

# The first months in the lifetime of the newly born jet associated to Swift J1644+57

A.J. Castro-Tirado<sup>1</sup>, J.L. Gómez<sup>1</sup>, I. Agudo<sup>1</sup>, M. A. Guerrero<sup>1</sup>, M. Bremer<sup>2</sup>, J.M. Winters<sup>2</sup>, J. Gorosabel<sup>1</sup>, R. Sánchez-Ramírez<sup>1</sup>, S. Guziy<sup>1</sup>, M. Jelinek<sup>1</sup>, J.C. Tello<sup>1</sup>, D. Pérez-Ramírez<sup>3</sup>, J. Reyes-Iturbide<sup>4</sup>, I.H. Park<sup>5</sup>, S. Jeong<sup>6</sup>, and A.S. Pozanenko<sup>7</sup>

<sup>1</sup> Instituto de Astrofísica de Andalucía (IAA-CSIC), P.O. Box 03004, E-18080 Granada, Spain.

<sup>2</sup> Institute de Radioastronomie Milimetrique (IRAM), 300 rue de la Piscine, 38406 Saint Martin d'Hères, France.

<sup>3</sup> Facultad de Ciencias Experimentales, Universidad de Jaén, Campus Las Lagunillas, E-23071 Jaén, Spain.

<sup>4</sup> Instituto de Astronomía, Univ. Nacional Autónoma de México, Apdo. Postal 70-264, 04510 México, D. F., México.

<sup>5</sup> Sungkyunkwan University (SKKU), 440-746 Suwon, Korea.

<sup>6</sup> Ewha Womans University, Daehyundong 11-1 Seodaemungu, 120-750 Seoul, Korea.

<sup>7</sup> Space Research Institute of RAS, Profsoyuznaya, 84/32, Moscow 117997, Russia.

## Abstract

We describe the evolution of Swift J1644+57, whose unique X-ray properties have led several groups to interpret its behavior as corresponding to an extraordinary event of tidal disruption of a star by a supermassive black hole in the nucleus of a ( $z = 0.3545$ ) galaxy, as derived by GTC. Multiwavelength observations (optical, millimetre, centimetre) are proving to be essential to reveal the long term nature of the emission in this source. In particular, we identify for the first time the properties of a forming relativistic jet. In our interpretation of the phenomenon, we leave the still open possibility that it may correspond to the onset of a dormant AGN, but this may only be tested with longer term X-ray, millimetre and centimetre monitoring.

## 1 Introduction

On 2011 March 28 *Swift* triggered on a newly discovered transient, which was initially thought to be a new gamma-ray burst (dubbed GRB 110328A; [6]). However, a second *Swift* trigger

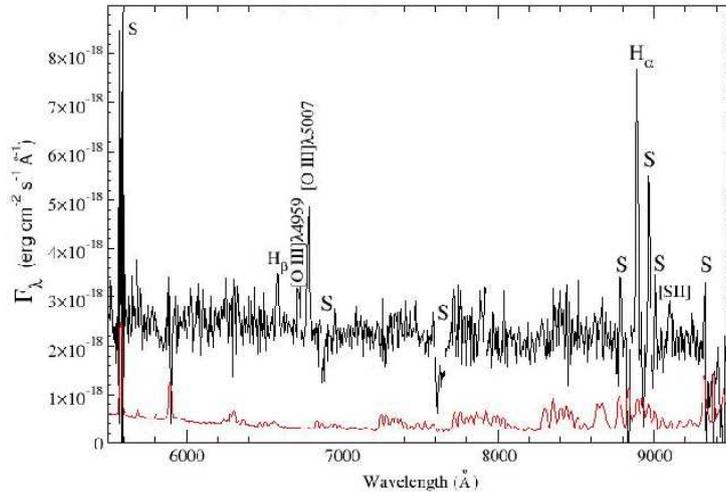


Figure 1: A spectrum was obtained on 26 June with the 10.4m GTC using the R500R grism (3x900s exposures) in the OSIRIS imaging spectrograph. The R500R grism was used with a spectral range of 5300-10000 A and a dispersion of  $\text{FWHM} = 2.4 \text{ \AA}/\text{pix}$  and a resolution of 634 (both at 7319 A). The  $1''$  wide slit was positioned on the location of the transient source and a  $2 \times 2$  binning mode was used.

on this source [1] started to cast doubt on the GRB nature of this source, suggesting that instead it may correspond to a new class of hard X-ray transient. This was confirmed by the pre-outburst optical detection in Palomar [5], which strongly disfavored a cosmological long-duration GRB. Furthermore, spectroscopic observations [7] revealed the extragalactic nature of the source.

Subsequent radio observations with the EVLA [9], CARMA [9], MRAO [8], and PdB [3] confirmed the existence of a radio source, coincident with the optical position of the nucleus of a host galaxy, with flux densities at cm and mm wavelengths of 5–25 mJy, with indication of long term evolution.

All this observational evidence points towards the possibility that the source is a very peculiar new type of X-ray transient [7], which may be interpreted [2] by a tidal disruption of a main sequence star by a black hole of  $10^{6-7}$  solar masses at the center of the observed host galaxy, leading to the formation of a “mini-blazar” with the jet seen face-on. This is also supported by energetic and variability arguments, which suggest that the jet is at least mildly relativistic, presents high collimation, and a spectrum dominated by synchrotron and inverse Compton emission [2].

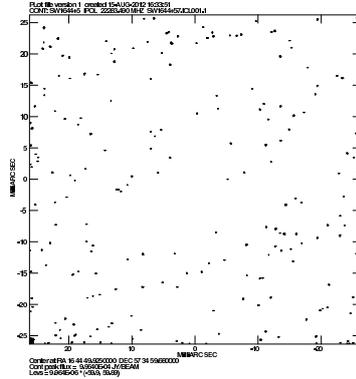


Figure 2: EVN map centred on the Swift J1644+57 showing no signal at the target position.

## 2 Multiwavelength observations

### 2.1 Optical and near-IR observations

A late epoch 10.4-m Gran Telescopio Canarias optical spectrum (Fig. 1) showed emission lines of  $H_{\alpha}$ ,  $H_{\beta}$ , [O III], [S II] from which a redshift  $z = 0.3545 \pm 0.0007$  was derived, confirming the value proposed in [7], also based on earlier epoch GTC data. See Fig. 1, none of the emission lines displayed a broad component, as it would be expected for active Seyfert galaxies. No variations in the line fluxes of the lines were noticeable when comparing to previous measurements [8], which supports that the line emission is formed in outer star-forming regions existing in the Galaxy. In addition to them, near-IR observations were conducted on Apr 15 and May 21 at the 3.5m telescope (+ OMEGA 2000) at the German-Spanish Calar Alto (CAHA) Observatory. Further near-IR observations (in the Ks-band) were conducted on the Apr 15 service night at the 4.2m William Herschel Telescope (+ LIRIS) at Observatorio del Roque de los Muchachos, unfortunately poor weather conditions prevented the polarimetric measurements although Sw 1644+57 was detected.

### 2.2 Millimetre observations

Our observations with the Plateau de Bure Interferometer (PdBI) started three days after the onset of the event. The counterpart was detected with an extremely high ( $>100$ ) S/N ratio, on the phase center coordinates (J2000, R.A. = RA: 16:44:49.97; Dec: +57:34:59.7). The observed dual polarisation continuum bandwidth was 1 GHz. They showed that, after an initial decay, the flux at mm wavelengths displayed a significant increase by a factor of more than a factor of 2 during May 2011.

### 2.3 Centrimetre observations

Effelsberg observations were attempted on 2011 June 12 (no detection due to poor weather conditions) and on 2011 June 19, with a marginal detection of  $\sim 8$  mJy at 4.8 GHz. Additional

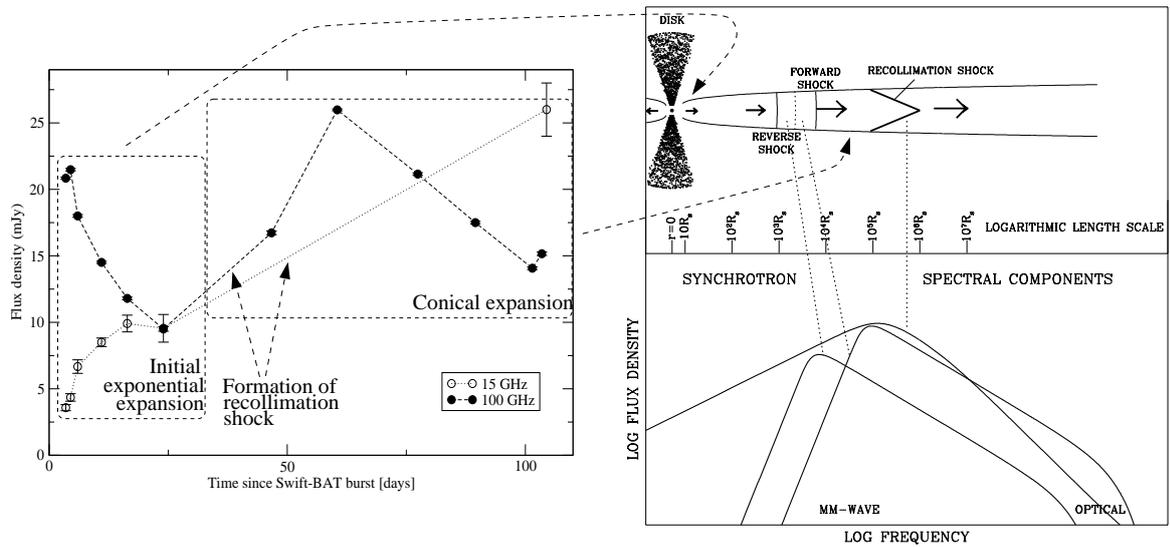


Figure 3: The proposed scenario to explain the light curves of Sw 1644+57, following [4]. *Left panel:* Millimeter and radio light curves of Swift 1644+57. After the initial decay, the mm lightcurve displays a second bursting episode, reaching a maximum flux density even higher than the one observed after the initial Swift detection. *Right panel:* Sketch of the main features of the proposed scenario to explain the light curves of Sw 1644+57. The length scale is given in terms of Schwarzschild radii. After the forward shock passes the location where the external pressure becomes nearly constant (rather than increasing toward the black hole), a conical recollimation shock forms and collimates the jet further. Electrons are accelerated to highly relativistic energies at all three shock fronts, creating the three spectral components sketched on the bottom.

observations were carried with Korean facilities, also imposing upper limits.

On 2012 February 28 we performed phase-reference observations of Sw1644+57 using the European VLBI Network (EVN) at a observing wavelength of 1.3 cm. These observations were aimed at detecting any possible proper motion, as well as to resolve its radio structure. Unfortunately, by the time of our EVN observations –337 days after the initial burst – the source had already decreased in flux well below the sensibility of our observations, preventing its detection (see Fig. 2). We have however been able to provide an upper limit (3-sigma) for its flux density at 1.3 cm of 0.97 mJy/beam.

### 3 Discussion

These (and further) observations have led us to suggest that the peculiar X-ray transient Sw 1644+57 may correspond to the onset from a dormant AGN [4]. See Fig. 3. In the case of the AGN onset, we expect that the jet originated by the flaring event that triggered the *Swift* satellite should conserve its mm and radio emission on relatively long time scales (of several

months more).

In conjunction with other multi-wavelength observations (like *Swift* which are being performed routinely), ongoing (and near future) observations of Swift 1644+57 will allow:

- to search for emission line variability in the optical spectrum, as might have been seen in other events.
- to determine whether the nature of Swift J1644+57 is related to a short time range tidal disruption flare of a star by a supermassive black hole, or to a longer term phenomenon as the onset of a dormant AGN as proposed in [4].
- to perform a detailed study of the long term evolution of the multi-wavelength afterglow emission over the first  $\sim 24$  months after the event. This will enable us to trace the evolution of the characteristic synchrotron self-absorption frequency, and the radio-mm spectral index, that will help help us to constrain among different jet models.

## Acknowledgement

This work is partly based on observations carried out with the 10.4 m GTC at the ORM and with the IRAM Plateau de Bure Interferometer. IRAM is supported by INSU/CNRS (France), MPG (Germany) and IGN(Spain). We also acknowledge the support of the Spanish MICINN Project AYA2009-14000-C03-01/ESP.

## References

- [1] Barthelmy, S., et al. 2011, GCN 11824
- [2] Bloom, J.S., et al. 2011, *Science*, 333, 203
- [3] Castro-Tirado, A.J., et al. 2011, GCN 11 880
- [4] Castro-Tirado, A.J., et al. 2012, submitted
- [5] Cenko, B., et al. 2011, GCN 11827
- [6] Cummings, J.R., et al. 2011, GCN 11823
- [7] Levan, A.J., et al. 2011, *Science*, 333, 199
- [8] Pooley, G., et al. 2011, GCN 11849
- [9] Zauderer, B A., et al. 2011, *Nature* 476, 425