the soft X–ray regime, where most SFXTs had not been observed before (see Romano et al. 2010, and references therein).

4. Conclusions and future perspectives

Swift offers a unique combination of autonomous fast repointing and flexible scheduling which, combined with the wide energy range, has made it a successful mission for GRB studies. The same properties, in addition to the support given to other missions such as *INTEGRAL*, *AGILE*, and *Fermi* have also made it the ‘go-to’ facility for non-GRB targets, such as CVs and novae, AGNs, and Galactic transients, as testified by the fact that about 55 % of the *Swift* publications are nowadays on secondary science topics.

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