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An Extremely Luminous Outburst from a Relativistic Tidal Disruption Event

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Abstract. We present the discovery and monitoring observations of *Swift* 1644+57, a luminous outburst from the nucleus of a galaxy at $z = 0.35$. Precise astrometry ties the source to within a few hundred parsecs of the nucleus of its host, and suggests a link to the massive black hole that probably resides there. The high luminosity and rapid variability are strongly indicative of a beamed source. We suggest that this event is best explained by the tidal disruption of a passing star by the supermassive black hole, which simultaneously created a powerful panchromatic explosion. However, it has also been proposed that such events may be related to the core collapse of massive stars. Future observations of a sample of similar events, focussing on their locations within the hosts, should distinguish in a straightforward manner between the two proposals.

Keywords. gamma-rays: bursts, galaxies: active, accretion

1. Introduction

Swift 1644+57 was discovered on 2011 March 28, and triggered the gamma-ray burst (GRB) detectors onboard the SWIFT satellite on a total of four occasions over a 48-hour period (Levan *et al.* 2011; Burrows *et al.* 2011). Such behaviour is unheard of for GRBs, which normally trigger the detector only once and then decline rapidly over the following hours to days, fading into invisibility (at least to the SWIFT X-ray Telescope, XRT) within a few weeks. In contrast, the light curve of Swift 1644+57 (shown in Fig. 1) remained bright for weeks and months after the initial trigger, and many months after the initial outburst it was still a bright X-ray source ($F_X \sim 3 \times 10^{-12}$ ergs s^{-1} cm^{-2}). Such behaviour immediately marked Swift 1644+57 as a new class of astrophysical source, especially once its cosmological nature was established.

In addition to bright X-ray emission Swift 1644+57 also exhibited bright emission in the IR (Levan *et al.* 2011, see also Figs. 1 & 2) and in radio (Zauderer *et al.* 2011). No optical variability was seen, suggesting that the source is highly obscured. However, the presence of the IR and radio counterparts enabled precise astrometry from VLBI observations and HST imaging. Those place the location of Swift 1644+57 to within $0''.03$ of the nucleus of its host galaxy (and fully consistent with a nuclear origin). While the galaxy is compact, and doubtless contains many stars within that compact radius (approximately 5% of the galaxy light lies within the region formally allowed at 1σ by our astrometry), such positional coincidence is strongly suggestive that Swift 1644+57 is associated with the black hole in the nucleus of its host galaxy.

The rapid rise from quiescence, the fast variability in the X-ray light curve and the absence of any clear AGN activity in the optical spectra clearly demonstrate that Swift 1644+57 is not a variable active galactic nucleus (Levan *et al.* 2011; Bloom *et al.* 2011a). The observed luminosity of Swift 1644+57 is $L_X = 3 \times 10^{48}$ ergs s^{-1} at peak, and corresponds to the Eddington limit of a 10^{10}-M$_\odot$ black hole. In contrast, our late-time IR observations, combined with the bulge mass–black hole mass relation, imply that the

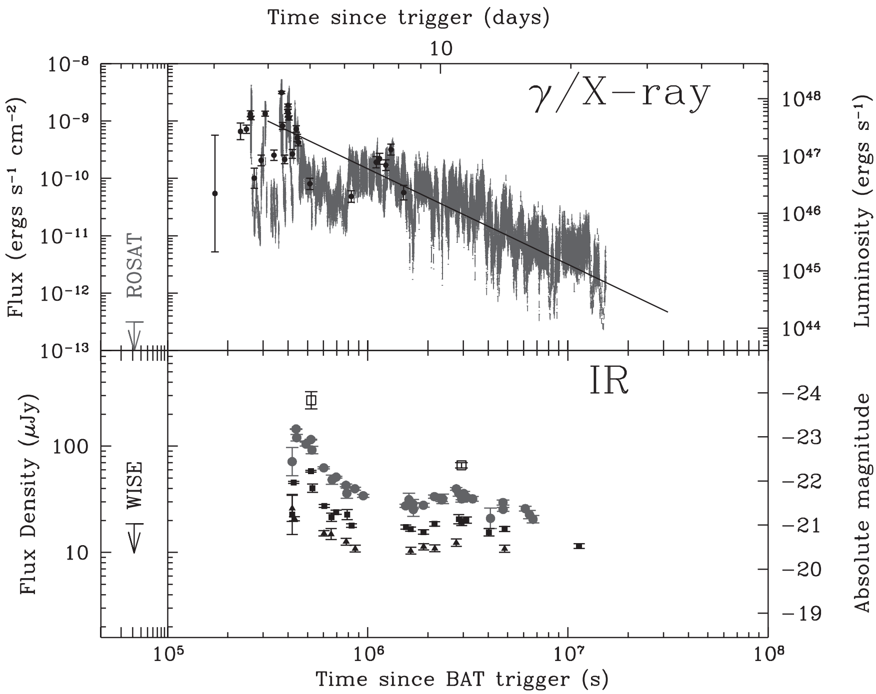

Figure 1. The high-energy (gamma-ray: black, X-ray: dense grey) and IR (L: open squares, K: grey triangles, H: solid squares and J: solid triangles) light curves of Swift 1644+57, taken from Levan *et al.* (2011) and Burrows et al. (2011). The light cuves show strong variability in X-rays, with increasing outburst intensity at redder IR wavelengths (probably because of heavy extinction within the host galaxy).

mass is unlikely to be greater than 10^7 $M_\odot$; variability arguments also lead to a low mass for the black hole (Bloom *et al.* 2011a, Miller *et al.* 2011). All that strongly suggests that the emission is relativistically beamed (Bloom *et al.* 2011a), and indeed the radio expansion implies a moderately relativistic source (Zauderer *et al.* 2011).

A natural possibility, first suggested by Bloom *et al.* (2011b) prior to the precise astrometric tie to the host galaxy, is that Swift 1644+57 represents a tidal disruption event, which simultaneously produces a relativistic outflow. In contrast to most TDE candidates, where we do not view down the jet, in the case of Swift 1644+57 we were viewing along the jet axis, causing us to see a very different observational phenomenon. While the properties of Swift 1644+57 were clearly unique, the presence of jets with TDEs has been suggested by van Velzen *et al.* (2011) and Giannios & Metzger (2011), who considered such jets and the likely impact they would have on the observed radio luminosity of “standard” TDEs at late times.

While the properties of Swift 1644+57 are broadly consistent with those of a relativistic TDE, it has also been suggested that such events could arise from core-collapse events, in which material far out in the collapsing star has sufficient angular momentum that it forms a centrifugally-supported disk (Quataert & Kasen 2011; Woosley & Heger 2011). That model differs from the one invoked for GRBs, where the disk is formed from material close to the core at the time of collapse and naturally leads to a longer-lived event, which may resemble Swift 1644+57.

The location within the nucleus of its host galaxy, the prediction of such jets from TDEs (van Velzen *et al.* 2011; Giannios & Metzger 2011) and the apparent late-time fading

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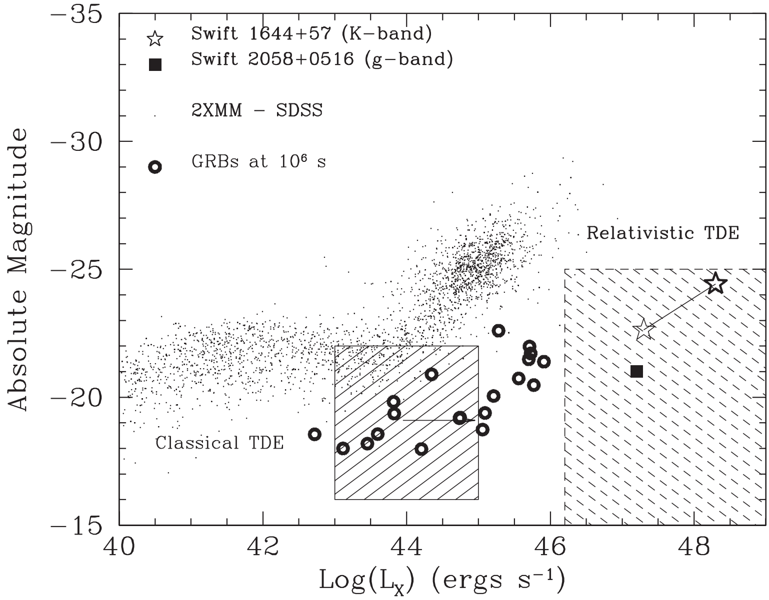

Figure 2. Comparative X-ray (x-axis) and optical (y-axis) properties of various X-ray emitting sources, compared to the properties of Swift 1644+57 (Levan *et al.* 2011) and Swift 2058+0516 (Cenko *et al.* 2011). The majority of sources represent manifestations of active nuclei in galaxies, while we also show the late-time properties of GRB afterglows and the expected locations of classical tidal disruption events (see Levan *et al.* 2011, and references therein for more details). Swift 1644+57 is offset well from any of those sources (the two stars for Swift 1644+57 represent its evolution from peak to 10^6s), at a location in parameter space where no sources have been seen before. Future examples of such events may therefore be identified by their location within that parameter space.

at $t^{-5/3}$ (expected for a TDE) all lend credence to a model in which Swift 1644+57 is created in a TDE event. However, from the available data we cannot rule out the collapsar hypothesis. Future observations of a sample of events should easily make that distinction. We would expect that any stellar event would occur across its host galaxy and not exclusively in the nucleus. In contrast, TDE events should be exclusively nuclear, and hence even a small sample (~ 5) of such events should provide a strong diagnostic of their true nature. Indeed, a second candidate event has already been uncovered (Cenko *et al.* 2011), and late-time observations of its hosts and the subsequent astrometry will provide a strong test of those models.

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