

## Observations of an X-ray transient in NGC 2770

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### 1 Introduction

During *Swift* observations of SN 2007uy beginning at 13:32:48.9 UT on 2008-01-09 (Obs ID 00031081002), a transient X-ray source was serendipitously identified and reported on Jan 10.58 (Berger & Soderberg, GCN Circ. 7159 and ATel 1353; Kong & Maccarone, ATel 1355). The source was observed to rise to a maximum flux about 65 seconds after the observation began, and then subsequently decay; the observed duration of the event is roughly 600 seconds. The X-ray emission was already in progress when this observation began, so the start time of the event is uncertain. The object was within the BAT field of view for approximately 30 minutes prior to the observation in which it was first detected (Burrows et al., GCN Circ 7179), but never triggered the instrument. Target of opportunity *Swift* follow-up observations were promptly scheduled to reveal the nature of the transient.

The first announcement of an optical counterpart was reported by Deng & Zhu (GCN Circ. 7160) on Jan 10.76 UT, and confirmed by NOT observations on Jan 11.0 UT (Thoene et al., GCN Circ. 7161).

A comparison of Asiago Observatory data taken Jan 7.0 and Jan 10.0 indicated that the optical counterpart brightened rapidly (Valenti et al., GCN Circ. 7163). Similarly, an early analysis of UVOT data from Jan 11.11 revealed a counterpart which had brightened since the previous *Swift* observations on Jan 9.6 (Kong et al., GCN Circ. 7164).

Spectroscopic observations of the optical transient were first reported by Soderberg et al. (GCN Circ. 7165), taken on Jan 11.3 UT with Gemini-N/GMOS and suggesting broad features possibly related to an emerging supernova. Malesani et al. (GCN Circ. 7169) classified the supernova (now designated SN 2008D) as type Ibc, based on VLT spectroscopy on Jan 11.3. Valenti et al. (GCN Circ. 7171) confirmed the type Ic classification with TNG spectra taken on Jan 11.1

A refined analysis of *Swift* follow-up data beginning Jan 11.12 revealed an X-ray counterpart (Page et al., GCN Circ. 7170; see also Section 3) in addition to the UVOT counterpart (Immler et al., GCN Circ. 7168; see also Section 4) which was detected in v, b, u, uvw1 and uvm2 filters. Soderberg reported the discovery of a radio counterpart by the VLA (GCN Circ. 7178), providing the most accurate position for this transient:

RA (J2000):  $09^h 09^m 30.6506^s \pm 0.0008$   
 Dec (J2000):  $+33^\circ 08' 20.14'' \pm 0.01$

### 2 BAT Observation and Analysis

An upper limit on the gamma-ray fluence (15–150 keV) of  $\sim 1.0 \times 10^{-7}$  erg cm<sup>-2</sup> can be estimated for the earlier observations when NGC 2770 was within the BAT field of view (Burrows et al., GCN Circ. 7179). During the pointed observation of the field, a deeper 15–150 keV limit of  $8.9 \times 10^{-8}$  erg cm<sup>-2</sup> can be placed. These limits assume a power-law spectrum with  $\Gamma = 1$  and are consistent with the extrapolation of the XRT spectrum into the BAT band (see below).

Ofek et al. (GCN Circ. 7172) and Modjaz et al. (GCN Circ. 7175) both estimate the start of the event to be around the beginning of the X-ray observation. However, we note that  $T_0$  cannot be constrained by the *Swift* data: there was no detection in the BAT band and, as will be discussed in Section 3, the X-ray emission was already present at the start of the pointing.

### 3 XRT Observations and Analysis

The XRT started observing the field of SN 2007uy (and, hence, this serendipitous X-ray transient) at 13:32:49UT on 2008-01-09. As can be seen from Figure 1, X-ray emission was already underway at this time. It is not possible to determine whether the emission we see is part of the initial event, or a flare on the underlying decay continuum, as is often seen in GRBs.

The light-curve is seen to rise for about 65 seconds, before beginning a steep decline for the remainder of the first orbit (GCN Circs. 7159, 7170). Because of the lack of an exact start time for the event, the light-curve has been plotted with an arbitrary start time of 13:30:00UT, to permit the use of a log time axis.

No detection of the transient was found during the previous observation of the field of SN 2007uy on 2008-01-06 (Obs ID 00031081001), to a  $3\sigma$  limit of about  $8 \times 10^{-4}$  count  $s^{-1}$ . Later observations were made under the target ID of 31089.

After the first orbit of data, the decay is seen to flatten off, fading only slowly out to at least  $5 \times 10^5$  seconds after detection. There is another, very nearby, source within the outer wings of the transient's Point Spread Function (PSF), at a position of RA, Dec (J2000) =  $09^h 09^m 31.50^s$ ,  $+33^\circ 08' 03.1''$  with an estimated error radius of 4.4 arcsec (90% containment); this second source has an almost constant count rate of  $(1.7 \pm 0.3) \times 10^{-3}$  count  $s^{-1}$ . To avoid contamination of the measurement of the transient's decay, an extremely small extraction region of 4 pixels (9.44 arcsec) radius was used to produce the light-curve. Figure 1 is corrected both for pile-up (first orbit only) and the loss of the PSF caused by the small extraction region.

Spectral evolution was seen during the first orbit of data, with a general softening trend. Taking a mean spectrum for this orbit, the data can be well modelled by either an absorbed power-law [ $\Gamma = 2.29 + 0.31/-0.29$ ;  $zN_H = (6.8 + 1.8/-1.5) \times 10^{21}$   $cm^{-2}$  at  $z = 0.006494$ , which is the redshift of NGC 2770; this is in addition to the Galactic value of  $1.7 \times 10^{20}$   $cm^{-2}$  [1]] or by an absorbed, thermal Mekal component [ $kT = 3.6 + 1.3/-0.8$  keV;  $zN_H = (5.1 + 1.4/-1.1) \times 10^{21}$   $cm^{-2}$ ].

Ofek et al. (GCN Circ. 7172) found no evidence for periodicity in the *Swift* X-ray data.

### 4 UVOT Observation and Analysis

UVOT marginally detected an optical counterpart to the X-ray transient on 2008-01-09 (GCN Circ 7168) in the b ( $3.4\sigma$ ) and u ( $3.0\sigma$ ) filters; no detection was obtained during the earlier observation of the field on 2008-01-06, to limits of at least 20th magnitude (GCN Circ 7168). Two days later, on 2008-01-11, the source had brightened and was detected at both optical and UV wavelengths (Kong et al., GCN Circ. 7164; GCN Circ. 7168). The source was then found to be fading (see also Li et al., GCN Circ. 7176), before brightening again (GCN Circ. 7185, Figure 2 and Table 1), confirming the onset of the supernova component.

### References

- [1] Kalberla, P.M.W., Burton, W.B., Hartmann, D., Arnal, E.M., Bajaja, E., Morras, R., Pöppel, W.G.L., 2005, A&A, 440, 775
- [2] Poole, T.S. et al., 2008, MNRAS, 383, 627

Filter	Magnitude	Exposure time (s)	Start time (UT)
v	> 19.9	412	2008-01-09T13:44:35
v	$18.54 \pm 0.19$	216	2008-01-11T02:50:35
v	$18.65 \pm 0.09$	939	2008-01-12T04:34:03
v	$18.65 \pm 0.08$	1315	2008-01-13T01:24:08
v	$18.46 \pm 0.09$	725	2008-01-14T01:24:58
v	$18.27 \pm 0.10$	496	2008-01-15T01:30:27
b	$20.51 \pm 0.31$	412	2008-01-09T13:37:18
b	$18.93 \pm 0.09$	353	2008-01-11T02:42:25
b	$19.32 \pm 0.07$	1002	2008-01-12T02:55:15
b	$19.33 \pm 0.07$	1314	2008-01-13T01:14:51
b	$19.24 \pm 0.08$	725	2008-01-14T01:17:58
b	$19.12 \pm 0.09$	496	2008-01-15T01:25:19
u	$20.20 \pm 0.36$	412	2008-01-09T13:35:49
u	$18.58 \pm 0.08$	664	2008-01-11T02:40:44
u	$19.18 \pm 0.10$	1002	2008-01-12T02:54:07
u	$19.37 \pm 0.10$	1315	2008-01-13T01:12:58
u	$19.57 \pm 0.16$	725	2008-01-14T01:16:32
u	$19.56 \pm 0.20$	496	2008-01-15T01:24:14
uvw1	> 20.81	1619	2008-01-06T00:31:23
uvw1	> 20.42	831	2008-01-09T13:32:53
uvw1	$19.83 \pm 0.17$	1707	2008-01-11T02:37:28
uvw1	> 20.94	2014	2008-01-12T02:51:56
uvw1	> 21.07	2634	2008-01-13T01:09:15
uvw1	> 20.74	1456	2008-01-14T01:13:43
uvw1	> 20.51	989	2008-01-15T01:22:11
uvm2	> 20.29	1143	2008-01-09T13:46:04
uvm2	> 19.84	571	2008-01-11T02:52:16
uvm2	> 20.72	2422	2008-01-12T04:34:56
uvm2	> 20.97	3604	2008-01-13T01:26:02
uvm2	> 20.65	2000	2008-01-14T01:26:24
uvm2	> 20.30	1247	2008-01-15T01:31:31
uvw2	> 20.79	1662	2008-01-09T13:38:48
uvw2	> 20.37	864	2008-01-11T02:44:06
uvw2	> 21.26	3814	2008-01-12T02:56:26
uvw2	> 21.44	5273	2008-01-13T01:16:47
uvw2	> 21.16	2913	2008-01-14T01:19:25
uvw2	> 20.93	1983	2008-01-15T01:26:24

Table 1: Detections and magnitude limits from UVOT observations. Magnitudes are on the UVOT photometric scale [2]

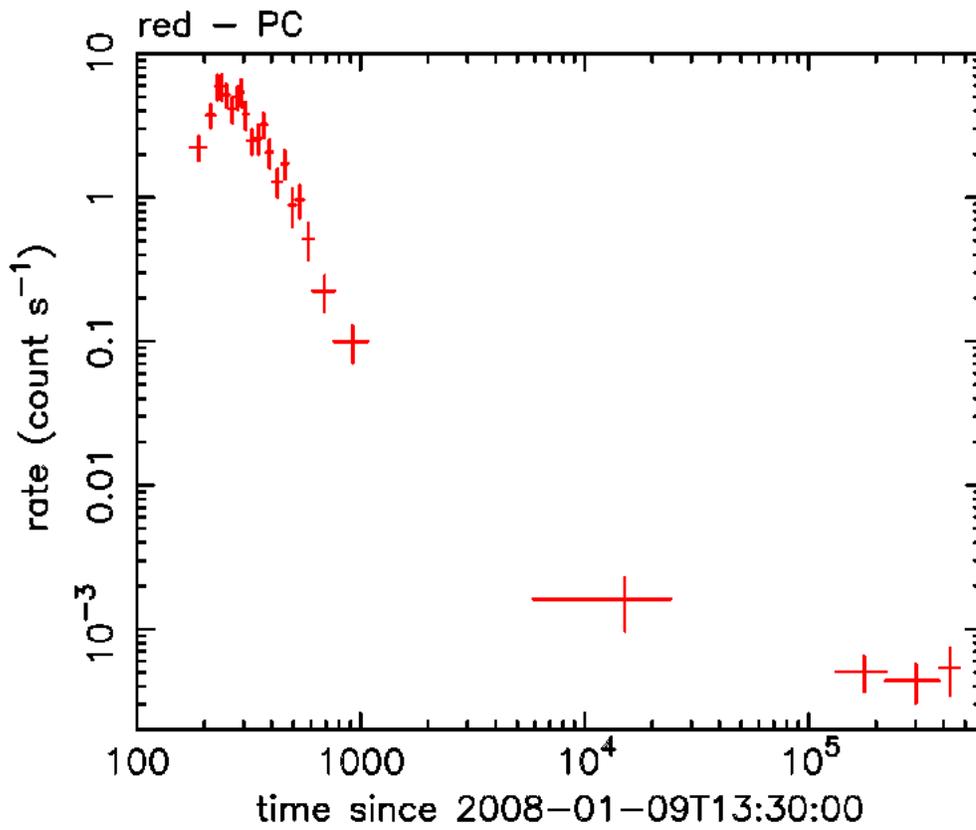


Figure 1: XRT lightcurve: count s<sup>-1</sup> in the 0.3-10 keV band, in Photon Counting mode. The approximate counts to flux conversion is 1 count s<sup>-1</sup> =  $\sim 4.9 \times 10^{-11}$  erg cm<sup>-2</sup> s<sup>-1</sup>.

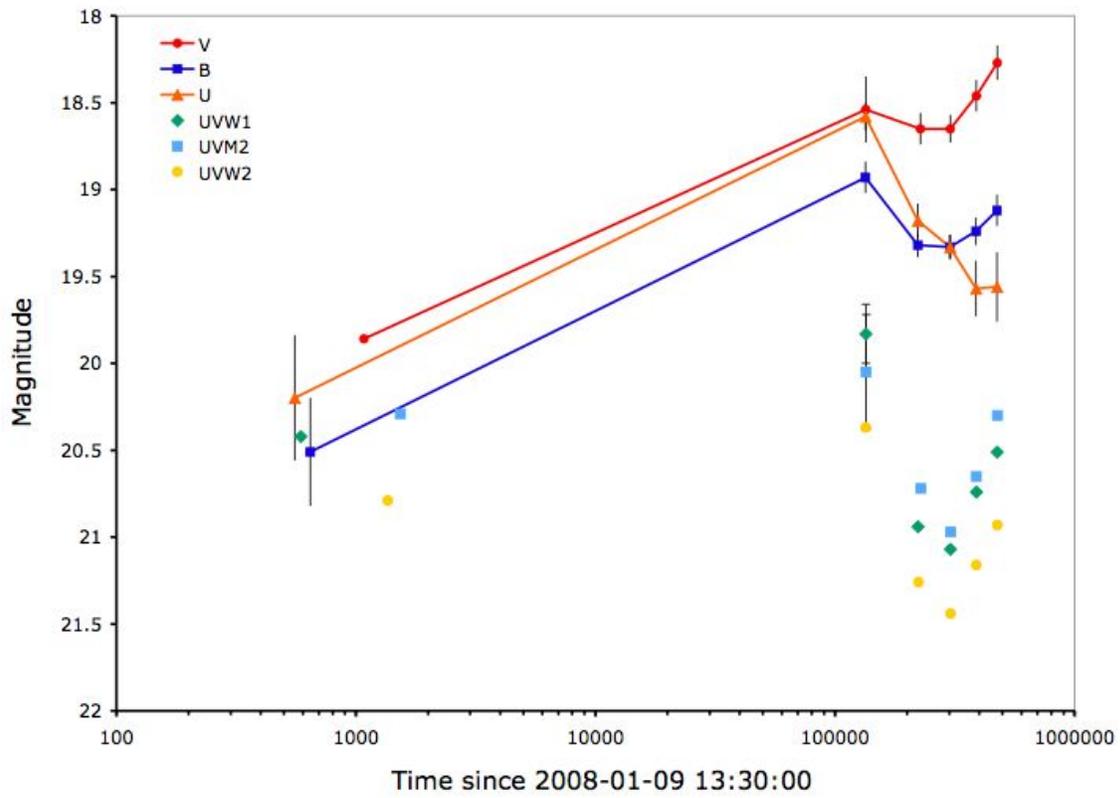


Figure 2: UVOT light-curve. Data points without error bars are upper limits.